PH.D. THESIS ABSTRACT 1980-1968

Sr No	Title	Supervisor	Author(s)	Year
1	Stability Studies Of Ac/Dc Power Systems	Padiyar K R & Pai Mangalore Anantha	Radhakrishna C	1980
2	Analysis Of The Steady State And Dynamic Performance Of Voltage Controlled Induction Motor Drives	Padiyar K R	Prabhakaran N	1980
3	Design Of Suboptimal Agc Regulatores With Performance Index Sensitivity Minimization	Hole K E & Aggarwal R P	Kumar Prabhat	1980
4	Investigation Into A Class Of Multiple Loop Amplifiers	Sarma K R& Prabhu S S	Padmanabhan S	1980
5	An Investigation Of Electromagnetic Wave Propagation Through Anisotropic Dielectric Waveguides	Paul D K& Mathur Naresh C	Chaudhuri Bidyut Baran	1980
6	Load Flow Contingency Evaluation And Optimal Power Dispatch In Large Scale Power Systems - Development Of New And More Efficient Methods	Aggarwal R P& Pai Mangalore Anantha	Arumugam N	1980
7	Execution Time Analysis Of Process Control Algorithms On Microcomputers	Rajaraman V	Govindarajulu R	1980
8	Studies On Oscillations In A Class Of Coupled Systems	Rao P R K	SinghYashwant Prasad	1979
9	Pole Assignment Techniques For Power System Stabilization	Padiyar K R& Prabhu S S	Gomathi K	1979

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12	Studies On The Process Control Of Device Parameters Of Silicon Pin Diodes	Tyagi M S	Korde Rajanikant S	1979
13	Studies In Nonlinear Discrete Time Systems	Subramanian R	Krishnan A	1979
14	Study Of Current Transport In Nonhomogeneous Rectifying Metal-Semiconductor Contacts	Sharan R	Visweswaran G S	1979
15	Some Iterative Tedchniques In Digital Image Restoration	Mullick S K Rathore R K S & Subramanian R	Ramakrishna R S	1978
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18	Studies On The Excitation Control Of Synchronous Motor Subjected To Voltage Dips	RamamoortyM & Padiyar K R	Sarma K Suryanarayana	1978
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22	Identificaiton And Equalization Of Fading Dispersive Channels	Sarma K R& RaoP R K	Mehra Daljit Kumar	1978
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25	Application Of Mathematical Programming Methods To Optimal Design Of Polyphase Reluctance Motors	Ramamoorty M	Rao P Jagannadha	1977
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37	Preventive Control And Diakoptical Optimization Of Large Scale Power Systems	Pai Mangalore Anantha	Paranjothi S R	1976
38	Stability Of Large Scale Power Systems	PaiMangalore Anantha	Lakshminarayana C	1975
39	Estimation Of Stability Domains For The Transient Stability Investigation Of Power Systems	Subramanian R	Bansal Raj Kumar	1975
40	Descriptive Inference In Pattern Recognition	Mahabala H N	Sadananda R	1975
41	Synthesis Of Multifunctions Active R C Filters Using Grounded Capacitors	Venkateswaran Shankara	Singh Ranjit	1975
42	A Class Of Formal Models For Languages And Translations	Basu Sanat K	Vaishnavi Vijay Kumar	1975
43	Detection Of Ligical Errors In Decision TABL Programs	Rajaraman V	Ibramshaw M	1974
44	Analysis And Optimization Of Large Scale Power Systems Using Diakoptic Method	Pai Mangalore Anantha	Jegatheesan R	1974
45	Optimal Scheduling In Hydrothermal Power Systems By The Method Of Local Variations	Prabhu S S& Aggarwal R P	Rao Kallury Surya Prakasa	1974
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48	Study Of Transmission Of Optical Signals Through Clouds Using Monte Carlo Technique	Sarma K R	Gupta Hari Mohan	1973
49	Transient Stability Investigation Of Powr Systems Using Improved Lyapunov Functions	Pai Mangalore Anantha	Murthy P G	1973
50	Minimal Trajectory Sensitivity Design Of Optimal Control Systems : A New Formulation	Sarma I G & Agashe S D	Hole Kashinath Eknath	1973
51	Transient Stability Analysis Of Power Systems Using Liapunov Functions With Improved Synchronous Machine Models	Pai Mangalore Anantha	Rai Vishwanatha	1973
52	Convergence Of Programs By Discrete System Techniques	Basu Sanat K	Venkatachalam P A	1973
53	Computer Aided Study Of Solid State Diffusion And Characterization Of Semiconductor Devices	Venkateswaran, Shankara	Hasan Mohammad Mozaffarul	1973
54	A Syntactic Pattern Analysis System And Its Application To Devanagri Script Recognition	Mahabala H N	Sinha R M K	1973
55	Analysis And Synthesis Of Two Dimensional Recursive Digital Filters	Sinha V P	Sekhon Harjinder Singh	1972
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60	Coordinate Transformations In Systems And Control Theory	Agashe S D	Rathore Virendra Singh	1972
61	Optimal Regulators For Synchronous Machines	Ramamoorty M	Arumugam M	1971
62	Quantization In Linear Transform Domains	Sarma K R& Prasada B	Moharir Pramod Sadasheo	1971
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64	Analysis Of Thyristor Controlled D.C. And A.C. Motors	Ramamoorty M	IlangoB	1971
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68	Analog Multiplier Circuits Using Silicon Junctions	Viswanathan T R	DeepGurdip Singh	1970

69	Design Of A Nuclear Quadrupole Resonance Spectrometer	SarmaK R	Viswanathan Tandur Lakshmi	1970
70	Study Of Photovoltaic Devices Based On Metal-Semiconductor Structures	Sharan R	Bhaumik Basabi	1970
71	Optimal Load Scheduling Of Power Systems Using Nonlinear Programming Techniques	RamamoortyM	RaoJammi Gopala	1970
72	The Identificaiton And Estimation Of Linear Monstationary Dynamical Systems	Rajaraman V	Rao Ponamgi Ramakrishna	1970
73	Some Problems Of Continuous Stochastic Optimal Control	Sarma I G	Mandke Vijay Vasantrao	1970
74	Power System Transient Stability By Methods Of Popov And Lyapunov	Sastry V R& Pai Mangalore Anantha	Mohan Mallavarapu Ananda	1970
75	N-Person Differential Games And Multiicriterion Optimal Control Problems	Sarma I G	Prasad U Ravikirana	1969
76	Design Of A Computer Aided Optimal Speed Regulating System For A Bar Mill Main Drive	Rajaraman V	Bhatt Purushottam Pramod Chandra	1969
77	Analysis Of Feedback Systems With Combined Pulse Modulation	PaiMangalore Anantha	Varadarajan MS	1969
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79	Conversion Of Computerprograms To Decision Tables	Rajaraman V	Gupta Virendra	1969
80	Models For Computer Aided Desiign	Kesavan H K	Sahasrabuddhe Hari Vasudeo	1968
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Title : Stability Studies Of AC/DC Power Systems
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Abstract

As modern power systems are becoming more and more complex, the stability investigations assume greater significance in the planning, design and operation of these systems. Although the stability of power system is a single entity, it is customary to classify it for purposes of analysis s 'transient stability' and 'dynamic stability'. The former refers to the stability of the system under large disturbances such as faults and the later to the stability under small perturbations caused by random load changes. In recent years, there has been tremendous interest in high voltage direct current (HVDC) transmission systems and their influence on the system stability. The feasibility of power modulation in a HVDC link to damp out the system oscillations has been well established and proved by practical experience. The modern trends in the system design and control require analytical tools for predicting the complex dynamic performance of power systems. This has led to the development of direct methods of transient stability analysis (to complement simulation techniques) for on line security assessment. The existence of undamped oscillations in large interconnected power systems has led to a study of effective methods of control using detailed system models. However, these developments in the stability analysis are mainly restricted to pure AC systems. Except in the case of digital simulation for transient stability studies, the analysis of the role of the DC link with its control has been performed in the past only for simple configurations of the system with one or two machines. A general formulation and analysis of large-scale AC/DC power systems for dynamic stability studies is not available in the literature. Similarly, direct methods of transient stability investigations of multicmachine systems have not considered the presence of DC links. The reasons for this gap in the literature are as much due to the difficulties in adapting the DC link models for the specific studies as the fact that use of DC links is still in its infancy. However, with progress in the HVDC technology it is expected that its use will increase considerably. This requires an accurate evaluation of the benefits of the DC link and its control in the system planning and operation. The objectives of this thesis are: i. Development of methods and models for the stability analysis of large-scale AC/DC systems; and ii. The investigations on the improvement of dynamic stability through the effective use of DC link controller and power system stabilizers. The major contributions of the thesis are listed below: 1) A practical approach is proposed for the direct method of evaluation of transient stability of AC/DC power systems using Lyapunov's techniques. The effect of the DC linked dynamics is considered as a parameter variation in the second order models of the generating units. The DC link is treated as a controllable load at its rectifier and inverter terminals; their effects, along with the other system loads, on the generators at their internal nodes are obtained as additional bus power injections, using the method of distribution factors. 2) A systematic procedure is developed for building a versatile system model for the dynamic stability analysis of large-scale AC/DC power systems. 3) Analytical methods are proposed for the determination of suitable locations of the controllers in the system to improve dynamic stability. 4) The effectiveness of the various feedback control signals for DC link and power system stabilizers, in improving the dynamic stability, is investigated and it is shown that conventional signals may not be adequate. An outline of the work reported in the reported in the thesis is given below: 1) The first chapter introduces the various aspects of the stability analysis of AC/DC power

systems and reviews the literature in this area. 2) The chapter 2 deals with the application of Lyapunov's direct method for the transient stability analysis of a single-machine connected to infinite bus through parallel AC/DC transmission. A simplified state space model is derived for the system. The chosen Lyapunov function is of the following type: 'a quadratic form plus integral of the nonlinearity'. Since the results obtained by the traditional approach are conservative, two modifications are suggested which are approximations of the basic approach using Kalman's construction procedure. These approximations differ only in the way in which the effect of DC link if considered. In the second approximation, the effect of DC link is considered. In the second approximation, the effect of the DC link dynamics is considered as a parameter variation in the second order model of the system and encouraging results are obtained. 3) The direct method of evaluation of transient stability of multimachine AC/DC systems has been attempted in the chapter 3. The dc link is treated as a controllable load at its rectifier and inverter terminals. The system loads including the terminal characteristics of the DC link are represented as constant current type loads and their effects on the generators at their internal nodes are obtained as additional bus power injections, using the method of distribution factors. This approach minimizes the transfer conductance's which are a source of trouble in the application of Lyapunov's method to multi-machine systems. The transient energy function is chosen as the Lyapunov function and the concept of center of inertia is utilized in the formulation of the system model. An effective and simple method, utilizing the potential energy function and its derivative, is employed for the determination of stability region. The technique proposed here has been demonstrated with a 3-machine power system example. 4) The chapter 4 presents the development of a versatile system model for the dynamic stability analysis of large-scale AC/DC power systems. Following are the novel features of the proposed method: (i) It is not necessary to reduce the power system network to eliminate non-generator buses. The network is described by power flow equations in polar coordinates and these are linearized using the Jacobian matrix similar to that given for Newton's load flow. Also any nonlinear voltage dependent loads can be considered. On thee other hand the methods requiring network reduction assume load representations of constant impedance. (ii) The development of system model proceeds systematically by the development of the individual models of various components and subsystems and their interconnection through the network model. The component models can be formulated to suit any degree of detail desired. This approach retains the identity of the generating unit and the DC link control in the system model. A 3-machine and a 13-machine power system examples are presented to illustrate the application of the algorithm for practical systems. 5) Improvement of dynamic stability through suitable locations of the controllers for DC link and Power system stabilizers (PSS) is investigated in the Chapter 5. Two analytical approaches are suggested. The first method is independent of the controller structure, and the second is based on eigenvalue sensitivity. It is shown that both the methods give nearly identical results in most of the cases. Validity of both these methods has been tested with several power system examples. 6) The principal aim of the Chapter 6 is to present a case study of a 3-machine system for the investigation of suitable feedback control signals in the design of the controllers for the DC link and the PSS for improving the dynamic stability. Root locus and modal control techniques are used for the study. The results show that the conventional control signals used for these controllers in the past are not necessarily the best and suggest better control strategies. 7) The concluding chapter summarizes the research results and indicates the possibilities for further work.

For more details click here Back

Title : *Analysis Of The Steady State And Dynamic Performance Of Voltage Controlled Induction Motor Drives*

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Abstract

It is a well established fact that the speed control of squirrel cage induction motors of small and medium sizes with fan-type loads is feasible, by voltage control, over reasonable ranges Although the voltage controlled induction motor (VOIM) drives are inefficient compared to inverter-fed and cycloconver-ter drives, the main reasons for its application are due to its reliability, simplicity and low cost Phase controlled thyri-stors can be effectively used for voltage control applications Although many schemes are possible, a wye-connected induction motor with a pair of back-to-back connected thynstors m each line is usually preferred for speed control applications. The use of VCIM drive for speed control applications re quires the analysis of the system response during steady state and transient conditions In this context the main contributions of the thesis can be summarized as follows 1) The application of "boundary value approach (EVA) to the steady state analysis using digital simulation 2) The development of hybrid models of induction motors sui table for transient and steady state analysis 3) Simplified, yet accurate,evaluation of the steady state performance of VOIM from the solution of nonlinear algebraic equations 4) Development of a linearized state space model of the VOIM and its application for predicting the stability of the VOIM drive from eigenvalue analysis 5) Development of transfer functions and the design and testing of closed-loop control system for the speed control A brief description of the work reported in this thesis is given below The BVA, which has been used earlier for the analysis of invert er-fed induction motor drives, is extended to the steady state analysis and simulation of the following cases, 1) wye-connected induction motor (isolated neutral) with a pair of back-to-back connected thyristors in eaoh line, 2) induction motor with delta oonneoted thyristors at the open star point, 3) wye-connected motor with a pair of back-to-back connected thyristor-diode combination in each line. BVA makes use of boundary relationships and superposition principles for the solution The mam features of this approach are a) the machine equations are invariant while the different modes of operation are accounted for by altering the forcing voltages, b) formulation becomes general and simple Analytical and experimental results and a comparative per formance of the drives with different thyristor configurations are presented Two hybrid models of an induction motor, that are well suited for the digital simulation of machines with terminal constraints, are developed The special features of the models are a) the identity of the motor terminals either on the stator side or on the rotor side is retained b) time dependence of the inductance matrix is eliminated c) the models are represented by simple equivalent circuits so that formulation of the state equations for any ter minal constraint is possible with direct application of network theory The following examples

are considered for the steady state and transient analysis using one of the hybrid models 1) a wye-connected induction motor with a pair of back-to-back connected thynstors m each line, 2) a delta connected induction motor with a pair of back-to-back connected thynstors in each line, A comparative study of the performance of these drives are presented A simplified analysis of a VCIM drive,during steady state, is described m which ,the motor performance is directly related to the control variables This relationship can be effectively used for the design of speed controllers during closed-loop operation Another feature of this simplified analysis is that the steady state operating variables (phase angle <fr, fundamen tal components of stator currents and rotor flux linkages and average torque) can be predicted accurately by solving three nonlinear algebraic equations for any given value of triggering angle, slip and source voltage The assumption made m the simplified analysis is that the rotor flux linkages referred to a synchronously revolving reference frame are constants during constant speed operation Validity of this assumption is confirmed analytically and justified by simulation results Using a linearized model, the stability analysis of the VCIM drive is performed Prom the eigenvalue analysis, it is observed that certain category of machines may experience instability at near maximum speed Using the linear model of the VCIM drive and its associated transfer functions, a speed controller for closed-loop operation is designed Classical control theory is used for the design of the controller Dynamic response of the closed-loop system due to perturbations m the load torque and reference input is determined both analytically and experimentally

For more details click here Back

Title : *Design Of Suboptimal AGC Regulatores With Performance Index Sensitivity Minimization*

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Supervisor(s) : *Aggarwal R P& Hole K E*

Abstract

Regulator design for power system automatic generation control (AGC) function is a multivariable system design problem and should be investigated using modern control techniques. The current advancement in optimal control theory coupled with the availability of high speed digital computes has enabled power system research workers to design advanced and ameliorated AGC strategies. The superiority of optimal control strategies designed using linear regulator theory over the conventional 'tie-line bias control' has been established due to better dynamic system performance, increased reliability and wider stability margins. However, an optimal regulator design is based on nominal plant parameter values while in practice the parameters are subject to variations. In the wake of parameter variations system performance deteriorates from its optimal value and may even become unacceptable. Therefore, it is mandatory to design AGC regulators ensuring minimal sensitivity to plant parameter variations. An optimal regulator implementation requires monitoring of all the state variables of the system of state reconstruction which may be prohibitive from cost and complexity considerations. To alleviate this problem, suboptimal output feedback regulator designs have been proposed in the literature. Most of the proposed AGC regulator designs are based on centralized control strategy whereas a decentralized regulator design is desirable to compete with the existing AGC schemes. Other problems of paramount importance are consideration of interaction between MW-frequency and MVAR-voltage loops, generation rate constraint and interconnection of several plants having widely varying characteristics. The implementation of an optimal AGC regulator on existing power systems also necessitates the investigation of some of the practical aspects. The present thesis addressed itself to the multifarious problems enumerated as above. A chapterwise summary of the work reported in the present thesis follows as described below: The first chapter introduces the automatic generation control problem along with the present trends in this area; thereafter, a review of the pertinent literature is given. The objectives and the scope of the thesis are also outlined. Second chapter is devoted to the design of a centralized suboptimal AGC regulator using output feedback. Minimal sensitivity to parameter variations is achieved by performance index sensitivity minimization approach. State-space model of a 2-area power system consisting of thermal plants with non-reheat turbines is considered assuming that each area represents a coherent group of generators. An iterative technique is presented for the proposed output feedback design based on the solution of a set of necessary conditions. In chapter 3, at the outset, a decentralized suboptimal regulator design based on multiple control structure constraints is proposed. The regulator in each area is constrained to be a linear time-

invariant combination of the output variables of that area only. An iterative algorithms is proposed constraining the gradient direction. Subsequently, the decentralized control design is modified to achieve minimal sensitivity to parameter variations with performance index sensitivity minimization. The decentralized control results in a performance degradation well within acceptable limits compared to be centralized controller implementation and an improved dynamic system response compared to that obtained with conventional control. System stability is ensured by checking the stability conditions with respect to fixed modes of the system. The fourth chapter addresses itself to the application of design algorithms discussed in chapters 2 and 3 to a system consisting of generating plants with widely differing characteristics. State-space model of a 2-area hydrothermal power system is considered. centralized AGC regulators are designed using feedback of a reduced number of state variables. Later in this chapter, decentralized AGC regulators are designed using different control configurations subject to multiple control structure constraints. In the fifth chapter, the interaction between the automatic generation control system and voltage control loop is considered. the objective of the study is to maximize the damping of frequency deviation with voltage regulator action. A state-space model of a 2-area power system is developed with exciter dynamics included in both the areas. A suboptimal decentralized AGC regulator is also designed. Sixth chapter is devoted to some of the aspects of controller design based on practical considerations. A suboptimal controller design is presented including the generation rate constraint by proper selection of state-weighting matrix elements. In the present chapter, some useful suggestions are also made for the implementation of AGC regulators designed using optimal control techniques on a typical power system considered. Finally, the seventh chapter concludes with a review of work reported in this thesis and gives an assessment of the further scope of research work in this area.

For more details click here Back

Title **:** ***Investigation Into A Class Of Multiple Loop Amplifiers***
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Supervisor(s) **:** ***Sarma K R&Prabhu S S***

Abstract

Deal with the deficiencies of the existing multiple loop amplifiers and new configurations and application have been developed. New one consists of only one positive feedback loop and the amplifier a is a finite gain amplifier. In the new structure unity gain a unity gain amplifier in the forward path and the emitter followers in the feed back path assure positive feed back loop for all conditions. Output of the using gain amplifier is inversely proportional to the loop gain A b DUE TO NEGATIVE FEEDBACK ua Av nearly unity. Linearization of up-to-isolators scheme eliminated the use of bandwidth limited operational amplifiers multiple loop amplifier suitable for Ic fabrication.

For more details click here Back

Title : ***An Investigation Of Electromagnetic Wave Propagation Through Anisotropic Dielectric Waveguides***

Author(s) : ***Chaudhuri Bidyut Baran***

Roll No : ***610462***

Supervisor(s) : ***Paul D K&Mathur Naresh C***

Abstract

For more details click here Back

Title : *Load Flow Contingency Evaluation And Optimal Power Dispatch In Large Scale Power Systems - Development Of New And More Efficient Methods*

Author(s) : *Arumugam N*
Roll No : *7710464*
Supervisor(s) : *Aggarwal R P& Pai Mangalore Anantha*

Abstract

This thesis concerns itself with the development of new and more efficient solution methods for load flow, contingency evaluation and optimal power dispatch in large scale power systems. Load flow is essential for power system planning, operation and control and provides voltages and power flows at different points in power system network for different operating conditions. Contingency evaluation involves determining the security of a system with reference to a set of next contingencies and constitutes the main function of the power system security analysis. Security functions like security monitoring and security analysis are now incorporated into the computer program to deal with different operating conditions as well as disturbances. On-line monitoring and real-time control of the system using process computer is essential in order to prevent or minimize costly system breakdowns. This led to the development or powerful calculation procedures for load flow and contingency evaluation procedure for load flow and contingency evaluation. These techniques must be simple, efficient and fast for implementation in real-time on moderate size process control computers. The Newton-Raphson method (NM) is the basic practical method best suited for off-line studies because of its quadratic convergence rate and better accuracy. Numerous other methods of load flow and contingency evaluation have been tested and published for off-line and/or on-line studies. The fast decoupled technique of Stott in polar coordinates (FDLP) gained popularity over other methods due to its fast computing speed and moderate memory requirements for off and on-line calculations. Recently, second order load flow techniques have been presented to improve accuracy and to reduce computer time of NM. The problem of optimal load flow (OLF) is very important because of the high fuel and other operating costs. The solution of OLF gives the values of control variables such as real and reactive power generations and transformer tap ratios for which the system operating cost is minimum. The OLF calculation is a complex operating cost is minimum. The OLF calculation is a complex nonlinear programming problem due to the large number of variables and constraints. To solve OLF efficiently for large practical systems, fast and accurate methods of load flow solution are needed. A comprehensive comparative analysis of different optimization techniques for the solution of OLF was given by Happ and Sasson. Dommel and Tinney proposed a practical and efficient method for the calculation of OLF by using NM. Later on, application of EDLP in the place of NM is also reported. The function of the economic dispatch program is to allocate the real power generation among the available on-line generating units so that the operating cost is minimized. To implement on real-time basis, it requires advances in the accurate calculation of penalty factors or a power flow solution which is both fast and accurate. This problem has been solved with approximate loss formulas as well as more accurate and faster methods. However, there is still a scope of improving these well known methods of load flow, contingency evaluation, optimal load flow and economic dispatch in terms of computation time. Present day power systems are large because of greater interconnections. To analyze such large scale systems with limited core storage, application of scarcity

oriented ordered elimination techniques and/or the various piecewise, decomposition and diakoptic techniques is needed. Recently, the hierarchical control of power system has been and continues to be studied intensively. In this method, the original system is decomposed into several smaller subsystems of areas coordinated by a central agency. It requires the use of small multi-computers with significant reduction in computer storage requirements. Sometimes, a net saving in computation time is also achieved. A survey of literature reveals that the hierarchical solution methods for OLF are limited to the optimization of real power flow only. (control of reactive power flow and transformer tap ratios is neglected). Keeping the above in view, this thesis presents solution techniques to the different problems considered. The scope of thesis is broadly divided into two parts. (1) Development of new load flow solution methods along with a theoretical study of the convergence characteristics with a theoretical study of the convergence characteristics for off-line and/or on-line studies and its adaptation to contingency evaluation and optimal load flow. (2) Development of load flow and optimal load flow methods for large scale power systems by a two level computation based on hierarchical control theory. The chapterwise summary of the work covered in this thesis is given as follows: Chapter I introduces the problems of load flow, contingency evaluation and optimal load dispatch. Then, the theory of hierarchical control is presented. A brief review of the state of the art and the scope of the thesis are enumerated at the end. Chapter II is devoted to the development of the following new load flow solution methods. i) Fast decoupled load flow in rectangular coordinates (FDLR): the rectangular version is derived by linear transformation from FDLP as well as direct from NM. It offers computational advantages of 5 to 10 percent speed over the polar version, while the memory requirements are similar. ii) Newton – Richardson method (NRM): this method is a variant of NM, obtained by combining both the chord method and the Newton-iterative method. It is about 2 times faster than NM for large systems and has the same solution accuracy and convergence rate as NM. The Jacobian is readily available for important applications like optimal power dispatch, sensitivity analysis and security constrained optimization, iii) Network – reduction method (NETR): The method is based on eliminating P-Q buses using sparse matrix techniques and applying NRM to an equivalent system consisting of only P-V buses. It is comparable to FDLP with regard to computing speed and memory space for the medium size systems. Test results of the IEEE 14 bus, 30 bus, and 57 bus test systems and a heavily loaded 28 bus system using FDLR, NRM and NETR algorithms are presented and compared with the results of NM and FDLP. In addition, the results obtained using FDLR for a 133 bus system are compared with the result of FDLP. Chapter III is concerned with contingency evaluation needed for power system security assessment. FDLR and NETR load flow algorithms developed in Chapter II are extended for the rapid and efficient simulation of network and/or power outages. FDLR incorporates the matrix inversion lemma and matrix updating algorithm in order to make use of the base case factors to obtain all contingency states as in prevalent competing methods due to Stott and Peterson. The proposed FDLR algorithm is faster than FDLP by about 10 percent. But the NETR algorithm has computational advantages over FDLP if the number of P-V buses is roughly about 10 percent. But the NETR algorithm has computational advantages over FDLP if the number of P-V buses is roughly about 10 percent of the total number of buses in the system. Digital simulation of a number of outage cases is carried out on the IEEE 14 bus, 30 bus and 57 bus test systems. The significant results of these system studies are presented and compared with the result of FDLP. Chapter IV deals with optimal load flow solutions and economic lad dispatch. A new optimal load flow calculation method using NRM load flow algorithm and a new fast economic load dispatch solution using NETR load flow algorithm in the solution approach of Dommel and Tinney are proposed. The method of solution using NRM gives an overall advantage in speed of approximately 2 to 21/2 times compared to

the approach of Dommel and Tinney without affecting the solution accuracy, convergence properties and generality of formulation. The solution approach by NETR is based on the assumption that the voltage magnitude variations at the P-Q buses are not too sensitive to the real-power changes and the reactive power equations of depend weakly on the phase angles of the voltages. This makes the algorithm very fast and operate with less storage. The optimal load flow and economic dispatch results of the adapted IEEE 14 bus, 30 bus and 57 bus test systems using the proposed NRM and NETR algorithms respectively are presented and compared with the result of Dommel and Tinney's approach. Chapter V describes a two level computational procedure for load flow and optimal load flow calculations in large scale power systems based on hierarchical control theory. It can be regarded as an application of decomposition. It is suitable for multicomputer configuration with less core storage requirement. It combines both the advantages of scarcity and decomposition. A two level load flow calculation method is described using NM, NRM and FDLP. Then, the multiarea optimization problem is formulated as an additively separable nonlinear programming problem in such a way that the optimization of both real and reactive power and transformer tap ratios is possible. The total Lagrangian function is decomposed into several sub-Lagrangians by introducing pseudo variables. The second level determines the pseudo variables and the associated lagrangian multipliers. The first level determines the subsystems solutions and the associated Lagrangian multipliers. The solution algorithm for optimal load flow calculations considering both equality and inequality constraints using the overall cost as the objective function is given in detail. The practical applicability of the proposed two level technique is demonstrated by obtaining the load flow and optimal load flow results for the adapted IEEE 30 bus and 57 bus test systems which are turn into 2 or 3 subsystems or areas. Chapter VI gives a theoretical study of the convergence characteristics of the load flow solution methods (FDLR, NRM and NETR) developed in Chapter II. The different load flow algorithms are expressed into the general nonlinear iterative scheme. For these algorithms, the convergence conditions, which guarantee the existence and uniqueness of load flow solution in a specified region of interest, are obtained by an application of the convergence theorem used by Wu. These conditions are verified by using an adapted IEEE 14 bus test system for different R/X ratio of the heavily loaded line. Chapter VII reviews the major contributions in the thesis. Further possibilities of research in this area are also indicated.

For more details click here Back

Title : *Execution Time Analysis Of Process Control Algorithms On Micro Computers*

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Abstract

Computer Process Control ha,s seen an upsurge mth the advent of LSI technology* A large number of such applications have appeared in recent literature* Algorithms have been designed to suit microprocessors. One of the aims of modern digital control algorithms is that the on-line control computations must be simple and fast* Standard estimation algorithms are reform.ulated and solved leading to algorithms which are easy to implement on microprocessera.With the availability of large number of microprocessor families, the issue of evaluation and selection of microcomputers, for a given application, has become significant. We believe, that the evaluation should be in terms of definite application areas^ Real time systems are characterized by strict timing constraints* In particular, microprocessors employed in process control applications must be able to meet the specified timing constraints# In other words the suitability of a processor for an application is execution time dependent* It is helpful if, for a given application, the estimation of execution time bound, on a given processor, is made without executing the program.Tills thesis attempts to contribute to the method of estimation of execution time bounds of control algorithms on microcomputers. This would aid in evaluation and selection of microcomputers for process control applications* We have assumed throughout the thesis that application programs will beXLXcoded in the high level language PASCAL, The PASCAL P-compiler has been modified to give, in addition to the P-code, information in the form of list structure of code embedded with key words which would aid in calculating execution times of programs* This list structure is taken as one of the inputs by an analysis program* The other inputs to the analysis program are the execution times of P-code instructions on various microprocessors and the number of times a program loop is iterated* Using these inputs the analysis program computes execution time bound of a program (which implements a control algorithm) on a microcomputer*Macros have been defined for P-code instructions on TDC316, LSI-U, PDP-ll/40, TI99O0, Z8000, and Intel 8086. Floating point routines were also written for the above processors* The processors are compared with respect to P-code implementation, implementation of floating point routines and implementation of several control algorithms*The control algorithms coded in PASCAL were PID controller algorithms, Kalman algorithms, Dahlin algorithms, Deadbeat algorithms, the finite time settling controller algorithm^ and the algorithm for optimal sampled-data control system* The estimation algorithms were the recursive least squares method and a Kalman filter* The digital filters were a notch filter and a Butterworth low pass filter* The modified P-compiler and the analysis program were used to obtain execution time boundsXlilfor each of the above applications* The compairison of microprocessors was based on execution time bounds obtained from the analysis program* Such an analysis is empirical as it assumes certain modes of translation of P-code to microprocessor code* The methodology adopted is quite general.Analytical formulae for execution time bounds were derived for several of the a,bove a^pplications* These formulae were parameterized in terms of microprocessor characteristics, such as execution times of arithmetic operations and

data movements, smd the basic structure of the algorithm with respect to its critical opera,tions. It has been shown that analytical formulae may be derived based on control a^lgorithm equations without writing PASCAL programs* It is found that the empirically obtained time bounds and the analytically obtained time bounds agree within + 5 per cent*�e have also shown that the currently available l6-bit microprocessors compare favourably with the last generation of 16-bit minicomputers both in terms of speed of execution and memory size required for implementation of control algorithms^ Among the microprocessors compared we have concluded that, with the published data, Z8000 takes the least time as well as storage to implement floating point routines. Based on our studies, we a^rrived at a relative evaluation of 16-bit micro--processors^XXTWe are conscious that it is an explorative attempt in the empirical study of microcomputers with respect to progrp,ns they exectite* Very many a,pplications must loe studied before a methodology can be generalized*has been attributed to excess point di^fect concentration generated at the high diffusion tempQ^^ature which gets

For more details click here Back

Title : *Studies Oscillations In A Class Of Coupled Systems*
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Abstract

Most of the physical systems are nonlinear. For the sake of simplicity in analysis, the nonlinear systems are approximated by linear models. In many cases, with may be sufficient but there are phenomena which cannot be explained by analyzing linear approximation. However, there does not exist any general method to analyze nonlinear systems with single/multidegrees of freedom. So the approach to study the behaviour of nonlinear systems is mostly through approximate methods. These approximate methods generally provide enough qualitative information regarding system behaviour. The most of the earlier works reported on synchronization and self-oscillations (which are important properties in nonlinear systems) deal with a system with single degree of freedom. There are a limited number of two degrees of freedom oscillator studies and these are mainly for freedom oscillator studies and these are mainly for conservative/quasiconservative systems. Of late, coupled VanderPol systems have become the subject of many investigations since they for the basic model for a variety of self-oscillatory physical situations. In this thesis, the recent method of solving weakly nonlinear differential equations, namely, the multitime technique, is used for analyzing synchronization (also sometimes termed as phase-looking), asynchronous quenching and self-oscillations in coupled VanderPol systems. The important contributions are: (i) A unified approach to the problem of synchronization and self-oscillations in a class of two-degrees of freedom oscillators through the method of multiple scales is proposed. Further analysis is carried out for the following situations. (ii) Synchronization in a system of VanderPol oscillators with weak linear coupling. (iii) Oscillatory behaviour of a system of VanderPol oscillators with weak nonlinear coupling. (iv) Oscillations which may be of a multiple frequency kind in a systems of VanderPol oscillators with strong linear coupling. (v) The jump hysteresis in a system of coupled oscillators consisting of a VanderPol oscillator and a tuned circuit. (vi) The synchronization and oscillations in coupled systems with external/parametric forcing. The chapter-wise summary of the work reported in this thesis is now given: The first chapter provides an introduction to the nonlinear systems and the nonlinear phenomena in oscillatory systems. A survey of some of the earlier works pertaining systems. A survey of some of the earlier works pertaining to this thesis is presented. The scope and objective of the thesis are also outlined. The second chapter contains a comprehensive discussion of the multitime technique to study the response of coupled oscillators for weak/strong and linear/nonlinear coupling. This constitutes the first part of this chapter. The second part considers weakly coupled oscillators. These are VanderPol oscillators with linear/nonlinear coupling. A detailed analysis for linear coupling of different kinds (i.e. displacement, derivative and acceleration) acting simultaneously has been carried out. The action of weak displacement/derivative coupling on the response of the coupled system is studied separately. The synchronization and oscillations are also investigated in weakly nonlinearly coupled VanderPol system. Here the response behaviour is completely described by a coupling parameter plane. In addition existence and stability of oscillations are discussed for all the cases. Digital computer simulation work is carried out to compare the analytical findings. The third

chapter considers the strongly linearly coupled situation. Unlike the second chapter where there is only single frequency for any particular oscillators; here there exist, in general, two frequencies of oscillations. Conditions for existence of stable oscillations are derived. There is no mutually synchronized solution in the sense that the two amplitudes variation of each oscillator are phase independent. Two separate models of the VanderPol oscillator are considered – one involving the usual nonlinearity and the other an additional fifth degree term. Various kinds of coupling between the two VanderPol oscillators are examined, specially linear strong coupling involving displacement, derivative and acceleration acting simultaneously. This case is fairly complex for the most general situation when there are unequal frequencies in the uncoupled state. For the case where there is only displacement coupling the more general frequency situation is analyzed. Both the models involving the cubic and cubic plus fifth degree tern are separately investigated. Significant difference between the two models are examined. The computer results are given to compare the analytical findings. The fourth chapter considers occurrence of jump hysteresis phenomenon in coupled VanderPol systems. A general model for the study of this phenomenon in coupled VanderPol systems. A general model for the study of this phenomenon is first developed. This model includes within it as a special case, models considered by VanderPol and Theodorchik. This model is ten analyzed for possible occurrence of jump in the amplitudes as well as frequencies. For examining amplitude of frequency jumps or discontinuities, the variable parameter is the uncoupled frequency of one of the uncoupled oscillators. The conditions for a jump up or jump down in amplitude and frequency are found to depend on the ratio between the damping constants of the two oscillators. Here also the digital computer simulation are given to verify the jump in the considered model. The fifth chapter discusses the case of weak linearly/nonlinearly coupled oscillators with external/parametric forcing. A general study of the linearly coupled forced VanderPol oscillators is carried out. The models of weak non-linearly coupled oscillators for the forces free case in the second chapter is again studied under the external forcing. It is shown in chapter two that in the coupling parameter plane two regions exist where there could exist stable oscillations at either of the two coupled frequencies. It is proved that external forcing to the other. Conditions are derived for the amplitude of the forcing which is required for this transition. In addition, the quenching of one of the two amplitudes is also illustrated. Furthermore, parametric forcing which gives rise to quenching of synchronized oscillations in linearly coupled oscillators is also investigated. The bound on the amplitude of parametric forcing is derived so that the synchronized oscillation gets quenched. The digital computer simulation results are provided for the verification of some of these results. The sixth chapter is the concluding chapter which presents an overall summary of the work and also provides some directions for future work.

For more details click here Back

Title : Pole Assignment Techniques For Power System Stabilization
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Abstract

This thesis is devoted to the application of various pole assignment techniqxiesi;o the practical problem of design of power system stabilizers. Power system stabilizers (PSS) are auxiliary feedback controllers which receive a signal from rotor velocity, frequency or accelerating power and provide a corrective input to the excitation system in order to damp out the oscillations in the system. The practical need for these controllers was felt by the power utilities when they started using fast acting static excitation systems. While it was initially thought that high gain voltage regulator loop with a fast acting static exciter would improve transient stability, the practical experience was that it led tp dynamic instability* I^namic stability is defined as the stability of the system for small perturbations such as random load fluctuations* Hence the dynamic stability can be studied using linearized system models* The problem of undamped oscillations in the system caused by high gain statip excitation systems has received much attention in the industry* A classic paper by DeMello and Concordia (IEEE Trans. PAS-88, April 1969) analysed the problem by constructing a simplified model of a single machine connected to an infinite bus and using the block diagram approach of classical control theory. Also by utilizing the intuitive concepts of synchronizing and damping torques, they explained the effect of the excitation system on the rotor oscillations and defined the objectives of a PSS. The confi guration of a PSS is chosen such that it provides a phase lead on the range of frequencies which may be experienced by the system depending on the loading conditions. Although the approach has provided a basic design method for PSS on individual generators in a system it has serious limitations. For example, there is the problem of coordination of PSS provided on different machines in a large system. One can say in general that the classical design techniques are heuristic in nature and are restricted to simple systems that can be reduced to a single machine infinite bus equivalent* Modern control theory has provided powerful tools for the analysis of control problems and design of control strategies even for large scale systems. In particular, they are characterized by problem formulation using general state space modelling and a systematic approach to the development of control algorithm to satisfy precisely defined control objectives in mathematical terms. A major development in modern control theoiy is the use of linear optimal regulators. These regulators have been suggested for the general problem of power system stabilization. Unfortunately this Has not been generally accepted by the power industry for the following reasons: (1) The controller is a proportional (gain feedback) type which requires feedback from all the states in the system. This is sometimes practically infeasible and definitely a drawback in large scale power systems. The philosophy of power system control has been invariably to use (a) decentralized controllers and (b) output feedback with dynamic compensation* Linear optimal regulator theory does not take into account these aspects

adequately. (2) The performance index used in designing optimal regulators is not directly related to the objectives of a practical designer. The study of pole assignment techniques in linear systems is of recent origin and continues to be an active research area of interest. The control objective is exact assignment of poles or eigenvalues in a system from the point of view of improving the system response. Modal control techniques require complete state feedback. There is a unique controller for a single input system, but-freedom is generally available in choosing the controller in the case of multi-input systems. Recent advances in modal control include utilization of the design freedom in a multi-input system to meet additional design criteria such as minimization of sensitivities of closed loop poles to system parameters* Pole assignment using algebraic or dynamic output feed back is of practical interest and much of the recent literature is devoted to this. Prom the viewpoint of system stabilization exact assignment of poles is not essential and pole assignment in a sector in the complex plane is of practical importance. However, the concept has not been investigated in the existing literature. In this thesis, the problem of design of PSS is viewed as that of assigning the poles corresponding to the dominant modes of the rotor oscillations,to stable locations. The design objective as stated by DeMello and Ooncordia is shown to be equivalent to shifting of the real part of the complex eigenvalues so that the rotor oscillations are damped out in reasonably short time* The exact pole assignment techniques using output feedback has been considered in this thesis for the design of PSS. The major part of the thesis is directed to the problem of dynamic output feedback with either a fixed or free structure of the compensator. Some of the existing algorithms have been modified for the particular problem under consideration and some new algorithms have been developed. A major contribution of the thesis is the development of an algorithm for the output feedback for pole assignment in a sector. Another algorithm for pole assignment into a sector which satisfies additional design criteria such as the minimization of controller gains, is also presented* The thesis considers the application of these techniques to both single machine and a large multi-machine system example. An outline of the thesis is given "below. 1) In chapter one, a review of the various PSS design methods as well as the pole assignment techniques from the existing literature is undertaken. The scope of the problem considered in the thesis is described* 2) In chapter two, the state space model of the system which is suitable for the PSS design is presented* The classical design objective of PSS is examined in the framework of state space modelling and pole assignmoat method. In particular, an analysis of the effect of excitation system on the rotor oscillations is undertaken using the state space model • It is shown that the calculation of synchronizing torque and the damping torque (introduced by the excitation system) is equivalent to "the approximate determination of the shifts in the imaginary and real parts of the complex pair of eigenvalues corresponding to the rotor oscillations. The conditions under which this approximation is valid are also derived. Thus an important contribution of this chapter is to present a mathematical basis for the concepts of synchronizing and damping torques, which are used by power engineers, and state the conditions under which they are valid* This establishes the background for the application of pole assignment techniques in the design of PSS* This chapter also presents a frequency domain analysis using Uyquist1 s(criterion which gives additional insight into the effpot of the excitation system on dynamic stability, 3) In chapter three, the modal control technique employing state feedback is considered* In addition to the objective of pole assignment • the important criterion of minimizing the sensitivity of closed loop poles to the system parameters is also met by the control algorithm. A new algorithm is presented where poles are shifted sequentially in groups and each time a dyadic controller structure is assumed* The final controller matrix is in general of rank greater than one and hernse this approach is considered to be more general than the one described in recent literature (G-owrishankar and Ramar, I.J.0.,April 1976). An example is given to illustrate this method and the results obtained are better

than those obtained using the previous method. 4) Chapter four is devoted to the study of the feasibility of exact pole assignment techniques for the practical design of PSS. In particular, two techniques are considered* The first one is based oa modal control. Here a fixed structure is assumed for the compensator. Output feedback gains are determined from a least squares minimization technique starting from a state feedback required for a specific pole assignment* The algorithm presented here is simple, but the final pole assignment is not necessarily exact. An algorithm based on the method of Sirisena and Choi (I.J.C., April 1975) for the design of dynamic output feedback has also be^n studied. Here the compensator structure is not assumed apriori but is obtained in the foim of a state space model* A nonlinear optimization routine is-used to minimize an objective function which L takes the minimum value of zero when the pole assignment is exact* This method is more general for the design of PSS; however the computations are significantly in creased. Both the methods considered in this chapter are illustrated using the example of a single machine system. 5) In chapter five, a new methodology for the - design of PSS is presented* Instead of arbitrary locations for the closed loop poles, the assignment is done into a sector in the left half plane with a precribed degree of stability* Both algebraic and dynamic output feedbacks are considered. An unconstrained optimization problem is formulated for pole assignment into the sector. New algorithms are also developed that assign the poles into the sector and, at the same time^ minimize an objective function such as the sum of the squares of the controller gains• Nonlinear programming methods are used for obtaining the solution• The methods developed in this chapter are illustrated by designing PSS for the single machine system* 6) A case study of a large practical system containing 13 machines is taken up in chapter six. The PSS is to be designed for three largest units in the system. This is a realistic example and the design of PSS based on single machine, equivalent ; system is often inadequate in such cases. However, the methods considered in the previous chapters are general enough to be | applied in a multimachine system and this case study illustrates j this point* i i The system model is first developed along the lines given in chapter three. However, a slight departure is made in obtaining the network: equations and eliminating the non-state variables. A novel method is presented where the power flow equations used for determining the operating point of the power system are directly used for eliminating the nonstate variables* For the sake of simplicity, saliency has been ignored and the machines not equipped with PSS are represented by the classical model of a voltage source behind transient reactance. The method developed in chapter five is applied for designing decentralized stabilizers in which the feedback signal for an individual stabilizer is obtained from the same machine for which it is equipped; The results of the case study are presented. 7) The concluding chapter summarises the research results and indicates possibilities for further work in this area.

For more details click here Back

Title : *Factors Of Program Complexity And Their Effects On Program Comprehension*

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Abstract

A prime concern of the software industries has "been development of programs which are easy to understand and maintain* Through a desire to reduce the perceived complexity of programs so as to make them easily understood, this has led to various studies directed towards identification of factors contributing to psychological complexity of programs and development of complexity-reducing methodologies* Program understanding may he viewed as two stage process* In the first (interpretation) stage, the explicit facts about the program are abstracted for mental represen tation. In the second (learning) stage, various meta-inferential techniques are applied to search for rules (implicit facts) hidden under the gathered explicit facts "by suggesting hypothesis for test and eventual confirmation into such rules* Several variants of the above model have been presented in literature as models of program under standing* * The psychological complexity of programs will be affected by all those factors which either aid or hinder the interpretation and learning of the programs The features of the program which suggest an analogy or estab lish an association with a problem domain are expected to facilitate learning by reducing the effort in search of hypothesis• These features of the program are contained in comments, variable names, data and control organizations, etc., and are collectively termed as ^eaningfulness1 of the program* The abstraction of facts about a program may involve mental expansion of program text in branch free sequences of statements or blocks followed by mental execution of these blocks. Control structure and data structure are expected to play an important role in formation of above blocks and their mental execution. They may also aid in ^eaningfulness* of the program* The limited capacity and volatile nature of human short-term memory make the size of the program an important factor of complexity* This thesis establishes these four algorithm dependent features: size, control structure, data structure and computation structure of program1 as factors of program complexity and studies their effect on program understand ing. The thesis also studies the effect of !meaningfulnessT of programs on their understanding. id The formal abstraction of structures of program objects or data are claimed to have important hearing on program under standing. Many new programming languages (OLU, ALPHAKD, etc,) have been designed to incorporate the methodology of data abstraction* Some formal aspects of data abstraction have been studied in the thesis. The major work of the thesis is outlined below along with results and conclusions* A four factor judgemental experiment was conducted with

experienced programmers as subjects to study the con tribution of factors of size, control structure, data struc ture and computation structure to program complexity* These factors will be referred as 4-factors of program. Information integration theory was applied to identify the underlying rule of integration of various factors of program complexity. The result of the experiment was: (1) Pour factors of the program contributed indepen dently to perceived program complexity. A second experiment was conducted to investigate the effect of TmeaningfulnessT of the expressions and the number of operands in the expressions on their evaluation• The 'meaningfulness* of the expressions were due to their referential meaning in some problem domain. The results of the experiment were: (2) It was easier to evaluate meaningful expressions than the meaningless ones* xii (3) The evaluation of expression "was affected by number of operands in them. The purpose of the third experiment was to study the effect of meaningfulness of the program and number of vectorsf matrices, etc., referred to as numerosity of data structures, on program understanding. The value of meaningfulness was controlled by selecting variable names which were suggestive of their meaning and purpose and familiarity of the subjects with the problem* The results were: (4) The Meaningfulness* of the program facilitated their understanding. However, there was one interesting exception to this conclusion. (5) The numerosity of data structures in the program did not affect program understanding significantly• The above result (5) and the exception to conclusion (4) are against the intuitive expectation* The results of the further experiments indicated that these unexpected results were due to special features of the program used in the experiment* The uncontrolled feature dominated over the controlled factors. Two measures of program comprehension were also compared in the experiment* These above experiments indicated the overwhelming strength of iirfluenceof 'meaningfulness1 factor- It was xlii decided to use programs which were as uniformly meaningful as possible in the experiments* Many programming standards of real life endeavour to achieve just this situation• A 3x3 factorial experiment was conducted to study the effects of control and computation structures on program understanding. The results of the experiment were: (6) Factor of computation structure (controlled by number of assignment statements and the number of operands in each) affected program understanding. (7) The numerosity of control statements in the programs did not increase their control structure complexity, The regularity in the syntax and semantics of the control structure of the progam facilitated under standing* The above three experiments were 1- and 2-factor experiments* The subjects of the experiment 2 and 3 were novice programmers* These experiments did not permit the study of interaction among the factors* The class-room environment and the strict time schedule of the course precluded use of large programs and inclusion of more factors in the experiment* A four factor experiment was conducted with experienced programmers as subjects* The results of that experiment were: (8) All the factors except program size and some of their interactions affected program understanding* The differences in the size of the programs were not large enough to affect program understanding. In another experiment, the sixteen programs used in the previous experiment were subjectively rated for their complexity. The results, in general, confirmed the findings of the previous experiment. The results of the

experiments suggest that all the four algorithm dependent features of the program along with tmeaningulness' of the program affect program understanding. Quantitative syntactic measures for complexity of the factors do not represent their contribution to psychological complexity of program* The limited data structuring constructs of FORTRAN did not permit the experimentation with various aspects of factor of data structure complexity. As an alternative to experimentation, different specification techniques for data abstraction were studied theoretically and compared for their good and bad features. (9) We have proved that Pamasf earliest (1972) specification technique is powerful enough to specify any computable function* Further, it has been proved that the completeness and consis tency of the specification are not decidable. Finally, some modifications are suggested in the above technique to facilitate the specification of any exception handling strategy and 'delayed effects1• The thesis, in the end, also discusses the limitation of the present work and suggests direction for further research•

For more details click here Back

Title : Dynamic Equivalents For Power System Studies
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Abstract

Two major problems in the stability studies of present day large scale power systems are (i) dimensionality of the model and (ii) numerical stiffness of the system equations. The problem of dimensionality arises because of the large size of the interconnected power system and the recent trend to represent the dynamics of a generating unit (synchronous machine and the associated controls) in greater detail. In addition to the dimensionality, the full scale dynamic model of a large power system is associated with the problem of stiffness in the numerical integration because it accounts for both slow and fast phenomena in the systems. Hence the digital simulation of large systems become expensive in terms of computer time. Since the digital simulation for different loading levels, network configurations and disturbances is a routine feature in the power system planning and operation, the use of full scale models is uneconomical and undesirable. Therefore, simplified and reduced order models of power systems which apart from alleviating the difficulties mentioned above, describe the response of the system within engineering accuracy are constructed. The problem of dynamic equivalence is concerned with deriving such reduced order model. This thesis addresses itself to some aspects of this problems for transient (nonlinear model) and dynamic stability (linear model) studies. The concept of study system and external system (Undrill 1971), which is generally used in the development of an equivalent for transient stability studies, is familiar to power engineers. Thus the reduced model of a power system for transient stability studies consists of the full scale representation of the study system and an equivalent of the external system. Such a reduced order model (which we will refer as the equivalent of system) is used to obtain the response of the study system for local disturbance as it is affected by the external system. Among the equivalents for transient stability studies, the principle of coherency based dynamic equivalence is likely to be widely used in power industry because of the its simplicity, accuracy and the fact that physical correspondence with the components of a power system is retained in the equivalent. The basic steps in the development of a coherency based dynamic equivalent are (i) identification of the groups of coherent generators valid for a set of fault locations in a given study system and (ii) dynamic aggregation of each coherent group into an equivalent generating unit. Identification of coherent generators constitutes a key step in the construction of a coherency based dynamic equivalent. Since the knowledge of coherent groups valid for a set of fault locations in the given study system is a basic requirement for constructing the equivalent the problem is to identify the

groups for multiple fault locations in the study system. The method for grouping the generators should be simple and efficient in terms of computer time. The reliability of results is of prime importance because there should not be any need to verify the results from the base case swing curves. Formation of coherent groups on the basis of base case transient stability studies results in prohibitively large computer times. Many of the existing methods of coherency analysis (Lee, Spadling, Voropai and others) do not reflect the maximum angular excursion between the generators during the transient period and hence are empirical. The method of linear simulation proposed by Pod more uses simplified swing curves and has been proved to be reliable by extensive testing. However, the method requires storage and comparison of swing curves. Furthermore the linear simulation has to be repeated for every change in the fault location. Therefore there is a need for a direct criterion for coherency analysis which is suitable for multiple fault locations and does not resort to storage and comparison of swing curves. Over the past few years, although the equivalising techniques have been perfected, the basis for determining the levels of complexity in modeling the generators (before an equivalent is developed) has remained largely heuristic. For example it has been a common practice to represent the generators away from the fault location with lesser detail than those in the vicinity of it, thereby ignoring completely the electromechanical effects during the transient period. In the literature, the admittance and reflection distance measures (Lee and Schweppe) are proposed for the above purpose. While the admittance distance is a static measures, the reflection distance partially reflects the electromechanical effects during the transient period. Therefore there is a need for an improved criterion which demarcates a power system into different regions for the purpose of modeling the generators. The existing techniques for simplifying the linear dynamic models of power systems for dynamic stability studies are mainly based on modal analysis (Kuppurajulu, Altalib, Van Ness and others) i.e. retaining the dominant modes and eliminating insignificantly excited modes. This however, involves the computations of eigenvectors and reciprocal basis vectors, which becomes unwieldy if the size of the system matrix is large. Therefore the time required to compute the reduced model may prove to be prohibitive unless the equivalent is used for multiple stability studies. The state variable grouping techniques (Kuppurajulu) does not require these computations but the method requires apriori knowledge of the behaviour of the state variables. Thus there exists a scope for developing simpler technique with a rigorous mathematical basis for simplifying the linear models of power systems for dynamic stability studies. This thesis present solutions of some of the above mentioned problems. The scope of thesis is broadly divided into two parts. (i) Identification of coherent generators and decomposition of power system using a new approach and construction of coherency based dynamic equivalents. (ii) Application of the singular perturbation theory to obtain simplified models and simulate the power system for stability studies. A chapter wise summary of the work done is this thesis is given below. The first chapter includes introduction to the problem a brief review of the existing methods and the scope of the thesis. The second chapter deals with a new method for identifying the coherent generators in power systems. The method is analytical and uses the concept of coherency index for grouping the coherent

generators. The linearised swing equations of the system are cast into the usual state space form after selecting the generator nearest to the fault location as reference generators. Effect of fault is taken into account in terms of an input vector for the linear zed system as done by Pod more. A closed form solution of the system equations is obtained in terms of the decoupled modes. The extent to which each mode is excited is determined by the fault condition under consideration. A new concept of coherency index which is a measure of the maximum angular excursion between two machines during the transient period is introduced. The coherency index exploits the nature of the closed form solutions in terms of the eigenvectors, reciprocal basis vectors and the state of the system at the time of fault clearing. Therefore the coherency index between two machines serves as a logical criterion to determine the coherency between the machines. When it is required to determine the groups for different fault location in the study system the eigenvectors and reciprocal basis vectors corresponding to a new reference generator are not recomputed. Instead they are derived from the existing ones by using a similarity transformation. The use of similarity transformation eliminates the repetitive computations for different fault locations. In a similar manner the method can be easily adapted for the change in the geographical configuration of the study system itself. Two power system examples are presented to validate the theory in practical systems. In the third chapter the problems of decomposition of power systems and construction of coherency based dynamic equivalent are taken up. The decomposition of a power system into different regions is primarily aimed at determining the relative degree of complexity in modeling the generators before an equivalent is developed. A new concept of electromechanical distance which is used as the basis for decomposition of a power system is presented. The concept is similar to coherency index except that it is measured between a generator in the external system and the reference generators in the study system. The decomposition of power system is linked with coherency analysis and the possibility of grouping the generators in each region separately is established. The equivalising methods for combining the terminal buses of coherent generators and the aggregation of coherent units are described. A case study of a typical power system in India illustrating the principle of coherency based equivalents is presented. The rest of the thesis is devoted to the applications of singular perturbation theory to the problems of dynamic simplification and simulation in power system stability studies. The primary motivation for using the singular perturbation techniques is that in this techniques the slow and the fast subsystems are solved separately and in two different time scales. The techniques first reduces the model by neglecting the fast phenomena in the system. It then improves the approximation by reintroducing their effects as boundary layer correction calculated in different time scale. Further improvements in the solution are possible by evaluating the subsequent terms in the asymptotic expansion. These features of the singular perturbation theory make it very suitable for applications in large scale systems. The techniques has been extensively applied in optimal control and linear regulator problems by Kokotovic and others. It has also been used in other branches of engineering. However so far the techniques has not been used in the stability studies of large scale power systems for model simplification and subsequent simulation. The fourth chapter describes the applications of singular perturbation

theory to power system dynamic stability studies. First a state space model of a multi machine power system for dynamic stability studies using the detailed representations of the dynamics of the generating units is obtained. These system equations are transformed into the singular perturbation form by properly identifying the perturbation parameter '$\in$' in small rotating masses, small time constants and large gains etc. the use of '$\in$' in practical systems is symbolic and represents the presence of fact as well as slow subsystems. The presence of these subsystems in a given model is identified by a criterion, which examines the eigenvalues of the systems matrix. The degenerate system i.e. setting $\in = 0$ in the system equations gives the simplified model of the original systems. In the simplified model, the identify of the corresponding state variables of the original systems is retained. The response of the degenerate system is further improved by adding the terms corresponding to '$\in$' in the asymptotic expansion to obtain a first order solution. A single machine infinite bus and a three machine example is presented to illustrate the theory. It is also established that the first order solution is a good approximation to the response of the original systems and can be obtained with far less computer time as compared to simulating the original systems. Chapter five deals with the singular perturbation approach to the transient stability studies in power systems. The techniques uses the method of asymptotic expansion as applied to nonlinear differential equations (initial value problem). The relevant theory is described and illustrated with the help of a numerical example. The difficulties encountered with nonlinear models of power systems are clearly brought out and explained. A summary of the contributions in the thesis and the scope for further research in this field are given in the concluding chapters.

For more details click here Back

Title : Studies On The Process Control Of Device Parameters Of Silicon Pin Diodes

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Abstract

There is no dearth of literature predicting the terminal characteristics of PIN diodes from the given device paraineters like the diode area^ the thickness and the resistivity of the I-region and the excess carrier lifetime in this region* On the other hand only few-publications deal mth obtaining the desired device parameters from a given wafer, may be due to the proprietory nature of the results* PIN diodes for microwave and photodetector applications need very high resistivity I-region for good perfoimance* Silicon wafers with an uncompensated resistivity as high as 30,000 ohm-*cm are now commercially available for PIN diode manufacture. Change iu sucfcL a W-gh value ot resistivity during wafer processing is a widely observed phenomenon^ Hence, a study on the degradation of resistivity and also excess carrier lifetime during wafer processing is of paramount |||iportanee« SuchXIa study has been made in the present work on PIN diodes fabricated on a number of wafers with different starting specifications* The various factors - crystallographic as well as metalliirgical - responsible for the degradation of the resistivity and the lifetime during processing have been examined. Finally» a process has been developed which nearly preserves the starting wafer resistivity^Unlike many other diode characteristics, the break-* down voltage of a PUT diode is not uniquely related to the device parajneters. This is mainly due to the electric field concentration at the junction surface and at the process induced defects generated in the I-region* Hence additional investigations were carried out to understand the cause for reduction in the breakdown voltage of fabricated PIN diodes• Conspicuously, achievement of nearly ideal breakdown voltage is a clear indication of the excellent quality of the processed wafer?16 5 Low oxygen content (less than 2x10 atoms/cm), 3to 10 K Ohm-cm silicon wafers with different dislocationdensities were used in the present investigations. Allthe crystallographic, metallurgical and electrical parametersof the starting wafers used have been specified. ResistivityXXIof the starting wafers was determined from C-Y characteristics of aluminum Schottky "barriers made on the wafers• The dislocation density of the wafers was checked by the Van Sirtl etching.For device fahricationy the wafers were cleaned^ chemically etcheci and were subjected to blanket diffusion of phosphorus and boron at 1200^0 for 25 hours* Different high temperature processing methods like wafer heating and cooling rates, simultaneous and successive diffusion and performance or omission of POGl^ souiroe gettering were adopted to study their influence on the resistivity and the excess carrier lifetime in the I-region# Most of the precautions suggested in the literature were adopted during high temperature wafer processing to avoid the plastic deformation of the wafers causing dislocation generation. The quality of the processed wafers was checked by the Z-ray topograph of the I--region of the diode • 'Eo plastic deformation or elastic strain was observed in this region. Nickel-^gold ohmic contacts to the diffused wafers were made by using electroless deposition* The wafers were then cut into 1.5x1.5 mm chips to obtain plane I^Ilt

diodes. Bach chip was separately etched chemically to remove the edge damage•X2.XXMeasurements were performed on the faTpricated diodes to determine the I-region resistivity and the excess carrier lifetime in this region* The resistivity was obtained from 1/C vs* V characteristic of the fabricated diodes* Open circ-uit voltage decay (OCVD)^ double pulse and forward I-V methods were adopted to estimate the excess carrier lifetime? Only the double pulse method was found to give a reliable estimate of the lifetime. Hence, this method was used to measure the excess carrier lifetime in I~region of fabricated diodes*Slow cooling of the wafers from elevated temperature has been found desirable not only for preservation of high value of starting wafer resistivity but also for achieving a higher excess carrier lifetime in fabricated diodes. Slow furnace cooling at the rate of S^T^G/minute has been found to be sufficient to preserve the high value of starting wafer resistivity* On the other hand considerable change in the resistivity and the lifetime has been observed in the wafers fast cooled* Here^ fast cooling means retracting the wafer loaded boat from the centre of the flat zone to the mouth of the diffusion tube in 5 minutes* The degradation in these two parajneters due to fast cooling has been attributed to excess point di^fect concentration generated at the high diffusion tempQ^^ature which getsXXVfrozen in the fast cooled wafers* The observation that the reduction in these parameters is more in case of dislocation free wafers than that for wafers with moderate and high dislocation density supports this hypothesis*9No appreciable improvement in resistivity is obtained in fast cooled wafers after P0C1« source gettering* This indicates that metallic impurities, particularly iron^ had no significant role ,to play in resistivity change* Wafer heating rate has been found to play little role in influencing the resistivity and the excess carrier lifetime provided that the plastic deformation of the wafer due to excessive thermal stresses is avoided during heating*The I-region resistivity in the diodes fabricated using successive diffusion (needing two high temperature heat-cool cycles) was not very much different from the resistivity in diodes fabricated using simultaneous diffusion (needing only one high temperature heat-cool cycle) xinder the same wafer heating and cooling rates* This indicates that repeated heating and cooling of the wafers do not degrade the resistivity* However, repeated heating and cooling has been found to degrade the excess carrier lifetime considerably•Breakdown voltage of diodes fabricated under the same process conditions was almost the same for dislocation freeXVand moderate dislocation density (around 2800 coimts/cm) wafers while it was 10-155^^ lower for high dislocation density (around 25^000 coimts/cm) wafers• In all the cases the breakdown voltage was considerably smaller than the theoretically calculated value? To check whether surface effects were responsible foi* this lowering or a major degradation had occured in the starting wafer quality, etch contouring studies, which minimise surface effects, were undertaken* Considerable enhancement in the breakdown voltage of diodes made on dislocation free wafers was observed while there was no noticeable increase in diodes made on high dislocation density wafers? This denotes that the breakdown voltage of diodes made on dislocation free wafers is influenced by the surface effects while the breakdown voltage of diodes made on high dislocation density wafers is inherently limited by the dislocations in the wafers# Some of the fabricated diodes showed abnormally low breakdown volt age • Van Sirtl etching of I-region of these diodes exhibited a linear defect with a dislocation and an impurity preciptate at its ends* Ohance dust contamination or particle contamination from devitrified quartz tube has been pointed out to be the cause for sudi a process induced defect CDMA systems. We observe that the OOCs constructed using.

For more details click here Back

Title : Studies In Non-Linear Discrete Time Systems
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Abstract

For nonlinear systems, described by either nonlinear differential or nonlinear difference equations there is unfortunately no general procedure for obtaining solutions in closed form. In fact, when a physical problem leads to nonlinear differential (or difference equations, one is most often content with a qualitative description of the solution together with a numerical approximation. Most engineering situations are inherently nonlinear, and can be successfully linearised only for particular operating in order to apply known linear techniques. However, a considerable number of useful engineering problems cannot be adequately linearised. Both weakly and strongly nonlinear continuous time systems have been investigated by various persons. However, little work has been reported on the analysis of discrete time systems, in particular nonlinear discrete systems. Since 1960 discrete systems have gone through a rapid change in the control area and the principle of optimal control, the concept of state variables, stability studies by Liapunov's method etc. have been used for discrete study. The well known technique of Krylov-Bogoliubov averaging method has also been applied to a restricted class of Nonlinear Discrete Time Systems to obtain approximate solution. In this thesis, nonlinear difference equations are considered and a detailed analysis is carried out for both autonomous and nonautonomous situations. Nonlinear difference equations arise commonly in the analysis of various discrete time problems such as sampled data control systems, digital filters, biological oscillations etc. analysis of nonlinear difference equations in the time domain have however been studied to a much lesser degree than their counterpart-non-linear differential equations. The major contributions in this thesis are listed below: 1. A new method, known as discrete multiple scale perturbational technique, for analysis of nonlinear difference equations is introduced, which is sufficiently general to consider both autonomous and nonautonomous descriptions. This method is based on the introduction of two separate independent time scales-a fast time scale and a slow time scale. This technique has been used extensively to study a class of differential equations (both ordinary and partial), but there has been no instance of its application to discrete time systems, except the paper by Hoppensteadt et al. dealing wit a system of difference equations in matrix form, in which the discrete time model is obtained through the well known Taylor series expansion. The proposed multiple scale perturbational technique, on the other hand is developed using the known properties of finite difference operators. 2. The discrete multiple scale perturbational technique has been applied to a class of nonlinear difference equations to obtain both qualitative and quantitative information. Linear and nonlinear difference equations under free and forced situations are analysed using the proposed technique. Super/sub harmonic oscillations under strongly forced condition are also investigated through the proposed technique. 3. The multiple time method is applicable only for a polynomial kind of nonlinearity. The

remaining part of the thesis is devoted to the analysis of nonlinear difference equations with saturation type of nonlinearities which are common in digital filters. These nonlinearities are due to adder over flow and quantization during addition or multiplication of two or more signals. The present study is limited to second order digital filters (which are in fact basis blocks for higher order systems) with over flow saturation nonlinearity. The present study has focused on the following new investigations: (i) The existence of limit cycles with different periods for parameter values outside the stability triangle. (ii) The location of a region outside the stability triangle in the parameter plane in which the output sequence dies down to zero monotonically. (iii) Under forced situation, conditions are derived for the existence of jump phenomenon as well as nonlinear sustained oscillations when the parameter values, the magnitude and the frequency of the input function are known before hand. A chapterwise summary of the work reported in this thesis is given now: The first chapter provides an introduction to the nonlinear systems and nonlinear discrete time systems in particular. A survey of some of the earlier work pertaining to this thesis is presented. A brief description of second order digital filters, the nonlinear phenomenon introduced due to finite wordlength registers and their effect on the normal operation of the filter are discussed. The scope and objectives of the thesis are also outlined. The second chapter is concerned with nonlinear difference equations with weak polynomial type of nonliterary under free and weakly forced situations. The proposed discrete multiple scale perturbational scheme is applied to linear as well as a class of nonlinear difference equations and the deduced results are compared with exact solution obtained by computer simulation. For weakly nonlinear systems, a Vander pol type model is considered and its limit cycle oscillations are investigated. The stability property is studied by a variational approach. The discrete version of the Duffing equation under free and weakly forced situations are also taken as illustrative examples and the response characteristics such as variation of amplitude with input frequency are obtained. For weakly forced and weakly damped case, the concepts like vertical and horiozontal tangents in the steady state response characteristics are also studied. Chapter three deals with the important concept of super/subharmonic oscillations in nonlinear discrete time systems under strongly forced situation and the analysis is carried out through the multiple scale perturbational technique as well as by harmonic balancing method. A Duffing type equation is considered and the possible super/sub harmonic oscillations are obtained. In the fourth chapter a saturation type of nonlinearity is considered which is common in digital filters. For a second order digital filter with overflow nonlinearity under force free condition analytical expressions are derived to obtain different regions in the a-b parameter plane for sustenance of different periods of limit cycle oscillations. Besides the stability investigation another interesting contribution is to locate the region outside the stability triangle in the a-b parameter plane in which the output sequence decays to the zero solution monotonically for a particular set of initial values of the filter variable. The region in the parameter plane and the initial condition loci and obtained for such a monotonic response. The fifth chapter focused on the investigation in digital filter under forced situation, known as 'jump phenomenon'. Jumps exist in second order digital filters, for a specific filter parameter values and the magnitude to periodic input function, whenever there is a disturbance in the filter variable. For a given input frequency, conditions are derived in terms of the filter coefficients and the magnitude of the input function for the existence of a jump or nonlinear sustained oscillation. Location of regions in the a-b parameter plane for existence of such nonlinear phenomena are also shown by graphical construction of the derived conditions. In addition to the above nonlinear phenomena in forced digital filter, the possibility of the existence of subharmonic oscillations are also investigated. The work reported and the contributions made in this thesis are reviewed in the sixth chapter. This chapter concludes with an assessment of the scope for further research work in this area.

For more details click here Back

Title : ***Study Of Current Transport In NonhoMogeneous Rectifying Metal- Semiconductor Contacts***

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Abstract

The study of metal semi conductor junctions started in 1874 with the work of Braun [1]. Although more than a century has elapsed since then, the understanding of the metal semi conductor junction is still far from complete. Perhaps the main reason for this is the fact that the performance of semi conductor junction is strongly dependent on processing, which in turn controls the conditions of the metal semi conductor interface. For example, it is commonly found that depending upon the condition at the inter face, the rectifying metal semi conductor junctions (Schottky barrier diodes) made on low doped silicon, GaAs etc. show either a temperature independent or a temperature dependent ideality factor. The study in the present thesis has been mainly directed towards the understanding and clarification of some of the ambiguities in those cases where the ideality factor is temperature dependent. Such ambiguities have been detected in the published literature concerning the assignment of the mechanism of current transport in some specific metal semi conductor diodes. The clarification of these ambiguities has been brought out in the present work by incorporating the fluctuation of geometrical and material parameters at the metal semi conductor interface [2]. A de scription of the ambiguities under consideration here would become easier if we first consider the commonly used method for assignment of the mechanism of current transport in 'homogeneous' Schottky barrier diodes; the term 'homogeneous' implies that there is no fluctuation of geometrical and material parameters across the metal semi conductor interface. The method of assignment of the mechanism of current transport for homogeneous Schottky barrier diodes; is well known and was developed by Saxena [3]. This method consists of obtaining the current voltage (I - V) characteristics in the forward region at different temperature (T), and thereby plotting nT versus T from the slope of the 1n I - V plot, where n is the ideality factor of the diode. Different mechanism s of current transport are identified by their characteristics nT versus T plot given in Fig. 1.2 where the curves I, II and III represent the cases where the thermionic emission (TE) is the mechanism of current transport with unity ideality factor, with i deality factor greater than unity and with T o effect respectively. Curves IV and V correspond to thermionic field emission (TFE) and field emission (FE) respectively. This method of assignment of the mechanism of current transport has been used by many workers. Some [4] have found that in the case of metal – (low doped) silicon diodes operating above room temperature the experimentally obtained nT is independent of temperature. Thus the assignment of transport is made to be by field emission. This however is contrary to the

common experience [5,6] that Schottky barrier made on low doped silicon and operating at temperatures higher than room temperature have thermionic emission as the mechanism of current transport. In the present work we have demonstrated that in the presence of fluctuations in geometrical and material parameters (transverse to the metal semi conductor interface) there is a definite possibility of obtaining a temperature independent plot of nT even in some of those cases where thermionic em ission is the dominant mechanism of current transport. Thus one concludes that the correspondence of field emission with temperature independent value of nT is not unambiguous. The repercussions of this conclusion are obvious – the nature of the nT versus T plot is not uniquely relatable to a specific mechanism of current transport. The role of fluctuations mentioned above in current transport has been incorporated in the present work in an intuitive fashion [2]. We have observed that the fluctuations of E o , which is a characteristic energy characterizing the interface distribution for a diode showing T o effect (see Levine [7], can play a dominant role in current transport. Further more, we have assumed that the different areas of Schottky barrier have dif ferent Eo, ‘s and the distribution is Gaussian such that SS iΔ =221psexp { - OIOIO EEE Δ− }2)(22s (1) where ΔS i is the area of a patch with E o between E oi and E oi + ΔE oi , E O is the mea n value of the E oi ‘s σ is the standard deviation and S is the total area of the diode. Under these assumptions the expression for the total current using thermionic emission model is given by I = ∑iS 221psexp { - }2)(22sOIO EE − A * T 2 exp (- kTBiq f) x exp ( )kTqV ΔEoi (2) Where φBi is the barrier height of the ith patch for an applied voltage V. using equations (1) and (2) the I - V characteristics and hence ( )1 V nI∂∂ - 1 were evaluated at different temperatures. Then using the relation, ( )1 V nI∂∂ - 1 = qnkT (3) the nT versus T plot was obtained. Depending on the values of E O and σ, it has been possible to get temperature independent nT for some temperature ranges, although the mechanism of current transport in equations (1) – (3) is only thermionic emission. Similar calculations have been carried out for Schottky barrier with a thin oxide layer between the metal and the semi conductor. Fluctuations in the interfacial oxide thickness have been incorporated in this calculation. It has been observed that the fluctuations in oxide thickness do not appreciably change the nature of the nT versus T plot. Thi an d the previous calculations considering the fluctuations in E o are the subject matter of the first and the second chapters of this thesis. An experiment has been designed to verify the theoretical model mentioned above. For this a large number of isolated small area (homogeneous) diodes have been prepared and the nT and T plot of each has been obtained. These show a straight line plot with an intercept T o where there is a scatter in the value of T o for different diodes. This has been true even in the case of diodes made on the same wafer. We have selected three or four diodes of different values of T o and connected them in parallel. Then the nT versus T plot of the combination has been obtained and it has been found that over certain range of temperature nT becomes independent of T. the condition under which these observations have been made and other details of the experiment are given in Chapter III. Having noted that the fluctuations in physical parameters could cause the ambiguities in the determination of the mechanism of current transport we have proceeded further to determine some phenomenological parameters which would correlate T o with

geometrical and material parameters of the interface. One such parameter, E o , which is the characteristic energy d escribing the assumed exponential distribution interface states has already been introduced earlier. Regarding E o , we note that the T o effect is not unique to an exponentially distributed surface states as predicted by Levice [7] but to the constancy of t he slope of 1nQ SC - φB plot at all temperature and bias, as noted by Crowell [8]. Here Q SC is the total depletion charge in the semiconductor and φB is the barrier height. Crowell [8] has been noted that the potential profile of metal – P (thin) - N diodes fo r a certain doping profile in the P - layer is such that one can obtain a linear1nQ SC - φB plot leading to T o effect. It is interesting to note here that a similar potential profile as in the case of M - P (thin) – N diodes, is also obtained in the case of He ine's model [9] of a Schottky barrier. It is well known that Heine's model starts on a very different premise form Bardeen's model [10] of Schottky barrier and primarily considers that the surface states are due to the tunneling of metal electrons into th e forbidden band gap of the semi conductor. A direct consequence of Heine's assumption is that in this case the surface state charges are not localized in space. This non localization of space charge makes the potential profile similar to that of M - P (thin) – N diodes. Hence we attempted to correlate the T o effect with the parameters of tunneling in Heine's model as developed in Pellegrini's calculations [11]. The details of this correlation are given in the fourth chapter. In the penultimate chapter, a novel method to determine the doping density of a semiconductor wafer using the dependence of T o on the current at which T o is measured has been described. This method requires the measurement of only the forward I - V characteristics of a Schottky barrier d iodes. A concluding discussion of the various observations made in the present work is given in the last chapter.

For more details click here Back

Title : *Some Interactive Techniques In Digital Image Resoulution*
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Abstract

SOME ITLERATIVE TECHNIQUES IN DIGITAL IMAGE RESTORATION It is well known that the problem of digital restoration of images which are degraded by optical imaging systems and are further contaminated by extraneous noise is of utmost importance in many field s of scientific and industrial research. Non - linear imaging systems are most commonly met with in practice, restoration in non - linear models has not achieved any significant progress owing to the requirements of prohibitively large computational effort and staggering storage space. The assumption of linearity is therefore usually made even though the system is known to be non - linear. Linear imaging systems may be space varying or space invariant. Further the image might have been contaminated by signal inde pendent and /or signal dependent noise. A variety of technique are available for the restoration of images in a space invariant system under signal independent noise regime. Restoration in a space variant model is comparatively less well developed. Most of the techniques for the space variant that the noise is signal independent even though it is well known that the detection/recording devices do introduce signal dependent noise. Many of these methods, including some of those proposed for the restoration in a space invariant model do not allow the incorporation of a priori knowledge about the original images. But the importance of the a priori information for realistic restoration is too well known to require emphasis. Except in a few special cases, space va riant restoration is a computationally formidable task. The wiener filter has been used recently for the restoration in a space invariant model in a signal dependent noise environment. The simultaneous presence of signal dependent and signal independent n oise disturbances, as in tv imagery, has however, not been considered. Also the wiener filter, in so far as its practical implementation is concerned, has several drawbacks, the most serious being the requirement of the exact power spectral density of the object field. An attempt has been made in this thesis to remedy some of these shortcomings of the wiener filter for the restoration in a space invariant model when both signal dependent and signal independent noise disturbances are simultaneously present. A recent development is the iterative restoration in the image space using the projection algorithm which requires considerably reduced computational effort for its implementation. All the a priori knowledge about the object can be easily incorporated in this method. However, the technique produces rather poor restorations in the presence of noise, signal dependent or otherwise. The computations are still enormous in space variant restorations. These two problems have received in this dissertation. Method s have been suggested to achieve savings on the computational time. Preprocessing the recorded image with the bernsatein polynomial is prior to the restoration by the projection method has been suggested to improve the fidelity of the restored image. The f ollowing main contributions have been made in this dissertation. 1. Restoration in the image space under a noise less environment is performed by the aid of the projection method and the recently developed residual projection method. New algorithms have been suggested for efficient

computation, thereby achieving considerable saving on the computer time. 2. Preprocessing the noisy recorded image prior to the application of these methods has been suggested with a view to arrest the spurious oscillations which would otherwise ruin the restoration. The Bernstein polynomials have been used for this purpose, as they possessa number of very desirable properties in the context of image restoration. Considerable attention has been paid to decide the order of the polynomial . 3. It is shown that a linear combination of a number of restoration obtained as the first few iterates from a fixed point iterative scheme can always yield a better restoration. 4. The continuous Wiener filter for the space invariant restoration in the presenc e of signal dependent and signal independent noise disturbances has been derived. An iterative Wiener filtering scheme is proposed which obviates the needs to know the exact power spectral density of the object field in addition to considerably remedying s ome of the other shortcomings of the Wiener filter. 5. The possibility of using the phase of the Fourier transform of the object (if available) to improve on the Wiener filter has been studied. 6. The discrete Wiener filter for the restoration in a general noise environment (signal dependent and signal independent) is derived in a linear algebraic framework. For a space invariant blur, restoration in the frequency space follows through the use of circulates. For space variant systems, the residual projection algo rithm has been proposed for efficient computation of the filter.

For more details click here Back

Title : Thyristor Controllers For Slipring Induction Motor
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Supervisor(s) : RamamoortyM

Abstract

Prom the beginning of industrial revolution, the trend has been toward automation of various ind"ustriaX operations. In the recent jhadt developments m solid-state electronic circuits have accelerated the automation trend at various levels. Simultaneous growth in the field of power semiconductors made the industrial drives amenable to the application of signal and power modulation techniques so far associated with data processing and communication equipments only.Most of the industrial drives are induction motors due to their economy and ruggedness compared to do drives. However, dc shunt motOr is still the champion in tewns of breadth of application m adjustable speed drives due to the easiness in speed control* But at has its age-old commutator arcing and maintenance problems* This has led to the development of variable speed controllers" fox ac synchronous fi^nd indu^ti^ motors* Speed centred of synchronous motor requires variable voltage and variable frequency source.XThe conventional methods of induction motor speed control are as follows,i) Stator voltage control 11) Stator voltage and frequency control Hi) Rotor power control iv) Rotor resistance control.The first method is simple but inefficient for low speed operation and gives poor starting torque. The second method gives wide range speed variation with very good efficiency. However, the complexity of this scheme makes it uneconomical for low power applications. The third and fourth methods are applicable to slipring induction motors only. Speed-torque characteristic of slip power controlled drive is similar to that of DC shunt motor. Method of rotor resistance control IS simple and economical m nature, though it duffers from poor efficiency at low speeds.The aim of the present thesis is to study the third and fourth methods of speed control techniques applicable to the sliprUig induction mot or > and propose mathematical models of the drive system for the analysis of steady^-state and dynamic performance.The principle of slip power recovery from the rotor circuit has been commonly utilised m rotating Scherbius and Kramer cascade systems. In recent years solni state frequency converters have been used m place of rotatingXauxiliary machines, providing compact, high efficiency, variable speed static drives with better dynamic response and good control characteristics.Feeding rotor power to line poses a difficult problem since the rotor power has both a variable voltage and variable frequency. The variable frequency problem IS overcome by rectifying the rotor output m which case only a line commutated inverter is re^^oiired to feed variable voltage dc powfer into constant voltage ac line*In this thesis, problems associated with slip power control are discussed, and it is pointed out that slip power control is economical only for sub-asynchronous operation. Super-synchronous operation requires that both the converters shoiold be fully controlled bridges. Moreover, designing firing circuits for wide variations m slip frequency requires elaborate firmg circuits and/or rotating transducers mounted on the same shaft.Though various techniques for power factor improvement are available such as asymmetrical triggering or forced commutation, these methods give increased distortion in line current. Hence these methods were not attempted here.A sub-synchronous slip

power recovery controller was designed for 3 SP slip-ring motor. The power'circuit comprises a diode bridge^ a fully controlled thyristorXIVbridge, a smoothing inductor, and a bleeder resistor. This arrangement is capable of only returning slip power from rotor circuit to ac Ime t,nd not vice-versa. The appropriate values of smoothing inductor and resifstor help m maintaining continuous current m dc path and hence linear operation of line commutated converters*DC circuit model is developed and comparison of speed-torque characteristics obtained from this model is made with that of experimentally obtained results.The CO-sine comparator art^angement is used m firing circuits. This gives luaear relation between average output voltage and control voltage to firing circuit. Hence, thyristor converter xs treated as a linear, switching mode power amplifier*A closed loop controller is designed to obtain improved speed regulation* The scheme is as follows:A PI controller is used for speed control loop. This loop contains another inner loop with PI controller for current control. The output of speed controller which has adjustable saturation level provides reference signal for current control loop» Because of this arrangement, during starting and -under overload ccndition motor current and hence torque is limited to preset value, corresp<aading to saturation level <?f ^peed controllerXVoutput. Moreover, current control loop maintains constant current against disturbances m supply voltage. The closed loop speed-torque characteristics of the drive are almost flat giving speed regulation better than 0.5 percent.The complete transient analysis of induction motor IS quite difficult. The presence of bridge rectifier and inverter makes it all the' more difficult. Therefore, it is not possible to derive analytically a transfer function that will be valid under all conditicais. However, transfer function that will be valid under certaan simplifying assumptions is derived.If voltage drop across stator impedance and voltage loss due to commutation is ignored, relation between motor torque and rotor current becomes linear. It is shown that this ass'umption is valid almost upto full load rotor current. Moreover, it is mentzoned earlier that thyristor converter could be considered as linear amplifier. Based on these assumptions transfer functions for motor and controller are developed. It is shown that these trans'-fer functions hold good over a wide range*These transfer functions are used io study the transient response of the drive for atep^input sa^gnal^. The design of PI controllers is also"based on the ^alire transfer functiojis*XVIComparison of motor speed and rotor current transient response computed from these transfer functions with experimentally obtained response is given. The Chapters 2 and 3 cover m detail the slip power recovery scheme mentioned above. The other method of speed control of slipring motor discussed m the thesis, is by rotor resistance control.Conventionally, the rotor resistance is controlled manually and in discrete steps. Using thyristors, the conventional resistance control scheme can be eliminated either by losing a ^-phase rectifier bridge and a chopper controlled external resistance, or phase controlled thyristors in the rotor circuit. Use of phase controlled thyristors require no commutation circuit, however, obtaining synchronizing signal corresponding to variable frequency rotor voltage is somewhat difficult. Hence wide range speed control using this method requires rotating sensors mounted on the shaft. JL chopper is a power switch electronically monitored by a control circuit. The equivalent rotor resistance is altered by changing the duty cycle of the chopper. A simple arrangement of switching resistor gives discontinuity m rotor currents and hence excessive harmonic losses. This problem is solved by introducing a filter in tl3.e rotor circuits This improvement gives contmiKms rxppXeXVllfree dc m the rotor circuit, and permits application of motor with almost 90 percent derating fact or •The chopper control scheme for variable speed control of slipring induction motor is discussed m Chapters 4 and 5» It has been shown that using a simple 1-R filter restricts the external resistance to a very small value resulting m not so wide variation xn the speed-torque characteristics. A superior scheme of using a second order, i.e., IJ-C-R, filter m the rotor circuit is suggested* Ihis arrangement permits very hi^ value {even removal) of external resistance, which gives

wide variations in the characteristics. It is shown that use of high speed thyristors will permit operation at higher frequency and hence reduction in filter component size. Design consideratiaae for second order filter are also given.DO circuit model for this scheme is derived. Comparison of speed-torque characteristios hased on this model and experimental results is alao given*With 2nd order filter it is not easy to get closed form solution for rotor current for the following reasons: 1, Bach switching operation introduces transients -and it la a tedious 3oh to determine "boundary valuesunder steady state condition*XVlll2. Presence of leakage reactance on the ac side makesit all the more diffic\0.t*Hence, iterative procedure is adapted to determine the steady state current wave form, and thereby average current and torque developed for the given motor speed.The rotor resi-feance controlled sliprin'g motor has very poor speed regulation with open loop c»trol4 In many industrial applicaticns, very good speed regulation of the drive is essential* Precision closed loop regulator for conventional rotor resistance control is impractical* Howeverr with thyristor chopper precision speed control could be obtained.Design of closed loop controller is same as that of slip power recovery scheme. The closed loop controX-ler used for chopper controlled drive also incoorporatea speed and current feedbacks. Speed regulation is better than 0»5 percent.Since for a chopper circuit without filter,current wave form could be highly distorted, derivation of average current feedback signal did pose a problem. To reduce the ripple amplitude in such current feedback signal would require a filter with large time constant, paxtioularly when the chopper frequency is low. Moreover, filter time constants would be differaat for different chopper frequency.XIXand also for different parameters of chopper filter. A simple filter in the current feedback path ma^ have adverse effect on the dynamic performance of the drive. To overcome these problems a novel high speed average current sensing circuit is developed. This circuit samples and holds the minimum and maximum values of rotor current for each cycle and outputs the average value for that\ cycle. It is shown that since the natxire of current increase or decrease is almost linear, the output signal corresponds to the average value of rotor current.Por 'chopper controlled slip ring motor' rotor winding ctarrents and dc equivalent circuit are similar to that of slip power recovery. Hence, the voltage drop across statOr impedance and voltage loss due to commutation could be ignored under light load for this scheme also. This ass\HaptiQn simplifies analysis by making torque and rotor current relation linear. Moreover, rotor circuit time constants during X^> and •OIP* modes are not equal* This resxalts in highly nonlineai* relation between rotor current and chopper duty cycle. However, transfer functions that will be valid for small perturbations are derived, the parameters being dependent on the given steady-state operating point*XXThese transfer functions are used to study the dynamic performance of the drive. The design of closed loop controller is also based on these transfer functions Oomparison of experimenxal and computed results based on these transfer functions is also given.

For more details click here Back

Title : Optimal Design Of ElectroMagnetic Devices
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Abstract

Mathematical programming technique is used effectively for the computer - aided design of electromagnetic devices. Nonlinear optimization procedure are applied to Specific examples off power transforms .The rotating machines are considered with rectified and nonsensical voltage supplies the feasibility of optimum design of alone mentioned electromagnetic services is demonstrated over a large number of constraints. Every NLP problem is converted into a sequence of unconstrained optimization problem using exterior approach & Powell's unconstrained optimization technique is employed to obtain minimum cost of the equipment concerned. The design optimization using NLP technique of IJO h.p.d.c separately excit ed & selies Motions are soled independently. Optimal design of three - 0phase squirrel age indication motors with variable frequency nonsinusoicded voltage constraints like power factor magnetizing current locked rotor current Brock down torque per unit tor que pulsations etc. are considered.

For more details click here Back

Title : *Studies On The Excitation Control Of Synchronous Motor Subjected To Voltage Dips*

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Abstract

It has been observed in certain process control industries, where large synchronous motors are used, that these motors are susceptible to loss of synchronism due to transient dips in the terminal voltage caused by faults or other disturbances. In particular starting of a large motor can cause voltage drop resulting in the pull-out of other running motors, thereby causing unwanted interruptions in the process. Stabilizing of synchronous motors under such transient disturbances is essential and this thesis is devoted to the study of this problem and control strategies to overcome it. A detailed model of a synchronous motor is used which is based on Park's equations. The power system to which the motor connected is represented by a constant voltage source (infinite bus) behind a reactance. The system studied consists of two motors connected to the same bus one of which is running and the other is started as an induction motor with field switched on when the speed reaches 90 percent of synchronous speed. The mathematical model of this two-machine system is derived and simulated on the computer. The degree of detail required for the starting motor is also investigated and it is found that for accurate prediction of system behaviour, it is necessary to have a detailed model of the starting motor. The simplified induction motor model (with algebraic equations) was found to give overly optimistic results. Once the system model is established the stability characteristics of the uncontrolled motor (with fixed excitation) are investigated for different value of system reactances. It is found that for the example considered the running motor is prone to be unstable under transient disturbance thereby justifying the need for proper control and stabilization. The subject of control of synchronous generators has been considered by many authors and recently there has been many applications of the linear optimal regulator theory. This theory is well established now and provides a linear state feedback law for linear time invariant systems. This is a radical departure from earlier methods of control system design using frequency domain and transfer function approaches which were not well suited for the analysis of multi-variable systems. The application of linear optimal regulator theory requires the system to be described by a set of linear state equations which in the case of a synchronous machine is possible only for small excursions of the state variables about a stable equilibrium point. Although this appears to restrict the use of the linear regulators, it has been observed that their performance is not

degraded even for large disturbances, simulated using nonlinear models. However, the major hurdle in the practical applications of the linear optimal regulators to synchronous machines has been the requirement of the measurements of all the variables, some of which may be inaccessible. This has led to the search for sub optimal controllers where only measurable variables are used as control signals or controllers based on output feedback. Although there is sufficient literature available in the area of application of linear optimal regulator theory to synchronous generators, there is hardly any publication on the control of synchronous motors. Although these may appear similar there are some points of difference. Apart from the fact, that synchronous motor stabilization can be achieved only through excitation control (whereas generators can utilize prime-mover control such as fast valuing and governors) the problem of loss of synchronism under transient voltage dips is peculiar to the motors under conditions described earlier. Thus, the results of the control studies on a synchronous generator subjected to faults or small load disturbances cannot directly be applied for the stabilization of the synchronous motor subjected to voltage dips. The control system developed should be tested under the actual conditions which can give rise to the instability of the motor. The major objective of this thesis is to investigate the various control techniques based on modern control theory for linear multi-variable systems, for the development of a suitable excitation controller to stabilize the synchronous motor subjected to voltage dips. Because of the limitations of the linear optimal regulator theory mentioned earlier, alternate control techniques have also been investigated. There are: i) Use of reduce order model of the machine to design sub optimal with feedback from only a few state variables. ii) Modal control for the assignment of closed loop poles. In this method instead of minimizing a performance index integral the closed loop poles are assigned to prescribed location which requires linear feedback of the states. The sensitivity of the closed loop poles to the feedback gains are also investigated with a view to eliminate the feedback from inaccessible states. iii) A parameter optimization techniques based on Lyapunov's direct method as suggested by Kalman and Bertram. All these techniques require system formulation in time domain using linearized state equations and this formulation is well suited to computer applications. The controller derived from each of the above methods is tested by digital simulation on the two-machine system (described by nonlinear model) mentioned earlier. The objective is to compare the effectiveness of the different control strategies and suggest suitable design techniques for problems of this type. One of the considerations in the design of the controller is to make it simple and reliable for practical applications. In this, context, it is observed from the results obtained from a case study presented in this thesis that feedback of all the states is not necessarily the best. The disconnection of feedback from some of the states can result in an unstable system. On the other hand, it is found that feedback from rotor velocity and the terminal voltage results in a stable system with adequate system performance. To summarize, the major contributions of this thesis are: i) Analysis and simulation of a two synchronous motor system for the study of this novel problem of instability described earlier. ii) Investigation of the applicability of various control strategies based on modern control theory. For stabilization of the motor, iii) Presentation of results and recommendation for the design of suitable practical

controllers for this type of system. A chapter wise summary of the work reported in this thesis is given below. Chapter 1 is a general introduction to the problem studied and review of the various modern control design techniques. Chapter 2 presents the model of the two-machine system considered. The machine model is based on Park's equations. The results of the uncontrolled system are presented. A single machine subjected to constant terminal voltage dips of varying magnitudes and duration is also analysed and these results are correlated with the results of the two-machine system. Chapter 3 is devoted to the design of a suitable excitation system by fixing its configuration and optimizing the parameter of the system based on a technique using Laypunov's direct method. This method is used not only to optimize the parameters of the voltage regulator (with feedback from terminal voltage) but also the feedback gains associated with the auxiliary control signals derived from rotor velocity and acceleration. In chapter 4, the design of an optimal linear regulator is carried out, minimizing a chosen performance index ∫∞ +=0)(21 dtuRTuQxTxJ , whre [Q] and [R] are the weight age matrices associated with state and control variables. In this approach the minimization is carried out for various values of control weighting matrix[R]. Feedback gains corresponding to the satisfactory location of closed loop eigenvalues are selected. An alternative approach is that in which the closed loop eigenvalues of the system are shifted to pre-assigned locations. This method of pole assignment or modal control forms the subject matter of chapter 5. This type of controller design gives the designer a feel for the behaviour of the system. Both methods of design of controllers, discussed in chapter 4 and 5 require the measurement of all states some of which are inaccessible. So, a technique to design a controller with feedback only from accessible states is considered, and is presented in chapter 6. In this the original linear systems is reduced to a lower order model (retaining the dominant eigenvalues) based on the eigenvalue grouping techniques given by Kuppurajulu et.al. An optimal control policy for this reduced order model is obtained and is used as a sub optimal controller for the original system. In the concluding chapter the results of the thesis are reviewed to arrive at broad recommendations for a practical control structure for synchronous motors subjected to voltage dips. The future line of research in this area is also indicated.

For more details click here Back

Title : ***Static Relays Using InTegrated Circuits And Digital Technique***

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Abstract

Introduction of solid state devices in protective relaying has granted new design freedom, higher speed of operation greater accuracy and reliability. Applications of digital principles using integrated circuits and digital processing techniques promises for greater advantages over discrete static circuits used so far. The main aim of this thesis is to reveal some of the many ways in which digital integrated circuits can be used to achieve greater advantages with regard to performance and cost for protective relaying. First chapter of this thesis introduces the application of integrated circuits to carry out basic relaying functions such as amplitude and phase comparison, integration function generation etc, in brief. Chapter two of this thesis describes a digital inverse time over current relay which is capable of generating inverse characteristics of various orders. Inverse time over current relays are very popular for unit protection. Each unit to be protected requires a matching relay characteristics to that of its thermal characteristic and the characteristics to other associated devices. This demands a relay which can generate inverse time over current characteristics of various orders. In electromechanical relays the order of the inverse characteristic cannot be varied greatly. Static relays generally achieve this with the help of nonlinear elements. Characteristics of non-linear elements are often not very stable and hence performance of these relays are not very reliable. In all these relays, it has not been possible to easily adjust the order of the inverse characteristic to meet the requirements of protection for different units. As such, relay is generally made to order for protection of a particular unit. The digital inverse time over current relay described in this thesis does not use any nonlinear element and it is very easy to adjust the order of its inverse characteristic to suit the requirement of a particular unit. The test results show a high degree of accuracy. The relay works on the principle of converting an operating current level into a train of pulses whose frequency depends on the current level. These pulses are passed through a rate multiplier that increases the rate of the pulses in a desired manner decided by the level of the operating current. After rate multiplication these pulses are counted in a counter. The time elapsed to fill a particular level of the counter is inversely proportional to the rate of pulses and as the rate of pulses has been increased in a desired manner before counting the elapsed time verses operating current level characteristic will have the required order. A digital phase comparator relay is described in chapter three. This relay is designed to remove the limitations of the comparators using the conventional block average scheme. Extensive field trials have been made on block average comparators and it is now established that practically fast operating relays with good transient free characteristics can be designed using this scheme. However, such comparators are basically two input comparators which have the limitations that they can generate relay characteristics that are either a straight line, a circle or segments of two circles; that too, with only symmetrical angular criteria. Present day heavily loaded extra high voltage transmission lines demand a

quadrilateral relay characteristics which is generally difficult to generate with conventional two-input comparators using block average scheme. Attempts have been made to obtain acceptable trip area using signal dependent phase angle criterion but it does not give quadrilateral characteristics. Use of several two input comparators each employing block average scheme to obtain a quadrilateral composite characteristic has also been disappointing. This is because optimum dynamic design consideration of the block average scheme do not permit a uniform operating time of the relay throughout its trip area especially near its boundary. This leads to serve time c0-ordination problem. The digital phase comparator relay described in this thesis is largely free of the above limitations of the conventional block-average scheme. Asymmetrical angular criteria can be applied in this comparator and the operating time of the relay is within one cycle throughout its trip region which abruptly changes to infinity at the boundary. The above qualities of this comparator relay made it ideally suitable for composite characteristics schemes using more than one comparator. Infact, it requires only two such comparators to obtain a quadrilateral composite characteristics. Digital phase comparator relay circuit uses up/down counters that count high frequency pulses gated during coincidence and anticoincidence periods of the two signals. By counting over a period of one cycle the counters conclude whether coincidence period is greater than anticoincidence period on an average over the cycle. If it is so a trip signal is issued. By using high frequency pulses of different frequencies during coincidence and anticoincidence periods, angular criteria can be changed from ±900. phase angle detector circuits are used to obtain asymmetrical angular criteria. Using additional logics it is shown that a single two input comparator relay with block average scheme is enough to generate a quadrilateral characteristic steady state and dynamic state characteristics of different two input comparator, relays are discussed in this chapter. Quadrilateral characteristics are easily obtained using rultiinput phase comparators bus their performance under transient state may not be an good as that of the two input comparators. In the case of the most of reported multiinput phase comparators, one of more input signals invariably require phase shifting, phase shifting networks aggravate the transient state performance. Further, the operation of some multi input phase comparators base either on block spake coincidence or block-block coincidence principle tend to mal-operate due to various spiken, generated from external sources. Preventive measure such as dual comparison or spike suppressor circuits are required to be provided for reliable operation. This thesis describes in chapter four, a digital multi input phase comparator relay that does not require phase shifting networks for the input signals and works on the principle of integration of voltage blocks rather than coincidence of a signals. Besides the digital multi input comparator possesses several additional features that are not available in earlier schemes. One of them is that it does not require memory action to issue a trip signal for near by fault. The other important feature is that the sides of the relay characteristics can be changed very easily in any desired manner. Having fixed the relative angular positions of the sides, the trip area enclosed can easily be changed by changing the resistance or set impedance. This renders the relay easily adaptable for three zone working with the help of a fault detector the trip area of the relay may be allowed to expand only in the direction of resistive each on occurrence of fault. This enhances the stability of the relay under system swing conditions. This digital multi input comparator with a quadrilateral characteristics work on the principle of testing the polarity of corner vectors (phasors joining tips of the set vectors IZR & IR in the voltage plane) during the period the adjacent side vectors pass through zero one after another. Two opposite corner vectors are required to be tested to conclude that the operating point is fully enclosed by the four sides of the quadrilateral. With the operating point within the trip area the polarity of the cornor vectors does not change during the period between the zero crossing of the corresponding two adjacent sides. This condition leads to the generation of two voltage blocks which are digitally integrated using

high frequency pulses and counters and a trip signal is issued from the final level of the counter. The counters are reset every cycle. The voltage blocks are reduced in area if the operating point is outside the trip region and the prevents the counter to fill upto the level from which the trip signal is derived. No trip signal is therefore issued in this case. Testing of trip condition is carried out once in every cycle. Static and dynamic testing of the relay have been thoroughly carried out. For protection of three phase lines, large number of single phase distance relays are required to meet the protection requirements under all types of fault conditions. Economic consideration demand a single simple relay which can cater for the protection of such systems. Several attempts have been made in the past in this line. Earlier schemes, known as switched distance relaying schemes used less costly simple auxiliary relays to provide proper relaying quantities to one main comparator relay. However such schemes proved to be very slow as sufficient time was required to be allowed for switching action of the auxiliary relays to be completed to avoid contact racing problems. Later schemes used compensated signals and one relay was used for all phase faults and another for ground faults dispensing with auxiliary relays. However all such relays suffered from the limitation of variable reach for different faults causing problems in relays coordination. Two overcome these difficulties besides being simple and economical. Performance of these relays has been investigated by static and dynamic testing carried out under system operating conditions on a model transmission system using a digital computer. One polyphase relay uses phase comparison principle and basically of set of four phase comparators. Three of these comparators compare the phase angle difference between the phase-to-neutral voltage of each phase and the respective compensated voltage with a fixed reference (± 900). The fourth comparator is also a phase comparator but it compares the phase difference between two suitable compensated voltage with the phase of one of them shifted by 900, with a fixed reference (± 900). The output of all comparators are 'OR' gated to initiate a trip signal. The relay is capable to clearing all the ten types of shunt faults on a three phase transmission system without any significant overreach or under reach. Digital block average scheme of comparison is suggested for the constituent comparators. The second poly-phase relay discussed utilizes the relative phase, disposition of the compensated voltage to defect the presence of faults on the system. The most attractive features of the relay is its simple circuitry using digital integrated circuits that render the relay economically adoptable. Only two since comparators with a few simple logic circuits constitute this relay that works on the principle of block spike coincidence. The relay is capable of clearing all the ten types of shunt fault and attain equal reach under restricted angular sine comparison. Performance of the relay is studied using a digital comparator. On a model transmission line for various system operating conditions. A brief description of a digital relay test bench useful for investigating the relay characteristic is also given here. Application of digital computers for primary protection of power systems did not receive much attention in the past because of reliability, speed to operation and cost considerations. Phenomenal developments in l.s.i. Technology has now made such applications possible. A computer used for protection purposes is generally required to be fast as the system variables change very rapidly following onset of a fault. The computer has to take samples on variables and has to process the datas to arrive at a conclusion within a very short time. Further accuracy demands several calculations from several sets of samples. A data processing techniques that requires less number of samples and fewer steps of calculations without sacrificing accuracy is likely to demand a slower and less costly computer. Several digital data processing techniques have been reported in the past. The most popular among them is the Fourior transform method. This method, though accurate is involved and a large number of samples and calculations steps are required to accurately predict the results. It is therefore, suitable with relatively costly computers only. Other data processing techniques such as that advanced by Mann & Morrison and gilbert and shevlin have

got the main disadvantage of being based on the assumption of sinusoidal input signals which is very difficult to meet in practice. Such assumption give rise to aliasing errors in calculations. To reduce the errors a large number of sample are required which places these data processing techniques to that of the first category. A signal processing techniques using digital filters forwarded by Jackson is promising but the results reported docs not show very high accuracy. A new data processing techniques is presented in chapter six of this thesis. The techniques does not make the assumption consecutive samples to predict the results. A through study on a digital computer reveals that this techniques is able to attain far greater accuracy than that achieved by others. A close comparison with the digital filter techniques is made to accentuate the fact that only four samples taken per cycle load of far greater accuracy in the techniques advanced in this thesis than that reported by Jackson, and ± therefore, it is believed to be easily and confidently adoptable for less costly digital mini and micro computers. Chapter seven of this thesis presents concluding remarks for further possible innovation of the relay circuits.

For more details click here Back

Title : Certain Generations Of Permutation-Invariant Systems
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Abstract

This thesis presents a generalized theory of permutation-invariant (P-I) systems that find applications in the processing of finite discrete data. The existing theory of such systems deals exclusively with only one-dimensional kind which accept finite-length sequences of reals as their input signals and which are the finite discrete counterparts of one-dimensional (I-D) linear shift-invariant (LSI) systems. The material presented in this thesis is an extension and generalization of the existing theory and covers two –dimensional (2-D) P0I systems whose input signals are finite 2-D arrays of reals, and also those P-I systems whose input signals are finite-length sequences with entries drawn from finite fields and rings of residue class integers. Having features similar to those of 2-D LSI systems and linear sequential circuits, these new categories of P-I systems are expected to have analogous application in signal processing. A 1-D linear system whose input and output signals are finite sequences of some arbitrary length N, has previously been defined to be permutation-invariant relative to a transitive abelian group of permutations G of order N, if the effect of permuting its input signal by any member of G is to permute the output signals also in the same manner. By analogy, a 2-D P-I system is defined here as a 2-D finite discrete linear system that exhibits invariance to certain kinds of permutations of the rows and columns of its input signal. To be specific, let G1 and G2 be transitive abelian groups of permutations of orders m and n respectively. Then, a 2-D linear system which accepts input signals given by finite arrays or matrices having m rows and n columns. Is defined to be permutation – invariant relative to the groups G1 and G2, if the effect of permuting the rows of its input signal by any member of G1 and the columns of its input signal by any member of G2 is to permute the output signal also exactly in the same manner. All 2-D P-I systems defined relative to the same pair of groups, G1 for the rows and G2 for the columns, are said to form a class of 2-D P-I systems is provided by the 2-D cyclic convolutional systems which can be shown to have permutation – invariance property with respect to cyclic permutations. The basic structural properties of 2-D P-I systems are expectedly the same as those of 1-D P-I systems except that they are centrally dependent upon two transitive abelian permutation groups rather than just one. Specifically, like the 1-D P-I systems, a class of 2-D P-I systems is characterized by a well-defined convolutional formula, a family of eigen vectors and a 2-D discrete transform. Each of these characterizations has been dealt with here in detail and several important results pertaining to them have been established. The arguments used in establishing these results are in spirit similar to those used in the case of 1-D P-I systems. However, since the input and output signals of 2-D P-I systems are matrices rather than column vectors, a more formal approach has been used. In the present approach, signals are treated as members of the vector space V of real m × n matrices and systems are treated as linear transformations on this vector space. With signals and systems so treated, it is shown that a class of 2-D P-I systems defined relative to

groups G1 and G2 forms a vector space whose dimension is the same as that of the pertinent signals space V of that class. Moreover, if Bij denotes the transformation or operator whose action on any 2-D signal X∈V is to permute its rows by the permutation Pi∈G1 and the columns by the permutation qj∈G2, then the set of operators Bij, i∈Zm, j∈Zn, where Zk denotes the set of integers 0 to (k-1), forms a basis for this vector space. By recognizing that these Bij's are normal operators, it is shown that all 2-D P-I systems of a particular class have in common a set of N linearly independent ortho-normal eigen vectors, where N – m.n. This equivalently means that each class of 2-D P-I systems has associated with it, a 2-D finite discrete transform (2-D FDT) which leads to the notion of transfer functions for 2-D P-I systems. In essence a generalization of the 2-D DFT and 2-D DWT), the 2-D FDT for every class satisfies a generalized convolution theorem. After developing the theory of 2-D P-I systems as an independent entity, attention is given to the relationships between 2-D and 1-D P-I systems. A key result in this context is that, for every class of 2-D P-I systems, there is an equivalent class of l-D P-I systems. This result is obtained in three stages. Firstly, methods are examined for transforming 2-D signals into 1-D signals with the help of appropriate one-to-one index mappings f: Zm × Zn → ZN, N = m.n. Next, considering an arbitrary 2-D signal X∈V, it is shown that permuting its rows and columns respectively by members of transitive abelian groups of permutations G1 and G2 is in effect the same as permuting the equivalent 1-D signal x∈RN by the members of the transitive abelian permutation group G which is characterized to within an isomorphism by the external direct product of G1 and G2. A general procedure for constructing the members of G, valid for any one-to-one index mapping f: Zm × Zn → ZN, has been outlined by writing down kronecker products of matrices in such a way that the rows and columns of the product matrix are ordered not lexicographically, but in accordance with the pertinent index mapping f under consideration. Utilizing these results, it is finally shown that every member of a class of 2-D P-I systems defined relative to G1 and G2 has an equivalent 1-D P-I systems defined relative to G1 and G2 has an equivalent 1-D P-I defined relative to G. The fact that every 2-D P-I system has an equivalent 1-D P-I system gives rise to interesting possibilities in the processing of 2-D finite discrete data. It is to be noted that the design of stable 2-D LSI systems and 2-D digital filters directly from 2-D specifications is beset with problems of spectral factorization of polynomials in two variables. A number of methods have therefore been proposed in the past for the design and implementation of 2-D digital filters indirectly by using 1-D techniques. These methods, however, are limited in their effectiveness by the fact that the exact 1-D implementation of a 2-D LSI system or a 2-D digital filter is a 1-D filter that does not possess the time-invariance property. As shown in this thesis, no such limitation exists in the case of P-I systems, in that, a 1-D system that is an exact equivalent of a given 2-D P-I filter retains the permutation invariance property. Further, if the 2-D data to be processed are finite, a digital filter may be interpreted as a P-I filter, so that for finite discrete data, it is possible to convert a 2-D filtering problem into an exactly equivalent 1-D filtering problem by resorting to P-I system theory. These facts have been discussed in detail in the general context of filtering 2-D finite discrete data in Fourier and Walsh domains using P-I systems. 2-D Walsh domain filtering corresponds to 2-D dyadic P-I filtering, and the 1-D equivalent to a 2-D dyadic P-I filter is a 1-D dyadic P-I filter. Likewise, it is shown that the 1-D equivalent of a 2-D Fourier domain filter is a 1-D cyclic P-I filter provided the number of rows and the number of columns of the pertinent 2-D signals are relatively prime. Attention is next given to those P-I systems whose input sequence are of finite length n, with entries drawn from (i) finite fields, and (ii) rings of residue class integers. For convenience, these systems are respectively referred to as P-I systems on finite fields and P-I systems on rings. The

main concern here is the transform domain theory of these systems, their sample domain behaviour being largely the same as that of 1-D P-I systems with real field inputs. The n-th roots of unity in finite fields and rings play an important role in the study of cyclic P-I systems of these types. The existence of these roots is accordingly first examined in detail and procedures for determining them are discussed. Cyclic P-I systems on finite fields and rings are then characterized in terms of their eigen signals and discrete transforms. These results for the cyclic class are then extended to general classes of these P-I systems and a characterization is given for them in terms of their respective eigen signals and generalized discrete transforms. It is observed that for appropriate choices of the modulus of the residue class ring, the transforms defined by the corresponding class of cyclic P-I systems given rise to the so-called number-theoretic transforms (NTT's) such as the Mersenne number transform and the Fermat number transform. These NTT's have been proposed in the last few years primarily as a means of efficient and error-free computation of cyclic convolution. Looking at these transforms from a system-theoretic point of view, it is shown in the thesis that just like the DFT and the DWT, the NTT's also have associated with them a specific class of P-I systems, the pertinent class of systems in this case being the class of cyclic P-I systems on rings of residue class integers. It is hoped that the generalized transforms derived here for different classes of P-I systems on rings would prove helpful in the evolution of newer varieties of NTT's having dyadic and such other non-cyclic convolutional properties.

For more details click here Back

Title : *Group Theoretic Considerations In The Analysis Of Power System Networks*

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Abstract

A power system network, which consists of three balanced sub networks, viz. generation network, transmission network and distribution network, possesses certain special kinds of symmetries. This is true not only of 3-phase conventional power system networks but also or 4-phase, 6-phase and multiphase networks in general. The symmetries involved are rotational and reflection symmetries in space and transnational symmetries in time. This thesis is concerned with the explicit use of these symmetries and group theoretic techniques of dealing with them to develop general methods of simplifying the analysis of power system networks. Group theoretic techniques have been extensively used in the past to study the implications of symmetries in molecular structures, wave guide junctions and linear networks and systems. However, the importance of these techniques has so far not been recognized in the area of power system analysis. This is perhaps best exemplified by the fact that the symmetrical and Clarke's components are at present regarded as two independent transformations whose derivation makes use of the network symmetries only implicitly. As shown is this thesis these transformation are in fact members of a general family of transformations for multiphase systems all of which have identical structural properties and can be derived in a unified manner based solely on symmetry considerations with the help of group theoretic techniques. The central theme of the results presented here is that by the application of group theoretic techniques, system equations of a power system network possessing symmetries can be put into a diagonal or at least a block diagonal form so that the original network can be replaced by a set of smaller disjoint sub networks whose analysis is considerably simpler. These are in all four different aspects of analysis considered here: i) Steady state analysis of 3-phase systems. ii) Transient analysis of 3-phase systems. iii) Analysis of multiphase networks with special emphasis on 4-phase and 6-phase networks. iv) Analysis of power system networks in general including those containing nonstationary elements such as synchronous machines. A 3-phase balanced network can be subdivided into two classes, one consisting of these elements which possess only rotational symmetries and another of elements which possess both rotational as well as reflection symmetries. The rotational symmetries of an n-phase network consisting of n-fold proper rotations together constitute the cyclic group Cn. If the network possesses only rotational symmetries then the symmetry dependent features of its coefficient matrix are completely characterized by the fact that it commutes with the regular representations of the group Cn. Based on this result a similarity transformation for diagonalizing the coefficient matrix is shown to follows. This transformation reduced to the conventional symmetrical component transformation for 3-phase power system networks. Balanced stationary networks such as transposed transmission lines possess reflections symmetries in additions to the rotational (i.e. cyclic) ones. These symmetries constitute the group Cnv consisting of n-fold rotations and n-fold reflections about its axes of symmetries. Applications of methods based on representation theory of finite groups have been used in this case to arrive at two general types of transformation, one with real basis and the other with complex basis. The transformation with real

basis yields the Clarke's components and that with complex basis, the symmetrical components transformation for a 3-phase system. The chief merit of the group theoretic approach is that it enables us to make use of symmetries in a unified manner not only for steady state analysis of 3-phase power system networks but also for the transient analysis of networks containing both spatial and temporal symmetries. It is to be noted that while symmetry based transformation such as symmetrical component and Clarke's components transformations have long been in use for simplifying the steady state analysis of power system networks, no such transformations have been available for dealing with problems of transient analysis. The results presented here show that the group theoretic techniques for block diagonalizing state dynamical equations can be successfully applied to the transient analysis of power systems as well. With state dynamical equations of a power system network written with respect to a normal tree possessing as many symmetries of the network structure as feasible the possibility of constructing a similarity transformation which transforms the state equations to the block diagonal form is pointed out. Several example illustrating the possibility and also the general procedure for obtaining pertinent block diagonalizing transformations presented. Multiphase power system networks are also examined in detail in this thesis. As already mentioned, such multiphase power system network are inherently symmetric, displaying either rotational symmetries or both rotational as well as reflection symmetries. For the analysis of such networks, while a generalization of symmetrical components transformations are already in use no real transformations similar to the Clarke's components is so far known. Further it is not recognized that these two kinds of transformations have a common origin as evinced by the results presented here. It is shown by specifically examining 4- and 6-phase system that the general multiphase case is amenable to group theoretic techniques of constructing appropriate diagonalizing transformations. Solely based on symmetries of the 4- and 6-phase system linear power invariant transformation matrices with complex elements similar to the symmetrical components transformation and with real elements similar to the Clarke's component transformation have been presented here. In addition expressions for sequence impedance and complex power for both 4-phase and 6-phase systems which are useful for the purpose of planning studies and fault analysis are also presented. Finally attention is individually given to the various components of power system networks such as static loads and their interconnections, transmissions lines, transformers, synchronous machines and induction machines. These components possess symmetries of different kinds, which constitute different types of groups such as Cs, Ci, Cnc, Sn, Dn, Dnh and Dnd. Relevant properties of these groups of symmetries along with their representations by permutation matrices are examined and the significance of these properties in system analysis are pointed out. It is expect that these properties will be helpful in extending on a wider scale the group theoretic techniques to problems of transient analysis of power system networks containing time-dependent elements such as synchronous machines whose inductance parameters are periodic but not necessarily sinusoidal.

For more details click here Back

Title : *Identificaiton And Equalization Of Fading Dispersive Channels*

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Abstract

In recent years due to the need for digital transmission at megabit rates on tropo scatter channel, there is an increasing interest in accurate modeling of fading dispersive channels and methods to overcome the intersymbol influence produced by such channe ls. Various models for such channels have been proposed in the literature by Bello and others. It is well known that a channel, which exhibits wide sense stationary uncorrelated scattering can be adequately characterized in terms of its scattering function . Scattering function can be obtained either experimentally by using wide band signal probing methods such as in Rake technique or through theoretical consideration of the physical phenomenon of scattering. For mitigating intersymbol influence produced b y such channels various adaptive techniques are proposed for processing of the received signal. In general, identification of the channel characteristics facilitates adaptive equalization. Kalman filter has also been recently considered for re covering the transmitted signal in the presence of intersymbol interference. However, kalman equalizer assumes the knowledge of channel characteristics. In this thesis, we consider the numerical evaluation of the scattering function using the booker and Gordon theory of single scattering for a troposcatter channel with given channel parameters. The approach is similar to the method used by Bello for computing the delay power spectrum. Scattering functions were evaluated fro various channels with adjacent layers exhibit ing isotropic scattering. The results are compared with the scattering functions obtained by Pool by a different approach. In the analysis and evaluation of the performance of various signaling schemes, a tapped delay line model of the troposcatter channel is often invoked. In such a channel the tap gains are taken to be the sampled values of the channels impulse response at various delays. In order to be able to generate these random tap gains that correspond to a given scattering function, the following a pproach is used. For each delay tap, a least square fit of the given scattering function is obtained using a rational spectrum. A stochastic state variable model for each tap is then obtained using the rational spectrum. Identification of the tap gain is considered next, under the assumption that past decisions about the transmitted symbols are correct. Stochastic approximation algorithm has been applied for the identification of, (1) constant tap gains, and (ii) slowly varying random tap gains. Simulatio n results are presented. We also consider the application of the kalman filter for the identification of the tap gains for the case of (i) constant tap gains, and (ii) slowly varying random tap gains. Results of the kalman filter and the stochastic approx imation algorithms are compared using simulation studies. We finally consider the adaptive equalization problem using the kalman

filtering technique. Implementation of such an equalizer requires knowledge of the kalman gains that evidently depend on the c hannel tap gains. For the computation of kalman gains, particularly when the channel parameters changes with time, we find it is advantageous to consider a non - singular linear transformation of the tapped delay line channel model. By using the innovations ' approach we then show than the kalman gains corresponding to the transformed system can be obtained as the estimates of the parameters of a related moving average process. These parameters are estimated using recursive scheme suggested by Kashyap. For a slowly varying channel, the kalman gains associated with the untransformed model may then be computed from the above estimates and the past estimates of the channel tap gains obtained by either of the identification schemes suggested earlier. Computer simu lation results are presented for the case of a channel with constant tap gains. 0

For more details click here Back

Title : *Solid State Speed Control Of Induction Motors*
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Abstract

The solid state variable speed a.c. drives find wide spread applications in to-day ls industries, The development of power semiconductor devices and solid state integrated circuita are responsible for the opening up of this new field in industrial drives. The solid state drives can claim many advantages, suoh as reliability, fast acting, long life, lees maintenance, high efficiency and low cost, over the older schemes which use motor-generator sets, magnetic controllers and gas discharge valves. The induction motor, which is the best choice among a.c. machines for many industrial applica tions, is simple, cheap and robust. It is baeioally a con stant speed motor. Many industrial applications demand a vari able speed-torque characteristic. The well-known techniques of speed control are j (1) stator voltage control, (il) stator voltage and frequency control, (iii) rotor power control, and (iv) rotor impedance control. Of all these techniques, first and last ones are simple and economical. The last method give© wide speed variation, and high starting torque, these two methods,are however less 'efficient particularly at low speeds, '•, Ahertfo*** they are usually 'employed for email motors and where economy and not efficiency is the prime consideration. The phase controlled bCRs connected in various configurations have been used for the st^xtor voltr>';-e control of squirrel cage and wound rotor induction nacidncs. Recently, attempts have also been made to .nako use of the phase controlled SGR circuits in the rotor of tii«* slip ring induction machines to • : have wide-range speed control. The main advantage of the phase control circuit is that it employs line or natural commutation and there is no need for additional commutating elements. How ever, the analysis of phase control circuits is quite compli cated because the instant at which the conducting SOR goes off [In the case of motor loads is unknown and it is difficult to" ! predict the voltage that may come across the open circuited ,. phase. Two well known methods have he@xi in use for solving j the thyristor oontrolled machine problems. They are i (i) state i space method and (ii) harmonio analysis method* In the present thesis the above two methods of analysis ! are applied to some of the economical a»o. machine speed • \ I oontrol schemes using phase oontrolled SORe either in the j i stator or rotor of the induction machine. The results obtained ; are compared with experimental values. | ! 3?he harmonio maljsis method is applied to a single j i phase a»o« machine which uses phase controlled SORs in the stator* • The suggested procedure iterates on the' conduction period alone' and'avoid©0 iterating on the'induced e.m.f* The results obtained by this procedure are^ compared with state space results and experimental values. A three diodes - three thyristors stator voltage control scheme for a three phase induction machine is discussed. The various possible modes of operation are explained. The firing angle and speed decide the particular mode of operation. A state space pro cedure which is already available in

the literature is exten ded to this system. A modified harmonic analysis method is also developed. An attempt has been made to consider the frequency dependency of the machine parameters using the modi fied harmonic analysis method. The analytical results are compared with experimental values, The applicability of harmonic equivalent circuits for the steady state performance calculations of inverter driven systems are also explained. Both voltage and current source driven systems are considered. A simple and fast iterative prooedure ie presented for the estimation of the steady state behaviour of the inverter driven systems including the input filter characteristics. The iterative prooedure explains , how the effect of the sixth harmonic ripples, which are present! in the input side of the inverter can be taken into account for calculating the performance characteristics. The rotor impedance control using phase controlled S0B§ in the rotor circuits in two different configurations has also been investigated in this thesis. A phase controlled resistance method of speed control using a controlled bridge iv and external resistance in the rotor is explained. The chopper controlled external resistance aethod of speed control has been already discussed in the literature. In this method, a diode bridge and a chopper in used in the rotor circuit of the machine, The povror is fed to the chopper controlled re sistance through the diod<. bridge. She effective rotor impe dance is varied by controlling the chopper on-off frequency. In the present scheme, a fully controlled bridge is used to j feed the external resistance* The effective rotor impedance ! is continuously controllable by advancing or retarding the j firing angle of the controlled rectifier. A smoothing reactor! is used In the d.c. side to make the current continuous, The \ different modes of operation of this system are explained, A j state space procedure is developed to obtain itie rotor current! and hence the performance characteristics of the system. The | state space procedure does not involve iterations and the variables used ar® the actual rotor variables of the machine, One of the important problems facing the investigators in obtaining the steady state performance of the thyristor controlled machine is the imposition of the open circuit condition for the thyristors in the mathematical model. I Iiipo and Kratise have suggested a procedure where the current aero is imposed by applying a voltage eq.ua! to the induced e,m»£f. across the. open circuited phase of the machine. In the- 'present work, an alternative concept is employed, fhea one of the phases of toe machine with isolated neutral gets open circx ited* the other twc phase currents and their * • : derivatives are esiual and opposite to each other. 5?hereforef one more differential equation io available and is used in the ' mathematical model* ^ simplified a„c« equivalent circuit is also developed for obtaining the performance characteristic of « the schema* The results obtained by the analytical procedures ; are compared with the experimental values which were already ; available* j The effective rotor impedance can also be continuously j varied by using deltas-connected phase controlled SOBs in the j rotor circuit* This scheme is also discussed in detail in ! the present thesis* fhe schemes use* equal external resistance in the rotor phases and the phase controlled SOls are placed ! i at the open star point of the rotor circuit. She speed of the j i machine 1P controlled by varying the firing Angle of the j phase controlled tfayrlstore* There are two different taodee of] operation depending upon the firing angle and speeds Oae 1* i 2/L mode where two thyristor and one thyristor conduction oocnuj alternatively and the other one is 1/0

mode where one thyrl- j etor conduction is followed by an off period. When the maohicM is in 1/D mode the rotor 'current is easily obtainable consider^ ing the. rotor induced voltage and the equivalent machine j parameters. A state space procedure similar to that described for the phase controlled resistance scheme is used to obtain ! rotor current waveform for 2/1 no do of operation. A harmonic analysis method suitable for this problem is also discussed. Hore an iterative procedure iJ usod to obtain the current zero ; instant. The iterations are carried out until the r.n.s. value of the phaso current c3uri;:^ the- off period is reaso- : nably low. Ihe analytical results obtained by these methods ; are compared with ejEperiaental observations, A simple and ' reliable firing circuit suitable for the rotor phase control sohemes is also presented. , I A feed-back control schen© for variable speed operation using delta connected SOR0 in the rotor is studied in this \ thesis. A voltage proportional to the speed of the machine j is compared with a reference voltage and the error signal is ! aiaplified and given to a controller. The output of the con- j troller adjusts the firing angle to the required value. For j the present studyt both p and PI controllers are used* Ihe j i behaviour of the olosed loop *ysteta for the perturbations j in load torque and refero&c© voltage are obtained analytically| and the result® are compared with experimental observations, j [i

For more details click here Back

Title : *Free And Forced Oscillations In A Class Of Non Linear Systems*

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Abstract

It is well known that there exist no general techniques for analysis of nonlinear systems in contrast to linear systems analysis. Particular classes of nonlinear systems have, however been studied in great depth and in particular nonlinear systems described by second order ordinary differential equations have been the subject matter of extensive research. The subject of periodic oscillations in free or forced systems is a very important area of study and for the autonomous situations the description of self excited oscillations or limit cycles has been exhaustively carried out on both a qualitative and a quantitative basis. The emphasis has been towards analyzing second order systems and early works of Minorsky and Hayashi contribute heavily to this aspect. The non autonomous situation with the attendant phenomena of synchronization, 'jump resonance', asynchronous quenching as well as generation of sub harmonics and super harmonics has also been investigated deeply by various persons. Here again considerable contributions are available for second order systems. There have as yet been, however, few attempts made for a detailed study of response characteristics of higher order systems. In this thesis, a class of third order nonlinear systems are considered and a detailed quantitative study is carried out for both the autonomous and the non autonomous situations. The non linearities considered are of the polynomial type and a major effort in the present study has been directed towards establishing conditions for sustenance of periodic oscillations in these systems. The important contributions of this thesis may be listed as follows: 1. Analytical investigation of response characteristics for both the forced and the unforced systems is executed using a new procedure – the multi time perturational approach. This technique ahs hitherto been used only for second order systems by Cole, Nay fed among others and its applicability for higher order systems is demonstrated in this work. 2. The multi time approach is used advantageously to derive some basic necessary conditions for existence of a periodic oscillation. For autonomous systems these derived conditions supplement the sufficiency conditions obtained recently by Noldus who used topological arguments. Detailed response characteristics such as amplitude, frequency of oscillation as well as the stability properties have been determined. 3. For weakly forced systems in the non autonomous situation, periodic inputs are considered and a 'resonance'behaviour similar to that for second order systems is obtained. There exist, however,

some significant difference between the properties of the resonant solutions in the two cases. The rule of ‘vertical tangents’ widely applied for second order systems is shown to be invalid for the considered third order systems. 4. Under strong excitation, various sub and super harmonics can be generated. Necessary conditions for synchronization of a particular order of a sub/super harmonic are derived. The stability of such solutions is also examined. The problem of Ferro oscillations response in a power system due to generation of different sub harmonics is considered as an illustrative example. A chapter wise summary of the thesis is as follows: the first chapter provides a brief introduction to the general topic of nonlinear systems indicating the different methods of analysis as well as a survey of the various kinds of phenomena unique to such systems. Second order systems have been exhaustively analyzed in the literature and a brief description of the properties of these solutions is also presented. The state of the art as far as investigations of free and forced oscillations in higher order nonlinear systems is then briefly reviewed with specialization to third order systems with which this thesis is concerned. The objectives and scope of the thesis are also outlined. The second chapter is concerned with the subject of free oscillations. The first part of the chapter is devoted to obtaining some necessary conditions for existence of periodic oscillations in constant coefficient third order nonlinear differential equations (zero input). General polynomial type nonlinear ties are considered and conditions for existence of single /multiple limit cycles are obtained. The multi time perturbational scheme is employed for this investigation and the results obtained are verified by simulation of some typical examples. The second part of this chapter considers modifications that arise in the periodic oscillation response when there are time varying coefficients. General expressions are derived that relate the dependence of the amplitude /frequency of the free oscillations to the parameters of the periodic coefficient. The third chapter focuses on the study of response of driven third order nonlinear systems. Weak forcing is considering and necessary conditions for existence of a periodic response at the driven frequency are obtained. A ‘response’ characteristic similar to that for second order systems is obtained. Important difference, however, exist between the two systems as regard properties of the solutions such as ‘jump phenomena’ etc. the rule of ‘vertical tangents’ is seem to fail for describing the stability properties of the periodic response. The fourth chapter deals with the study of response in strongly forced third order nonlinear systems. Under such conditions, sub and super harmonics may be generated and necessary conditions for their existence are derived. Both transient and steady state response are examined as well as a stability investigation of the periodic solutions. Illustrative examples are provided to support the theoretical studies. A general review of the results of this study, as well as some suggestions for further work in this area form the theme of the concluding chapter.

For more details click here Back

Title : ***Application Of Mathematical Programming Methods To Optimal Design Of Polyphase Reluctance Motors***

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Abstract

For more details click here Back

Title : *Stability Investigation InMulti Machine Power Systems*
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Abstract

Transient stability investigation of large scale power systems has been investigated in recent years via Lyapunov's direct method by various researchers. This method gives an important piece of information namely, the critical fault clearing time through a single integration of the faulted system differential equations and can be used to specify the stability margins without making actual stability calculations. However, there are certain difficulties to be overcome with this method. Important among them ar e I) that the stability regions obtained by this method are often much smaller compared to the actual ones and ii) that the mathematical models and the corresponding Lyapunov functions do not take into account the transfer conductance's which at times may have considerable influence on the estimate of the critical clearing time obtained by this method. This thesis is devoted in part, towards solving these difficulties. For estimating the transient stability regions the method of Walker and Mc Clamroch and Wise Berger have frequently been used. Williams has already suggested the use of open Lyapunov surfaces and optimum Lyapunov functions for getting improved regions. In this thesis we investigate in detail the pole shifting technique to obtain larger region s of stability. The advantages of the technique are that slight improvements in regions over and above that of open Lyapunov surfaces can be obtained and also that the construction of the Lyapunov functions via the Kalman's procedure becomes easier. The te chnique is applied to a single machine connected to the infinite bus and stability regions with and without pole shifting are compared to demonstrate the effect of pole shifting. Theoretical extension of the technique to the multimachine system is presente d. Lyapunov functions constructed for multimachine system so far in the literature have neglected the presence of transfer conductances in the mathematical model of the system. This practice may considerably influence the estimate of the critical clearing time in a system in which the transfer conductances are far from negligible. In this thesis we have investigated as to why it has not been possible up till now to construct valid Lyapunov functions in the presence of transfer conductions. The terms which present difficulty in construction of the Lyapunov functions have been identified. An approximate model of the power system is then derived including the transfer conductance's. The Lyapunov functions for this model can b e obtained in a straight forward. Manner. It is shown that this approximate model is superior to the one in which all the transfer conductance are neglected. Numerical example of a 5 machine 12 bus system is given. This thesis also deals with the decomposition and coherency identification which is a basic step in

constructing dynamic equivalents for large power systems. In many a case a large number of generators in a power systems are modeled not because their behaviour is of direct interest but because they have a combined significant eff ect upon the behaviour of a smaller area which is usually called the study area or the internal area. The generators not included in this area are said to belong to the external or remote areas. Dynamic equivalents are then formed by combining the coheren t generators in the external area. The criterial available in the literature for decomposing the power system and identifying coherency for constructing the dynamic equivalents in this manner are mostly empirical with little mathematical justification. In this thesis a new criterion is derived from linear approximation of the system equations for grading the generators in a large power system according to their electromechanically distance form the fault. The grading is then used for the purpose of decompo sing the system into internal and external areas. The criterion unifies the concept of the 'admittance ' and the 'reflection' distance measures proposed by Lee and Schweppes. Its applications needs only the prefault load flow data and the network parameter s of the prefault and the faulted system. The criterion also identifies the coherent generators it he external areas without processing any swing curves. In most of the literature on dynamic equivalents this information is usually obtained either from a ba se case transient stability study or from a fast simulation of a linear approximate model. In both the cases computer simulation is necessary for identification of the coherency alone. The criterion presented in this thesis completely eliminates the swing curve calculation and is thus very useful in the procedure for constructing dynamic equivalents based on coherency. Use of linear approximation gives it a theoretical base which is not the case with the earlier approaches of Lee and Schweppes and Spalding et al. an algorithm based on the proposed criterion is presented and implemented on a 71 bus 13 machine system of a typical utility for the purpose of decomposition and coherency identification. Another contribution of the thesis is in the computation of stability regions for large practical systems. Walker and McClamroch's work on system with single no linearity is extended to multinonlinear systems. Computational aspects are discussed with particular reference to large power system. A method which reduce s the computational effort and gives a closer estimate of critical clearing time is suggested. Chapter wise distribution is as follows: Chapter I discusses the problem of transient stability in general and its state of art with respect to large power sys tem in particular. Lyapunov's direct method is briefly reviewed. Different method of improving transient stability regions are discussed. The current status regarding transfer conductance's is explained. An overview of the literature on dynamic equivalents is given and finally the scope of the present thesis is outlined. In chapter II the pole shifting technique is applied to a single machine infinite bus system. The Lyapunov functions are constructed and the stability regions obtained with different amoun t of pole shifting. Some recent claims regarding the improvement in the transient stability regions by modifying the linear part have been disproved. Theoretical extension of the technique to multi machine systems if presented. The inclusions of transfer conductance's in the model for multimachine power system is treated in chapter III. The effect of transfer conductance on the sign definite properties of the Lyapunov functions and its derivative is examined and the difficult terms isolated. An

approximate model of the power system is then derived including the effects of transfer conductances for which the Lyapunov functions can be constructed in a straight forward manner. A numerical example of a 5 machine 12 bus system demonstrates the superiority of the model over the one neglecting all the transfer conductances. Chapter IV presents a new criterion for decomposing a power system into internal and external areas and for identifying coherency among generators in the external areas. The criterion is derive d from the linear approximation of the system equations. Fundamental concept such as natural frequency of oscillation and steady state level of operation are then invoked to obtain certain indices that determine the effective electromechanical distance of a particular generator for the fault. An algorithm based on the proposed criterion is implemented on a large power system for the purpose of decomposition and coherency identification. Actual simulation is performed to show the effectiveness of the criteri on. Chapter V is devoted to the discussion on certain computational aspects of finding multi machine transient stability regions. Recent methods of computing the same based on the sector violation information of the nonlinear are further extended and trie d on practical systems. A method that considerably reduces the computational effort and still given better estimates of critical clearing times is suggested. The concluding chapter VI gives a resume of the work done, highlights the contributions made in the thesis and suggests the areas for further research.

For more details click here Back

Title : Dynamic Stability And Control Of Multi-Machine Power Systems
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Supervisor(s) : Pai Mangalore Anantha & Padiyar K R

Abstract

An essential requirement for the successful working of any interconnected power system is the synchronous operation of all the generators connected to the network. A multi - machine system operating under steady state conditions can be conside red to be at an equilibrium state if the system stays in the neighborhood of the equilibrium state when subjected to small perturbations . Hence a power system cannot maintain the requirement synchchronous operation system cannot maintain th e required synchronous operation unless a stable equilibrium point exists or in other words the system possess dynamic stability .All dynamic stability problems can be analysed using linear system technique e of multivariable control t heory . A power system is desired buy a set of algebraic and differential machines with their exestuation and governor systems. Since many of these equations are nonlinear they are linearized around an operating point and the sy stem is expressed in the state space from by eliminating the non - state variables .Then the dynamic stability of the system is studied by examination the eigenvalues of the system matrix .Therefore it is necessary to have a smile and eff icient algorithm for the system matrix formulation of multi - machine power systems. The recent practice of using high speed rectifier excitation systems even though improves transient stability has resulted in decreased damping of the machine oscillation to an extent that steady state stability may be lost eve en at normal full load operating conditions . This problem is especially prevalent in large interconnected power systems with long EHV transmission lines and remote hydrogenation . Hence it is often necessary to design appropriate control strategies to improve the dynamic behaviour of the system. In this thesis the investigations and the contributions are made in the followin g three aspects: (i) A systematic and efficient algorithm for the formation of the [A] and [B] matrices of a multi - machine power system without involving any matrix inversion .(ii) Calculation of eigenvalue sensitivities of the [A] m atrix with respect to the system parameters and a sensitivity based design technique to control the dominant modes. (iii) An optimal model control of multi - machine power systems and design of sub -optimal decentralized control strategies . The first chapter defines the dynamic stability and control problem and gives a brief review of the literature in this area . The objective and scope of the thesis is also outlined . In the second chapter , a systematic algorithm for the [A] matrix formulation proof multi - machine power systems without involving any matrix inversion is presented .The synchronous machine is represented by a 6 - winding hybrid parameter model of Riaz that uses comm only available machine constants such as reactance and time constants . The rotor equivalent voltages instead of flux linkages are used as state variables. By neglecting subtransient saliency the synchronous machine is represented by a volta ge behind subtransient impedance, which is related to the state variable by a simple transformation, .The network is represented by a reduced constant admittance matrix at the internal nodes of the generators . These features simplify

the alg ebraic manipulations and facilitate the elimination of non - state variables thus avoiding the necessity of matrix inversion .This results in a simple and efficient building up of the [A] matrix in terms of the submatrices . The algori thm is applied for obtaining the [A] and [B] matrices of a 3 - machoine system of 44 th order that includes detailed representation of the machines turbine - governor and exitation systems with power system stabilizers. The construction on of the [A] matrix in terms of the submatrices is efficiently done and the final structure is also indicated in terms of the submatrices. The dynamic behaviour of a power system can be improved either by the proper choice of the control parameters of the various machines of the system or by the synthesis of feedback controllers using optimal or model control .The optimal parameter selection requires the evaluation of eigenvalue sensitivities with respect to system parameters . In Chapter 3 the eigenvalue sensitive with respect to the control and machine parameters are computed for the 44 th order three - machine system using the system matrix formulation in Chapter 2. The [A] matrix formulation gives in the second chap ter is well suited for the evaluation of partial derivatives of [A] since it does not involve any matrix inversion and it is easy to locate the parameters in the submatrices .The eigenvalue sensitive are helpful in identifying the param eters sensitivities are helpful in identifying the parameters which gave significant influence on any deign - value of interest . The fourth chapter gives a sensitivity based design technique for the optimal selection of control param eters in order to shift the dominant eigenvalues as far to the left in the complex plane as possible satisfying the requisite constraints .An objective function is minimized using gradient technique that uses eigenvalue sensitivities .The me thod is simple to implement since it use the existing control structure of the power system . However, it is not always possible to shift all the dominant eigenvalues to desirable locations making use of this type of fixed control structure .Th e results are presented for shifting the eigenvalues corresponding to the electromechanical oscillations of the rotor of the three - machine system. In Chapter 5 model control is used to design feedback controllers in order to shift the dominant eigenvalues to pre - assigned locations such that the response of the system is improved . This method eliminates the need for selecting suitable weighting matrices as in optimal control using regulator theory and does n ot impose any restriction on the control structure used in the sensitivity based design technique . The dominant eigenvalues are shifted to desirable locations in groups sequentially by using the dominant input for each groups and t his results in the optimal feedback matrix .But in any large multi - machine system comprising of several machine spread over a wide geographical area it is not 4 particularly feasible to feedback all the state variables of the system . Hence a method of designing a decentralized model controller at each machine utilizing the state variable of only that particular machine is proposed .The condition under which this technique gives good results is studied with the help of a three machi ne example . The concluding sixth chapter reviews the investigations and contributions made in this thesis and gives suggestions for future research in this area.

Title : ***Analysis Of Imperfect Cathode Conditions In Transferred Electron Devices***

Author(s) : ***Krishnan Cherukulangara Narayanan***
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Supervisor(s) : ***Sharan R***

Abstract

Deal with the analysis of imperfect cathode boundary conditions in transferred electron devices. Critical cathode conditions have been studied using the control characteristic techn ique introduced by Kroemer. The current transport through a proposed Metal - n+ (thin) cathode structure has been analysed using three different models in chiding a recent quantum using three different models of intimate metal - semiconductor contacts. The con trol of characteristics and their temperature variation have been studied for the M -n+(thin) cathode the schottky - barrier cathode and the heterojenction cathode all characterized by an energy barrier. Analysis has also been done of cathodes having a dopin g notch and those having a mobility notch. The results of the analyses have been shown to provide an expiation for an observed experimental trend reported in literature of the cathode structures analysed the M - n+ (thin) cathode has been shown to corr espond closest to the injection - limited cathode and shown to be the most - suitable from the paint of view of temperature - independent performance. The analytical expression for the transmission coefficient of a precession for the transmission coefficient of a precursor parabolic energy barrier and the analytical solution of the poisson equation for a schottky - barrier structure with a thin Gaussion -doped intermediate layer have been suggested to be of general applicability.

For more details click here Back

Title : Design Of Buffered Electronic Cyclic Memory Systems
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Abstract

New cyclic memories, e.g., charge-Coupled-Devices (CCDs) and Magnetic Bubbles fillthe wide gap of price and performance between semiconductor/core RAM, and magneticdisks and drums. We call these memories Electronic Cyclic Memories (ECMs) asinformation bits mover in such memories .The class of ECMs includes dynamic and staticshift-registers (SRs) as well .The clock rate is assumed to be constant in a dynamic SRwhereas it can be varied and reduced to zero in a static SR.We use the terms ECM andSR interchangeably. Buffering of ECM will lead to a memory organization whoseperformance approaches that of a high memory and price/bit that of an unbuffered ECM.The them of this thesis is the design of buffered ECMs which can be used with variousaccess disciplines namely FIFOandLIFO. We consider an ECMof size N with a transferrate of 1/Ts. Requests are assumed to following Poisson distribution. The mean inter-request time is denoted by MRT. We define the performance-improvement (?) of abuffered ECM over an unbuffered ECM as (1-Tb/Tu) x100 percent, where Tb and Tu aremean access times in the buffered and the unbuffered ECMs respectively. We propose two schemes for designing buffered stack memories one of them usesan ECMwith a fixed clock rate and the other uses an ECM with a variable clock rate.Mathematical models are developed for both the schemes .For the buffered stack memorywith variable clock ECM, a queuing model is developed from first principles. Simulationstudy was carried out for both. Simulation results agree well with the analytical results .Aperformance-improvement (?) of mere than 95 percent for MRT= 100Ts is obtained witha buffer of size 6 for a constant clock ECM of size 512 whereas a buffer of size 12 isrequired for variable clock ECM of the same size. In order to meet the requirement of a large storage with FIFO access disciplinevarious digital system and to satisfy random request arrivals we propose a bufferedECM organization with two small size buffer on input and output ends of the ECM.ECMwith constant clock rate is preferred as an additional small size shift register isrequired to set a condition to initiate the recalculation of information in ECM withvariable clock rate. We propose modified Skinner's models with a finite queue to model the abovescheme and develop a computationally convenient method to analyses this model.Simulation was carried out for the above scheme. Analytical values for the performance-improvement and the fractional loss of information agree with those obtained from thesimulation. With the constant clock ECMof size 512, and mean inter-insertion time andmean inter-retrieval time, MRT= 100 Ts, addition of buffers of size 6 exhibits theperformance-improvement of more than 95 percent and buffers of size 12 are required toachieve the fractional loss of insertions of retrievals less than 10-3. We propose a novel technique for multiple insertions and deletions in an ECM.Asingle buffer of size 16 added to an ECM yields a mean request-service time less than0.75 cycle for mean burst –length = 4. Finally we propose an associative memory organization consisting of variable clockECMs and small size buffers .The ability to vary the clock rate and the high ratio of dataarea to key area in a record are exploited to reduce the size of the content addressablememory (CAM) which is an expensive ingredient in this system. We strongly feel thatelectronic memories like CCDS and Magnetic bubbles will emerge as cost-effectivememories in the design of computer systems. At is concluded in this thesis that withappropriate buffering of ECMs, it is possible to design a variety of useful memorysystems with excellent performance characteristics.

For more details click here Back

Title : A Study Of Permutation-Invariant Linear Systems
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Abstract

This thesis presents a comprehensive and unified theory of a general family of finitediscreates linear systems having permutation-invariant property. Such system calledpermutation-invariant (p-I) systems; have features similar to those of linear time-invariantsystems. By a finite discreate system is meant a system with input and output defined over afinite index set Zn: o, 1, n-1; n signifies the length of signals and is arbitrary. If thesystem in addition is linear, i.e. additive and homogenous it is called a finite discretelinear system. A finite discrete system is said to be permutation-invariant if the effect ofpermutation the input signal in a certain manner is to permute the output signal alsosimilarly. Two very special classes of P-I systems have been recently investigated in detail.These are cycle are cycle and dyadic convolution systems. The generalization of thesesystems as given in this thesis is based on the observations that sets of shifts associatedwith the above two classes of systems corresponds to two special kinds of permutationson Zn and that in all there an permutations on Zn. Then by a suitable choice of varioussets of permutations from these n; permutations, it is possible to define with respect tothem, a general family of class as of P-I systems, which includes cyclic and dyadicclasses as special cases. The sets pf permutations with respect to which various classes of P-I systems aredefined are in fact transitive abelian permutation groups of degree n. By making use ofthis fact in conjunction with the well-established results in the theory of finite groups thatany finite groups of order n is isomorphic with a regular permutation group of the samedegree and that a transitive ablian permutation group is a regular permutation group it hasbeen possible to enumerate classes of P-I systems for any given value of n simplyenumerating all distinct abstract abeline groups of order n. Towards characterizing several of P-I systems, the crucial step consists of obtaininga general formula describing the effect on signals of permutations corresponding to thepertinent classes of P-I systems. This has been accomplished by suitably ordering thegroup elements in accordance with the notion of representating numbers with respect tomixed-radices .A simple defining equation for the elements of permutation matricesrepresenting transitive abelian permutation groups easily follows. These results areultimately utilized to obtain a well-defined generalized conventional relationship forvarious classes of P-I systems. This relationship implies that the system in each are fullycharacterized by the their unit sample response. Representations of P-I systems by matrices called P-I matrices are considered andproperties investigated in detail .It is shown that P-I matrices corresponding to anyparticular class of P-I systems constitute a vector space of dimension equal to thedimension of the signal space on which the P-I systems of that class operate; therepertinent set of permutation matrices serves as a basis of this vector space. Theeigenvectors of P-I matrices turn out to be the discrete versions OF Levy's generalizedWalsh functions. The corresponding modal matrices are shown to be the members of thefamily of generalized Hadamard matrices introduced by Butson. The eigenvalues of P-Imatrices are accordingly the components of the generalized Walsh-Hadamard

transform(GWHT) of their zeroth column. Other Properties of P-I matrices include closure underinversion and multiplication, which are communities. The fact that model matrices diagonalize the corresponding system matrices pavesthe way for the generalized convolution theorem, viz .The GWHT of the generalizedconvention of two signals is equal to the point wise product of the GWHT of individualsignals .The expression for the GHWT has been obtained in an axiomatic frameworkfrom postulates requiring that the desired transform should have certain basic properties.This approach differs from the conventional approach in which a transform is firstexplicitly defined and then its properties investigated .It is also shown that Physical'stheorem is valid for all P-I systems. After having thus established the theory of P-I system in general, attentation is givento dyadic P-I systems. In particular it is shown that besides the usual dyadic permutationmatrices the matrices representing Gibbs or dyadic differentiation of order upto n-1where n is a power of two also constitute a basis for the n-dimensional vector space ofdyadic matrices which represent dyadic P-I systems. This result is then used to obtainexplicit realizations of dyadic P-I systems in terms of Gibbs differentiators. Finally as an application of P-I systems a theory for P-I filters is outlined in whichthe role of complex exponential functions in classical filter theory is taken over by theeigensignals (generalized Walsh functions) of the particular class of systems to beemployed for filtering operation. The filtering of signals by cyclic and dyadic P-I systemsis considered in detail. The concern is in the sample domain implementation schemesrather than in the transform domain implementations using fast Fourier and Walsh-Hadamard transform techniques. Good approximations to the ideal filter characteristicsare obtained and implementation scheme based on the expansion of cyclic and dyadicmatrices with respect to their various are suggested.

For more details click here Back

Title : Study Of Tracking Filter FM Demodulator
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Abstract

In recent years, a greater deal of research has been done in the area of threshold extension FM demodulators and threshold extension has been achieved by several types of demodulators namely frequency feedback (FMFB), phase-locked loop (PLL) and tracking filter (TF) systems. The equivalence of FMFB and PLL demodulators has also been explicitly studied. Both of these systems in turn can be conceptually considered as variations of FM demodulator, however has not been studied per se, as extensively as the other two. This thesis is concerned with the study of a tracking filter structure which exhibits an interesting response behaviour in that it offers wide bandwidth to FM signals and narrow bandwidth to AM signals. The similarity in structure of this filter to PLL to some extent suggests its possible threshold extension capability. This class of filter structures arose out of an earlier, relatively unknown phaseplane study by Robinson* of the forced response of a quasi-linear second order differential equation to narrowband signals bearing amplitude and/or phase modulation. He showed that for forced oscillations, the nonlinear terms of this equations can be interpreted as a form of parametric feedback and consequently, using equivalent linearization techniques a general from of phase plane equations is obtained in terms of feedback parameters. By appropriately choosing the functions form of the feedback, the phase plane equations describe filters with a variety of response behaviour. This approach led to the synthesis of a narrowband tracking filter for FM demodulation. In an analog FM communication system employing this demodulation scheme the signal tracking capability of this filter reduces the noise considerably because of its narrow bandwidth while recovering the signal information unimpaired at the same time. To study its tracking behavior, the filter has been simulated on an analog computer and the results have been found to be in agreement with theory for various input and filter parameters of interest. Two forms of nonlinear ties have been considered for FM demodulation and a comparison made between them for their performance parameters. Analytical expression for lock range is also obtained in each case. To study the behaviour form the view-point of threshold extension capability of these filters, their performance for noise additive signals has been evaluated. The analysis has been done for a carriers signal in the presence so weak as well as strong noise. The stochastic differential equations desorbing the filter performance in terms of output phase and amplitude are first obtained. For strong carrier to noise ratio (CNR) case the non linearities are then replaced by their first order approximations and the steady state probability density function (pdf) for the output process is obtained using the foker-planck formulating. In this case, the steady state pdf of the output phase process for the tracking filter is shown to have a from similar to that first PLL and thus the steady state pdf as well as probability distribution functions are readily plotted for various values of nonlinearity parameters. In addition, the mean and variance of the output amplitude and phase have been obtained sung both the spectral analysis and the extended kalman filter equations. The result are again compared with those available for first order PLL. In case of weak CNR, the flkker-planck equations has been obtained for the joint probability density function of output amplitude and phase process. This equations has been solved for the pdf of the output phase process. This allows the derivation of an analytical expression for the phase error variance. Subsequent comparison of the phase error variance of the tracking filter demodulator studied here, with that of the first order PLL demodulator demonstrates at least theoretically a significant improvement in parameters thus confirming the intuitive justification for carrying out this study.

For more details click here Back

Title : *On The Binding Number Of A Graph*
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Abstract

The concept of the binding number of a graph was first defined by Woodall in 1973. For convenience, we give below the definition of the binding number. Let G=(V,E) be a graph. Let x ∈ V. denote by r(x) the set of all vertices adjacent to x in G. If xSV, define r(X) = UXxXr∈)(. The binding number of a graph G is defined as follows and is denoted by bind (G). Bind (G) = |||)(|min)(XXrVXrX## f In this, thesis, we study the properties of the binding number of a graph. In chapter 1, we give some basic definitions in graph theory and state some known results which are used in the other chapters. In chapter 2, we study the relationship of the binding number with different graph invariants, like independence number, chromatic number and diameter. The relationship between the binding number of a graph and the binding number of its powers is also studied. We show that bind (Gi) ≥ (bind (G))i, if Gi is not a complete graph using the above results and the other results, we prove that, if bind (G) = c and cr ≥ 2 > cr-1, where r is a positive integer, then the diameter of G is at most 2r. We also show that, if s = })1(2{ −cc is a positive integer then d ≤ s+1 where d is the diameter of G. as a corollary to the above results, we show that if bind (G) ≥ 2 51 + (golden ratio) then the diameter of G is at most 3. The binding number of sum of two graphs is also studied. In particular, we study the binding number of G+Km. the upper and lower bounds are obtained on the binding number of G1 + G2. Graphs with certain binding number are also constructed here. We study the binding number of a disjoint collection of graphs. The bipartite graphs with binding number 1 are characterized. (n-4) – Hamiltonian graphs are characterized in terms of the binding number where n denotes the number of vertices in a graph. The upper bounds and lower bounds are obtained on the arithmetic mean and the geometric mean between the binding number of a graph and its complement. A lower bound on the binding number of a graph is also derived. In chapter 3, binding number of four types of products of graphs, viz. Cartesian product, tensor product, strong Cartesian product and lexicographic product, are studied. Since it is difficult to determine the binding number of products of arbitrary graphs, we have restricted curselves to product of two graphs G and H where G and H could be any one of the following types of graphs: complete graph (Kn), complete bipartite graph (Km,n) circuit (Cn) and path (Ln). let G X H denote the Cartesian product, G⊗ H denote tensor product, G * H denote strong Cartesian product and G(H) denote lexicographic product Of two graph G and H. we have determined the binding number of 1. Km XKn, 2. Lm XLn, 3. Ka,b ⊗ Km,n, 4. Km ⊗ Kn, 5. Lm ⊗ Ln, 6. Ka,b ⊗ Kn, 7. Km * Kn (=Km(Kn)), 8. Lm * Kn (=Lm(Kn)), 9. Cm *Kn (=Cm(Kn)), 10. Ka,b * Kn(=Ka,b(Kn)), 11. Kn(Ka,b), 12. Km(Ln), 13. Km(Cn). In chapter 4, we study the relationship between the binding number and the existence of cycles and complete graphs in a graph. We show that, if bind (G) =

c > 1 and |V(G)| > 1 + ,)1(2−c c then G has a cycle of length 4. As a corollary, we have the following results: if bind (G(≥3/2 then G has a cycle of length 4. we have also shown that if bind (G) ≥3/2 then G has a cycle of length 5. we have proved that, if bind (G) ≥1/2)51(+ then G is Hamiltonian. Through this results is weaker than the results of Woodall (Woodall's results states that if bind (G) ≥3/2 then G is Hamiltonian) our proof is easy. M-Hamiltonian graphs are also studied in relation to the binding number. The existence of a complete graph in a graph is given by the following results. We show that, if bind (G)G ≥ r-4/3, where r is an integer ≥ 3, then G contains Kr. We study the relationship between bind (G) and bind (G, V). We have constructed graph with n vertices of binding number 3/2 for every n ≥ 5, n ≠ 6. In chapter 5, we give some open problems and conjectures.

For more details click here Back

Title : Optimal Modal Control Of Power Systems
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Roll No : 220461
Supervisor(s) : Pai Mangalore Anantha & Prabhu S S

Abstract

Recent decades have witnessed a phenomenal growth in the size and interconnection of power systems all over the world. The problems of design and operation of these systems are complex and require sophisticated techniques, expecially from the area of system theory for their solution. Production of large amounts of power at low cost has necessitated employment of generators of high capacity, exploitation of remote hydro-electric sources and trans-mission of bulk power by e.h.v. Transmission lines and increased interconnections to obtain economy and reliability. The fundamental problems in the design and operation of such systems are those associated with system stability, economic operation reliability of supply to the consumers, security and operation within the constraints such as those on system voltages and frequency. Many of these problems can be posed as problems in the area of automatic control. Consequently there has been considerable activity, in recent years, in formulating these problems and determining efficient solution techniques to them using techniques of modern control theory. Earlier approaches to improve the power system stability by the employment of the fast acting exciter voltage regulating system resulted in improved transient stability of the system. However, these systems generally exhibited poor damping of machine angle swings. These swings cause variation in system voltages and frequency and in extreme cases may even result in system instability. An appropriately designed feedback controller may overcome this problems. Therefore in the recent past researchers have paid great attention towards the development of suitable controls to damp out quickly the machine angle oscillations and at the same time retain the improvement in the transient stability. A major difficulty with this problem is that the system equations are nonlinear and of order. An approach which is usually employed makes use of a linear system model valid for small departures of the system from its nominal operating conditions. Optimal infinite time linear regulator theory is then used to obtain linear, time-invariant feedback laws. The following difficulties are encountered in this approach (a) It is difficult to determine apriori what the state and control weighting matrices, Q and R respectively, should be to obtain satisfactory closed loop system performance. It is necessary to solve the optimal control problems successively, for various Q and R matrices, till satisfactory system performance is obtained. The method does not provide the designer with a feel for the problem and the computationally unattractive. (b) The method requires accessibility of all states of the system for measurement. The use of observes which overcomes this drawback, introduces its own computational complexity. (c) The system should be completely state controllable. (d) The feedback law obtained for one operating point of the system may be inappropriate at others. (e) Furthermore, there is a problem associated with feedback gains. From the practical point of view large feedback gains should be avoided. The

approach referred to above does not provide direct control over the feedback gains. This thesis attempts to overcome some of the problems mentioned above by developing suitable techniques stemming from modal control theory. Like the classical root locus techniques modal control approach provides the designer with a feel for the problem and his engineering judgement can be better utilized for developing suitable designs. In many practical situations, system behaviour is governed mainly by a small number of dominant eigenvalues. A suitable design can usually be obtained by determining a feedback controller which shifts these eigenvalues far enough into the left half plane without disturbing the locations of the non-dominant eigenvalues. Complete state controllability in not necessary for achieving this objectives. This thesis reports a techniques for minimizing feedback gains to obtain optimal modal controllers and procedures which facilitate determination of modal controllers, optimal and non-optimal for high order systems. In the case of high order systems grouping of eigenvalues and use of appropriate control inputs to shift these eigenvalues is proposed. Using these techniques and coupled with the knowledge regarding sensitivity of the eigenvalues to system parameter perturbations, wide range modal controllers have been developed. These controllers give satisfactory system performance for a range of operating conditions. The thesis also considers design of incomplete state feedback and output feedback modal controllers. Modal control techniques developed has been also applied to design an output feedback dynamic controller. The design techniques developed pertain to finite-dimensional linear, time-invariant systems; they can therefore be applied in situations where the physical systems can be adequately represented by such mathematical models. In addition to applying the technique to the control of a power system with its associated controls, the thesis also illustrates the use of some of the techniques to the design of Load frequency controllers and controllers for high order systems. Specifically modal controller design of a forty-first order system describing a chemical plant has been given for the purpose of illustration. A chapter wise summary of the work reported in this thesis is given below: The problem of design of feedback controllers for power system is introduced in chapter 1. A review of the recent developments in this area is given. Chapter 2 is devoted to the development of the state space model for a power system which is used for illustrating the techniques of control developed in chapter 3, 4, 5 and 6. The power system considered consists of a synchronous generator connected to an infinite bus through a transmission line and has an exciter-voltage regulator and a turbine speed governor. The generator is driven either by a hydraulic turbine, or a steam turbine (as a prime-mover). The nonlinear equations describing the system dynamics are derived. Linear models are obtained by linearizing the nonlinear equations. The model for the design of load frequency control scheme for a two area system is also briefly described. The control problems associated with the above models have been enunciated. Chapter 3 introduces the concept of optimal modal control by suggesting appropriate performance indices. The indices involve minimization of feedback gains. The closed loop eigvenvlaues are decided as in classical control theory based on feel of the problem. A solution technique for designing an optimal modal controller is then described. Using this algorithm optimal modal controllers have been designed for a power system. The algorithm has also been applied to the design of a load frequency controller for a two area problem. The

responses are compared with conventional schemes as well as uncontrolled responses. The problem of designing controllers for high order systems are discussed in chapter 4. A straight forward application of the technique developed in chapter 3 will result in high feedback gains. This will be so in spite of the feedback gain optimization due to the constraints imposed on the structure of the feedback matrix. By relaxing the constraints an alternative design procedure for optimal modal control of large systems has been developed. This procedure is based on grouping of eigenvalues and moving these groups to desired locations successively through appropriately chosen inputs. Modification of this procedure which results in advantages in computations as well as implementation has been indicated. Three illustrative problem for the design of controllers for power systems have been solved and the results discussed. To demonstrate the efficacy of the algorithms developed, they have been applied to the controller design for a chemical plant having forty-one state variables and eight control inputs. Linear regulators for power systems are usually designed for a particular setoff system operating conditions. However, these conditions change with the load demand on the systems. In chapter 5, the design of a wide range modal controller is developed using modal control theory and eigenvalue sensitivity analysis. The design reduces the variation in closed loop pole locations with change in operating conditions. A numerical example of the design of the wide range controller has been given and the practical implementation discussed. Modal controller design requires feedback of all the state variables. In practice it may be difficult or impossible to do so. A technique to design modal controller with accessible state or output feedback is described in chapter 6. The chapter also includes the design, using modal control approach of a dynamic output feedback controllers. Chapter 7 reviews the work reported and contributions made in the this thesis and concludes with an assessment of the scope for further work in this area.

For more details click here Back

Title : *Accurative Evaluation Of transients On Double Circuit EHV Transmission Lines*

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Abstract

An overhead transmission line is subjected to over voltage transients due to lightingswitching operations or faults. Among these the over voltages caused by the lightning isindependent of the operating voltage of the line whereas the over voltages due theswitching operations or faults depended on the operating voltage of the line. Therefore oflate as the transmission voltages are increasing the studies of switching and faulttransients have gained more importance. Accurate calculation of these over voltagespermits reduction of safety margins and eventually reduces the cost of insulation oftransmission lines and associated equipments. The various methods of calculating these over voltage transients describesed in theliterature may be broadly classified into the lumped parameters method (including theTransient Network Analyser studies) time domain methods such as Lattice Diagrammethod Uram and Miller's method and finite difference method and transformationtechniques. In this thesis the modified Fourier transform method first applied to thepower system transient studies by Mullineaux et al and later by Battission et al andWedepohl and Mohamad has been made use of Briefly the Fourier transformationmethod of calculating the transient involves solving the transformed differentialequations of the trans is ion line for transformed and current at any point on there linesatisfying the boundary conditions at the ends of the line by the method of model analysisand the transformation of the response to the time by performing the truncatednumerical integration .The resistance and inductance matrices of a transmission line arein reality frequency dependent because of the variation of the conductor resistance withfrequency due to the skin effect phenomenon and the finite conductivity of the earthreturn path. Hence an exact study of transients on transmission lines cells for theinclusion of the effect if frequency dependency of line parameters. The Fourier transformmethod being a frequency domain method has the special advantage that the frequencydependence of line parameters can be directly incorporated without involving almost anyadditional computational effort. The double circuit transmission line is a common feature of any power system. In thepublished literature except not been studies the double circuit lines have their conductorsplaced A mirror symmetrical positions with respect to a vertical plane .For a transposeddouble circuiting whose conductors are so symmetrically lolocated a frequencyindependent model transformation is shown to exist in this thesis. For the untransposeddouble circuit line of the above structure the deign-value even-vector analysis of two 3x3matrices are to be performed at each frequency in the integration range to arrive at themodel transformation matrix. The objective of this thesis is to study the fault and energizing transients on a typicaldouble circuit line using the modified Fourier transform method. The engergisation and re-energisation overgisation over voltages on a transmissionline can be contained within the limit as low as 1.5 p.u. By various control methods suchas the multi-step resistance closing controlling the timing of the closure of the individualpoles of the circuit breaks etc. When such effective methods of controlling theenergisation and reenergisation transient over voltages are employed the over voltagesthat arise due to fault imitation may become the limiting factors. Ninety percent or moreof the faults experienced by a power system are single line to ground faults .In the eventof a single

LINE to ground fault transient over voltages of the order of 2 p.u. May beexperience by the sound phase. This calls for an accurate calculation of transients due tosingle line to ground fault ignitions. Various authors have studied this problem. Kimbark and Legate have used the TNA to evaluate the fault initiating transient on asingle circuit there phase line and have presented a lattice Diagram approach for atheoretical study of the problem with certain studies of the problem have been reported.Bonnyubol et al have made use of the Laplace Transform method and evaluated the faulttransient employing the Residue Theorem for the inverse Laplace transformation.Except for a few TNA studies in all the above studies only single circuit lines have beenconsidered. Moreover the lines have been assumed to be transposed and the effect offrequency dependency of line parameters has not been investigated .In this thesis themodified Fourier transform method has been applied to study the transient due to theinitiation of single line to ground fault at any intermediate point on a double circuittransmission line. The need for the modeling of a double circuit line for fault transientstudies has been established by comparing the fault transients on single and double circuitlines .A typical 4000 KV double circuit lines has been considered taking into accountthe mutual coupling between the two circuits .For line fed on both the ends by inductivesources the mid span fault transients have been evaluated assuming the line to be bothtransposed and untransposed .The effect of frequency dependence of line parameters onthe fault transient over-voltages for both the transposed and untransposedconfigurations of the line has been investigated .The fault location is changed to variousoff-center points and the fault transients have been studied. The mid span fault has beenfound to give rise to the maximum peak over voltage. The energisation of a double circuit line involves closing of both circuits. In practicethere is bound to be time delay between the closing of the first and second circuits of adouble circuit line. This delay is at least a few seconds if not a few minutes. During thisperiod the transient due to the enertgisation of the first circuit would have died down andthe first circuit would be in steady state. Thus essentially two transients are involved inthe study of the energisation of a double circuit line (viz.) (I) the transient due to theclosing of the first circuit keeping the second circuit unenergised (ii) the transient due tothe closing of the second circuit when the first circuit is already in steady state .The thesispresents the calculation procedure and the results of the above mentioned studied on adouble circuit line. A typical 400KV double circuit line open at the receiving end hasbeen considered and the voltage waveforms at the open receiving end subsequent toenergisation from an inductive source have been calculated for both transported as anduntransposed configurations of the line. The effect of the frequency dependence of lineparameters has been incorporated in the studied by using the Carson's formulae for thecalculation of the line parameters.

For more details click here Back

Title : *Design And Analysis Of Graph Algorithms*
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Abstract

Graphs have been used to model a wide variety of practical problems. In solving these problems, one often encounters large graphs, which are difficult to study without the aid of a computer. There has thus been a continuing need for devising efficient algo rithms to solve graph problems. In the last fifteen years, a number of graph algorithms have been proposed and some have been analysed. In this thesis, after surveying various computational problems in graph theory, we examine the influence of computer mo dels and of data structures on the efficiency of graph algorithms. We also suggest a new representation for graphs (called K - L arrays), which facilitates an efficient implementation of some of the algorithms in FORTRAN. We have also classified different co mputational graph problem according to their complexities. This may help in choosing an appropriate data structure and in establishing the complexity of a new problem. Various searches, like breadth - first search (BFS), depth - first search (DFS), and mixed search were proposed in the past for solving many graph problems. The BFS, DFS, and mixed search procedures generate spanning trees of the given graph, which are called bush, palm and pine trees respectively. We examine the structural properties of these s panning trees. In particular, we characterize them in terms of forbidden subgraphs. The eccentricity of a bush tree is used in improving the upper bound for the eccentricity of a central tree. The relative performances of various searches are also discusse d. For example, it is shown that mixed search outperforms DFS for generating fundamental circuits. Using BFS, and efficient algorithm is given for finding the entropy of a graph. The centre of a graph is also found using BFS. To determine connectivity prop erties of a graph, it is necessary to search through the edges of the graph at least once. It is known that certain algorithms employing search procedures for determining such properties are optimal. We survey different arguments for proving the optimality of graph algorithms. Also the complexity of any algorithm which tests whether or not the given graph satisfies a nontrivial property is given here. We propose linear algorithms (in the number of vertices) for testing the strong connectedness of a transiti ve digraph and for determining whether or not a graph is a star graph. In studying problems of polynomial complexities, the squaring of several special types of Boolean matrices (such as symmetric, upper triangular, and banded) is shown to be computational ly equivalent to Boolean matrix multiplication. The problem of realizing a reach ability matrix as a digraph with minimum number of edges is considered next. It is proved here that his problem is of the same complexity as that of Boolean matrix multiplicat ion. The isomorphism problem for graphs is proved to be polynomially transformable to the isomorphism problem of bipartite graphs. It is also proved that the isomorphism problem for weighted compete graphs is at least as hard as the usual isomorphism probl em for unweighted graphs. A particular effort has been made to study NP - complete problems. Several problems, such as vertex deletion problems and Hamiltonian completion problem for bipartite graphs, are shown

here to be NP - complete. A few researchers have observed that some of the NP - complete problems can be solved in polynomial time, if the graphs are restricted to special classes of graphs such as planar, bipartite, and transitive. In this thesis, some additional problems, such as, finding a minimum feed back vertex set, a minimum feed -back edge set in transitive digraphs, and finding a minimum equivalent digraph of a given digraph for acyclic and transitive diagraphs, are contributed to this class. It has also been observed in the past that in some cases NP - complete problem is drastically restricted. We further reinforce this interesting observation by showing that the problem of finding a Hamiltonian circuit remains NP -complete in bipartite and in transitively orientable graphs. Further, the problem of fi nding a degree - constrained spanning tree is shown to be NP - hard.

For more details click here Back

Title : *Design Of Building Blocks For Bipolar Linear Integrated Circuits*

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Abstract

Although modern bipolar linear integrated circuits are quite complex and capable of performing involved functions, essentially these consist of various basic circuits like bias networks, input stage gain stages function generators, reference sources etc. in conventional IC design variable swapping between current and voltage is done very often. In doing so the input-output relationships of many building blocks tend to be temperature-dependent. Bandwidths are often limited because of the need for large voltage swings at the various nodes inside the circuit. On the other hand it is well-known that the basic element namely the junction transistor in bipolar linear Ics, is essentially a current operated device. It is possible to design Ics in which the current forms the main variable and the voltage swings at different nodes in the circuit can be kept small. The main advantages which accrue from this approach are large bandwidths and temperature insensitive input-output relationships. But voltage signals are more often encountered in practice the thus it is necessary to have a voltage-current transducer (VCT) as a front-end for signal processing to be performed completely in current mode. If a voltage output is required, the current is converted into voltage at the output-end. The work described in this thesis deals mainly with the voltage-to-current conversion in a linear and temperature independent fashion. Many designs of VCTs presented. A VCT is considered to be composed of a voltage-to-voltage transducer (VVT) terminated in a Tran conductance defining resistor Rm followed by a current-to-current transducer (CCT) to sense the current through Rm and to provide a proportional output current the VCTs discussed are divided into two groups. The first group comprises of the VCTs whose design is based on inverse function principle. This principle is discussed in detail as it has many other applications. The other class of VCTs are similar to conventional designs in which a unity gain VVT is obtained by providing negative feedback around a VVT having a large open-loop gain. But the important difference in its performance is due to the biasing arrangement which desensitizes the open-loop gain variation with temperature. Thus it becomes possible to employ low open-loop gains which results in increased band widths. Besides providing interfacing the VCTs and other circuits discussed form useful building by themselves. These could be used for a variety of applications. A few important applications are considered in the thesis. The first application is a design of an intermediate frequency (fo 500 KHz) band-pass filter for which the center frequency and the selectivity (Q 50) can be adjusted independently. The filter is realized using positive real axis zero approach because of reduced overall gain requirements. Theoretically the sensitivity of Q with respect to transducer gains is proportional to Q itself. Because the

transducer gains themselves are stabilized, in practice these sensitivities are very low. The structure presented also lends itself to very easy trimming and tuning operations. The other application is a design of a highly linear current-controlled oscillator (CCO) based on the emitter-coupled astable multivibrator in which the nonlinearity and the temperature dependence of output frequency are eliminated by replacing the transistors by high Tran conductance element. Computer-aided circuit analysis combined with experimental observations forms thebasic approach for the design of the blocks. A computer-aided analysis package: Bipolar linear integrated circuits simulator (BLICS) based on nodal admittance matrix formulation and ccrout's method for solution similar to ECAP has been used to study circuconfigurations and conclusions have been drawn from the results thus obtained. For experimental purposes commercially available monolithic transistor-and resistorarrays have been used. Bread-boarding techniques have been employed for investigating new useful circuit configurations. Frequency response measurements upto 5 MHz could be done on the bread-boarded circuits. Printed circuits have been used to measure frequency response between 5 Mha and 100 MHz. The temperature stability is studied by heating the circuits in range 200C to 800C. To fully exploit the potential of bipolar-technology, the linear integrated circuits should be operated in the current-mode. The design philosophy and the building blocks presented in the thesis should be useful towards this end.

For more details click here Back

Title : *Preventive Control And Diakoptical Optimization Of Large Scale Power Systems*

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Abstract

The primary objective in the operation of a power system is to provide an uninterruptedsupply of power at a given operating state and to meet all the demands of the customersat slandered frequency and voltage .The operating state of a power system ischaracterized by two sets of constraints viz., power flow (equality) and operating(inequality) constraints. The power flow equations describe the steady state equilibriumconditions of the power system network. The capability limits of generating source andthe limits ion voltage magnetic and line flow variables constitute the operatingconstraints. Of these the limits on bus voltage magnitude and line flow variables arereferred to as simple security constraints since they pertain to the present state of thesystem .It is often desired to operate the system with a specified level of system security.For this purpose the vulnerability of the present (base case) state f the system is chekedagainst a set of postulated next contingencies .If all the post –contingency state exist andare found to be normal (i.e., all the equality and inequality constraints are satisfied) thenthe present state is defined as secure /.On the other hand even if one of thecontingencies result in a state which is not normal or result in an emergency state(I/.e., all equality constraints are satisfied but some of the inequality constraints areviolated) then the present state is defined as alert (or insecure) If the present stateis insecure then preventive control action is required to make the present state asecure one. The security constraint optimization (SCO) is a problem of determining the bestpreventive control action to restore the vulnerable system to a secure normal state.That is the SCO determines the generation schedule, which minimizes an objectivefunction (generally the system generation cost) object to power flow constraints operatingconstraints and logical security constraints. It has been recognized that solving this totalproblem will be difficult because of the computational complexities involved. Toovercome this difficulty the SCO problem is decomposed into two subproblems. The firstsub problem known as optimal power flow (OPF) problem determines the optimalnormal state of the system without considering n the logical security constraints .If thisstate is insecure the second sub problem (preventive rescheduling determines acorrective reschedule to result in an optimal secure normal state of the system .Thepreventive reschesduling problem will be difficult to solve if one considers the system'sbehaviour under transient dynamic and steady state periods for each of the credibleoutages as well as the numerous logical security constraints imposed by them. Toreduce this complexity the generally accepted partice is to consider the effect of thecredible outages on the steady sate performance of the system at its current operatingstate. One of the objectives of

this thesis is to purpose a method for on-line applicationsfor the above twin optimization problems. For on-line applications LP technique withlinearised equations is found to be one of the best suited methods. But in the LPformulations proposed so far either the schedule of real power generations areconsidered or decoupled real and reactive power optimization procedures are utilisedd.This separate a MW dispatch and voltage control problems could not incorporatedproperly the interactions among the two solutions and could not consider properly theconstraints on reactive power flow MVA flow variables etc. In this thesis therefore an LPmethod is proposed which considers the MW dispatch problem and the system voltagecontrol problem as an integrated optimization problem within the framework of systemsecurity. With the increase in the number and importance of interconnecting linescommissioning of larger generating units and faster rate of system growth theoptimization procedure (especially first sub problem, viz., OPF) has been found to bedifficult to manage with the available modern computers due to large size of the problemnumbers of variables and the large number of constraints imposed. The piecewisesolution technique has been found to be the best alternative to overcome this difficulty. Inthis approach the large-scale system is decomposed into a number of subsystems eachwith a smaller independent sub problem. The integrated system objective is achieved bycoordinating the solutions of the subsystem problems. This piecewise technique willrequire less computing effort compared to the original untorn system problem.Historically the large scale power system optimization problem gas been solved byeither retaking real power only (ignoring the reactive power control) or decoupling realand reactive power. Therefore the second objective of this thesis is to propose piecewisesolution TECHNIQE has been found to be the best alternative to overcome thisdifficulty. In this approach the large-scale system is decomposed into a number ofsubsystems each with a smaller independent sub problem. The integrated systemobjective is achieved by coordinating the solutions of the subsystem problems. Thispiecewise technique will require less computing effort compared to the original untornsystem problem. Historically the large scale power system optimization problem hasbeen solved by either taking real power only (ignoring the reactive power control) ordecoupling real and reactive power .The refer the second objective of this thesis is topropose piecewise solution procedures (based on diakoptics and multilevel solutionprocedures (based on diakoptics and multilevel control) to schedule both and reactivepower generations. The following is the chapter-wise summary of the work reported in this thesis: The first chapter introduces the problem of security constrained optimization andoptimization of large-scale power systems. Following a brief review of the state of the artthe cope and objective of the thesis are outlined. In chapter 2 a successive LP formulation is proposed o solve the optimal power flowproblem using a linnearised a power flow model .The use of the linearised modelapproach is justified because the change in the load pattern in the minute-to-minuteoperation of power system is small. The LP problem is formulated in terms in terms ofthe control variables viz., real and reactive power generations and transformer tap rations.This has been achieved through the differential relation known as incremental powerflow equation, which relates the small change in the slack bus power to the small changein the control variables. For satisfactory operation of a power system

large number ofconstraints vix. (I) Simple security constraints –the constraints imposed on liner flow andbus voltage variables of the present operating state of the system (ii) constraints onslack bus power and (iii) the constraints on control variables are imposed which result ina high dimension LP problem. Therefore to reduce the core memory and to increase theprogram speed dual LP formulation is adopted .The feasibility of the proposedformulation is demonstrated by 5 bus system example and IEEE e30 bus system example.Since the minimum generation cost is obtained partially in 1to 2 interactions thisformulation is well suited for one-line applications. From system security point of view the most economical operating point should befound which not only satisfies the simple security constraints but also the logical securityconstraints imposed due to there postulated next contingencies. Therefore to find thesecure operating point the dual LP formulation proposed in Chapter two is extended toinclude the logical security constraints as shown in chapter 3. To achieve a fast particalpreventive rescheduling algorithm (I) only the violated (effective and sub effective)constraints are considered and (ii) a decoupled linearised power flow model whichexploits the weak coupling that exists between P-? and Q-V variables is utilized .Theresults obtained for the medium size IEEE 30 bus system example for the proposedformulations (full and decoupled model) are compared with the result of an NLPprocedure by Alsac and a Stoat. A piecewise diakoptic method is proposed in chapter 4 for the large power systemoptimization problem .The power system is decomposed into a number of subsystems orareas by removing certain branches in the system known as cut lines. The diakopticformulation is then obtained by treating the real and reactive power flows in the cutlines as additional problem variables. Real and reactive generations are scheduled tominimize the system cost of generation satisfying operating constraints. With certainapproximations the Jacobin inverse matrix is identified in terms of the elements of thebus impedance matrix and this constant Z-type matrix is utilized in finding the feasiblesolution and the; Lagrange multipliers .The feasible solution is updated using the firstorder gradient technique .The proposed method is programmed for IEEE 14 bus and 30bus test systems. In Chapter 5 a two levels optimization procedure is proposed for large-scale powersystems .The Real and reactive power optimization problem is formulated as anadditively separable NLP problem. The two level structures are obtained by theintroduction of pseudo variables. The optimization of the systems problems areperformed at the first level and the second level coordinates the subsystem solution s toarrive at the optimum solution of the integrated system. The major conclusions reached in the course of the thesis are reviewed in Chapter 6and suggestions for further investigations are indicated

For more details click here Back

Title : *Stability Of Large Scale Power Systems*
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Abstract

Transient stability of a power system is an attribute of the system which denotes the conditions in which the various synchronous machines of the system remain in synchronism with echo other when sudden disturbance occur on the system. Stability studies are necessary for planning new facilities for future load growth and also for a reliable operation of the system. For such studies it is now acknowledged that Lyapunov method yields satisfactory results as compared with the conventional method using repeated integration of the system equations for different assumed clearing times. Even since the original works of El-Abiad and Nagappan, Gless and Aylett in this area there has been considerable interest in the use of Lyapunov functions for assessing power system stability. However, after 1972, the interest somewhat declined due to some of the practical difficulties encountered in the successful applications of this method to reasoistic power systems. Some of these are: (i) Determination of the stability boundary for the post-fault system, this involved the computation of 2n-1 – 1 unstable equilibrium points. This was a formidable task even for off line studies, (ii) The larger size of the system necessitated the use of simpler models for the synchronous machines, (iii) Increased interconnection of the system required the construction of the dynamic equivalent and their incorporation in Lyapunov methods. In this thesis solution to some of these problems is presented. As regards the determination of the stability boundary the recent work so Prabhakara and El-Abiad marks a big step forward. However, it has certain drawbacks in terms of choices of reference machine and an adequate theoretical basis. In this thesis the problem of detemining the stability regions as formulated in the context of a multinonlinear Lure'-Popov system where the nonlinearities satisfy the sector condition only in a region around the origin of the state space. Utilizing this sector violation information often nonlinearities, a generalization of an earlier result due to Walker and Mc'Clamroch and Weissenberger is obtained. This result is further suitably modified to suit its application to the power system model. The method of Prabhakara and El-Abiad is shown to be a special case of the general result obtained. The problem of handling large scale power systems. Is analyzed by suggesting a method of decomposition and the use of a new theoretical concept of vector Lyapunov functions. The large scale power system is decomposed into low order models called the 'subsystems' and the stability properties of these subsystems are analyzed separately by constructing scalar Lyapunov functions for each of these subsystems. On the higher hierarchical level these scalar functions are used to define a vector Lyapunov function for the composite system. Using this vector function together with the nature of interactions among the subsystems, the stability of the overall system is inferred. A 3 machine example illustrates the application of the proposed method. A third contribution of the thesis is in the area of using energy or energy type Lyapunov functions to identify coherency and also subsequently develop dynamic equivalents for large power systems. Stability analysis by both conventional and Lyapunov based methods is carried out for the reduced and the unreduced systems, and the results are compared. The following is a chapter wise summary of the work reported in this thesis: The first chapter introduces the problem of stability analysis of large power systems using the second method of Lyapunov. The state of the art is briefly reviewed and then the scope and objective of the thesis

are outlined. The second chapter is devoted to the development of state space models of power systems. Although a proper rationale involving the control theoretic concepts of controllability and observability has been given for a proper choice of the state variables, the reasons for such uncontrollability are not evident. In this chapter it is shown that this state uncontrollability is partially due to the state over description in the model and hence the corresponding state vector is not of the proper order. A legitimate order of the state vector is obtained and is shown to be the same as that obtained by the control theoretic approach. Thus some additional light is thrown on this already settled controversy on the minimal order of the system. The third chapter introduces a new concept of vector Lyapunov functions for the stability of a large scale power systems. The theory of vector Lyapunov function is developed to suit the power system problem. A decomposition of the power system into lower order subsystems is obtained. Each of these subsystems is shown to be identical in form and in order. Lyapunov functions for each of these subsystems are constructed using the Moore-Anderson's theorem. These functions have a positive definite quadratic from with a negative definite derivative. A vector Lyapunov function is defied for the composite system. Conditions for the stability of the overall system are then derived. A scalar Lyapunov function is also defined for the composite system and is proved to possess a negative definite derivative. This scalar function is subsequently used for determining the stability domain. Illustrative example of a three machine case is given. The fourth chapter deals with the problem of obtaining stability region for a multimachine power system without computing the unstable equilibrium points. The problem is posed first as a multinonlinear problem of the Lure' – Popov type in which the nonlinearities violate their respective Popov sectors. Using this sector violation information, an expression for the stability boundary is obtained constituting a generalization of the results of Walker and Mc'Clamroch obtained for a system with a single nonlinearity. The technique is then extended to a multimachine power system for estimating the stability domain. Two algorithms are proposed for practical implementations. The methods are illustrated with reference to a 5-machine example. The fifth chapter addresses itself to the problem of stability analysis using reduced order models of the power system. A criterion using energy functions for identifying coherent group and for the development of the dynamic equivalent is proposed. Test results on a 44 bus system with 15 generators are presented. A general review of the results of this research, identification of some unsolved problems and suggestions forfuture work form the theme of the concluding sixth chapter.

For more details click here Back

Title : *Estimation Of Stability Domains For The Transient Stability Investigation Of Power Systems*

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Abstract

The transient stability problem arises in a power system due to the occurrence of large or sudden changes, these changes being typically due to factors such as sudden changes in the system load or changes in the network configuration due to faiilts etc. The system is said to be stable if it settles down to a steady state value after the disturbance. This problem has been studied by solving the system differential equations to obtain explicit solutions as fiinction of time - a procedure which is still the most widely losed method.In recent years, there has been great interest towards the application of Lyapunov*s direct method for the estimation of stability domains to investigate the transient stability of power systems. This method provides a considerable saving in the computational effort involved for the stability studies, since the computation of critical clearing time (information about which is iiseful in specifying the speed of circuit breakers) requires aXIsingle integration of the faulted system differential equations while in the conventional step by step method, many integrations are necessary for different ass-umed clearing times. Some recent works also indicate the possibility of using lyapunov functions for on--line stability and security analysis. However, these appear to be certain difficulties in the application of this method. The chief drawbacks of this approach have been the lack of systematic methods for the construction of lyapunov functions andthe conservative estimates of the resulting stability regions.The present thesis is eon-cerned with the development of systematic me'thods for the estimation of stability regions for various mathematical models of power systems• The initial part of the thesis is devoted to the constrxiction of stability domains using lyapunov functions that are either purely quadratic in state variables or that are a combination of a quadratic form in state varia,bles along with a quadratic form in the derivatives of state variables. The later part of the thesis is concerned with the determination of regions of stability using techniques that do not involve the construction of a Lyapunov function• Two approaches have been indicated* The first approach deals with thexiiapplication of pattern recognition techniques to estimate a decision surface that separates the stable from the unsta,ble regions* A numerical integration technique based on Lie-series is used to generate the set of data points that constitute the classes required for the application of pattern recognition techniques» She second approach has been towards examining the nature of the trajectories in the phase space and studying their dependence on certain machine parameters• The concept of a 'critical surf8.ce* in phase space is introduced in order to obtain estimates of critical fault clearing-times* Both the approaches are believed to be quite promising and have not been considered earlier for investigation of transient stability of power systems. A brief outline of the various chapters is given below.The first chapter deals with the description of the transient stability problem and the organization of the thesis.Erasovskii's method for the construction of lyapunov functions that are quadratic in the derivatives of the state variables is investigated in the second chapter• Its application to the power system problem is discussed and some drawbacks of the method are pointed out, Erasovskii*s lyapunov function augmented with aXXXIquadratic form in the state variables is then considered and

generation of such lya-punoT fimctions requires in general, the solution ox a nonlinear programming problem. A sequential unconstreaned minimization technique due to Fiacco and McGormick is used for this purpose and has been described in this chapter.Chapter 3 considers the use of lyapunov functions that are quadratic purely in the state variables. A technique proposed by Davison is investigated for generation of these Lyapunov functions which are such that the hypei*volume contained in the region of stability is maximized. The approach consists essentially of a direct search method for the systematic construction of theweighting matrix P which provides a stability boundaryT given by X P x = 1»0» Details of the com put actionalalgorithm as well as numerical examples illustrating thesuitability of this method have been provided.Chapter 4 deals with the estimation of a decision surface that separates the stable and the unstable regions, Pattern recognition techniques are employed to obtain this decision surface from a set of data points genera.ted by the solution of Zubov*s partial differential equation* Applications of the Ho-Kashyap algorithm for linear inequalities towards obtaining the decision surface isXXTdescribed• A detailed description of the nimerical integration technique based on lie-series used for' the solution of Zubov's partial differential equation has been given* Different numerical examples describing various mathematical models of power systems have been provided to test the usefulness of the proposed techniquesIn Chapter 5, dependence of the exact stability boiondaries on system parameters has been investigated* For a certain critical set of parameters, the demarcation between the stable and the unstable region in pliBBo space- is obtained through a stability boundary which passes through the nearest unstable equilibrium points, surroimding the stable equilibrium point. The boundary or surface in phase space has been termed a.s a * critical surface*. A Pourier series method for the construction of this surface and evaluation of the critical value for the set of system parameters for which it exists is detailed* Critical fault clearing times are computed using this surface as a sta,bility boundary. Numerical examples have been included to test the suitability of the proposed techniques.In the concluding chapter, the resizlts of the thesis are reviewed and future lines of research are indicated.ates has been explained in terms of a lower symmetry arising out of the hindered rotations of the nitro groups. The xsomar shifts of these compounds indicate that TC-back donation between the metal atom and nitro group is very weak.

Title : Descriptive Inferencee In Pattern Rcognition
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Abstract

It is generally accepted that the best examples for the study of intelligence are the recognition of visual scenes or pictures. Historically speaking, Pattern Recognition is seen as an attempt at classification, and of late, the view that what is being looked for is not just a classification but more a sort of description of the subject matter, is gaining ground. If pattern recognition is viewed as an intelligent activity, any model of pattern recognition needs to be equipped with dynamic internal mechanisms. It is clear that human memory for instance, is not a passive store-house of abstract descriptions but is capable of complex operations on these description. It is capable of rearrangement of the descriptions as directed by the requirements of the problem and has the ability to generate fresh descriptions out of the existing descriptions. It is therefore felt that an adequate model of recognition should possess a mechanisms to draw inference on the stored descriptions; the complexity of the mechanisms being decided by the requirement of the problem is hand. The other question that arises is whether there exists an objective meaning for the word intelligence at all. Should one then suppose it to be a highly subjective attitude elusive of scientific investigation perhaps such a question itself may be irrelevant to any scientific investigator since science itself is based on the faith that there exists an objective reality. It was Aristotle who opposed the doctrine that there are innate ideas in favour of the view that al our knowledge is derived from particular things: thinking he maintained is a matter of proceeding from the particular to the general and then by analysis of the general back to the particular. In this study attempts are made on simple pictorial problems, in what one could consider as generalization from particular observations. A few alternative set of formulations have been attempted to bring out the concept of generalization is applied to pictorial data. The concept of exception is inseparable from the concept of generalization. Though no attempt is made in this work to develop an ontologically acceptable meaning of these words, an intuitively acceptable criterion is what one is looking for. In particular, the thesis report the design of a system called "CONCEPTRERENCE". CONCDEPTRERENCE is a system that can develop concepts on pictorial information and utilize these concepts while drawing inferences on the pictorial information. CONCEPTRERENCE is designed to work in two phases. In the first phase the system is exposed to a scene. Then various attributes of the scene are evaluated and by associating these attributes with the appropriate pictorial objects, the system is able to develop the general concepts of the environment in which the system has to function. In the second phase the system is exposed to its environment. The environment has certain similarities with and differences from the first. The similarities with the first are that the concepts developed about the individual pictorial objects of the first are adequately general without being vacuous, to accommodate the individual pictorial objects of the second. The differences are that the second could be a totally different organization of the individual pictorial objects and there could be new

pictorial objects without having corresponding concepts arising out of the mutual organization of the objects, developed from the first. Thus the system maintains its information bank in the form of a cropus consisting of well formed formulae of the first order predicate calculus. Also built in the system are some universal relations true to the domain of the pictures under consideration and they are available within the system in the form of well formed formulae. In order to facilities deduction using the Resolution principle the well formed formulae are expressed in clause form. The system is then in a position to accept question of non-trivial nature expressed as well formed formulae of the first order theory. Considering the formulae as an assertion to be established in the domain of the theory, the deductive mechanisms based on the Resolution principle is called into action. Besides the system can not only establish assertions of interest in the pictorial data but also identify in terms of the context the pictorial objects of interest. The model employs heuristics in carrying out the process of resolution heuristics based on the requirements of the problems. CONCEPTRERENCE is both inductive and deductive in its process. The system integrates both a system of logic and its execution the requirements of the problem. CONCEPTRFERENCE is modular in its construction and possesses inherent generally and could work under a variety of domain of discourse. Not only three dimensional scenes but also non-pictorial problems could be attempted under the frame work. The study of necessity includes the related areas of psychology and other disciplines which form the philosophical foundation of models in pattern recognition. The system is designed for implementation in Lisp 1.5, available on the IBM 7044 at IIT Kanpur. The power of description, the ease with which the subroutine could be developed and assembled, the dynamic storage facilities and the debugging facilities available in Lisp have been the main factors directing the choice of the language.

For more details click here Back

Title : *Synthesis Of Multifunctions Active R C Filters Using Grounded Capacitors*

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Abstract

Active RC filters have widespread applications in modern electronic instruments and systems. The absence of inductors coupled with the commercial availability of the operational amplifier at low cost has immensely influenced the design and development of such filters. Both theory as well as design of active inductor less filters are covered extensively in the literature. The work described in this thesis deals with synthesis of active RC filters with an additional constraint of using grounded capacitors. A grounded capacitor has simpler high frequency circuit model than an ungrounded capacitor. The fabrication process of a filter which employs grounded capacitors involves less number of metallizations. In addition, for the second order filter, a readily available component, viz, the ganged capacitor can be used in the circuit. This feature permits accurate tracking at high frequencies. Besides, the errors due to CMRR at high frequencies are less for a class of active RC filters which use earthed capacitors. The factors mentioned above are further elaborated in the first chapter. They directly contribute to the superior high-frequency performance of the active RC filters employing grounded capacitors. Three distinct active RC circuits are synthesized. They realize voltage transfer functions of order two. The operational amplifier (OPAM) is used as the active element. The passive elements used are assumed to be linear, lumped bilateral and time-invariant. The use of a gyrator is not permitted. The resulting circuit configurations are canonic and posses multifunction capability. The design equations of the three filters are simple and straightforward. Particular attention has-been paid to keep the spread in component values small. A separate chapter is devoted for detailed treatment of each circuit. The first circuit is a symmetric notch filter. This has been realized using basic concepts of signal flow graph and feed back. A discussion on the performance criteria of the symmetric notch filter is given. Three independent parameters, viz, notch frequency quality factor, and de gain form the basis for specifying such filters. The circuit uses four operational amplifiers. Stability and sensitivity aspects are examined and a method for fine-tuning is given. The filter is versatile and provides low pass as well as band pass characteristics across appropriate ports. Experimental results for a range of filters parameters are give. Pertinent precautions necessary for the realization of high Q filters are listed. The second and the third circuits deal with the problem of realizing biquadratic voltage transfer function. The synthesis has been carried out using state variable approach. In both these circuits the quality factor and pole frequency are capable of variation without interaction. There is unity spread in the capacitor values and high Q is realized with moderate spread in resistance values. Both the circuits use differential input differential output OPAMs. This feature obviates the use of double input summer, simplifying

thereby the adjustment procedure for the numerator coefficients of the biquad. Though the four OPAMs are used for a general biquad yet the second circuit realizes low pass, high pass and band pass filters with three OPAMs only. Similarly the use of differential output is not necessary for special cases of practical interest like low pass, high pass, band pass and notch filters. The third circuit is an improvement over the second circuit. This stems form the fact that the basic block used in the former is shown to have superior performance than the basic block used in the latter. The high frequency performance of the biquad is analyzed using state space concepts. The circuit is shown to possess sixth order a A-matrix. The dominant eigevalues of this matrix are evaluated which yield the actual values of pole frequency and quality factor. The computer programs using different numerical techniques have been developed for the purpose. The close agreement between experimental and computed values indicates the validity of the model assumed for the OPAM under stipulated frequency range. Modification of the circuit to take leakage resistance of capacitor into account is proposed. Computer simulation of the effect of increased open loop gain with the without keeping open loop bandwidth constant, has been carried out. Full details of the experimental considerations are given. A theorem that conversion from extended form of state space equation to standard form is stated and proved. All the three circuits have been tested for wide range of filter parameters. The experimental results demonstrate the high performance capabilities of the circuits proposed.

For more details click here Back

Title : *A Class Of Formal Models For Languages And Programs*
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Supervisor(s) : *Basu Sanat K*

Abstract

There are two models in language theory which have been extensively studied and which have been particularly useful in specifying to certain extent the syntax and semantics of programming languages. These models are those of the context free grammar and the syntax directed translation scheme. These models are not however, powerful enough for modeling accurately various structures and mappings that we come across in various areas such as programming languages and pattern analysis. As a results, recently there has been considerable interest in more powerful models of languages and translation which also lead to informative structural descriptions. It has also been felt that different formal models of languages (respectively, translation) are of interest in language theory because a specific model that is capable of characterizing certain aspects of a language structure (respectively, mapping between the structure of the domain and the range languages) naturally, may be unsatisfactory in some other respect. It is in this background that the work reported in this thesis should be viewed. Certain recently proposed models for languages such as the simple matrix languages and various generalizations of the syntax directed translation scheme can also be looked at from this angle. We have in this thesis proposed and studied a class of generative grammar which we call coupled grammars, which can serve as models for languages as well as for translation. Context-free grammar and syntax directed translation schemes are special types of coupled grammars. Again we have shown that the classes of simple matrix languages and equal matrix languages, which have been studied in recent years, are generated by certain restricted classes of coupled grammars. Thus the concept of a coupled grammar unifies and generalizes the concepts of a context-free grammar an equal matrix grammar a simple matrix grammar and syntax directed translation scheme. Intuitively, we can think of a coupled grammar of degree n, $n \geq 1$, as defining ntuples of labeled rooted trees <T1,…,Tn>, which we call n-derivation trees, where T1 is a derivation tree in a certain context-free grammar and each Ti, $2 \leq I \leq n$. is formed from T1 by altering T1 at each node; deleting and/or introducing descendants with terminal labels, and reordering the nonterminal descendants according to some fixed rule. Within this framework of ideas, each sentence X of the language generated by a coupled grammar of degree n, called an n-coupled language, can be written as x1 … xn such that for a certain n-derivation tree <T1,…,Tn> defined by the grammar, xi is the results of Ti. Similarly the (m, n-m)-coupled translation, $1 \leq m \leq n-1$, generated by coupled grammar G of degree n is { (x, y)| x –x1…XY=Ym+1…Yn, for an n-derivation tree <T1,…,Tn> defined by G, xi is the results of Ti, $1 \leq I \leq m$, and Yi is the results of Ti, $m+1 \leq I \leq n$}. The concepts of an n-derivation tree introduced informally above plays an important role in developing the theory, in this thesis. The domain as well as the range of translations generated by coupled grammar are coupled languages. Thus a study of coupled languages is a contribution to the study of coupled translations as well. Because of this fact and also because the class of coupled languages is interesting on its own right, as well we primarily

concentrate on coupled languages in the thesis. We can divide the work reported in this thesis into four pats: 1. We identify certain complexity parameters of coupled grammars degree order and simplicity and impose certain restrictions on the productions. In this process we define a number of subclasses of coupled languages and translations. Some of these are n-coupled,n-smple coupled, n-right linear coupled langueages and (m, ncoupled translation. We investigate the structures induced on languages and translations by restricting the productions and various associated complexity parameters. Some of the specific rustles are the degree and order induce infinite proper hierarchies on the classes of coupled languages and translations. 2. we define a class of machines: n-turn generalized checking automata (generalization of n-turn checking automata) and show that these are machine characterization of n-simple coupled languages. We also give the machine characterization of (1, n) coupled translation. 3. We study some of the closure properties and decision problems of n-coupled and nsimple coupled, language. We find that many of these results are similar to those of context free languages. 4. Finally, we show that (i) The class of coupled languages contains the class of context free languages and is properly contained in the class of context sensitive language. (ii) The class of n-simple languages is the same as the class of simple matrix languages of degree n, and (iii) The class of n-right linear coupled languages is the same as the class of equal matrix languages of order n.

For more details click here Back

Title : *Detection Of Ligical Errors In DecisionTabl Programs*
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Supervisor(s) : *Rajaraman R*

Abstract

Computer programs are presently being extensively used to solve a variety off problems.However if solutions to problems are to be obtained the results of any6 program shouldbe reliable. In other words the program should produce correct results on all data. It isgenerally agreed that right approach to show that a program produces correct outputs is toprove that the program is correct .In the literature many variations of a basic philosophyare expounded to prove the correctness of a program .If the proof is successful then theproblem for which the program development was undertaken is solved. However if theprogram is not correct was undertaken is solved. However if the program developmentwas undertaken is solved. However if the program is not correct the proof proceduresgenerally indicate the existence of logical error than identifying the particular error. Aftermodifying the program to eliminate error the proof has to be attempts all lover again.Thus a necessary first step to prove the correctness of a program is to establish that theprogram has no logical errors. Depending upon the manner in which the program wasdeveloped it may sufficient to show that the program has no logical error to conceive usabout the correctness of the program. Thus the problem of detecting logical errors is thebasic problem of concern in this thesis. Since in many areas like business data processing compiler development and otherthe identication and analysis of complex conditions are involved a programminglanguage consisting of decision tables is chosen in this thesis. Taking view that at any ofproblem analysis a complex problem is broken down into a set of simpler problems it issuggested that the computer can be used to advantage in checking whether the followingconditions are satisfied or not .The conditions are:(a) The sub-problems completely cover all possible situations of the given problem;and(b) The sub-problems correspond to mutually exclusive situations. In other words forsome situation two different solutions are not attempted. These are easily represented able in decision table and correspond to checkingwhether a decision table is complete and unambiguous. Thus an interactive program development cycle which is an iteration of “programwriting-checking weather conditions (a) and (b) above are satisfied –if not programmodification”, is suggested as a technique to develop program free of logical errors. Inthe interactive cycle a computer, which details logical errors in a given program, willplay an important role. Having identified the problem, the next step is to define the scope of the. Towardsthis end the following result, which restricts the analysis to a class of programs withnon-interesting loops, only is established. “The class of decision table programs, called D-programs, with(a) Linear functions alone as atomic statemeters,(b) Predicates which check the stability of linear inequalities alone as atomicpredicates; and(c) A structure properly nested loops of maximum depth of two, Computer all partial recursive functions. “ Thus the problem of detecting logical in D0-programs (D-programs without anyloop) and D1 –programs (D-programs with with non-interesting loops only) isanalysed in detail .Due to the analysis the following results are presented1- The problem of ducting logical errors in D0-programs is equivalent todeciding the satisfiability of a finite set of linear inequalities. Thus theproblem is solve for D0-programs using techniques from the theory of linearinequalities.2- The problem of detecting

logical errors in D1-proorrams is equivalent todeciding the satisfiability of a possibly infinite set of linear inequalities.3- For a sub-class of D1-programs the problem of detecting logical errors canbe formulated as a non-linear optimization problem. The conditions underwhich such a formulation can be made are identified.4- A simple D1-program for which the problem of detecting logical errorscannot be formulated as a non-linear programming problem is given.5- A simple heuristic method, which indicates whether, the problem of logicalerror detection can be formulated as a non-linear optimization problem or notis given. This help to identify the programs that cannot be successfullyhandled by the theory developed in the thesis.6- A recent result by Mateyacevich (1971) establishes that Hilbert's ' tenthproblem is unsolvable. Thus even for those D1-programs for which theproblem of detecting logical errors can be formulated as non-linearoptimization problems one cannot guarantee that the problem is solvable.7- Due to the fact that a few programs are not analyzable automatically theminimum probability that a given program is free of logical errors issuggested as a measure of program correctness and to evaluate the measurefor a given program are given.8- An algorithm, ANALYSER, which analyses a given –program and whenanalysis terminates then either asserts that decision tables of the givenprogram are free of ambiguity and incomplete-specification, or proceduresdata leading to the logical error during execution is implemented. A briefdescription of ANALYSER is given in the thesis.And 9- A few samples are analysed using ANALYSER and error free programs aredeveloped .A few snapshots of these experiments in interactive program developmentalso are given.

For more details click here Back

Title : *Analysis And Optimization Of Large Scale Power Systems Using Diakoptic Method*

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Abstract

Power system engineers are continually faced with the problems posed by the increased size of the systems of be handled due to greater interconnections, expansion of the systems, need to represent the systems more accurately etc. for the various kinds of studied that are to be carried out this means that a larger computer memory will be required. If a computer is already available, the size of the problem that can be solved will be decided by the available core memory. The obvious solution of going in for a bigger computer to handle large system may be both uneconomical and not feasible. Hence other alternatives of using the existing computer more efficiently have to be sought. There are basically two approaches to handle the large scale power system problems on the computer. The first method exploits the sparsely in the system matrices like bus admittance matrix, jacobian matrix and Hessian matrix through optimal ordering and compressed storage schemes. This scheme pioneered by tannery is now finding application not only in power systems but in larger scale structural systems and integrated circuits as well. The second method of piece wise solution was originated by korn. In this method the original system is torn into several subsystems, each is solved independently and the solution of all the subsystems are tied up so as to yield the complete of the original system. Such a piece wise solution procedure which is popularly known as the diakoptic method, requires less computer core memory. The diakoptic methodic applicable to electrical as well as non-electrical systems. The practical use in multi area control of power systems with multicomputer configurations besides system studies has been demonstrated by Happ. The piece wise solution procedure was originally developed by kron under the name of diakoptics in 1953. This has been further expanded by Happ and applied to power system problems. Kron and Happ have used the orthogonal network theory to explain the diskoptic method. Their development is more general and covers larger networks containing both dependent and independent sources and hence not restricted to power system networks alone. However the power system networks do not contain such sources in an arbitrary manner. In fact in most of the power systems studies, active sours will appear only in the form of voltage source or equivalent current sources between a bus and the reference bus which is usually the ground bus. The rest of the network is passive. Consequently the development of diakoptics and it use for different system studies through the orthogonal network theory is unnecessary. Rather using a few basic relations derived from the concepts of linear graph theory, one can develop the diakoptic models. Such an approach makes the treatment of diakoptics straight forward and easily understandable. In the literature so far diakoptics has been applied mainly to load flow study; but extension to other studies has not been done. It is the principal aim of the thesis to develop the basic theory of diakoptics for power system problems, based on the generalized bus impendence algorism which in turn is derived form topological consideration and to discuss its applications to the various types of studies such as short circuit load flow transient stability and optimal power flow in a consistent manner. Effort is made to underline the unifying conceptual frame work of diakoptics in all these studies. The applications to short circuit, transient stability and optimization are discussed in detail form the view point of impending them in a two level

hierarchical scheme viz. area and pool computers. Closely allied to the problem of developing the diakotic model is the question of tearing the network in an optimal manner. In other words since different tearing will result in different storage requirements the question is how to tear the network so that core storage will be minimum. This question is answered in this thesis by developing an efficient heuristic algorithm to decompose the power system networks automatically. The algorithm has been tested on system upto 843 buses to prove its validity. A brief description of the chapter contents follow. In chapter 1, preliminaries of large scale power system problems, diakoptic method and diakopmodels are stated. Further, the organization of the thesis material in the subsequent chapters is briefly outlined. In the second chapter, the generalized bus impedance algorithm is developed. Making use of certain fundamentals of graph theory a comprehensive algorithm is developed to incorporate the network changes such as additions of link (s), addition of branch (es) and removal of link(s). The development takes care of phase shifting components and mutual couplings between the elements ofthe partial network and the element (s) to be added or removed as the case may be. Further special cases like removal of redial line isolated bus and parameter changes are also discussed at length and the merits of the generalize bus impendence algorithm are spelt out. Finally the implementation of this generalized bus impedance algorithm is illustrated through certain numerical examples. Since the generalized bus impedance algorithm presented in the second chapter utilizes the network topology, is applications to the development of the diakoptic models of the transmission network is quit natural. In chapter 3, first the impedance diakoptic model of the transmission network is developed using the addition of links algorithms. The corresponding admittance diakoptic model is obtained by using householder's special matrix inversion formula. These diakoptic models are more general as they permit the presence of mutual couplings between the cut network and the subnetworks. Finally in this chapter the multi-level tearing concept due to Happ is derived based on the results of the generalized bus impedance algorithm. Chapter 4 is concerned with the application of the diakootoc method to threshers circuit analysis of large called power sites. When all the shunt parameters are neglected the impedance diakoptic model of the transmission network with ground as reference bus does not exist. To circumvent this difficulty, first the combined transmission-generator system is considered and its diakoptic model is developed. The fault representation is now combined with the above model and the formulas for the current and the bus voltages under the faulted conditions are derived. The piece wise solution procedure both for symmetrical and unsymmetrical faults are discussed. Numerical test results as applied to the IBM 30 bus alpha system are presented. Chapter 5 is devoted to the load flow study. Since this problem is well discussed in the literature, the presentation is confined to outlining the study using the impedance diakoptic model. Chapter 6 deals with the transient stability study of large scale power systems. Both the admittance and the impedance diakoptic models of the electrical network required for the study are developed by combining the representations of the loads and the generations with the diakoptic model of the transmission network. For each switching interval the disturbance representation is properly accounted network. For each machine the dynamics of the elecromechanical system is described by the swing equations. The swing curves as well as the voltage profile during the transient period are obtained by solving the overall diakoptic model of the electrical network and the swing equations of the machines alternately. Convergence difficulty is observed in the admittance formulation and a method to overcome it is discussed. In the impedance formulation the solution is obtained directly consequently there is no convergence problem. For the purpose of analysis a 44 bus system is considered. The effects of core storage and the solution time for different tearing schemes are also studied and the test results are presented. Chapter 7 describes an efficient heuristic algorithm of decomposing the larger power system networks. To start with all the busses are isolated, all

of them representing different subnetwork. In fact this is one of the extreme solution the other one being all the buses in one subnetwork. Optimal solution lies some where in between these two extreme solutions. A search procedure is used to identify the optimal solution. At every stage, merging of the sub networks is carried out following certain rules which make the search procedure not exhaustive. Various constraints such as fixing the maximum number of sub networks, maximum number of buses in any sub network, inclusion of particular type of bus in every sub network, inclusion of specified lines as cut elements can be easily handle. The solution obtained by this algorithm may not be uniquely optimal . However from experience with many test systems upto 843 buss the suggested algorithm to found to give very good results. Chapter 8 is concerned with the optimal power flow solutions of large-scale power systems using impedance parameters. The problem of minimizing the total cost of generation, taking the real power generations as the control variables, is discussed in three stages namely (i) load flow study using impedance method (ii) single are optimal power flow solution (iii) multi area optimal flow solutions. With certain approximations the inverse of the jacobian matrix computed at the no load condition misidentified in terms of the elements of the bus impedance matrix. Stationary Newton's method is used is used in finding a feasible solution and the solutions is updated using the first order gradient techniques. For the multi area cases, the real and reactive power flows in the cut lines are taken as the additional problem variables. The problem is formulated in such a manner that piece wise solution procedures is possible which can be implemented in big power pools through multi computer configuration. The suggested method is tested for single area and multi area can the test results are presented. In chapter 9, highlights of this thesis are briefly reviewed and suggestions for future research are indicated.

For more details click here Back

Title : *Optimal Scheduling In Hydrothermal Power Systems By The Method Of Local Variations*

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Abstract

In an interconnected power system, it is possible to supply a given load demand in many ways, and hence it is natural for the operator to look for the 'best' or 'optimum' operating strategy. Thus optimal scheduling in a power system implies the determination of a strategy which would optimize stipulated operating criterion. A particular choice of this criterion in power system operation is the cost of the fuel consumed and the objective is to minimize the same. Early work in this area was that of Kirchmayer, who solved a purely thermal system problem, using the coordination equations derived by the Lagrange multiplier technique. In this formulation, the effects of the equality and inequality constraints imposed by the transmission and generating systems were either approximated or completely neglected. Carpentier in 1962 formulated this purely thermal problem more rigorously, taking into consideration the several equality and inequality constraints of the system, which were not considered by Kirchmayer. Subsequently several solution techniques were proposed in the literature to solve the problem formulated by Carpentier. However, the interest in this thesis is directed towards a power system which consists of thermal as well as hydro (including pumped storage) plants. The optimal scheduling of such as system is different from a purely thermal system in the following aspects. No fuel cost is associated with hydro stations and the total amount of water that is available for power generation over a specified period is limited. Hence the solution to this problem at any given time consists of determination of a plan for withdrawal of water from the hydro reservoirs for poser generation and determination of the corresponding thermal generations so that the total cost of fuel is minimized. At the same time, the total power demand on the system is met and the operational constraints such as limits on the reservoir storages, the rates of discharges from the reservoirs, the power generations at various units, the voltages and phase angles in the network, the reactive power generations, and the line flows stipulated by stability considerations etc. are satisfied. The dynamics of the hydro system makes this a variational problem. Several attempts have been made in the past to solve the above problem by dynamic programming, incremental dynamic programming, and several indirect optimization methods like the discrete maximum principle or the continuous maximum principle. In all these attempts, the difficulty encountered was that of enormous computational requirements for a problem of realistic size. Therefore, this investigation is aimed at finding an algorithm, which is simple, easy to implement, and requires less computational effort and storage. A direct search method known as the 'Method of Local Variations' (MLV), (due to Krylov and Chernous Ko') is found to meet the above requirements due to its simplicity, efficiency, and ease of implementation. The essential features of this

method are a discrete-time description of the system, a decomposition of the combined system into hydro and thermal subsystems, a starting nominal trajectory of hydro generations, and a systematic iterative method of perturbing the nominal trajectory such that the total fuel cost is monotone decreasing from iteration to iteration till a satisfactory convergence to an optimal trajectory is obtained. At every stage of the algorithm, all the constraints of the problem are satisfied. In this thesis, two mathematical models of the hydro-thermal system are considered, pertaining to (1) a short range scheduling problem, and (2) a long range scheduling problem. In the short range model, the electrical network of the power system is represented in detail. This enables consideration of various engineering and operation constraints on voltages, reactive powers and line flows etc. for the entire scheduling period. In the long range problem, however, only an approximate solution is sougth. Instead of representing the electrical network in detail, the transmission losses in the system are approximated by Kirchmayer's loss coefficients. No other electrical constraints like those on voltages, reactive powers etc. are considered. Ofcourse in both the formulations, constraints on hydro storages, discharge rates and power generations are considered. To illustrate the applicability and advantages of the MLV. First a one-hydro-one-thermal problem similar to the one solved by Bernholtz and Graham (using incremental dynamic programming method) has been solved. Next a more complex long range problem consisting of three hydro and four thermal plants has been solved. The computational advantages of the MLV approach are established. Next a short range problem consisting of two hydro and two thermal plants, similar to the one considered by Bonaert, El-Abiad and Koivo has been solved. It is shown that the MLV applied to this problem is superior to the method used by Bonaert etal. A modification of the basic MLV approach, which consists in varying the stepsize in the algorithm is presented and it is shown that this can further reduce the computational effort significantly. Finally the optimization problem which includes pumped storage hydro plants is also considered. It is shown that the MLV approach permits this situation to be considered without any major modifications. Numerical results are presented to illustrate the method.

For more details click here Back

Title : *Leaky Wave Antennas Using Artificial Dielectrics*
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Abstract

A number of traveling wave antennas are based on the propagation of a leaky wave along the structure. These leaky wave antennas may be grouped into two categories, (i) Perturbed wave guide leaky wave antennas (ii) Open guiding structure leaky wave antennas Per turbed wave - guide leaky wave antennas are derived from rectangular and circular wave - guides. Open guiding structures which support leaky wave modes include dielectric slabs and plasma slabs. Leaky wave propagation along a plasma slab is based on the fact t hat at frequencies higher than the plasma resonance frequency, the plasma medium has an effective dielectric constant less than unity. An effective dielectric constant less than unity can also be obtained by using some artificial dielectrics. This thesis r eports some investigations on this new type of leaky wave antennas using artificial dielectrics (Ads). The AD used for antennas reported here has been realized by a two - dimensional array of conducting wires embedded in a loss less dielectric medium. When an electromagnetic wave properties in a direction perpendicular to the direction of wires and has the electric field component in the direction of wires (as in TE made), the structures has effective dielectric constant less than unity. The work reported includes the following. General radiation characteristics of leaky wave antennas are studied. Analytical expressions for the half power beam width are obtained for infinite and finite lengths of antennas. Expressions for gain and first side lobe level are also derived. The results obtained for the beam width and the side lobe level from these analytical expressions are compared with the results obtained numerically from radiation patterns and are found to be in good agreement. Three leaky wave antennas usi ng AD have been studied theoretically and experimentally. These are: (i) Narrow beam antenna (ii) Frequency scanned antenna and (iii) Dielectric AD layered antenna. (i) Narrow beam antenna Radiation characteristics of a narrow beam leaky wave antenna fabricated from an artificial dielectric (array of wires in Air) have been investigated. The complex propagation complex propagation constant for TE mode has been evaluated for grounded and ungrounded AD slabs. Propagation of various modes along the structures and variation of transverse electric field for these modes have been studied. An approximate but fairly accurate expression for the complex propagation constant is derived. Experiments are performed with an antenna designed for X band. The experimental antenna structur e is 20 cm wide and 80 cm long. It has five rows of straight wires in the x - direction separated by a distance of 1 cm. In the direction of propagation there are 80 columns of wires separated by a distance of 1 cm. Experiments are performed with the antenn a using two types of excitation: line source excitation and horn feed excitation. In line source excitation the structure is excited by feeding power to the central wire. The position of the beam varies from 17 o to 47 o away from

broadside when the frequenc y is changed from 8.6 to 11.5 GHz. Over this frequency range the beam width varies from 5.6 o to 4.8 o . The agreement between the theoretical and experimental results is reasonably good. Using wave - guide horn excitation the beam width obtained is about 2.5 o at 10.0 GHz. (ii) Frequency scanned antenna This antenna uses a two dimensional array of wires embedded in a solid dielectric (Perspex). It has been shown that the increase in dielectric constant of embedding dielectric medium improves the frequency scanning characteristics. The experimental antenna structure is 20 cm wide and 40 cm long. It has nine rows of wires in the x - direction separated by a distance of 0.555 cm. In the direction of propagation there are 50 columns of wires separated by a distance of 0. 8 cm. The structure is excited with the help of a flared horn at one end. Experimental radiation patterns are obtained at various frequencies and compared with the theoretical radiation patterns. Beam position changes from 10 o to 50 o when the frequency is changed from 8.13 to 9.05 GHz. Over this frequency range beam with lies between 5.5 o and 6.6 o . This frequency - scanned antenna has been compared with other frequency -scanned antennas like Honey antenna and frequency scanned arrays and found to have much be tter temperature stability. (iii) Dielectric – AD layered antenna It is found that if a two layered structure with one layer of a dielectric ($\varepsilon m > 1$) and another of an AD is used, very narrow beams can be obtained. This antenna has been studied theoretically an d experimentally. The propagation constant for the TE made has been calculated by solving the dispersion relation numerically. An approximate expression for the propagation constant has been derived for the dominant mode. Experiments are per formed by usin g line source excitation.

For more details click here Back

Title : ***Steady State Security Assessment And Preventive Control Of Power Systems Using Sensitivity Based Models***

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Supervisor(s) : ***Pai Mangalore Anantha***

Abstract

Proposes a unified approach to solve the twin problems of steady state security assessment transition of the state through the transient and dynamic per iods are not of concern using sensitivity based unwearied models. The assessment problem is formulated as a straightforward sensitivity analysis around the base case state by characterizing the branch outage as change in the parameter vector and the genera tor outage as a change in the control vector of the system. The preventive scheduling problem id formulated as a successive linear programming problem using the more accurate linearized model used for assessment. The proposed assessment method is sho wn to be consistently modeled accurate than other single N - R iteration methods based on numerical experimentation with a 20 - bus system. One iteration of the control algorithm is shown to be sufficient to obtain a secure state on application to typical s bu s systems. The method has been improved in terms of speed and practicality in case of assessment. An improved algorithm has also been used for the case of general multiple contingency involving simultaneous outage of two or more branches and efficient and has been found to be faster and efficient than a constant matrix method for a 30 bus test system A fast preventive rescheduling algorithm based on the linearied decoupled model has been developed and its validity verified by applying it to IEEE 30 bus syst em.

For more details click here Back

Title : *Study Of Transmission Of Optical Signals Through Clouds Using Monte Carlo Technique*

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Abstract

The optical coMnunications between spacecraft and earth is severely affected by the presence of overcast sky* The transmission of optical signals through such communication channel involves multiple scattering due to cloud, haze or fog. Various workers have studied such channels through analytical means and computer simulations. The present thesis report is an attempt to characterize such channels using Monte^ Carlo simulations with particular reference to cloud as medium*Haggestad obtained the P'-dimensional impulse response of the cloud channel by obtaining impulse response for a thin cloud layer and then applying superposition for thick clouds. Above analytical formulation fails for clouds with very large and very small optical thicknesses. Other analytical technique used by Dell-Imagine is to integrate a transport equation in accordance with the radiativeXItransport theories of Chandrasekhar and Sobolev* The solution is given only for optically thin clouds composed of non-absorhing water spheres. The solution of transport equation for thick clouds is very tedious*The only practical way of obtaining a solution to this class of transport problem is with the use of Monte* Carlo simulation techniques programmed for calcula.tion on high speed computers* Danielson, Moore and Van de Hulst, Plass and Kattawar and Thompson and Wells obtained transmittance and reflectance u^ing such techniques• Very recently Bucher used Mcnte* Carlo simulaticii to study the propagation of optical pulse through nen-abscrblng clouds from communication^s view point.In the present study, a plane, parallel, fixed, homogeneous^ cloud is illuminated at the top by an optical signal which is impulse in space and step in time. The intensity of the transmitted optical signal is computed, since the coherence is lost due to multiple scattering. A receiver with specified field of view is placed at a specified distance below the cloud. The purpose of Monte' Carlo simulation is to obtain the angular and spatial dispersion of intensity at the lower surface of cloud and the transient response of the receiver. The optical signal is considered as the stream of photons* EachXIXphoton is characterized hy a six^dimenie-'ional state consisting of its intensity weight, position and direction. As photon travels in the cloud its state changes after everjT-collision in the random fa.shion in the sense that the direction and position of photon are random vpriates with the distribution functions depending on the characteristic parameters of cloud* 'Thus the travel of a photon creates a Markov chain^ A transmission function is continuously estimated after every st^^te * change. The transmission function contains information about the intensity weight, spatial and angular dispersions, and time dalay of the signal reaching lower boundary of the cloud. Obviously transmission fimction is a random function* The different random walks are continued till the statistical fluctuations in this function become tolera.ble.The

cloud is assumed to be composed of absorptive, spherical water droplets with poly-dispersion. The size distribution function is assumed to be a moc'lfied gamma distribution functiont The characteristic parameters of the cloud i.e, average volume scattering coefficient, average albedo of single scattering and the average normalized phase function are eraluated bv using Mie formalism. These parameters are essential inputs to the i^^onte^ Carlo simulation.XlllTwo simulations are carried outt First simulation OPBCiiTl is used to obtain the response for thick cloud. In this simulation scattering angle is selected from the normalized phase function and the distance "between successive collisions is selected from the exponential distribution. Second simulation 0PSGAT2 uses Russian Roulette to select angle of scattering and forced collisions to select successive distances for variance reduction in the thin clouds*All computations are done for cumulus clouds and for optical signals at 10\6 \x wavelength*The forced collision and Russian Roulette proved to be effective variance reducing devices.The bottom, of the cl^ud tends to become uniformly diffused as the cloud thickness increases.The spatial spread tends to saturate with the cloud thickness.The rise time of the recf.iver is found to be of the order of the time taken by a ray to propagate directly across the cloud.ions for the average lengths of the crystalline and amorphous regions are used. The model parameters are reported* Preliminary observations on low-angle X-ray scattering from wool are also given.

For more details click here Back

Title : *Transient Stability Investigation Of Powr Systems Using Improved Lyapunov Functions*

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Abstract

There has been great interest in recent years in applying techniques based on methods of Lyapunov and Popov for assessing transient stability of power systems. The interest mainly stems from the fact that for computing critical clearing times of circuit breakers one single integration of the faulted system suffices, compared to the existing method of repetitive integrations for different assumed clearing times. Hence Lyapunov's method offers an attractive alternative in terms of reducing the computation time. There is also research work to indicate the potentialities of this method for on-line stability and security analysis. However, the advantages offered by these methods have to be weighed against the difficulties inherent in applying the method. These are mainly (i) construction of improved Lyapunov functions of yield large stability regions, (ii) relaxation of some of the assumptions generally made for first swing transient stability, and (iii) computation of unstable equilibrium point closest to the stable equilibrium point of the post fault system. These unstable equilibrium points can be as many as (2n-1 – 1) in number an consequently very large for a modest multimachine system. This thesis addresses itself to the first problem primarily and to some extent the second problem. As far as the third problem is concerned it is possible with the Lyapunov functions obtained in this thesis to compute the region of asymptotic stability without solving for the unstable equilibrium state closest to the stable equilibrium state of the post fault system. In trying to evolve improved Lyapunov functions the problem is formulated in the minimal state space using concepts of modern control theory. Interpretation of results becomes consistent and a recent controversy on this issue in the literature is thus settled. Using this formulation, improved Lyapunov functions are found based on a theorem due to Moore and Anderson. This theorem in turn relies on concepts of positive real matrices. A feature of the method is to systematically arrive at the diagonal matrices N and Q in the multiplier (N + Qs) appearing in matrices Popov frequency condition. None of these matrices thus obtained is a null matrix. The resulting Lyapunov functions are shown to yield large stability regions. Another contribution of the thesis has been the inclusion of transfer conductance's in the swing equations. Hitherto they were neglected since a Lyapunov function V(x) having the required sign definiteness properties could not be found. A change in variables in the definition of nonlinearities and use of finite sector condition enables one to construct Lyapunov functions with the required sign definiteness properties. Finally the effect of damping on the region of stability is also discussed. here there have been conflicting results in the literature. It is shown that the effect of damping is to improve the system stability. Here again the concept of minimal state space is invoked to clarify the results.

The following is a detailed summary of the various chapters. The introduction Chapter I contains a critical review of the literature on Lyapunov's direct method as applied to power systems. The well known concepts of the degree of a rational function matrix of system theory and minimal realization of control theory are introduced in the beginning of Chapter II. Further, the relation between controllability, observability and minimal realizations is established for 2- and 3 – machine power systems. This provides the necessary theoretical basis for the proper choice of state variables. Also in this chapter, the problem of an n-machine power system is formulated for stability studies in the minimal state space. In Chapter III, the systematic construction of Lyapunov functions in the infinite sector is presented for the state models of an n – machine power system obtained in Chapter II, using the system theory criterion for positive real matrices due to Anderson and a generalization of Popov's criterion to the multi – input multi – output systems due to Moore and Anderson. The properties of positive real matrices have been made use of in arriving at the proper choice of the diagonal matrices N and Q that appear in the multiplier of the matrix Popov frequency condition. The state model formulation of an n-machine power system, taking into consideration the transfer conductance's in transmission line network, machines and nonzero power factor loads which are represented as static admittances to ground is presented in Chapter IV. By a proper formulation of the state model in the minimal state space, this problem has been brought within the frame work of Lyapunov-Popov method. Lyapunov functions satisfying the required properties are then obtained in a systematic manner for a 2-machine power system in the finite and infinite sectors. In Chapter V the usefulness of the Lyapunov functions obtained in Chapters III and IV demonstrated by giving numerical examples of 2- and 3- machine power systems. Since it is possible with these Lyapunov functions to compute the region of asymptotic stability without solving for the unstable equilibrium closest to the stable equilibrium of the post fault system, the method proposed in this context is implemented in the case of the 3-machine example considered. The effect of damping on the critical clearing time is shown for these numerical examples using these Lyapuov functions. The influence of damping on the regions of asymptotic stability is critically reviewed. Further, the stability regions in the case of uniformly damped system are compared in the (2n-2) dimensional state space while those of non-uniformly damped system are compared in the (2n-1) dimensional state space since, as it is, they are not conformable for comparison in the same state space. In Chapter VI, the results are reviewed and suggestions for future research are indicated.

For more details click here Back

Title : *Minimal Trajectory Sensitivity Design Of Optimal Control Systems : A New Formulation*

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Supervisor(s) : *Sarma I G &Agashe S D*

Abstract

Any design of an optimal control system which does not take into account sensitivity considerations is unreliable due to the possibility of parameter variations. These variations make it necessary to develop design techniques for obtaining optimal controller structures which in some sense also simultaneously ensure least sensitivity to parameter variations. The general approach to minimum trajectory sensitivity design of optimal control system has been to postulate the controller structure to be a linear feedback of the state and the sensitivity vectors. Higher order terms in the sensitivity equations resulting from such a control law, are usually neglected. This apart from necessitating the generation and feedback of the sensitivity vector also introduces a truncation error in the sensitivity problem at the stage of formulation itself. These difficulties are avoided in this thesis by postulating the control to be a combination of the familiar open and closed-loop forms [u(t)=ko(t) + K(t) x(t)]. The two degrees of freedom afforded by such a controller structure are exploited to achieve the twin objectives of nominally optimal control and minimum trajectory sensitivity. With the above controller structure the sensitivity equations are exact and at the same time the need for feedback of the sensitivity vector is eliminated. This thesis is concerned with the minimum trajectory sensitivity design of optimal control systems. Chapter II reviews contributions to sensitivity study including design techniques. Two new minimum sensitivity design methods are given in chapter III for the system described by x = f(x, a, u). (i) weighted performance index solution, and (ii) hi8erarchical solution. In the case of the weighted performance index solution, the sensitivity equations are adjoined to the system equations and the new performance index considered is the convex combination of the system performance index and the sensitivity index. The solution of this problem results in a set of non-inferior controls for different combinations of the two indices. One among these noninferior solutions is then chosen depending upon the acceptable level of degradation in the system performance index. In the hierarchical solution the design is completed in two steps. The first step consists of solving the conventional optimal control problem to obtain the optimal control u*(t). The feedback gain matrix k*(t) is obtained in step II by solving the sensitivity problem. With the knowledge of the optimal control u* and the feedback gain matrix K*, k * o (t) is obtained so as to realize the nominally optimally control u*. Both the cases of free and fixed end-point situations are considered. Explicit expressions for Ko(t) and K(t) are obtained for linear systems with quadratic performance indices. It is shown through a numerical example that zero terminal sensitivity can be achieved with these design techniques, as it is included in the problem formulation itself. In Chapter IV, two new simple design techniques are

presented. Both are applicable only to linear systems with quadratic performance indices. While the first method leads to a suboptimal design for a general class of problems the other method though exact is only applicable to a restricted class of problems. In the first method, the conventional optimal regulator problem is solved and the corresponding closed-loop system equations are obtained. The sensitivity equations are adjoined to the closed-loop system equations to form a new system of 2n-th order. The feedback gain matrix K that minimizes the sensitivity index is obtained by treating the auxiliary 2n-th order system as an optimal output feedback problem, the output consisting of the sensitivity vector. The solution results in a suboptimal value for the sensitivity index. The other method, which results in the optimal value for the sensitivity index is an exact one but is only applicable to a restricted class of problems. This method consists of solving three sets of nth order Riccati equations and two sets of linear differential equations apart from the system equations. This technique, however, always results in time-varying feedback gins even for linear systems with quadratic performance indices and infinite interval of optimization. Several examples illustrate the two techniques. Chapter V considers minimum sensitivity design of a partial state feedback problem. In sensitivity problem is formulated as a 2n-th order multiple structure output feedback problem by adjoining the sensitivity indices are added together. The new structure of the problem formulation necessarily leads to only suboptimal values for both the system index and the sensitivity index. The two degrees of freedom afforded by the controller structure are used to achieve nominally suboptimal control. Chapter VI concludes the thesis with a summary of the results obtained and suggestions for future work.

For more details click here Back

Title : *Transient Stability Analysis Of Power Systems Using Liapunov Functions With Improved Synchronous Machine Models*

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Supervisor(s) : *Pai Mangalore Anantha*

Abstract

The transient stability problem arises in a power system when the power balance between the mechanical input and electrical output of synchronous machines gets altered suddenly due to occurrence of large disturbances such as faults, removal or addition of large loads etc. depending on the nature and location of the disturbance, the rotors of the machines may accelerate or decelerate. If the system settles down to a steady-state following such a disturbance or after the fault has been cleared as the case may be, the system is said to be stable. Historically this problem has been studied by the step-step methods which is still the widely used method with the aid of the digital computer. In recent years however, the Liapunov's direct method has been applied to investigate the transient stability problems and the method is now acknowledged as being able to give results in satisfactory concordance with those provided by the step-step method. Furthermore the method has certain advantages. When the transient state has occurred due to a fault, an important piece of information of interest is the critical fault-clearing time. The Liapunov function approach yields this information through a single integration of the faulted system differential equations while in the step-by-step method, repetitive integration of the system equations for different assumed clearing times is involved, each integration necessarily having to be carried on far beyond the fault clearing instant, even for the 'first swing; stability investigation. For a given clearing time the method will also indicated whether the system will remain stable or not. The Liapunov method can also be used to specify stability margins or stability indices, without making any actual stability calculations. Because of all these reasons, the chances are, that Liapunov approach may prove to be an effective method for on-line-stability and security analysis. However, there are certain difficulties still to be overcome with the method. A chief drawback of the Liapunov approach has been the conservative nature of the results. One of the contributing factors in inherent in the method itself, namely the sufficiency nature of the Liapunov's theorem. Another important factor has been the simplified-and therefore approximate-models of the synchronous machines that have been used. It is well-known that factors like damping, saliency, transfer conductance, flux-decay, voltage regulator and governor dynamics have appreciable effects on the stability of a power system. However, inclusion of all these factors in modeling the synchronous machine results in very complex system of equations and the derivation of a Liapunov function becomes quite difficult and in some cases impossible as of to-day, particularly when dealing with multimachine systems. In the literature, many of these effects have not been taken into account so far in a comprehensive manner. This thesis seeks to cover some new grounds in this direction. The power system problem is formulated with the synchronous machine modeled with varying degree of details and Liapunov function is sought for each case. Results are obtained both for single machine and multimachine systems. The basic philosophy in general, is to cast the power system dynamics in the form of an 'indirect control system' equations of Lur'e's form and then derive a Liapunov function. Depending upon the nature and form of the nonlinearities, different techniques are called for, in arriving at a Liapunov

function. Once the Liapunov function is available, the stability region or equivalently the critical fault-clearing time can be computed. The effect of parameter variation can also be studied with great ease and speed, using this Liapunov function. A brief outline of the various chapters is given below. The first chapter is devoted to the statement of the problem of transient stability in power systems using the Liapunov method. The scope and objective of the thesis are enumerated and organization of the thesis material is briefly sketched. The second chapter deals with the transient stability problem including saliency effects. A single machine connected to an infinite bus is considered first, with the synchronous machine modeled with damping and transient saliency taken into a account. A Liapunov function of the 'quadratic form plus integral of nonlinearity' type is developed using Kalman's construction procedure. This Liapunov function is used to determine the stability region and the critical clearing time. A detailed parameter analysis is carried out for a specific numerical example and useful conclusions drawn. The results with and without transient saliency are compared. Next a two-machine power system with transient saliency, is dealt with. Two distinct cases arise when dealing with multimachine systems; one is known as a system with 'uniform damping' while the other as a system with 'nonuniform damping'. Both these cases are discussed and appropriate Liapunov functions derived. A general k-machine system with saliency is briefly discussed. The difficulty in systematically arriving at a Liapunov function for this system is pointed out. It is due to the fact that when cast in the Lur'e form, some of the terms in the non-linearities cannot be determined explicitly in terms of the state variables. The third chapter considers a single machine-infinite bus system. The synchronous machine is at first modeled with the flux-decay and voltage regulator dynamics included in addition to damping. This model results in two nonlinearities requiring a matrix version of Kalman's construction procedure is difficult because of the fact that the nonlinearities happen to be of the 'multi-argument' type. Using results of Desoer and Wu on stability of nonlinear systems with multiplicative nonlinearities, a systematic method is evolved to arrive at a Lyapunov function having the requires properties in the region of interest. Effects of voltage regulator parameters and flux decay on the critical clearing time are studied through a numerical example. Next a more general model of the synchronous machine including transient saliency, flux decay, voltage regulator and governor dynamics, is used to derive a generalized Liapunov function. Chapter four is concerned with multimachine system with flux decay effect included. It is observed that the resulting model is not amenable to the procedures discussed so far. Hence, recourse is taken to a version of 'integration by parts' method to arrive at a Liapunov function. Using this technique Liapunov functions are derived for two-machine and three-machine systems. The results of the two-machine and three-machine systems are extended to a general k-machine system, by induction, to arrive at an appropriate Liapunov function. Chapter five deals with power systems with transfer conductances. A two-machine system is formulated and a Liapunov function derived using Kalman's construction procedure for the uniformly damped case. A three-machine formulation on similar lines reveals that the Popov frequency criterion is not satisfied for this system. Indeed this is true for systems having more three-machines also. Hence this particular line of attach has to be upto two-machine system. In chapter six a brief review of the results and some concluding remarks are given. The problems that have surfaced during the course of this work and which require further investigation are indicated.

For more details click here Back

Title : *Convergence Of Programs By Discrete System Techniques*
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Abstract

There has been considerable interest in recent years in proving computer programs. Several authors have suggested specific approaches to this problem. We have attempted to formulate in this thesis an algebraic approach to the problem of proving program convergence of a simple and well defined class of programs. First we consider general form of program called abstract program or program scheme. The formal definition of program scheme, pertial and total interpretation execution sequence and value of the program are given. We introduce a method to generate a system of recurrence relations to represent a program scheme in general. Then we define a class of programs called simple programs. For the simple program we formulate a set of recurrence relations with loop iteration parameter as the independent variable. This system of recurrence equations for simple program forms our basic mathematical model. We classify the simple program as linear simple programs and nonlinear simple programs. We analyse the system of recurrence relations of linear simple programs for stability using the stability theory of discrete systems. We have related the asymptotic behaviour of these system of equations with the convenience property of program. This leads us to introduce two new properties of programs called f-convergence and f-divergence. By analyzing the asymptotic behaviour of linear simple programs we have obtained certain results about the f-convergence (f-divergence) of these program. Then we have extended this analysis to special classes of programs listed below and obtained definite results about the f-convergence (f-divergence) of such programs: (i) Linear simple C programs (ii) Data independent simple programs (iii) Linear multilevel simple program (iv) General class of linear single loop programs (v) A restricted class of non linear simple programs We have developed a program which will analyse a given linear simple program for f-convergence (f-divergence). This program is called program analysis programs. In appendix D we have given the brief description about the functional operations of various routines of the above program. The attempt to study program properties using recurrence relations obtained form the program and discrete system techniques seems to be new.

For more details click here Back

Title : ***Computer Aided Study Of Solid State Diffusion And Characterization Of Semiconductor Devices***

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Abstract

The invention of transistor led to an extensive study of solid diffusion of impurities in semiconductors to seek a more efficient method of fabrication and develop improved semiconductor devices. This resulted in the development of planar technology and pr esently almost all the silicon discrete devices and monolithic integrated circuits are made using solid state diffusion of acceptor and donor impurities for p - n junction formation. Generally, a simple diffusion theory is used to describe the diffusion proc ess in semiconductors. The solution of the resulting diffusion equation gives a complementary error function (erfc) profile for the case of constant source diffusion. Experimental observations show considerable deviations form erfe profile even for moderat e surface concentration of impurities. It has been observed that for high concentration of diffusing impurities, the diffusion coefficient becomes a function of impurity concentration. The equation describing such a diffusion process becomes nonlinear. In ternal electric field aids the diffusing impurities and this effect is incorporated by replacing the concentration independent diffusion coefficient (D) b a concentration - dependent or effective diffusion coefficient (D eff). If H is the enhancement factor due to field aiding then D eff =DH. The numerical solution of the resulting nonlinear partial differential equation gives the impurity profile. It is observed that inclusion of this effect alone is inadequate for high surface concentration of impurities. T he enhancement factor of D eff is modified to take into account additional effect which causes enhanced diffusion. At high concentration of diffusing impurity.extra vacancies are created because of strain or plastic deformation of the silicon crystal. Thai has reported a mathematical model of diffusion incorporating this effect. H is modified as H' =HP where H is enhancement factor due to internal electric field and P is enhancement factor due to increase in vacancy concentration in silicon crystal. Now D e ff =DH'. The nonlinear partial differential equation is solved using numerical techniques for the case of constant source. However, in planar technology, generally a two step diffusion process is used. The profile mentioned above is for the case of first s tep diffusion deposition with a constant source. The second step diffusion drive in process is also described by the same nonlinear partial differential equations with different initial conditions. If the diffusion confident

is assumed constant during the two step diffusion processes then the final impurity profile is given as Geussian distribution. This is obtained with crude approximation. An improved mathematical expression for this case is reported by Kennedy and murley. But these characterizations of d iffusion process are inadequate for high concentrations of diffusing impurities. In the present work nonlinear partial differential equation related to drive in solved numerically employing difference equations and actual deposition profile is used as the initial condition. A suitable computer program is developed for impurity profile at the end of two step diffusion process. The impurity profile given by this method is closer to the experimental results. Chapter III of the thesis presents details of the n umerical evaluation techniques for the diffused impurity profiles. Computer aided characterization of semiconductor devices based on the physical processes, is presently receiving much attention. This is because of its scope in better device design and im proved fabrication process control. However, most of the device characterization is based on an assumed impurity profile in the device structure. For example, in the case of n - p - n transistor structure, it is common practice to assume erfc profile for the e mitter diffusion and Gaussian profile for base diffusion. Some investigators have used Kennedy Murley profile for the two step diffusion process. Actual impurity profile in the device structure must be used in order to characterize the device closely, in this thesis, the analytical techniques for describing diffused impurity profiles, and characterization of the resulting semiconductor devices have been integrated. Use of a good digital computer is imperative for this kind of study. In chapter III, details of the characterization of a nGaAs - pGe heterojunction transistor is given. The heterojunction transistor is fabricated by a one step diffusion of gallium in germanium for base formation and the emitter is formed by epitaxial growth of gallium arsenide. B ase transit time and cutoff frequency are computed. Computed cut off frequency compares well with the measured one. In chapter IV some silicon planar devices are used for characterization. Important parameters of a silicon planar diode, like junction capa citance, built in voltage, and electric field distribution in the depletion layer are computed. For a n - p - n transistor, base and emitter impurity profiles are obtained, base width is determined, and base transit time and cut off frequency are calculated. T he entire characterization is repeated for the case of Kennedy Murley profile. However, the computed value of cut off frequency given by the profiles of nonlinear diffusion equation is much closer to the measured value. Data and measured values were provi de by professor D.J. Routston of the university of wsaterloo.

For more details click here Back

Title : *A Syntactic Pattern Analysis System And Its Application To Devanagri Script Recognition*

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Abstract

The design of the proposed Syntactic Pattern Analysis System (SPAS) is mainly motivated by the attempts to recognize Devanagari Script*. PLANG (picture language for a class of pictures) design is influenced by the problem of generating description of Devan agari Script for recognition and generation. Devanagari Script is a modernately complex pattern. Unlike simple juxtaposition in Roman Script, a word in Devanagari Scriptis composed of composite characters joined by a horizontal line at the top. A composite character in Devanagari Script is made up of legal attachment of a matra and / or diacritical marks on a character or a composite character; or a combination of half letter with a character / composite character. Attachment of a matra, diacritical mark or combinations of half letters results in natural breaks in the composite character. Thus Devanagari Script recognition consists of three phases : segmentation i.e. segmenting a word in Devanagari Script into composite character; decomposition i.e. decompos ing the composite character into meaningful parts; and recognition i.e. recognizing the decomposed part of the composite character. the classificatory approach to the problem of recognition is seen to be inadequate for complex patterns like Devanagari Scri pt because it treats the pattern as single atomic entity which is assigned a value based on some computations done on it; and classification is based on partitioning of this assigned value space. There is a need for analyzing the structure of the input pat tern and for articulating its various aspects on the basis of its structured analysis. The design of picture language PLANG which is embedded in system SPAS, is an attempt to provide a descriptive schemata for a class of pictures made up of line like cu rvilinear elements. The principal aim o f the present study is to design a suitable pattern processing model and demonstrate its capability to deal with complex patterns like Devanagari Script. In the monitor of the system SPAS, PLANG descriptions of all t he non terminal symbols of the picture class are stored. The interpretive as well as the generative devices coupled to the monitor of SPAS, on the basis of 'parse' of the stored description make an appropriate call to look for a part of the picture in case of interpretation or to generate the picture part in case of generation. Some contextural informations are used to aid interpretation as well as generation. The typical form of PLANG description is illustrated by means of an e x ample given below: 'DEVSY MKA :Begin: describe KA (Φ) : (*((HRZ (LT) (RT)) (VERT (MT) (MB)) (DE (MM) (RB)) (CRL (MM U LM)))) Compose : ((CRL (R)) (* ((CE (MT R) (MB R)) (DE (MT R) (MB R))))) END' Here DEVSYMKA is name of the picture class; KA name of the non ter minal symbol of the picture class; HRZ VERT CE ε DE are primitives (primitives are atomic pictures which are recognized as single entity) and CRL is a compose macro. PLANG assumes a rectangular picture frame which is divided into nine equal regions named as left top (LT), left middle (LN), left bottom (LB), middle top (MT), middle middle (MM), middle bottom (MB), right top (RT) right middle (RM) ε right bottom (RB). • denotes super position of many frames over each other. denotes the total design of the picture frame. Thus the meaning associated with the description of KA is : draw a horizontal line from left top to

right top of the picture frame, a vertical line from middle top to middle bottom of the picture frame, a D curve from middle middle to right bottom of the picture frame and a circle in a region which is union of the middle middle and left middle regions of the picture frame. Here a compose macro named CRL (denoting a circle) is used in the description. Compose macros are like function sub programs in a Fortran program. They define sub patterns which form part of many main patterns of the picture class, in terms of primitives and a dummy region (denoted by R in the above description). Having defined the composit ion of compose macros, they are used like primitives of the picture class. The original work and main contributions of the thesis are the following : (a) development of a picture language for a class of pictures (the class being two dimensional pictures com posed of line like curvilinear elements) called PLANG. (b) Development of PLANG embedded Syntactic pattern analysis system (SPAS) and development of uniform scheme for the generation and interapretation of patterns within its framework. (c) Implementation of Deva nagari Script recognition scheme within the SPAS framework. Besides these, the contributions lie in the development of various primitive recognition routines, thinning algorithm etc. In comparison with some other related works (Narasimhan (64 - 70), Shaw (6 7), Guzman (67), Clows (67), Anderson (68), Ledly (65), Kirsch (64), Evans (68) some of the distinguishing features of the author's work are the following: (1) an uniform procedure developed for the generation of pattern description which is independent of th e pattern size and has inherent capability of incorporating pattern deformations. (2) Pattern composition is in the form of super position of compose macros or primitives (which may have 'meanings' attached to them) giving the schemata a power to describe pa tterns with natural breaks, unconnected pattern superimposed patterns in a natural fashion. (3) The definition of compose macros empowers the system to give generalized strkuctural definition of a sub pattern which may be used like a primitive in the descripti on of patterns. (4) Relational constraints on compose macros or primitives of the pattern are specified in terms of the 'regions' of the pattern frame. 'Regions' are rectangular areas of the pattern frame and are described relative to the frame dimensions. Suc h a schema offers the system to account naturally for the variations in pattern size and for pattern deformation. (5) An uniform procedure for the parsing and synthesis of patterns within the SPAS framework is given. Primitive recognition algorithms are more l inguistic in nature and not much of arithmetic computation or geometric properties are exploited. Continuity of local properties in the specified region of the frame forms the basis for the primitive recognition routines. (6) Development of a scheme for the i mposition of pattern semantics in case of Devanagari Script

For more details click here Back

Title : ***Analysis And Synthesis Of Two Dimensional Recursive Digital Filters***

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Abstract

Two dimensional digital filters are used for digital processing of two dimensional signals commonly encountered in areas such as image processing geophysics, radio astronomy etc. for most of the filtering problems their implementation in the recursive form results in increased computational speed and storage economy. Never the less, a satisfactory theory for the analysis and synthesis of recursive filters in the sample and frequency domains has so far been lacking. The purpose of this thesis, which is stimu lated by the above considerations, is two folds; a) to outline the basic concepts of two dimensional digital filters in general, and b) to develop frequency domain and sample domain analysis and synthesis procedures for recursive filters. The contribution made in various directions is summarized below. a) a necessary and sufficient conditions is derived for the stability of a special class of linear and position invariant two dimensional digital filters in terms of the absolute summability of the sample respo nse. An equivalent stability criterion is also given in the frequency domain. (the frequency domain version has independently been reported else where also.) b) the concept of frequency response and transfer function is built u by extending the notion of eige nsignals and eigen values to two dimensional digital filters. A proof as to the only possible form of two dimensional eigensignals for linear and position invariant filters is also given. c) two dimensional z - transform is considered as a tool for the analysis and synthesis problem of these filters. a formal proof of the inverse two dimensional z -transform is outlined. The final value theorem for two dimensional z - transform is also proved. This is useful in studying the steady state behaviour of two dimensional digital filters for a given input signal. d) After obtaining a general form of the transfer function of two dimensional recursive digital filters through the two dimensional z - transform is method special properties of amplitude and phase responses of such fi lters are examined. In particular conditions for quadrantal symmetry of the amplitude response are derived. e) Basic hurdles in the general frequency domain synthesis of two dimensional recursive filters is introduced and a procedure of realizing ideal two d imensional amplitude characteristics (such as low pass, high pass, etc.) with the help of such filters is outlined. It is shown that the equi ripple realization of these ideal characteristics can be obtained by two single dimensional equi ripple filters. Further, it is established that for the two dimensional case also, frequency transformations are equally use ful in converting a low pass equi ripple filters into other standard classes (such as high pass band pass, etc.). f) The problem of realizing separable but arbitrarily specified amplitude characteristics is also taken up. To this effect an iterative technique of synthesizing single dimensional recursive filters approximating the given squared amplitude response in the minim ax sense is first given, and t hen its application to synthesize two dimensional amplitude characteristics is discussed. A frequency transformation is given to realize special ‘angular’ two dimensional amplitude characteristics from the transfer function of a single dimensional digital filters. g) Procedures are given for sample domain synthesis of recursive filters and equalizers. In particular, a procedure is given to synthesize a recursive filter with separable denominator polynomial for approximating a given sample response in the minim ax sense. The problem of designing an equalizer is considered as a problem of inverse filtering of two dimensional digital signals. An iterative technique for inverse filtering is outlined for finite signals.

For more details click here Back

Title : ***Some Applications Of Fixed Point Theorems In Control Theory***

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Abstract

Many control problems can be represented in the form of integral equations (IE). Noting that these are special cases of operator equations, a functional analytical view point (mainly the constructive approaches) to study the qualitative properties, like existence and uniqueness of solutions, of these equations has been adopted. Emphasis has been given to show how these techniques can be applied to control problem rather than giving best possible results or solving complicated large practice oriented problems. Several numerical examples have been included to demonstrate the procedures. For boundary value problems (BVP), of both two point and multipoint cases, a simple equivalent IE representation has been given. The technique involved can accommodate large class of constraints on the system dependent variable (called state) and other parameters. Using this technique, as illustration, a very general non-linear controllability problem has been given an equivalent IE representation. With the help of some modifications of Banach's fixed point theorem, the equivalent IE for the BVP has been studied. The most important aspect of this work is the study of the controllability problems. For this problem, our approach is motivated by the fact that these are essentially two point BVPs, where an unknown parameter, called control is to be found out, which will steer the system between any given pair of states. A set of IEs has been given, the solution of which represents a solutions of the controllability problem. Using fixed point theorems on these IEs existence of at least one control has been assured. The method presented here also finds out the numerical values of the control. A very simple results has been obtained for the controllability of non-linear system, when the dimensions of both the state and control vectors are identical. The stability problems have also been investigated by fixed point theorems. For the non linear forced system, when the forcing function is dependent on both state and independent variables (called time) of the system Banach's fixed point theorem has been used. And for the open loop systems that is when the forcing function is dependent only on time, a modifications of kakutani's theorem to banach spaces, given by bhonenblust and karlin, has been used without any convexity conditions on the system.

For more details click here Back

Title : *Optimal And Suboptimal Control Of Multiareaload Frequency Control Systems*

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Abstract

Some computational methods to determine suboptional controllers for multiarea LoadFrequency Control Systems are presented and their nearness to the optimal controller isevaluated. Further some of the realistic factors, which are usually assumed to be absentfor the sake of simplicity, are considered here in their complete shape and their effect onthe response of the Load Frequency Control (LFC) system studied. The small perturbation (linear) model of a multiarea LFC system is considered inChapters 2and 3 wherein two methods of reduction in computation are given. In the firstmethod a three-equal-area system comprising of 11 state variables is approximated as atwo-unequal-area system having 7 state variables. This is achieved by combining two ofthe areas (in the three-areas system) into a single large area treating it as connected to thethird-area by equivalent tieline. The optimal response of the reduced system is thendetermined and compared with that of the original system. The method is then extendedto a three-unequal –area system which is approximated as a two-unequal-area system. A second method of reduction in computation of optimal control of linearsystems invokes the theory of aggregation of Aoki. In this method the original two-area-system comprising of 9state variables is reduced to a system consisting of 6 statevariables, which has as its eigenvalues the dominant eigenvalues of the original system.The optimal feedback controller is then computed for the reduced and is used as asuboptimal controller for the original system. The nearness of this sub optimal control tothe optimal one is examined by comparing the following. A) The suboptimal responseswith optimal ones b) the subioptimal performance index with that of the optimal one andc) the stability of the closed-loop systems in both the cases. This method involves correctknowledge of the eigen-vectors of the original system. In a multiarea LFC system the tieline power flow between any two areas is afunction of the sine of the angular difference between the voltage vectors at either end ofthe tieline. Fiore small perturbations this angular different is small and the tieline flowcan be taken as a function of the angular difference it, which makes the system linear.However for large perturbations the above assumption cannot be made and the systemmust be treated as nonlinear. In Chapter 4and 5 advantage is taken of thetrigonometrically since term occurring as the nonlinear term in LFC systems and themethod of reduction by aggregation is extended to reduce a higher order nonlinear systeminto a lower one .The method of Lukes given for regulation of autonomous nonlineardynamical systems is then conveniently applied for the reduced nonlinear system. As inthe case of linear systems the optimal feedback controller of the reduced nonlinearsystem is utilized as a suboptimal for the original nonlinear system. With the help of a 4thorder example it is shown that the suboptimal

response closely resembles the optimalone. One of the usual assumptions that are made while computing optimal control ofLFC systems is that three is no interaction between the Megavar-vlotage and Megawatt-frequency control loops. This is not strictly true in the actual state of affairs. The effect ofinclusion of excitation control on the frequency variation, which is obtained control onthe frequency variation, which is obtained as a function of time, is studied in the last partof this thesis. A second realistic factor included in the LFC systems and studied in thispart is the construction of an observer in the event of nomeasurability of some of the statevariables and its effect on the response of the state variables. It is shown that the error inthe response thus obtained is small and also decays exponentially with time, thusachieving a near-optimal controller with the help of the observer. The above two aspectsare covered in Chapters 6 and 7 of the thesis. In the author's opinion the following contributions are made in these thesis:i) Elegant and efficient computational techniques are developed for the optimaland suboptimal control of linear multiarea LFC systems.ii) Suboptimal regulation of nonlinear multiarea LFC system is achieved byreducing the order of the non-linear system to a computationally convenientsize.iii) The effect of excitation control on the response of the LFC system isdetermined taking into account the interaction of the area voltage on the areaload also.iv) An observer is constructed when some of the state variables are assumedto be nonmmeasurable of the state variables so obtained in the optimalcontroller structure.v) Finally, concluding remarks are made on all the computational methodspresented in the thesis.

For more details click here Back

Title : *Analysis And Performance Of Transistor And Integrable Mixers*

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Abstract

The principle of heterodyne frequency converter has been known for at least forty years. Essentially it consists of combining signals at two different frequencies in a non-linear (or time varying element) to produce a desired third frequency (usually the difference frequency). The non-linear element may be a vacuum tube, semiconductor diode or transistor. The theory of both vacuum tube and semiconductor diode mixers is well understood. The transistor mixer has been the subject of many investigators. The present trend is to analyse the transistor mixer based on (i) The non-linear property of carrier transport across the junction of the device (analysis based on device model theory), (ii) The equivalent circuit of the device. The first method gives insight into the physical process and properties of the junction itself. The second method is more familiar to circuit designers and basic network theory concepts can easily be applied for analysis. However, under identical physical conditions both methods should give the same result. Meyer has analysed the transistor mixer circuit by assuming a high frequency device model. He solved the nonlinear differential equation for the conversion conductance on a digital computer using numerical techniques and obtained good agreement between his computed and experimental results except at high emitter currents. Many attempts have been made to give an exact equivalent circuit for the transistor mixer. A model was first suggested by Read. The equivalent circuit given by him is crude because it was found necessary to modify the transconductance by a factor 0.4 to make theory agree with experiment. El-said also proposed another equivalent circuit but no experimental evidence was given in support of his circuit. Moreover his circuit gives errors at high emitter currents. In chapter II of this thesis, an exact analysis is given which leads to a hybrid-pi equivalent circuit. Experimental results in support of this analysis are provided. Good agreement between calculated and experimental values is obtained. The performance of the transistor mixer for pulsed local oscillator drives is studied in Chapter III. The conversion conductance is expressed in terms of new functions which are evaluated using a digital computer. Experimental results are presented for comparison. The analysis and performance of the cascode transistor mixer is presented in Chapter IV. Optimum conversion conductance plots are given. The variations of conversion conductance and mid-frequency to different ambient temperatures are measured and plotted as graphs. Introduction of integrated circuits created the necessity to dispense with inductors and transformers in mixer circuits so that the system can be fully integrated. Coupling transformers at the input are avoided by resorting to different arrangement. The inductance in the output tuned circuit is eliminated by simulating inductive

impedances of equal value and of equal Q at each collector of the differential pair, using the circuit proposed by Radhakrishna Rao and Venkateswaran. The performance including sensitivities and design of such an integrable differential transistor mixer is presented in Chapter V. the measured sensitivities of Q factor, mid-frequency and conversion conductance to changes in supply voltages, local oscillator crest voltage and temperature are within prescribed tolerances. The analysis of the circuits presented in Chapters III to v follow a common pattern and are based on the hybrid - pi equivalent circuit presented in Chapter II.

For more details click here Back

Title : *Stochastic Optimal Control Problems: An Algorithmic Approach*

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Supervisor(s) : *Borwankar J D Ramkrishna D & Sarkar B*

Abstract

Generally speaking it is not possible to give a precise and complete description of any physical process. In some eases, certain idealizations lead to a satisfactory deterministic description. However, it becomes necessary at times to account explicitly for the stochastic features in the given process which results in a probabilistic description of the system. Discrete-time stochastic systems are generally modeled by random difference equations forced by white-noise sequences whereas the continuous-time systems are modeled in the state form by I to integral equations. Stochastic control deals with the control of physical systems subjected to stochastic inputs. The stochastic control problem consists of finding the control that optimizes a given performance functional under the constraints imposed by the system dynamics and observation mechanism. The optimality conditions may be derived through the dynamic programming and sometimes through the pontryagin's maximum principle. The associated equations have been solved completely for linearquadratic-gaussian cases, and vast body of literature is available on this problem. However, in the case of nonlinear problems attempts so far, have been mainly restricted to approximating the given problem by a linear quadratic one. As the mathematical model is greatly complicated by explicit inclusion of stochastic features in the system description it becomes necessary to analyze the system behaviour to ascertain whether accounting for these stochastic disturbances would lead to a controller superior to the one obtained form the deterministic description of the same system. In view of this, the analysis problem becomes particularly important. It may be pointed out that no general analytical methods are available to us except in the simple linear and a few nonlinear cases. Unlike the case of deterministic optimal control problems no computational techniques for direct optimization are available in the area of stochastic control. Development of a computer-based numerical technique to simulate an I to integral equations and investigation of the possibility of using stochastic approximation techniques as direct optimization tools, provide the motivation for this thesis. Through out this dissertation it is assumed that the state variables are unobservable or if observable can be perfectly measured. I to integral equations are based on a stochastic integral which is interpreted in I its sense. However more than one definition can be given to a stochastic integral. This multiplicity of definitions leads to an ambiguity in the choice of state models. Chapter 2 contains a review of stochastic state modeling and a comparison of various state models for the continuous-time systems. In chapter 3, algorithms which can be easily implemented on a digital computer have been derived to generate sample path-wise solution for scalar and a class of vector nonlinear I to integral equations. Using these algorithms two examples of stirred tank

chemical reactors, subjected to stochastic disturbances have been analyzed. It has been shown by this analysis that the predictions of the reactor behaviour using linear model can be erroneous. Chapter 4 contains a review of techniques available to solve stochastic control problems. In chapter 5 it has been shown how Robbins-Monro procedure of stochastic approximation can be used to solve algorithmically a discrete-time stochastic optimal control problem. It has also been shown that Robbins-Monro procedure, along with the algorithms derived in chapter 3, can provide a computational method to solve a continuous-time stochastic optimal control problem. A few examples have been solved to establish the validity of this approach. Chapter 6 contains conclusions and a summary of these results obtained in this thesis.

For more details click here Back

Title : *Coordinate Transformations In Systems And Control Theory*
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Abstract

Many examples of simple physical systems are known which cannot be described globally by a single coordinate system, and so for the study of such systems it is necessary to perform coordinate transformations. In its modern form the theory of coordinate tra nsformations is included in the theory of differentiable manifolds which can also be considered as coordinate invariant approach in analysis. The theory of differentiable manifolds provides a topologically way of looking at the system, and thus by avoiding unnecessary assumptions concerning a specific choice of coordinate system enables one to concentrate on 'intrinsic properties ' of a system. In Chapter 2 we point out the relevance of some of the concepts from the theory of differentiable manifolds for s ystem theory. In particular, we show that representation of n - part networks in frequency domain admits a natural Grasmann manifold structure, and also give an example of a system described by ordinary differential equations, the state space of which is non orientable. Next we describe a 'manifold model' for a class of reciprocal networks and also give a coordinate invariant formulation for linear networks which may contain nonreciprocal Clements. In the last section of this chapter we present an outline for reformulating Kron's work on electrical machines, in modern terminology. In Chapter 3 we present a new proof of the Pontryagin's maximum principle. The system under consideration is first transformed into a canonical form which on able one to take full ad vantage of geometrical insight. The main advantage of our proof is that it does not use the Brouwer Fixed Point Theorem or equivalent algebraic topological results (which are quite difficult to prove), but instead uses the Inverse Function Theorem. Also th e proof is more or less constructive in nature and it should be possible to develop an algorithm for numerical computations based on it. In chapter 4 we show that an uncontrollable linear time invariant system can be rendered controllable by an arbitraril y small perturbation in the system matrices. This imp lice that the concept of controllability is 'structurally unstable' and so merely ascertaining the controllability of a system may not be useful. To avoid this difficulty, we propose some measures of co ntrol ability for linear time invariant system, which vary continuously with respect to system parameters and are invariant with respect to linear coordinate transformations. Finally in the appendix we present the necessary definitions and results from th e theory of differentiable manifolds.

For more details click here Back

Title : Optimal Regulators For Synchronous Machines
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Abstract

In recent times, the attention of power system engineers has been focused on methods of increasing transient and dynamic performance of power systems in order to minimize or eliminate the effects of severe system oscillations, using modern control theoretic concepts. By regulating the terminal voltage and speed to some fixed reference, it has been shown that the transient performance of the synchronous generations can be improved. The conventional design procedure for such voltage regulators and speed governors assumes apriori knowledge of suitable configurations for the regulating and stabilizing equipments. This has drawbacks in the arbitrary choice of the controller configurations and the cut and try procedure involved in the selection of regulator parameters to meet the design specifications such as overshoot, steady state error and stability limit. Even when these specifications are met, it may not be the best possible design. The notion of modern and optimal control theory provides a convenient frame-work for incorporating the design specifications and for studying has system dynamic behaviour. Through the proper choice of an appropriate performance criterion, it becomes possible to impart the desired features the system transient and dynamic behaviour. The objective of the present thesis is to formulate the synchronous machine control as an optimal control problem and then to obtain an integrated control for the excitation and prime mover control which is optimal with respect to a chosen performance criterion. Chapter I is a general introduction giving a brief discussion on the synchronous machine control problem and the modern development with particular reference to the present status of optimal control of power system dynamics. Chapter II is devoted to the development of a mathematical model for the synchronous machine connected to an infinite bus system. The sate space model of the single machine system is derived using winding currents as some of the state variables instead of flux linkages, in a form most suitable for the applications of optimal control theory. For small disturbances in the system which occur continuously during the normal operation, linearized system models are satisfactory. Thus the state model is derived in the form X=A X + B u. choosing a particular voltage regulator and speed governor configuration, the system behaviour for impulse type of disturbance is studied. The various conventional methods of selecting the regulator parameters so as to improve the stability limits is discussed in chapter III. The second method of Lyapunov is used to obtain the voltage regulator and speed governor gains, so as to have minimum settling time in the event of a system disturbance. In chapter IV, the system is formulated as an optimal output regulator problem. Choosing a quadratic performance index, an optimal integrated control law is obtained by Pontryagin's minimum principle. Both finite time and infinite time regulator problems are discussed. The performance of the system with the optimal regulators is then compared with that using conventional regulators. The optimal regulator obtained in chapter IV, cells for measurement of all the state variation for feedback. It is seldom that all of these are accessible for measurement. A compatible dynamic observer is designed in chapter V which reconstructs the entire state vector from the available output measurements. The optimal controller cascaded with the observed gives the overall configuration of the controlled system. The transfer matrix relating the output to the inputs are also derived. The observer designed in the last chapter introduces dynamics in the control loops and also

exponentially decaying error. Hence it is desired to find a control law which is a functions of measurable outputs. Chapter VI deals with the sub optimal control of synchronous machine system. Here the regulator is constrained to be a linear time invariant function of the measurable system outputs. Using an iterative algorithm the feedback control matrix is determined. The effect of the sub optimal control law determined for a particular operating point when used at different load levels is discussed and conclusions are drawn. The stability of a conventional synchronous machine delivering leading power factor loads is poor because of lower excitation. The problem of maintaining stability under these conditions by using a divided rotor synchronous machine is discussed in chapter VII. A state space model is derived and the behaviour of the system with conventional angle and voltage regulators is investigated. In chapter VIII, the optimal and sub optimal control of the divided winding rotor synchronous machine is dealt with. The system behaviour with the optimal controller for large disturbances is discussed. The superiority of optimal regulators over conventional regulators is established. The disturbances occurring in a power system are random in nature and also uncertainties are introduced in the output measurements. Hence the design of optimal regulators should take into effect the presence of random disturbances. In chapter IX the optimal control of synchronous machine in the presence of such random disturbances is described. The disturbances are assumed to be white noise with known statistics. The average behaviour of the system in the presence of noise is then determined. The optimal control law for these conditions is the same as that for the deterministic case; but the performance index value is increased on an average. In response to the demands of the system growth and more interactions of control systems, the dynamic analysis becomes more expensive and time consuming even on a fast digital computer. The question might, therefore, be asked whether simplified models might not be appropriate for such systems. A method of simplifying such large linear dynamic systems using Schwarz canonical form which does not require the computation of eigen values and eigen vectors as hither to done in existing methods, is described in chapter X. the response of the original and simplified models is compared. The method of state variable grouping is used to obtain a reduced model for multivariable control systems. Using the reduced model, an optimal regulator is obtained. This control law is used a sub optimal control law for the original system. The performance of the original system is investigated with this sub optimal control law. In the concluding chapter, the results of the thesis are reviewed and future lines of research are delineated.

For more details click here Back

Title : Quantization In Linear Transform Domains
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Abstract

Signal processing may be of interest in problems such as parameter extraction, signal classification compact storage for future retrieval and reduced bit rate transmission with a given fidelity criterion. Most of the earlier pictorial signal processing studies have used conventionally scanned version of the picture for further processing 1, 2. One can also use linear transformation of the signal to map it into an alternative description 3-15. Alternative descriptions thus obtained are important for two reasons. Firstly, they may possess statistical characteristics which may make them more amenable to efficient statistical coding. Secondly they may be more suitable for the exploitation of perceptual redundancy than the conventional version of the signal. In this thesis, Fourier transform and hadamrd transform have been used to obtain alternative descriptions of the signal. The thesis is particularly addressed to the study of the effects of quantization in the transform domain on the reconstructed signal. The important results of the thesis are summarized below. If the signal is amplitude-bounded, the transform domain samples are also amplitude-bounded. In the Fourier domain these amplitude bounds are different for different sets of samples. Thus the Fourier domain is partitioned into sets of samples such that members of any set have the same amplitude bounds. In both Fourier domain and hadamrd domain the amplitude bounds can be tightened if the zero frequency sample amplitude is given. These amplitude bounds are also set dependent, the sets being the same as in the case of strict bounds. The knowledge of an appropriately chosen subsequence of Fourier domain sample amplitudes can be converted into the knowledge of mutually exclusive and exhaustive subsumes in the signal domain. Under the knowledge of these subsumes, the amplitude bounds on the Fourier domain samples, not included in the subsequence, can be tightened. The Fourier domain subsequence referred to above consists of all the samples belonging to some the sets in which Fourier domain is portioned. The bound thus obtained are also set dependent. The delineations of the sets are the same as above. The Fourier domain subsequence may be augmented by including sample amplitude belonging to one more set and new bounds obtained on the Fourier domain sample amplitudes excluded from the augmented subsequence. Thus the bounds on the Fourier domain amplitudes may be obtained recursively. A group of sample amplitudes can be selected in the hadamrd domain and the knowledge of these can be converted into the knowledge of mutually exclusive and exhaustive subsumes in the signal domain. The definition of these subsumes is governed by the particular selection of the group of hadamrd domain sample amplitude. Under the knowledge of these subsumes, amplitude bounds on the hadamrd domain samples excluded from the group can be tightened. These tighter amplitude bounds are the same for all the sample excluded from the group. However, they might be used only for some f them and these samples can e used to segment the group. With the augmented group be the hadamrd domain sample amplitude, newer bounds can be obtained on the remaining samples. This procedure can be followed recursively. By virtue of the recursive procedure to augment the group of the hadamrd domain sample amplitudes and to obtain the bounds on the remaining sample amplitudes at that stage of recursion, the hadamrd domain can be partitioned into sets of samples. Al the

sample of a particular set then have the same recursive amplitude bounds. Two such recursive procedures of the many possible have been worked out. In view of the natural partitioning of the Fourier domain and the partitioning that can be imposed on the hadamrd domain as discussed above any uniform quantization transfer characteristics in the transform domain would be wasteful, because the quantum levels beyond the set dependent dynamic range would always be empty. Therefore different quantizaion transfer characteristics have been proposed for the different sets of samples that constitute the partitioning in the transform domain. Each of these quantization transfer characteristics is restricted within the appropriate dynamic range and is assumed linear though this assumption can be removed. Analysis of the effect of transform domain quantization on the reconstructed signal has been carried out for the set dependent quantization scheme proposed. For the Fourier domain quantization, the bounds on the error amplitude in the reconstructed signal are different for different sample locations. Thus if all the samples that have the same error amplitude bounds are grouped together, the signal domain gets partitioned into various, sets the delineation of the sets being similar to thus in the Fourier transform domain. For the hadamrd domain quantization the bounds n the error amplitude the reconstructed signal are the same every where and no partitioning of the signal domain is suggested. The study of quantization in both one-dimensional and multi dimensional transform domains is carried out. In case of the Fourier domain quantization, cases of both real and complex signal are dealt with. If the signal having a correlation that decreases as a function of the distance is available on the rdimensional sampling lattice, the following conclusions are drawn. With the total number of samples held constant, the best hadamrd domain quantization schemes is r-dimensional. For the best Fourier domain quantization scheme, from the r-dimensional signal, a signal of as high a dimensionality as possible is constructed till the number of sampled along as may dimension as possible is 4. The bit rate required to describe the transform domain can be further reduced without changing the pattern of errors in the reconstructed signal by applying the following procedure. After set dependent normalization and quantizaiton in the transform domain one tests whether the sample amplitude is within a restricted dynamic range or beyond it. If it is within a restricted dynamic range, truncated quantization transfer characteristics is used for it. Efficient computational algorithms for the transform domain quantization schemes are worked out. Quantization schemes in one-dimensional and two-dimensional Fourier and hadamrd domains have been simulated on IBM 7044.

For more details click here Back

Title : *Digital Calculation Of Transient Phenomena In EHV Power Systems*

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Abstract

The study of transient phenomena in power systems has become extremely important, especially with the increasing voltages of transmission systems. The basic insulation level, now a days for extra high voltage (EHV) transmission, is determined more by the b ehaviour of the system under switching and fault conditions then by its response to lightning surges. The details regarding the decay of follow up current are useful to decide whether single pole reclosing could be adopted. The sending end and receiving en d currents during faults and transient voltages after reclosing etc., are helpful in the design of hhigh - speedrelays and lightning arrester coordination respectively. Various methods are described in the literature for the evaluation of transient phenomena like lumped parameter method graphical methods, transform methods, etc. The objective of the present thesis is to develop and extend the existing methods for the digital calculation of the transient phenomena in EHV systems. A finite difference scheme ba sed on central differences is developed to solve transient phenomena and the Uram and Miller's procedure is extended to handle intermediate faults and to incorporate frequency dependent transmission line parameters in digital simulation. After briefly rev iewing the existing methods discussed in the literature and describing the organization of the present thesis in Chapter I, chapter II is devoted to the development of the basic algorithms using the method of finite differences to solve transient phenomena . Stafford, Evans and hingorani have discussed a finite difference scheme which is not applicable to systems with junctions and terminations. The relative ease with which the nonlinear elements can be handled and the possibility to incorporate special feat ures like corona have provided the motivation for developing a finite difference scheme that can handle junctions and terminations. Thus, a stable finite difference scheme, based on central differences, has been proposed and the application of the scheme i s illustrated through various examples. The numerical stability of the proposed scheme has been discussed and a criterion which assists in the proper choice of time interval and length of a line section x for digital simulation of transient is furnished. After having illustered the application for the scheme to single - phase systems in Chapter Ii, the extension of the procedure to polyphase system is furnished in chapter III. In this chapter transients in transposed and untransposed systems and atabekov's a pproximations are discussed. Chapter IV develops the necessary algorithm for handling junctions and loops and furnishes the details regarding the fault representation opening and closing operations of the breakers. A flow chart showing the details of a gen eral - purpose programme is included. The finite difference scheme proposed here has the following advantages. 1) It can handle any terminations (including nonlinear elements), ii) the input disturbance can have any arbitrary wave shape, and iii) the accurac y of the method is comparable to all the existing methods. Uram and Miller's procedure using Lap lace transforms as originally reported did not discuss the algorithm to handle intermediate faults. Chapter V deals with the

necessary algorithms to be used fo r studying the transients due to intermediate faults. With the present extension of the Uram and Miller's approach line disturbances like component flash over can be studied. Chapter IV discusses the application of the procedure developed in chapter V to study the fault transients follow up current currents through the breakers etc. to examine the possibility of adopting single pole reclosing. For communication purpose or for reduction of line losses at peak loads insulated ground wires are used. Depending upon the ground wire connections the zero sequence impedances of the transmission lines vary. The effect of the variation of the zero sequence impedance on the fault transients is investigated in Chapter VII. Nonzero earth resistively causes the transmiss ion line parameters to very continuously with frequency. Various studies have been reported, to see the effect of frequency dependent line parameters. Chapter VIII deals with the extension of the Uram and Miller's procedure to incorporate the frequency dep endent line parameters in transient studies. The chief advantage of the procedure is saving in computation time with good accuracy comparable to the Fourier transform method. For the digital calculation of transient phenomenon in EHV power systems various methods have been reported in the literature. But each method is developed based on certain approximation and hence the choice of a particular method depends on the accuracy desired, computation time involved and the nature of the problem. Chapter IX is de voted to the discussion of the relative merits of the various methods. In the concluding Chapter, the results of the thesis are reviewed and future lines of studies are indicated.

For more details click here Back

Title : Analysis Of Thyristor Controlled D.C. And A.C. Motors
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Supervisor(s) : Ramamoorty M

Abstract

The advant of thyratrons introduced a new concept in the sped control of motors, namely the phase control. The grid control was used to achieve switching in of the motor at desired instants of time. Of late, thyristors have replaced thyratrons and being so lid state devices, thyristors are far more efficient in operation faster in switching, occupy much less space require least maintenance and also cost less. The phase control of D.C. and A.C. motors using thyristors has introduced special problems in the m athematical analysis. Firstly, thyristors impose current constraints during the blocking period. In the case of A.C. motors, this calls for special modelling techniques to facilitate application of current constraints without increasing the computational t ime. Secondly since natural commutation is used, the duration of the conducting period and blocking period are not known apriori. This introduces challenging problems in the mathematical analysis of D.C. and A.C. motors. Thirdly, if numerical methods are resorted to, in which case the duration of the conducting or of the blocking period need not be known initially, computational time increases considerably. For, the initial conditions are not known and if the solution is started form arbitrary initial cond itions, the volume of computations required to reach steady state is very large. Also it is necessary to simulate thyristor characteristics by suitable logical instructions which enhance the programming time as well as compilation and execution times. The present thesis seeks to solve these difficulties as applied to the most popular motors, namely the D.C. series and shunt motors and the single phase and three phase induction motors. In all the methods of analysis developed here, the need for simulation o f thyristors and the need for integration from arbitrary initial conditions are totally avoided. Algorithms are given for obtaining the steady state solution of the various motors. They are suitable for digital simuation,easy to program and fast in executi on. Theoretical simplicity and computational rapidity are the unique features in these algorithms. Part I of the thesis deals with D.C. motors and Part II with induction motors. Chapter I is a general introduction giving a brief historical review and moder n developments in the speed control of motors, with particular reference to phase control. The second chapter looks upon the series motor is a servomotor and develops a simple closed loop block diagram with parameters depending on the steady - state operat ing point. Equations are derived using the block diagram to predict the temporal variation of average current and average speed of the motor for small sudden perturbations of load torque or of triggering angle. Results form the block diagram and rigorous n umerical analysis are compared and concordance established. The steady state operating point before perturbations may be obtained either from numerically determined performance curves or from the simple methods

developed in the third chapter. The third c hapter considers the steady state analysis of phase controlled D.C. series and shout motors. Simple algorithms are given to predict the steady state operating point for given torque and triggering angle, without resorting to rigorous numerical solution. Th e interesting phenomenon of hunting of a thyristor controlled shunt motor, the reason for its existence and a method of its suppression are discussed. the model developed in thrown into the state space form by solving this equation numerically and applying boundary matching conditions for steady state, an algorithm is given to determine the initial condition vector for directly obtaining the steady state solution. The computational time is less then that for other known techniques. Chapter x gives concludin g remarks for the thesis.

For more details click here Back

Title : *System Design Of A Parallel Processing Computer For Information Retrieval*

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Abstract

This thesis is an investigation of problems in information retrieval and the system design of a computer system well matched for information retrieval. Performance of retrieval systems, namely, recall and precision can be improved by using multi - attribute s for information representation and user feedback about relevant and irrelevant retrieval. An algorithm to select the set of attributes for a data base has been proposed in this thesis. The algorithm is based on the information obtained from statistical c o - occurrence of attributes in the data base and when applied to a sample data base gives the keywords and citations as the two most important attributes for library information system. The improved performance obtained in feedback retrieval process as comp ared to non - feedback processes has been studied and formalized. Considering these aspects of retrieval problem a special purpose computer system is proposed. The motivation for this design in three fold. In information retrieval, matching of documents wi th the query need not be sequential. This kind of "inherent parallelism" in retrieval problems should be exploited. There is a hierarchy of operations involved in information retrieval like query analysis, retrieval operation and output presentation, and each of these has its own special requirements. It is desirable to study the feasibility of design of a computer system well matched to each of these levels. There is an increasing need for computing power at a lower cost due to the rate of information g rowth and need for improved performance. Also the multi attribute system and feedback retrieval could improve the performance at the cost of computing time. A computer system with a hierarchy of processors is proposed. This system has a preprocessor operat ing in a time sharing mode for query analysis and managing the second level processors. The second level of the system has one or more processors which perform the retrieval function and select pointers to the relevant documents. These second level process ors have been economically designed by specializing their function. The output processor in its simplest form can be a soft copy display. The main difference between this architecture and other array processing machines such as SOLOMON and ILLIAC IV is th at inter processor control and communication is only through the central controller. This modularizes the system and endows it with flexibility to meet growing requirements. Performance degradation which might occur due to the lack of direct communication between the parallel processors can be reduced by a suitable file organization technique which minimizes the need for such communication. The proposed architecture is described in PMS and ISP notations which are developed by Bell and Newell to describe com puter systems. A system level simulation of this computer architecture has been

carried out with a program written in FORTRAN. System characteristics like arrival rate of customers and computational time required per customer are inputs to this simulator. The number of parallel processors, the number of channels for file access, and the number of output channels are the system parameters. Average waiting time of the customers, response time and utilization of the resources constitute the outputs of this si mulator. The results of simulation are used in developing a methodology for the system design. The use of this simulator in general system design of this kind is discussed. The use of an analytical model which supplements this simulation model has been con sidered. By making the second level parallel processors highly special purpose a wired in logic for completely hardware oriented search is proposed. A coded representation of the documents and its use in hardware oriented search are discussed. In this met hod the cost of the parallel processors is no more than the cost of a few gates and registers. The main conclusion of this thesis is – It is feasible to design a hierarchical special purpose parallel processing computer system well matched for informati on retrieval problems. Further it may by made modular to meet the growing needs of an information retrieval environment.

For more details click here Back

Title : ***Active RC Synthesis Of Driving Point Impedances, Impedance Inverters Converters, Oscillators And Filters***

Author(s) : ***Rao Kote Radhakrishna***

Roll No : ***662491***

Supervisor(s) : ***Venkateswaran Shankara***

Abstract

For more details click here Back

Title : *Stability Power Gain And Port-Immittances Of Linear Active Two Port Networks*

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Abstract

When one varies the source and load reactance's during tuning of RF and IF amplifiers oscillations usually occur. This is due to the feedback within the device. Sufficient energy is feedback at the input terminal to cause oscillations. Feedback also makes the input immittance a function of the load immittance and the output immittances a function of source immittance. The device may be represented as a no unilateral active two - port network and a black box approach can be adopted for the analysis of these pr oblems. Stern proposed a stability factor, k, in terms of the two port parameters. For the two port to be absolutely stable his stability factor k 1. Venkateswaran proposed another stability factor, s, which unlike Stern's stability factor is an invariant in h - , z - , y - and g - matrix environments. Provided s 1 he showed that this stability factor and the maximum available power gain are simply related through the loop gain modulus. He also proposed an align ability factor, δ , which is an invariant in the fo ur matrix environments. This factor specifies the maximum interaction between parts. In the present work, it is shown (without evaluating the optimum terminations) that conjugate matching passive terminations provide the maximum power gain for a given abs olutely stable two - part network. These optimum terminations are derived based on a simple application of the well - known image parameter theory. A practical method is presented for quickly computing the 'invariant stability factor'; optimum terminations an d maximum available power gain from eight simple measurements. A detailed study is carried out on the variation of port immittances for various terminating immittances at the opposite port. It is shown that the locus of port immittance is a circle for pur ely real terminations at the opposite port. Expressions are given for evaluating the load for a given input immittance on this circle. Sensitivity or interaction between ports is also investigated. These results are used to obtain a design procedure for h igh Q inductive reactance form the circuits of Jindal and Dutta Roy. This design procedure is in terms of two port admittance matrix parameters.

For more details click here Back

Title : *Analog Multiplier Circuits Using Silicon Junctions*

Author(s) : *Deep Gurdip Singh*
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Supervisor(s) : *ViswanathanT R*

Abstract

Analog multiplication plays a central role in analog signal processing. Operations such as modulation phase sensitive detection sampling etc. need multipliers with a wide variety of bandwidth and accuracy requirements. A precision better than one per cent is generally specified for low frequency multipliers used in general purpose analog computers, instrumentation and control systems. While a precision of two to five per cent is often acceptable for signal modulators in communication systems, there may be a special requirement in terms of a wide range of temperature over which the circuit must function satisfactorily. Thus one can see the demand for a wide variety of multiplier circuits depending upon the system in which these design has accentuated the demand for multipliers. With the advent of integrated circuits, multiplier circuit configurations which exploit those features that can be achieved only through monolithic silicon technology (such as matched junctions with close thermal coupling) and which will abide within the limitations imposed by it must be evolved. Recently some integrated multiplier circuits have been described in the literature1-3. The work presented in this thesis is a study aimed towards the above objective. The thesis begwith a broad survey of the methods used for analog multiplication. The underlying principles are reviewed briefly. Attention is concussed on the use of silicon p-n junctions to obtain logarithm and antilogarithms of analog singles through which multiplication and division are naturally performed. Schematic circuit arrangements are discussed in chapter II with a view to explain the underlying principle of the multiplier operations. Temperature dependence of V-I characteristics of the pjunction is considered and a compensation technique to render the circuit operations insensitive to ambient temperature variations is proposed. In chapter III, the exponential terminal characteristics of silicon junctions is examined in detail with a view to isolate a current range which can be adopted for use in multiplier circuits. For obtaining the logarithm of an analog voltage E, a current I proportional to the voltage e must be passed through a diode. The simples way of doing this which is often employed, is by connecting the voltage source in series with a resistance and the diode. The diode drop makes the relationship between E and I nonlinear unless the voltage E is very much greater than the diode drop itself. Since this configuration by virtue of its simplicity is attractive the results of a computer aided analysis of this configuration is given view to examine the errors introduced. There are several ways of overcoming this nonlinear effect. In chapter IV, novel circuits arrangements of increasing complexity to improve the compensation for the diode nonlinearity are discussed and compared. These compensation techniques use operational amplifiers in negative feedback configuration and dependent transistor current

sources. The effects of offset voltages and bias currants of the operational amplifiers on the circuit performance are discussed. Similarly various methods of obtaining antilogarithm are described. Limitations are imposed on the frequency response of the multiplier circuits by the operational amplifiers used in the circuits and ultimately by the logarithmic diodes themselves. These are examined separately both for small signal and large signal conditions. The diode diffusion capacitance is taken into account and the nonlinear differential equations characterizing the circuit behaviour have been numerically solve and the results are presented. In chapter IV, a few multiplier circuits are described and their pertinent design considerations are outlined. Most of the circuits will perform best when fabricated in the form of hybrid integrated circuits. Experimental results from the multiplier circuits built using discrete components, matched transistor pairs, and available integrated circuit blocks, are presented. Methods to generate functions like squaring square rooting etc., which are building blocks required to implement useful functions such as the root mean square are outlined. The emitter-coupled transistor pair used as a differential amplifier has become a basic building block in linear integrated circuit design. A large signal analysis of the circuit using ebers and moll model for the transistor operated in the linear active region brings out the various interesting properties of the circuit. Recently gilbert1 has explicated this for multiplication. In chapter IIV these properties which are useful in signal processing applications have been discussed briefly.

For more details click here Back

Title : Design Of A Nuclear Quadrupole Resonance Spectrometer
Author(s) : ViswanathanTandur Lakshmi
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Abstract

The study of the phenomenon of nuclear guadrupole resonance (NQR) exhibited by certain solids aids the under standing of their structure. The resonance frequency is characteristic of the substance and can be anywhere in the frequency range of hundreds of kilohertz to hundreds of megahertz. The instrumentation involves the location and display of the absorption line. This is done is placing the sample in the tank coil of an oscillator circuit. When the frequency of the oscillator coincides with the resonance frequency, the substance absorbs a minute amount of energy and this manifests itself as a small change in the tuned circuit impedance. The fractional change in impedance will be of the order of one part in 106. This causes a minute change in oscillation amplitude which is detected with the help of an envelope detector. The detector output only contains the signal due to absorption but also noise from the oscillator circuit. The aim of the present work is to improve the instrumentation from the point of view of sensitivity and signal to noise ratio. The lower the frequency of absorption, smaller is the amount of absorption; and hence the instrument used to locate the absorption mist be more sensitive. Generally speaking, increasing the sensitivity results in the increase of noise, and the ultimate objective is to obtain higher signal to noise ratio. Spectrometer system based on marginal oscillators is chosen since it is known to reproduce the line shape faithfully. An experimental approach was first used to study the popular circuit configurations with a view to compare their performance and select a circuit configuration with optimum component values. As a first step towards better performance. Low noise field effect transistors were employed in place of vacuum tubes used in the existing circuits. A low frequency analog simulation technique of the oscillator circuits was employed to optimize the circuit components for obtaining maximum sensitivity. Instrumentation with improved signal to noise ratio was evolved for the 30 MHz region based on the oscillator-detector circuit arrangement used Knight (KNIGHT, 1961; VISWANATHAN ET AL., 1968). Further simulation studied led to a simpler and more sensitive oscillator circuit which was used to detect NQR both at 3 MHz and 30 MHz (VISWANATHAN ET AL., 1970). An analytical approach to the problem of oscillator behaviour from the point of view of NQR detection was undertaken. The nonlinear differential equations which characterize practical oscillator circuits are difficult and very often impossible to handle from the standpoint of obtaining closed form solutions. Some workers have attempted to express the nonlinear device characteristic in a polynomial form. But, the results obtained have very little practical value, since it is difficult to synthesise the desired nonlinearity at high frequencies. Either one has to look at the nonlinear terminal behaviour of the existing low noise devices and pick the one which is nearer to the desired characteristic or choose a nonlinearity which can be synthesized. The

analytical approach used in this work is to study the properties of oscillator circuits with piecewise linear characteristic for the active device. The simplest of these which can be easily synthesized is the one with two segments, viz., an amplifying segment and a limiting segment. The differential equation characterizing the circuit behaviour is solved using the Kryloff-Bogoliuboff's first approximation. The sensitivity is defined as the ratio of the fractional change in amplitude of oscillation to the fractional change in the tuned circuit resistance. The result show that higher sensitivities are obtained as the nonlinear characteristic becomes softer, i.e., the slope of the limiting segment approaches that of the amplifying segment. But the price paid for obtaining higher sensitivity is in terms of the stringent control required over the loop gain. The analysis has been extended to circuits with a piecewise linear characteristic with three segments, one amplifying segment and two limiting segments. A similar characteristic has been suggested by Robinson (ROBINSON 1959). The analysis shows that the sensitivity derived by Robinson is the limiting value obtained for large values of loop gain, whereas when the loop gain is in the neighborhood of unity, higher sensitivities are obtained. The overall sensitivity of the three segment nonlinearity is lower than the two segment one. The technique used for the detection of absorption generally involves methods of making the absorption periodic by either frequency modulating the oscillator or magnetic field modulation. It is known that the response of the oscillator circuit to periodic absorption varies with sensitivity. Thus, it is important to evaluate the effective detection bandwidth before choosing the modulation frequency. The analysis shows that at higher sensitivity conditions the effective detection bandwidth decreases, so that the sensitivity bandwidth product remains constant. Experiments show that there is an overall improvement of signal to noise ratio at higher sensitivity. An oscillator detector system has been designed which is based on a piecewise linear characteristic for the active device to operate at the 3 MHz region. Improved performance has been observed. This type of synthesis should be expected to be more effective at lower frequencies.

For more details click here Back

Title : *Study Of Photovoltaic Devices Based On Metal-Semiconductor Structures*

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Abstract

Recently these has been an intense interest in utilizing photovoltaic conversions of solar energy for terrestrial applications. This has led to the exploration of novel structures which would provide an alternative to the conventional P-N junction solar cells. Our interest in this thesis has been in studying some of these novel structures which are based on metal-semiconductor junctions and act as schottky barriers or analogously related devices. Particular attention has been paid to the understanding of the following aspects of these novel structures. 1. The characteristics of the schottky barrier solar cells (SBSC) are rather well known [1]. In the published literature, there are also some reports on the effect of temperature on the characteristics of these cells. For example, it has been reported that the short circuit current Iof silicon SBSC increases with increasing operating temperature. Following the concepts prevalent at that time (1975), the increase in ISC has been attributed to the availability of extra photons, belonging to the long-wavelength range of the solar spectrum, due to the lowering of the forbidden energy gap of silicon with increasing temperature. Our study [2], presented in chapter 1 of the thesis, however shows that the contribution to the increase of ISC due to the mechanism mentioned above is negligible and cannot explain the experimental results. Instead, it has been found that good agreement with experimental results is obtained when the increase in ISC with increasing temperature is calculated by taking the change of the absorption coefficient of the semiconductor with temperature at all wavelengths. This conclusion is not limited only to SBSC but would be valid for P-N junctions or other type of cells made on indirect band gap semiconductors like silicon. 2. The major disadvantage of SBSCs is due to their low open circuit voltage. There are two ways in which this can be obviated. One of these is by using schottky (MIS) cells [1] and the other is by using schottky (oppositely doped semi conducting interface) cells [3]. In the case of former cells, the performance critically depands on the thickness of the interfacial insulating layer. When this thickness is large, both the short circuit and the open circuit voltage decrease leading to a decrease of the conversion efficiency. The mechanisms responsible for this behaviours have been found to be the variation of the illuminated barrier height and that of the density-surface states with the variation of the thickness of the interfacial layer. The details of this analysis are given in the second chapter. The other type of cells where on oppositely doped semi conducing interface layer is sandwittched between the metal and the bulk semiconductor have so far not received the attention they deserve. Keeping in view that the increase of effective barrier height, which is obtained due to the presence of a thin oppositely doped semi conducting interface, would be of interest not only from the point of view of solar

cells but of many other devices where schottky barriers are employed, we have developed a rather general method of analysis including the effect of mobile carriers for these devices [3]. This is given in the third chapter. 3. All the devices mentioned above require a very thin film of metal to form the schottky barrier because these films have to be transparent to light. This places stringent demand on the choice of the metal because it is required to simultaneously meet the optical, electrical and mechanical criteria. A way out would be to use a lateral (gridded) structure where the metal film is not thin and continuous, but thick and very finely gridded. Since the carriers are photogene rated in the area where there is not metal and are laterally collected by the thick film of metal forming the schottky barrier, we call this a lateral SBSC. Its analysis entails the solution of a twodimensional continuity equations. A further complication arises because all the boundary conditions are not known. A method of analysis which assumes the functional form of the boundary conditions has been developed [4] and is given in the fourth chapter. It allows the determination of the boundary conditions by proper matching and leads to the solution of the continuity equation. A brief summary of the properties of different types of cells considered in this thesis is given in the concluding fifth chapter.

For more details click here Back

Title : *Optimal Load Scheduling Of Power Systems Using Nonlinear Programming Techniques*

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Supervisor(s) : *Ramamoorty M*

Abstract

Whenever the installed capacity in a power system is in excess of the load and theaccompanying transmission line losses various generation schemes are possible optimalload scheduling consists in obtaining that particular scheme which results in minimumoperating costs .An early pioneering work in this area has been that of Kirchmayer .Theformulation of load scheduling problem as given by Kirchmayer has two main drawbacksnamely the engineering limits such as plant capacity are not considered; the reactivegeneration or equivalently the voltage magnitude of generator busses are not decidedoptimally in reducing the cost of generation through reducing the transmission linelosses . Carpenter considered these two aspects and formulated the problem as anonlinear programming problem. It has been realized by him that to obtain thetransmission line losses exactly one has to solve the power system circuit. Such exactmethods are of current interest in view of the increasing use of digital computer in theoperation of systems and some recent advances made in the solution techniques fornonlinear programming problems. Of particular interest among these techniques to theload-scheduling problem are the sequential unconstrained minimization techniques ofFiasco and NcCormick conjugate gradient algorithm for minimization of unconstrainedfunction due to Fletcher and Reeves and Lasdon's decomposition technique for additivelyseparable problems. In Chapter II of the thesis the above techniques are briefly describedand their significance in the solution aspects of nonlinear programming problems isdiscussed. A purely thermal system is considered in Chapter III and the exact load-scheduling problem for such system is formulated in terms of bus voltages. Thisformulation results in a lesser dimensions nonlinear programming problem with fewerquality constraints .Two algorithms based on sequential unconstrained minimizationtechniques are developed one of interior point type and the other exterior point type. Therelative merits of the algorithms are discussed .In these algorithms the minimum of thetransformed function is obtained using an efficient conjugate gradient method. Someexample is worked out using the algorithms. Further the method of obtaining optimal tapsetting and phase shifter transformer positions is described. Finally the methods ofobtaining the new optimal solution for a small deviation in loads are discussed. In Chapter IV load scheduling of hydrothermal systems is considered .In a combinedhydrothermal system there is no generation cost associated with hydro stations. Howeverthe total energy available at each hydro station over any given period of time isdetermined by the amount of water available for generation and as a consequence theproblem of hydro-thermal system has to be treated separately .Two distinct cycles thatrepeat in time in the operation of hydro-thermal system are the day on which a

loaddemand cycle repeats and an year in which river water-flow s and seasonal demand .Itwill be necessary because of the available information about the system to split theproblem into long range (year) and short range (day) problems. With reasonableassumptions the short-range problem can be formulated as an additively separableproblem the objective being the minimization of thermal generation cost over a day withthe constraints of load demand water availability at hydro stations and engineering limitson the system. The resulting problem is usually of very large dimension. It is found thatLasdon's technique I useful here to make the problem tractable .An example is solved. Chapter V is addressed to the problem of load scheduling of interconnectedsystems. Interconnected systems have to be considered separately in view of their largesize because of which the dimension of the problem becomes very large and also becauseinterconnected system are usually operated by separately controllers in each sub system(multi-area operation). Here also the load-scheduling problem has been formulated interms of bus voltage as an additively separable nonlinear programming problem. Thesubs systems are coupled through interconnections among them and suitable couplingequation are obtained. Lasdon's technique has been applied which splits the largedimension problem into smaller dimension sub problems, which are to be solvediteratively. Each sub system defines a sub problem and coupling equations are satisfiedusing Lagrange variables .The method is illustrated by three examples. Certaindifficulties encountered in the application of the decomposition technique for the loadscheduling of interconnection system are brought out. In the concluding chapter the results of the thesis are reviewed and further lines ofresearch are indicated.

For more details click here Back

Title : *The Identification And Estimation Of Linear Monstationay Dynamical Systems*

Author(s) : *Rao Ponamgi Ramakrishna*
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Supervisor(s) : *Rajaraman V*

Abstract

In recent years a great many schemes have been proposed for the identification or the estimation of linear as well as non - linear dynamical systems. The interest in such schemes has apparently arisen from the need to control partially characterized systems in a so called adaptively optimal manner. However most of these approaches tend to ignore two important considerations. The first of these concerns the observability of the parameters characterizing the dynamical system from the given input - output record o f measurements on the system. The second consideration that is often brushed aside is the implementability of the procedure suggested for real - time identification or estimation of the parameters of the dynamical system even for a sub - optimal control of the system. The notion that a partially characterized 'black - box' can be identified in a one shot operation just given the input - output measurements without further elaborate experimentation seems to be an exaggerated one. This thesis is concerned with the l imited objective of considering the problems involved in the identification and the estimation of the parameters of linear dynamical systems. Is assumed that a priori knowledge of the form of the equation governing the dynamic behaviour of the system is av ailable. Specifically, the class of systems that can satisfactorily be described by vector - matrix differential equations are considered. After emphasizing that the estimation of the parameters of even a linear system, in general belongs to the area of non - linear estimation in chapter II four representative schemes of estimation that have been proposed in the literature are examined. It is contended that in spite of their seemingly different approaches the various schemes, a least in practice, entail restric tive assumptions concerning the form of the parameter variations and /or knowledge of the initial estimates. In chapter III the identification problem is considered. It is shown that for a given input and state record of observations on a linear dynamical system with a known input - coefficient matrix there exist infinitely many system coefficient matrices all of them leading to the same input - state record. This points out the need to have a priori information about the form of the parameter variations. For a class of parameter variations that are uniquely specified by a constant parameter vector, a necessary and sufficient conditions for the observability of the parameter vector given the input - state record of observations is obtained. When only the input - ou tput record is available the existence of an unique parameter vector is intimately connected with the observability of a non - linear system with an infinite series type of non - linearity. It is shown that the conditions of the observability of the parameter vector given the states and the observability of the states given the outputs do not imply the observability of the parameter vector given the outputs. Finally the similarity of the format in which the identification and estimation problems are formulated is discussed. Chapter IV discusses an approximate method for the identification of a system given only the input - output measurements by using an updating procedure. The results of some numerically controlled experiments are presented. In chapter V the dif ficulties involved in obtaining the solutions of linear random differential equations are considered. In a brief digression the equivalence of the currently popular state -

space approach and what may be called the integral equation approach familiar to comm unication engineers, as applied to the estimation problems is discussed. Finally a mini - max formulation that can incorporate in ignorance of the non -random parameter vector characterizing the system coefficient matrix is carried out. How the optimal estima tes of the states so obtained can be used in turn to estimate the parameter vector is indicated. The conclusion of this thesis is that successful determination of the parameters - on - line or off - line of even linear dynamical systems, without linearlizing as sumptions, by any one scheme of estimation depends on the particular problem at hand and may require considerable numericals experimentation. In the absence of an explicit criterion for the observability of the parameters given the inputs and outputs, this situation, in view of the inherent non - linearity of the problem, perhaps is inevitable.

For more details click here Back

Title : *Some Problems Of Continuous Stochastic Optimal Control*
Author(s) : *Mandke Vijay Vasantrao*
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Abstract

During the past decade much progress has been made in the formulation and study of discrete stochastic control problems. However a corresponding development of the theory of continuous time stochastic control was hindered mainly due to the non -a vailability of the required mathematical tools. The recent developments in probability measures and integration the Ito calculus and Freshet differentials have of late sparked considerable interest in a mathematically rigorous formul ation and study of these problems. The question regarding the existence of an optimal control and deriving a set of necessary and sufficient conditions to obtain it which a - re of fundamental significance in deterministic optimal control and deriving a set of necessary and sufficient conditions to obtain it which a - re of fundamental significance in deterministic optimal control case . Therefore familiar notions such as the controllability and the observability principle and the Dynamic prog ramming have to be extended to continuous stochastic systems. The Markovain property that the probability laws of the further depend on the present ignoring the past is know to be satisfied by the solution of an Ito equation . As this property represents the stochastic counterpart of a similar property possessed by the state of a deterministic syst4em it plays a key role in developing a general theory of continuous stochastic optimal control problem .For this reason the plant dynamic a re assumed to be characterized by Ito type stochastic differential equations. The state variables are considered to be inaccessible and only noisy observations of the state are available .The observation equation satisfied by the observation proces s is also assumed to be Ito equation .The Problem is to chose an optimal control that minimizes an internal type performance index a functional subject to the constraints imposed by the plant and the observation equations. While Chapter II constrains a brief review of some of the result's concerning solution of Ito equations, Chapter III is deviated to the problem of stochastic control -liability and obserbvability notion signifies that the error vector between the desired ter minal state and the actual terminal state attained must remain bind in some sense. On other the observability is concerned with studying the boundeness of the difference between the executor value of the system state at any instant and its estim ate .In this sense these problems of controllability and observability are shown to be related to the problem of stochastic stability .As the notion of stochastic observability is involved in the problem of estimation the solution of which forms th e first step in solving the general control problem the rest of chapter III is concerned with a detailed study of stochastic observability . A more general description of the control problem discussed earlier is obtained by makin g provision for the inclusion of uncertainty in the system characterization . Itself. Chapter V and IV devoted to a study of the stochastic control problem in the presence of uncertainty . Method suggested for the removal of

this uncertainty involve subjective criterion .The Markov Position Game formulated and studied in Chapter V provides a game theoretic approach to this problem.The necessary conditions for obtaining the optimal strategies are given in the form of a pair Hamilt on - Jaacobi -Bellman equations involving Freshet differentials. The adaptive control problem formulated and studied in chapter vi uses the concept developed in the previous chapter .The unknown plant parameter is assigned t he role of an antiagonist.Them problem reduces to that of obtaining a least favorable distribution for the plant parameter and a Bayes optimal strategy with respect to the least favorable distribution .To obtain the least favorable distribution we the notion an equalizer strategy .The Bayes optimal strategy so obtained is also a Minami strategy representing the desired solution for Adaptive Control problem.

For more details click here Back

Title : *Power System Transient Stability By Methods Of Popov And Lyapunov*

Author(s) : *Mohan Mallavarapu Ananda*
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Supervisor(s) : *Pai Mangalore Anantha &Sastry V R*

Abstract

The application, in some recent works, of Lyapunov's direct method to power system transient stability problems is viewed with great interest by power system engineers, since the direct method affords in principle a considerable saving in the computational effort involved in transient stability studies. While these works have established the basic feasibility of applying the direct method to power systems, the progress necessary to bring practical systems within the scope of this method has been slow, owing mainly to certain theoretical difficulties. The most conspicuous among these is the problem of construction of Lyapunov functions, thus, only relatively simple mathematical models of power systems have been amenable to this method to-date, the Lyapunov functions for these models having been arrived at by trial and error and physical considerations like system energy. The present thesis addresses itself to the problem of development of systematic methods for construction of Lyapunov functions for various mathematical models of power systems. Recent and powerful results in nonlinear stability theory due to Popov, Kalman and Yakubovich, and their extensions, provide the basic theoretical foundation for this work. The central result used is that due to Kalman and Yakubovich: the satisfaction of a frequency-domain condition, known as the 'Popov frequency condition', by the transfer function of the linear part of a dynamic system is both necessary and sufficient for the existence of a Lyapunov function of the 'quadratic form in state-variables plus integral of the nonlinearity' type. Further, it is possible to give a systematic procedure to construct this Lyapunov function. This type of Lyapunov function is a natural generalization of the energy function, and almost all the Lyapunov functions proposed for power systems till now are particular cases of this general type. The problem of estimating stability regions based on such Lyapunov functions and admits of a systematic and simple solution, the first ideas in this direction being provided by the recent work of Walker and McClamroch, and Weissenberger. After briefly reviewing the transient stability problem and describing the motivation for and the organization of the present thesis in Chapter I, attention is accorded to single-machine models of power systems in Chapter II. Relevant results from nonlinear stability theory on dynamic systems with a single nonlinearity are introduced and then applied to a single-machine model with constant damping and a single time-constant liner representation of governor action. The linear part is shown to satisfy the Popov frequency condition, and Lyapunov functions are obtained in closed form which show the effect of damping and governor action. Higher order linear representations of the governor can be treated by straight-forward application of the methods of this chapter, as the theory places no restriction on the order of the linear part of the system and, further, an elegant graphical interpretation due to Popov enables one to test the frequency condition with ease. Chapter III deals with multi-machine models of power systems. These are systems with several 'single-arguments' nonlinearities, and need the application of a matrix version of the Kalman-Yakubovich Lemma due to Narendra and Neuman. By virtue of this lemma, the satisfaction of a matrix version of the Popov frequency condition by the transfer function matrix of the linear part of the

system is necessary and sufficient for the existence of a Lyapunov function of the 'quadratic form plus multi-integral' type, and it is possible to give a systematic procedure to construct it. The construction procedure is detailed in steps, one of the major steps being the spectral factorization of a rational matrix associated with the system. The method of chapter II for estimation of stability regions is then extended to the present multi-nonlinear case. And is shown to necessitate the solution of a nonlinear programming problem in general. The theory is applied to a 3-machine power system and a Lyapunov function and stability region in closed form are obtained. Also for 3-machine systems, a new Lyapunov function, which shows the effect of damping, is proposed and shown to be within the frame-work of the above theory; the corresponding stability region is determined. While the methods of this chapter are applicable without theoretical modification to 'k' – machine systems with linear representations of governors, the testing of the matrix Popov frequency condition is a tough problem and does not admit, at the present time, of a simple graphical interpretation of the type available for single-nonlinearity systems. Chapter IV is devoted to the problem of construction of Lyapunov functions for single-machine models with the flux-decay effect. The mathematical models incorporating the flux-decay effect involve 'product type' nonlinearities and fall into the class of systems with several 'multi-argument' nonlinearities, this class being more general than that studied in Chapter III. A new theorem for the existence of Lyapunov functions for systems with 'multi-argument' nonlinearities is presented, and determination of stability regions using these Lyapunov functions is discussed. The theory is applied to successfully generate Lyapunov functions for a single-machine model which not only includes the flux-decay effect but also a single time-constant representation of the governor. It is then indicated how higher-order linear representations of the governor can be treated systematically by the same theory. Finally, the possibility of constructing Lyapunov functions for single-machine models with flux-decay effect as well as voltage regulator dynamics is considered. A 4-state-variable model, wherein the action of the voltage regulator is represented by one first-order nonlinear differential equation, is shown to be within the frame-work of the theory developed. However, the matrix Popov frequency condition for this system is satisfied if and only if a certain restriction on the parameters of the system is satisfied, and it is found that this parameter restriction is not satisfied in practice. Since the frequency condition is a necessary and sufficient condition for the existence of Lyapunov functions of the indicated form, it is concluded that such Lyapunov functions do not exist for this particular model. Illustrative numerical examples are included at appropriate places. In the concluding chapter, the results of the thesis are reviewed and future lines of research are delineated.

For more details click here Back

Title : *N-Person Differential Games And Multiicriterion Optimal Control Problems*

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Abstract

Deterministic two person zero sum Differential Games were first studied by Isaacs mainly in connection with Pursuit Evasion problems. Berkovitz gave a rigorous mathematical foundation to this subject. Recently N - person differential Games have started to re ceive attention. In N - Person Games, the payoff function vector of the players orders only partially their joint strategies and hence the solution of these games require the invoking of Super criteria. In this sense, N - Person Games are related to problems o f Vectro Programming and Decision Maker under Uncertainty. Extension of these interrelationships to a multistage setting under dynamic constraints to study N - Person differential Games and Mulitcriterion Optimal Control Problems provides the motivation for this Thesis. N - Person differential Games admit various Information Patterns and levels of Cooperation among the players. The solution concepts of Finite Games are generally applicable to these games. Thus the Noncooperative Solution is given in terms of Eq uilibrium and Minimax points, and the cooperative solution is given by Pareto Optimal Points. The application of these concepts in the case of deterministic Differential Games is discussed in Chapter II. In Chapter III, Necessary Conditions, similar to t he minimum principle of Pontryagin, are derived for the Noncooperative solution in terms of Equilibrium Points. It is established that the optimal strategies of the players necessarily induce Equilibrium Points in the Hamiltoniants, one for each player, wi th the usually associated EulerLagrange equations and the Transversality and Corner conditions. A general N - Person differential Games exhibits a variety of switching surfaces similar to those encountered in two person zero sum games. These can be broadly classified into Transition, singular Dispersal and Abnormal surfaces. While the Transition Surfaces are obtained by the application of corner conditions, the others require further conditions for their determination. For example, the singular surfaces are constructed by the application of the Legendre Clebsch condition in its generalized form. Chapter IV is devoted to a discussion of these surfaces and their construction. The concept of Pareto Optimality is discussed in detail in Chapter v along with the C oorperative Solutions of Differential Games. The necessary conditions for Pareto Optimality show that pareto Optimal solutions are obtained by solving a class of parameterized optimal control problems with the criterion functional given as convex combinati ons of the payoff functional of all the players. The various cooperative solutions differ in the underlying Super criteria to single out one Pareto optimal point as the solution. It is shown that multicriterion optimal control problems can be solved as coo perative N - Person differential Games without side payments and with equal information to all the players. A computational method is suggested for the resulting Nash Cooperative Solution. The solution

of the double integral plant with the twin objectives of minimizing time and fuel is given as a running example of a two person nonzero sum game throughout the thesis. The study of imperfect and incomplete information Differential Games is initiated by considering multicriterion optimal control uncertainly in Chapter VI. Because of their equal information feature, these problems are easier to solve than the corresponding Differential Games. A thorough study of such problems requires additional mathematical concepts form Stochastic optimal control and Markov Pro cesses and is suggested for further investigation.

For more details click here Back

Title : ***Design of Computer Aided Optimal Speed Regulating System For A Bar Mill Main Drive***

Author(s) : ***Bhatt Purushottam Pramod Chandra***

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Supervisor(s) : ***Rajaraman V***

Abstract

In this thesis an optimal design of a speed regulating system for a bar mill main drives has been obtained. In earlier design of speed regulating systems, although concepts of mathematical modeling were used, the merit of the control configuration was jud ged by experimental observations and analog computer simulation. This left open the question of optimally. In this thesis, a new technique of designing speed regulating systems is evolved by using dynamic programming concepts. Use of dynamic programming e nables one to answer questions about the goodness of design with certainly. There are two notable features of modeling of a main drive. One is that, for both armature current and air gap flux varying with time, a product term appears in the state equation s another is that, the field system in main drive has a nonlinear B - H characteristics. It would appear that no explicit optimization technique has so far been suggested for systems described by state equations that involve product terms. However, if one of the two variables (armature current and air gap flux) is time invariant, then a single valued piecewise linear approximation of B - H curve may be used. Consequently, optimization techniques for "nearly linear" systems may be employed in this case also. Th e optimization method developed here is based upon the premise that the product term can be approximated by a weighted linear combination of both the terms with time varying coefficients. Starting with an initial guess on the trajectories of both the varia bles and suing them as time varying coefficients, the corresponding set of time varying linear or non - linear differential equations is constructed. The approximation of product terms is improved iteratively by taking Gateaux gradient functional o a non – ne gative function along each of the guessed trajectories. The optimal solution is obtained by using parametric expansion in each iteration. Thus one essentially solves a sequence of optimal problems which converge to the required solution. A control program implementing this optimization process has been written in a form that is adaptable for use in control computers. On - line execution of this program for both generator field control mode as well as motor field control mode of operation has also been discus sed.

For more details click here Back

Title : *Analysis Of FeedBack Systems WithCombined Pulse Modulation*

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Abstract

Recently there has been a great interest in the area of pulse frequency modulated (PFM) feedback systems. The applications these systems have been diverse ranging frommodeling of neural etc to use in incremental servos. During the post decade pulsewidth modulated (PWM) systems have also been investigated in great detail . pwmsystems are employed in speed control of motors attitude control of space vehiclesetc. Study of systems containing a modulator which has more than one modulationlaw has however not received much attentation .It is claimed that feedback systemswith combined pulse width and pulse frequency modulations have better range ofcontrol since the PFM law is advantageous for small errors. Stability studies havebeen done by kuntsevich and Chekhovoi on a feedback system containing a combinedpulse modulator where the PFM and the PWM law depending on the error variableat discreate instants of time are fixed a-priori. In this thesis it is proposed to examine feedback systems containing a general classof combined pulsar modulator where the PFM law depends on past history of theerror signal and the pulse width is proportional to the error signal a the samplinginstants which are now unequally speed .The law governing the sampling intervalsmay be of the Relaxation PFM (RPFM) type or the integral PFM (IPEM) type .Itis believed that these schemes while being more general have some advantageover the discrete PFM-PWM law in terms of better noise immunity etc. A generalcombined pulse modulator (GCPM) incorporating both the pulse frequency andthe pulse width modulations is first mathematically proposed .Three classes ofGCPM namely Discrete PFM-PEM PPM-PWM IPFM-PWM are discussed .These arereferred top as they I Type II and type III modulators respectively and feedbacksystems containing these modulators are called as Type I type II and Type III systemsrespectively .Next the nonlinear discrete equivalence of the three system isestablished .This involves the determination of the vector sequence(Tk k? k?) where kT(= tk+1 –tk) is the sampling rate k? is the width of the pulse starting at t = tk and k? isthe sign of the pulse .For Type II and type II systems the derivation of the determination for Tkresults in an implicit equation involving Tk and state vector Xk .A circuit for TypeII modulator is implemented and from analog simulation studies it is found that thetransient response of type II system is better than that of the RPFNM system. Chapter IV is devoted to the stability analysis of Type I Type II and Type systemsbased on the second method of Lyapunov and the concept of the stability of anequilibrium set ..Also for Type I systems a procedure for the maximization of thestability sector is indicated . Chapter V deals with the question of existence ofperiodic oscillations (class ? equilibrium ? where ? represent s the number ofpulses per global period T). Using the nonlinear discrete equivalence conditions ofthe existence of various models of equilibrium are obtained for IPFM feedbacksystems as well .It is

belibed that this approach to the examination of periodicoscillation s conceptually easier and straightforward. In Chapter VI method of contraction mapping as applied to multinopnlinearsampled-data system is used to find stability limits of the type I system .Finally thethesis concludes with a number of suggested problems of research in the area ofcombined pulse modulation systems .

For more details click here Back

Title : *Analysis Of Conversion Of Decision Table To Computer Programs*

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Supervisor(s) : *Rajaraman V*

Abstract

In this thesis, problems relating to the analysis and conversion of decision tables to computer programs are considered. Existing methods of converting decision tables to three programs are critically examined. Subsequently, the shortcomings of three programs for decision tables are discussed leading to algorithms which provide a satisfactory method for coping with ambiguities in decision tables. Finally, the problem of modularizing a decision table into subtables is considered. The main results are: 1. simplification of decision rules in a limited entry decision table is direct by the application of the Quine-McCluskey procedure for switching functions. Selections of an optimum set of prime-implicants for constructing an efficient three program is formulated and a lower bound on the cost of any tree equivalent to the given limited entry decision table is obtained. A heuristic algorithm for constructing efficient tree programs from the optimum prime-implicants is given. 2. the inadequacies of tree programs for decision tables are discussed. Decision tables have a parallel structure and in going from them to tree structure (sequential test procedures) the advantages of parallel structure are lost. The following drawbacks of tree programs for decision tables are pointed out: (a) They have no capability for detecting ambiguities at execution time. In fact, it is required that no apparent ambiguity be present in a table in order to obtain a tree program. It is proved that it is not possible to pinpoint ambiguities at compile-time and hence tree structure undermines the use of decision tables as diagnostic aids. (b) When extended entry decision tables are mechanically transformed into limited entry format, the resulting tables are large in size and contain apparent ambiguities. Elimination of these requires an analysis of the semantic content of the conditions. Thus extended entry tables cannot be directly converted to tree programs. (c) Algorithms for obtaining optimal trees consume long compilation times due to the partial exhaustive search and backtracking involved. This results in a large overhead when rule probabilities change or when later stations are made to the original table. (d) Tree structure is not suitable for handling adaptive decision tables. In an adaptive table, a decision rule is modified dynamically. 3. An algorithm which stores the information in a decision table and in the data in separate binary arrays is developed for converting decision tables to computer programs. The importance or proper choice of codes in simplifying the mechanics of selection of appropriate decision rule is brought out. The algorithm is simple to use, requires only a small compile time, detects ambiguities at execution time and can handle limited entry adaptive tables. Based on this algorithm, a decision table to FORTRAN IV translator for IBM 7044 has been developed. The translator accepts decision tables embedded in FORTRAN IV statements and outputs a FORTRAN IV program. Extended entry tables are processed without converting them to limited entry form thus minimizing storage requirements. 4. when the size of decision tables is large it is useful to reorganize them into smaller tables by isolating the conditions and the decision rules into independent subsets. The parsing algorithm developed in the thesis analyzes the pattern of relevant and optimal condition entries and provides a partition of the conditions and the rules

which divides the original table into two or more independent subtables. The parsing algorithm is extended to tables not completely parable. The question of linking the subtables of a parsed table optimally is formulated and a simple solution is given. This reduces execution time (the only advantage of sequential or tree structure) and storage by combining the tree and mask approaches of programming decision tables. 5. an altogether different approach to programming a decision table is to associate an integer variable with each condition row and assign unique, nor-zero, positive integers to the condition states of each row. This procedure transforms a decision table to an integer function. Methods are given for formulating an arithmetic expression to evaluate the integer function. The value of the function is used for branching to the appropriate action via a 'computed GOTO' statement. Unlike other similar algorithms suggested in the literature, the methods outlined do not require to expand a table to explicitly express all combinations of conditions. It is also pointed out that this approach is useful only in cases of extended entry tables where the data is directly available in coded form. In binary machines, the execution time for evaluating the integer function is reduced by choice of code numbers in powers of two.

For more details click here Back

Title : Conversion Of Computer Programs To Decision Tables
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Abstract

Two important seemingly different problems feeing computer scientists have been the detection of logical errors in programs and the problem of converting programs written for one computer to that of another one. This thesis proposes the use of decision tab les as an intermediate step in solving both these problems. If algorithms for conversion of computer programs to decision tables were available then the resulting decision tables would be very useful for detecting errors in logic .As programs for conve rting decision tables to machine language are available decision tables would be a good intermediate language in converting programs written for one computer to those for another. This thesis attempts to develop such algorithms. Most of the literatur e on decision tables deals with conversion of computer programs to decision tables. Applications of decision tables to file handling and system design among others have also been discussed in literature. The approach in this thesis has been to use decisi on tables; (I) As an intermediate language in conversion of programs written for one computer to that of another, and (ii) As an aid in debussing and documentation. These are areas in which the potentials of decision tables have not been explored so f ar. The following are the main results reported in this thesis. (i) An algorithm to obtain decision corresponding to syntactically correct FORTRAN programs has been developed. The given program is scanned from the first statement. While scanning two tables A and Bare formed .All the control statements are entered in Table A and all executable statement with statement numbers in table B. Using the above tables the algorithm gives a systematic procedure for obtaining the decision table. Based on the abo ve algorithm LOGITRAN, a translator to convert FORTRAN programs to decision tables has been developed. This translator takes syntactically correct FORTTRAN programs as input and procedures the corresponding decision Tables as output. LOGITRAN has been wri tten in FORTR AN – IV and has a high degree of machine independence .If a large decision table is fed as input to LOGITRAN it would also parse it into smaller tables. (i) The applications of Boolean matrices associated with a flowchart or a computer program ar e critically analysed and their shortcomings discussed .a structure matrix is proposed as better and more general representation of program structures. (ii) Based on the above mentioned structure matrix an alternative procedure to get the decision tables has been developed. (iii) MATDT a scheme that combines the potentialities of matrices and decisions tables is proposed as an effective debugging and documentation aid. (iv) A method is suggested whereby using decision tables as an intermediate language can pass some of the difficulties of translation of assembly programs. An algorithm to convert assembly language programs can be by passed by using decision tables as an intermediate language. An algorithm to convert assembly language programs to decision tables is developed .The decision table along with a certain amount of pre and post editing it is felt would lead to some useful ideas for solving the decompiler problem.

For more details click here Back

Title : Models For Computer Aided Desiign
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Abstract

There is increasing interest of late in extending the possibilities of computer-aided designfor the solution of a large class of problems. A large amount of the present work in thisarea has been confined to network design problems. An excellent of such work isfounding the special issue of the Producing of IEEE on computer-aided design. Intimately associated with this problem of computer-aided design are the relativemerits of on-line computation versus batch processing .In either of these the theoreticalstudies in developing proper simulation models have engaged the attentation` of manyresearch workers. One important theoretical study of nature is sensitivity analysis which constitutes animportant link between analysis and design .In this thesis sensitivity models have beendeveloped which are algorithmic in nature and hence can easily be incorporated intocomputer formulation and solution. These computer models for sensitive analysis constitute extensition of the state-spaceformulation of linear and non-linear networks. While reviewing this necessary material acontribution is also made for a rigorous inclusion of non-linear components which non-monotonic characteristics .The equations for such components do not satisfy an essentialcondition to satisfy the sufficiency conditions for equations. Considering suchcomponents as dependent drivers circumvents this difficulty. Thus restrictions in the fromof terminal equations are shifted to restrictions in topological considerations. These laterconditions are stated. If design concepts are to be based on this analysis further study of the models isnecessary. Thus for example higher-order sensitivity coefficients are required for theformulation of the minimization of sensitivity of network. Models for determininghigher-order sensitivity coefficients have also been developed. For establishing design objectives based on sensitivity were need measure ofsensitivity. These measures are defined both in the frequency -domain as well as in thetime-domain .The models that are developed here are equally applicable for eitherfrequency-or time-domain analyses and therefore lend themselves for design purposebased on sensitivity measures. In stability analysis the question of sensitivity appears quit naturally. For exampleLyapunov defines local stability in terms of the initial conditions. These aspects havebeen discussed here quit explicitly. Determination of nth order sensitivity coefficients for a linear network depends on theresponse of the given and a knowledge of the sensitivity coefficients of order (n-1).However the basic data that is required for determining higher order sensitivitycoefficients is just the information about the network graph and its component terminalequations the rest of the information required for the final solution can be determinedfrom these. For a non-linear network however additional information about thecomponent terminal coefficient. The next important problem considered in this thesis is the

optimization problem.Again the thesis is that it would be advantageous to develop network models for thisstudy so as to render computer use. A proper network interpretation has been given to thestate equations of a network thus preserving the structural features of the problem, whichare usually not considered in control theory. Having systematized the formulation of co-state equations in terms of network modelsthe it is shown that in certain studies of the optimization problem the existing networkanalysis programmes can be used for the solution of the resulting two-point boundaryvalue problem. It is also shown that sufficient condition for optimality such as the onesdiscussed by Robbins does not admit a network interpretation. Another type of optimization study, which has interested research workers, is theparameters optimization problem. A component-oriented formulation of this problem ispresented. The component-oriented formulation has distinct advantages over other formulationprocedures where the parameters do not correspond to the individual components. In theprocedure given here the need for algebraic manipulation is minimized and error analysisbecomes quit straightforward. One of the interesting theoretical questions in parameter-optimization studiesconcerns the search procedures within the parameters space; it would be interesting toknow that part of the parameters space in which the search procedures are effective. This question has been partially answered in the thesis. Leeds and Ugron have conjectured that if in a network designed for minimalsensitivity the number of components is increased it is always possible to reduce thesensitivity. This conjecture is shown to be incorrect by means of a counter-example. This thesis uses network uses network language exclusively. However the analysisis equally applicable to all discrete physical systems. The range of applicability isachieved by means of graph-theoretic formulation procedures, which are quit valid forother systems also. Exclusive use of the network language is made for the sake ofsimplicity in presentation.

For more details click here Back

Title : *Studies In Differential Games With Applications To Optimal Control Under Uncertainty*

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Abstract

A basic framework for answering many conceptual problems arising in differential games and related reams is developed. In particular the notion of a generalized differential game, termed the 'Positional Game' is introduced .A positional Game consists of a system whose position is observed according to different laws by the various players whose actions influence the system. These action are required to be determined in terms of he observation and interface only By considering the different effects of unc ertainty in the system description and the nature of information allowed the players in the form of memory observation constraints unequal information incomplete and imperfect information different game problems have been identified .We consider the deterministic game problems in chapter 3 and 4 games with uncertainty in chapters 5 to 7. In deterministic games the formulations of linear differentiation games with constraints is treated in function spaces. The formulation is also examined for games with partial deformation. A related problem for linear games is that of playability of strategies and the considerations of controllability absorbability and sufficient coordinates. These are also treated .The generalization of two - person d ifferential games to N - person differential games is of recent origin .A heuristic derivation of the necessary conditions for the class of differential games given by Berkovitz is given in the non -cooperative case. This is applied to there problems viz., th e national economy model of two nations the system design problem with two criteria and study of 'silent' and 'noisy' 'races' In the games under uncertainty positional games with different information patterns to the players are investigated. I n the persons of uncertainty decisions have to be taken by players under either certainty risk or ignorance. These require subjective and objective factors to be considered and the implication in on - line and off - line games is examed .The trainer – learner g ame and the dangerous game arte examples of positional games with uncertainty (Perhaps ignorsence tool). The solution an formulation of linear stochastic game with; complete and random partial information reveals that a sddlsemesnt cannot in general be sat isfied in the latter problem in the pure strategies. Further since each player uses subjective criteria the appropriate conditions are those obtained in the corresponding N - person non - cooperative theory. The conceptual problems raised in chapter 5 lead to the notation of a two - person Markiv positional Came in chapter 6 and a general N - person Markovc Positional Game in chapter 7. A decomposition of the umpire's state into observed inferred recombered and ignored states is established. The properties of mix ed behaviour equalizer etc. strategies are examined for the Markov game .The theory parallels the dual control theory (as developed by Aoki) .In the N - person game the conversion of an incomplete structural information game to one with incomplete position information is shown. The notion of playability is generalized to incorporate certainty risk and subjective factors .It is shown that a Nash equilibrium point exists if a completely mutually playable tuple exists with strategies, which are all stationary and equalizers. We conclude finally by retreating the large number of conceptual problems raised above as also the vast potentialities for future work in this area.

For more details click here Back