PH.D. THESIS ABSTRACT 1990-1881

Sr No	Title	Supervisor	Author(s)	Year
1	Simulation Of Transients In Synchronous Generators And HVDC Links And Study Of Torsional	Sachchidanand & Padiyar K R	Senthil J	1990
2	Analysis Of Voltage Stability And Power Modulation In HVDC Links Connected To Weak AC Systems	Prabhu S S & Padiyar K R	Sreedhara P N	1990
3	Galois Switching Functions:	Siddqui M U	Varghese George	1990
4	Wireless VLF/ELF Mine Communication	Mahanta Anil& Raghuram R	Gogoi Anup Kumar	1990
5	Study Of Signals And Systems In The Framework Of Morkov's Constructive Mathematical Logic	Sinha V P	Rajan Ethirajan Govinda	1990
6	Investigation of Symmetry in Multi-phase Systems, etc Consequences and Analysis	Singh L P	Gaber Ahmed Zaki Ahmed	1989
7	Transform Domain Study Of Cyclic And Abelian Codes Over Residue Class Integer Rings	Siddiqui M U	Rajan B Sundar	1989
8	Effect Of Morphology And Mineralogy On Compressibility Of Sands	Yudhbir &(CE) GokhaleK V G K(CE)	Abedinzadeh Rahim	1989
9	Digital Protection Of EHV/UHV Transmission Lines	Bose Sanjay Kumar& Singh L P	Islam Kazi Khairul	1988

10	Control Of Static VAR Systems For Improvement Of Dynamic Stability And Damping Of Torsional Oscillations	Padiyar K R	Varma Rajiv Kumar	1988
11	GTO Convertor FED DC Motor Drives	Doradla S R& Dubey G K	Khan Badrul Hasan	1988
12	Standard Cell Placement And Routing	Hasan M M& Dhande Sanjay Govind(ME)	Rao D Sreenivasa	1988
13	Direct Stability Evaluation And On-Line Dynamic Security Asstssment Of Power Systems Using Structure Preserving Energy Functions	Padiyar K R	Ghosh K K	1987
14	Finite Deconvolution Data Recovery Schemes For Block Data Communication Over Dispersive Channel	Siddiqui M U	Poonacha P G	1986
15	Optimal Control Systems Design With Vector-Valued Performance Index	Sarkar B	Nandakumar, M P	1986
16	Multi Phase (II-PHASE) Systems: Dynamical Modelling And Analysis	Singh L P	Choudhary Madan Mohan	1986
17	Power Factor Improvement And Harmonic Reduction In Thyristor Converters	Dubey G K	Patel Hirabha K	1985
18	Analysis And Of Simulation HVDC-Turbine Generator Torsional Interactions	Padiyar K R	KothariA G	1985
19	Investigations Into The Design Of Power System Stabilizers	Padiyar K R &Prabhu S S	Anwar Anwaruddin	1985
20	Linear Sequential SystemS Over Residue Class Polynomial Rings: Theory And Applications	Siddiqui M U	Bhat K N Hari	1985

21	Selection Of Nominal Point For LQSF Regulator And Determination Of Parameter Range For A Specified Suboptimality	Hole K E	Mahanta Prafulla Chandra	1985
22	Reactive Power Control And Security Analysis Of Power Systems	Padiyar K R& Aggarwal R P	Jose T	1985
23	On The Phoshorus Diffusion In Silicon In Oxidising And Chloro-Oxidising Ambients	Tyagi M S	Gupta A K	1984
24	Novel Distance Relaying Schemes For The Protection Of Ehv/Uhv Transmission Lines Using Digital Techniques	Dubey G K& Singh L P	Kellogg Anug Jaiprakash	1984
25	Application Of Topological Energy Functions For The Direct Stability Evaluation Of Power Systems	Padiyar K R	Sastry H S Y	1984
26	Analysis Of Sub-synchronous Resonance And Its Control Through Excitation System	Gupta Sumana& Padiyar K R	Chanana M L	1983
27	Anaysis Of New Types Of Waveguide And Microstrip Discontiruity Structures and their Practical Applications	C Das Gupta	TomarR S	1983
29	Origins Of Excess Forward And Reverse Currents In Silicon Diffused Junction Solar Cells	Sharan R	Lal Rakesh K	1983
30	Ultra High Speed Protection Relaying Schemes For EHV/UHV Transmission Lines Based On Travelling Wave Phenomena	Singh L P	Desikachar Kandala Vedanta	1983
31	Fully Controlled Converter With Controlled Wheeling	Dubey G K	Subbanna Bhat P	1983
32	Broadband Microstrip Antennas Using Coupled Resonators	Gupta K C	Kumar Girish	1982

33	Digital Simulation And Stability Analysis Of Multi Terminal HVDC Systems	Padiyar K R	Sachchidanand	1982
34	Microwave Measurements Of Complex Dielectrfic Constant Of Solod And Liquid Films	C Das Gupta	Pramanick Protap	1982
35	Mathematical Modelling And Analysis Of Six-Phase (Multi-phase) Power Systems	Singh L P	Tiwari Shri Niwas	1982
36	Reliability Evaluation And Planning Of Bulk Power Systems	Padiyar K R	Shanbhag R S	1982
37	Desegmentation Method And Its Applications To Circularly Polarized Microstrip Antennas	Gupta K C	Sharma Pramod Chandra	1982
38	Analysis Of Power System Dynamic Stability Influenced Loads And Thyristor Controlled Var Compensators	Padiyar K R	Rajasekharm P	1982
39	Analysis And Design Of Vlf Antennas	Raghuram R & Mathur Naresh C	Rajasekharm P	1982
40	A Study Of Over Voltage Problems In Ehv Systems	Aggarwal RP & Padiyar K R	Saxena N S	1981
41	Synthesis Of Active R Filters, Oscillators And Delay Networks	Venkateswaran Shankara	Venkataramani Y	1981
42	Determination Of Effective Device Parameters Of silicon Juncition Field Effect Transistors	Sharan R& Biswas R N	Nandi Prasanta Kumar	1981
43	Analysis And Performance Of Chopper-Fed D. C. Motors Under Motoring And Regenerative Braking	Dubey G K& Singh L P	Satpathi H	1981

44	Triangular Segments And Two Dimensional Analysis For Microwave Integrated Circuits	Gupta K C	Chadha Rakesh	1981
45	Optimal Control And Parameter Determination In Volterra Type Integral And Delay Differential Systems	Prabhu S S& Das Purna Chandra (Math & Stats)	Patel Nalini Kumar	1981
46	Design Performance And optimization Of Reflection-Type In Diode Phase Shifters	Gupta K C	Trivedi Devesh Kumar	1981

Title   :   Simulation Of Transients In Synchronous Generators And HVDC Links And Study Of Torsional

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Abstract

High voltage Direct Current (HVDC) power transmission has been in use all over the world since the first Gotland link was commissioned in 1954. this is in a large measure due to the development of high power tryristor valves and novel control techniques. The economic design and optimal operation of an HVDC system requires detailed investigation of the dynamic performance of the system both under steady state and transient conditions and the performance evaluation of converter controls under various system conditions. Although an HVDC simulator (physical model) can be used and they do offer several advantages in terms of realistic controller models and fast interactive computation, the cost of these simulators is prohibitive to be used on a large scale. Digital simulators on the other hand offer significant benefits in terms of cost and flexibility. Thus, digital simulation can be used to supplement the HVDC simulator. Among the several different digital simulation programs which have been reported for the transient analysis of AC/DC systems, the Electromagnetic transients program (EMTP) [1] has come to be accepted internationally. Programs similar to EMTP but more specialized have also been developed [2]. Transient analysis of AC/DC systems using a digital computer requires modeling of the various subcomponents depending on the nature of study. For example, for the study of switching surges which persist for a very short duration, a simple model of a synchronous generator behind a sub transient reactance is adequate. However, study of transient phenomena persisting over longer periods such as those of sub synchronous resonance between the mechanical electrical systems require detailed synchronous machine models. Although, a lot of work has been reported in the literature in the area of transient analysis of AC/DC systems with simplified AC system representation, digital computer study of transients in synchronous generators and HVDC links has not received much attention. Digital simulation of transients in synchronous generators and HVDC links requires detailed representation of machine, its associated torsional shaft dynamics, the HVDC system and the converter controls. The synchronous machine equations are nonlinear in nature. Hence, the solution of synchronous machine with the network equations which are handled using the Dommel's approach [1], requires suitable interface technique. The interface techniques reported in the literature can be classified as requiring either the Thevenin equivalent of the network as seen from the generator [7] or the Thevenin equivalent of the generator themselves [8,9]. The method described in (7) has the drawback that if there are more than one synchronous machines in the network, their mode is should be separated by distributed parameter lines. This is because, superposition of node voltage is valid only if the system as seen from synchronous machine terminal is linear. The drawbacks of (7) are avoided by considering the

Thevenin equivalent of the generator as described in [8,9]. In this approach the emf term is to be predicted by the prediction of d and q components of either the stator currents or the stator flux-linkages and the rotor speed. Since the stator windings are connected to the network, any drastic change which occurs on the network side will be reflected on the stator flux-linkages. The numerical stability of the interface can be enhanced by having an interface algorithm which relies on the prediction of rotor flux-linkages rather than the stator flux-linkages and also by avoiding the prediction of rotor speed. Converter controls form an essential part of any HVDC system. The design of adequate control system must take into account the HVDC-AC system interactions. The possibility of adverse HVDC-turbine-generator interaction was discovered only recently. The first experience of such interaction occurred at the Square Butte DC project when the DC link operated radically [4]. It was found that there is a potential for torsional instability when a turbine-generator has a torsional mode whose frequency is within the bandwidth of HVDC current controllers which is typically around 10-30 Hz. Subsequently, HVDC simulator studies were performed to understand this phenomenon and identify parameters affecting it. The Phenomenon of sub synchronous resonance (SSR) in series compensated AC systems has been studied in depth using digital simulation programs and a lot of insight has been gained into this. There is however not much work reported on the study of HVDC-turbine-generator interactions using digital computers. Recently Padiyar and Kothari [5] have analyzed this phenomenon using dynamic digital simulation with detailed representation of generator and its mechanical system. However, in their study, the inverter of the DC system is represented by a constant DC voltage source. Also, the effect of auxiliary Sub synchronous Damping Controllers (SSDC) in reducing the torsional oscillations has not been investigated. Generators connected at the HVDC inverter bus are subject to problems of power reversal on load-rejection. Nakra et al [3] conducted studies on hydro-generators using HVDC simulator to understand this phenomenon, based on their studies they have suggested modifications in the converter control to reduce the resulting shaft stress. However, before the necessary control modifications are incorporated, detailed study is necessary to analyze the effectiveness of the control strategy in reducing the transients. The objective of the work reported in this thesis are: 1) To carry out digital computer studies of torsional interactions in turbo-generators connected to HVDC links (at the rectifier or inverter). Studies of this nature are important because many physical simulators do not have the feature for detailed representation of the synchronous generators with its associated torsional shaft dynamics. 2) To develop a digital simulation program for the transient analysis of AC/DC system with detailed representation of synchronous generators and the DC system. Since the BPA EMTP was not available, a transient analysis program along the lines suggested by Dommel had to be developed. 3) To present an improved method for interfacing synchronous generator mode with Electromagnetic Transients Program. The major contribution of the thesis are as follows: 1) A new technique, which relies on the prediction of rotor flux-linkages, for interfacing synchronous generator models with an electromagnetic transients program. 2) Development of a digital computer program for the transient analysis of AC/Dc systems. The program incorporates detailed representation of converter and its controls, the AC and DC systems, and the synchronous generator with its associated mechanical system. Results of transient

analysis of a two-terminal HVDC system obtained using the digital simulation program are validated by studies on a physical simulator. 3) Study of the HVDC-torsional interactions through digital dynamic simulation and investigation of the effect of subsynchronous damping controllers in reducing torsional oscillations. 4) Digital computer study of converter control strategy for reducing stresses on the shafts of turbo-generators connected to HVDC inverter bus. A brief description of the work reported in the thesis is given below: The first chapter introduces the various aspects studied and presents literature survey in this area. Chapter two describes a new technique for interfacing synchronous machine models with an electromagnetic transients program. this is based on the synchronous machine is represented by constant (subtransient) inductances in parallel with current sources which are dependent on rotor flux-linkages. The machine model handles subtransient saliency by introducing an additional dummy coil on the rotor q-axis. The machine inductances in parallel with the current source are constants and can therefore be included with the rest of the network. The influence of the time step on the accuracy, and the inclusion of AVR on the interface technique is analyzed. The validity of the proposed interface technique is tested on a sample network. Chapter 3 deals with the development of a digital simulation program based on Dommel's approach [1] for transient simulation of network and the generator models described in the previous chapter. The transients program incorporates detailed representation of converter along with its associated controls, and the AC and DC system models. The transients programs has been tested from the case study of a wo-terminal HVDC system reported in [10]. Chapter 4 is concerned with the simulation of HVDC system on the physical simulator at Central Power Research Institute, Bangalore. The scaling procedure on the simulator, and the setting up of various system components such as infinite bus, transmission lines, filters, converter transformers, converters and their controls are illustrated. The results of the case study reported in chapter 3 are validated by studies on the physical simulator. In this study, the generator has been modeled as an infinite bus. The various test cases which have been considered for validation are remote three phase-to-ground faults, single phase-to-ground faults, and three phase-to-ground faults both at the rectifier as well as the inverter bus. Chapter 5 reports on the digital computer study of HVDC-torsional interaction in a two-terminal radial HVDC system with detailed representation of rectifier and inverter, and their associated controls. The generator and its associated mechanical system is represented in detail. Auxiliary subsynchronous damping controller (SSDC) with signal derived from rotor speed has been considered. plots of frequency spectrum of the shaft torques are given to illustrate the effect of SSDC in reducing the torsional stress. Chapter 6 describes the digital computer study of transients in turbo-generators connected to HVDC inverter bus. In the even of load – rejection, the effect of ramping down the inverter DC voltage in reducing the shaft stress and the dynamic overvoltages in investigated. Chapter 7 outlines the conclusions drawn from the thesis and gives suggestions for further work in this area.

For more details click here   Back

Title : *Analysis Of Voltage Stability And Power Modulation In HVDC Links Connected To Weak AC Systems*

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Abstract

Since the advent of thyristor valves and related developments, the application of High Voltage Direct Current (HVDC) links for the expansion of power transmission systems has been on the increase. In particular, use of HVDC links are proved to be advantageous for long distance bulk power transmission ad AC system interconnection. The benefits accruing from asynchronous interconnection for AC system integration is well recognized. Most of the existing HVDC links are two terminal systems for transmission of power from point-to-point. Recently, there is a growing interest in Multi-Terminal DC (MTDC) transmission systems because of flexibility of system operation. New MTDC transmission systems are being planned. The tapping at Corsica of the existing Sardinia-Italy link is a specific example of MTDC operation and a five terminal Hydro Quebec – New England system is under construction. It can be expected that the application of MTDC systems will increase in future. HVDC systems can also be used to augment the stability of interconnected AC systems by fast modulation of power flow in the link. Power transmitted through the DC link is independent of bus angles but depends only on bus voltage and control setting (current or power). Control settings can be changed almost instantaneously through the electronic converter controls. If the set current or power is modulated by a suitable external control signal (ECS) derived from bus frequency or other AC system quantities the resulting variation in the power flow through DC link can help in damping out oscillations in the AC system. However, the effectiveness of DC link modulation depends on strength of AC system at the inverter bus. The strength of AC system at a converter bus is measured in terms of short Circuit Ratio (SCR). Short circuit ratio is defined as the ratio o fundamental short circuit capacity of AC system at converter bus to the rated power of DC link. If SCR is less than three, the AC system is considered to the weak. A weak AC system is characterized by large equivalent impedance as seen from converter terminals. Low short circuit ratios are more commonly encountered with asynchronous DC links. If the AC system in which the DC link is embedded in weak, additional problems arise in the operation of DC link [1]. Problems of concern are: (i) voltage instability, (ii) dynamic (temporary) over voltage, (iii) harmonic instability, (iv) increased incidence of commutation failure in inverters, (v) loss of effectiveness of power modulation, (vi) restrictions on the recovery rate after shut down of DC link. Of these, voltage instability is one of the major operational problems. Transient or steady state stability is defined as the ability of a power system to operate stably without loss of synchronism among generators after a large or small disturbance respectively. On the other hand voltage stability is the ability of the system to maintain load voltage magnitudes within specified operating limits under steady state conditions [2]. Maintaining converter bus voltage magnitude within operating limits under all conditions of operation of DC link is a major problem if the host AC system is weak. This problem calls for detailed investigation at the planning stage of DC link. To overcome the problem of voltage instability in AC-DC systems, two remedial measures have been proposed. These are (i) to adopt alternative control strategy for converter control, or (ii) to use a static var system (SVS) at

converter bus. In a two terminal DC link, normally rectifier will be on current control and the inverter on constant extinction angle (CEA) control. The CEA control has the advantages of minimum voltage ratings and losses in the converter valves and minimum reactive power requirements. However, the major disadvantage of CEA control is the negative resistance characteristics of inverter as seen from rectifier terminals. Weaker the AC system at the inverter, more pronounced will be the negative resistance characteristics. Few of the novel inverter control strategies mentioned in literature are: (i) constant AC voltage control, (ii) a constant DC voltage control, (iii) constant reactive current control, (iv) constant reactive power control. Some of these control techniques have already been implemented in some of the existing systems. Alternatively, a well designed SVS installed at converter bus can alleviate voltage instability. The effectiveness of current or power modulation in a DC link reduced as the AC system connected to the inverter becomes weak. This is due to the fact that the DC current modulation at the rectifier is accompanied by inadvertent and counteracting modulation of the DC voltage at the inverter which is caused by the variation of the AC voltage magnitude. In the case of synchronous HVDC link, the modulation of DC link power can be partially offset by the accompanying modulation current in the parallel AC link when the SCRs at both rectifier and inverter are low. One of the techniques suggested for improving the effectiveness of the power modulation in DC link is to introduce gama modulation with control signal derived from the inverter bus AC voltage. In general, in a two terminal HVDC, link the auxiliary controllers can be employed along with the converter controller at both terminals in order to modulate alpha at the rectifier and gama at the inverter. It is to be expected that two auxiliary controllers give a better performance than a single controller. Power modulation is also beneficial with asynchronous HVDC links in damping electro-mechanical oscillations in the associated AC systems. Here, the bus frequency signal (derived from rectifier and inverter bus) can be used individually instead of a difference signal which is used in synchronous HVDC links. The objective of this thesis are: (i) To investigate in depth the steady state and dynamic voltage instability problem in AC-DC systems in both two terminal and multi-terminal DC (MTDC) systems. (ii) To investigate the effectiveness of power modulation and damping control in synchronous and asynchronous HVDC links connected to weak AC systems. The voltage instability problem can be analyzed (i) using only algebraic equations, (ii) using dynamic equations. In both cases the equations are linearized around an operating point. The dynamic analysis is more comprehensive and stability can be judged by the location of the eigenvalues of the linearized system. Although appearing to be simplistic, the steady state analysis can provide a fast and reasonably accurate method for identifying potential voltage instability problems. Yoshida [3] has used a simple dynamic analysis employing Routh-Hurwitz criterism for a two terminal HVDC link with CEA control at the inverter. However, the analysis considers only the earlier proportional type and not the present day proportional-integral (P-I) type controllers. Also the novel inverter controller and SVS controllers have not been considered. Recently Hammed et al [4] have presented a new approach for the steady state analysis at inverter bus of a two terminal HVDC link. They define a criterism for voltage instability based on the computation of Voltage Stability Factor (VSF). This is used to investigate the performance of a novel inverter controller based on AC voltage regulation. However, this analysis has not been extended for alternate inverter controllers and MTDC systems. While there are several papers for the design of auxiliary controllers for power modulation in HVDC link, a detailed study of the alpha and/or gama modulation in synchronous and asynchronous HVDC links connected to weak AC systems has not been reported. The major contributions of the research work are as follows. (i) A novel and basic approach for the dynamic analysis of voltage instability problem in HVDC-AC systems using a block diagram retaining the identity of individual converter controllers. By defining a set of constants (analogous to

Heffron-Philips constants) that depend on the operating conditions and system parameters, the concept of voltage stability are clarified. (ii) A detailed and comparative study of the voltage instability at the inverter bus (of a two terminal HVDC link) with different converter controls and static var system control. (iii) Generalization of the concept of voltage stability factors for the analysis of voltage stability of MTDC systems. (iv) The investigation of rectifier current and inverter gama modulation in two terminal synchronous links in improving the damping of electro-mechanical oscillations. Different control signals derived from the frequency, generator rotor velocity and converter bus AC voltage are considered. The effectiveness of the modulation as a function of the network impedance is studied. The outline of the work reported in the thesis is given below: (i) In the first chapter, some of the problems of concern for operation of high voltage direct current links in weak AC systems are discussed. Power modulation is presented. The scope and objectives of the thesis are outlined along with the chapter-wise summary of work reported in the thesis. (ii) In the second state analysis, rectifier is assumed to be either on constant current control or on constant power control. The concept of the voltage stability factor [4] defined at the inverter bus is used for stability study of system with different operating conditions. The operating point is changed either by changing the power transmitted by the DC link at a fixed SCR at converters or by changing the inverter SCR when DC link is transferring the rated power. The influence of AC system impedance angle on voltage stability is investigated. In dynamic voltage stability analysis, the system is represented by a bloc diagram retaining the identify of converter controllers. The block diagram constants are evaluated at different operating points obtained by varying the AC system impedance magnitude on the inverter side. The rectifier is assumed to be on constant control. The DC link is considered to be fully loaded as this condition presents worst situation as far as the voltage stability is concerned. Two different converter control structures are considered in the analysis. These are (i) Proportional-Integral (P-I) controllers with a compensator and (ii) Proportional-Controller. The dynamic equations of the system are derived in terms of block diagram constants and the system state matrix is obtained. Eigenvalue analysis is employed for stability characterization of system. The effects of converter control parameters, SCR on inverter side and dynamics of a synchronous generator on inverter side are presented with the help of a case study. In the last part of this chapter a comparison is made between steady state and dynamic voltage stability analysis by deriving the system transfer function in terms of block diagram constants. 3. Chapter three deals with dynamic voltage stability analysis of asynchronous DC link with novel inverter controls. In this, constant AC voltage control, constant DC voltage control and constant reactive current control at the inverter are considered. The system representation using the block diagram given in Chapter 2 is considered for the analysis. The controller structure is assumed to be P-I type for rectifier current controller and inverter controllers. The DC link is assumed to be at its rated and the operating point is changed by changing the SCR on inverter side. The state equations are derived in terms of block diagram constants and the state matrix is obtained. Eigenvalue is used for voltage stability study of the system. The influence of AC system strength on rectifier side, AC system strength on inverter side and control parameters on voltage stability characteristics of the system are investigated. A static var system of fixed capacitor-tyristor controlled reactor (FC-TCR) configuration is considered at inverter AC bus to study its influence on voltage stability of the system. In this case, the inverter is assumed to be on constant extinction angle control. The VSF is computed as the steady state value of the transfer function between AC voltage magnitude and the reactive power injection at the inverter bus. 4. In chapter four, steady state voltage stability analysis of multi-terminal DC systems is considered. A general formulation for the steady state voltage stability analysis of n-terminal DC systems is presented by defining a matrix VSF with self and mutual terms. A two terminal HVDC link is a particular case in the above formulation. Of

the n-terminals of a MTDC system, any one terminal can be selected as voltage setting terminal (VST). The following control strategies are considered at the voltage setting terminal. Constant (i) AC voltage control, (ii) DC voltage control, (iii) extinction angle control, (iv) reactive current control, (v) reactive power control and (vi) power factor control. All other (n-1) terminals are considered to be either on (a) constant current control, or (b) constant power control. The analysis is illustrated by taking up examples of (i) a two terminal link and (ii) a four terminal system. The effect of choice of VST, control strategy adopted at VST and control strategy employed at other terminals on voltage stability characteristics of the system are investigated. 5. Rectifier current and/or gama modulation of two terminal synchronous and asynchronous links in influencing system stable region of operation and damping of synchronous generator rotor oscillations are discussed in chapter five. In the case of asynchronous HVDC link, the synchronous generator is considered on the inverter side. The following signals are considered for the gama modulation of the inverter: (i) inverter bus AC voltage and (ii) bus angle of inverter bus. The generator on the inverter side is represented by a detailed model with a fast acting automatic voltage regulator. The influence of the control parameters, choice of modulating signal and AC system strength on inverter side in damping of rotor mode oscillation and the system stability are presented with the help of a case study. In the case of synchronous link, the generator on rectifier side is modeled in detail. The parallel AC tie is assumed to carry a power equal to the rated power of DC link. On the inverter side, the SCR is variable and the source is of infinite capacity. The DC link is steady state is assumed to carry its rated load. The modulation of rectifier current only and simultaneous modulation of current and gama are considered. The external control signals considered are, for rectifier: generator rotor velocity and bus frequency and for inverter: inverter bus AC voltage. The results of a case study are presented to illustrate the effects of various parameters on the damping of the rotor mode and system stability. In both the cases, the converter control parameters are selected based on eigenvalue analysis and time response studies. 6. The last and the concluding chapter gives a brief review of the general conclusions based on the study results and major contributions of the thesis. Suggestion for further research work are also presented.

For more details click here   Back

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Abstract

This thesis is concerned with algebraic structure and applications of Galois switching functions (GSFs). GSFs are a generalization of binary switching functions (Boolean functions) with domain and range assuming values from finite (Galois) fields GF(p k) a nd GF(p n) respectively, where p is a prime and integer k is not necessarily equal to integer n. the treatment of GSFs in this thesis is confined to the practically important case of p = 2. although GSFs are of interest in a wide range of areas such as swit ching systems, error control coding, cryptography and image processing applications of GSFs considered in this thesis are restricted to the areas of characterization classification and synthesis of switching functions, and error control coding. Switching functions over finite fields have been studied by several authors. However, only few results are available on algebraic structures and properties of these functions. This aspect of GSFs is emphasized in this thesis and properties of signals representable by GSFs are studied in an algebraic framework. Advantages of spectral characterization of discrete signals and systems defined over finite index sets are well known. Specifically, discrete Fourier transform (DFT) over finite fields has been employed exten sively in error control coding for characterization of codes. However, the utility of DFT is restricted to those signal lengths that are relatively prime to the characteristic of the finite field. One solution to this problem is to impose alternative struc tures on the index set of signals under consideration so that a finite field transform which can accommodate signal lengths that are not relatively prime to the characteristic of the field, can be defined on them. One such structure is that of a cyclic mon oid. The algebra of discrete signals whose index set has the structure of a cyclic monoid is called a cyclic monoid algebra. GSFs qualify to be members of a multiplicative cyclic monoid algebra M(2 k) of dimension 2 k . the nonzero elements of index sets of GSFs constitute a multiplicative cyclic group of order 2 k -1. however, the multiplicative inverse of the '0' element of the index set is not defined, thus giving rise to the structure of cyclic monoids to the index sets. The two binary operations in the cyc lic monoid algebra are pointwise addition and an appropriately defined convolution. The cyclic monoid algebra is isomorphic to a residue class polynomials algebra over an appropriate finite field extension. The two binary operations in this algebra are pol ynomial addition and polynomial multiplication modulo (kx 2 - x). the isomorphism between these two algebras is a finite field transform, called Galois Transform (GT), which transforms convolution in the function domain to pointwise multip lication in the spectral domain. This transform is essentially an extension of DFT over finite fields, thus making it possible for conjugacy relations in the case of the latter to be extended to the former. Polynomials representing GSFs under this isomorph ism (transform) are called Galois polynomials (GPs). It follows that the coefficients of the GP representing a GSF are the GT coefficients of the signal vector over GF(2 n) of length 2 k . if the transform vectors lie in an extension field of GF(2 n), then the GP representing a GSF is shown to have remarkable properties which provide a means for their realization through parallel processing techniques. This is because conjugacy relations permit the terms in the GP to be grouped into disjoint Frobenius cyclies w hich can be realized independently. Since computation of Frobenius sum in a Frobenius cycle involves repeated squaring of an element in that cycle, the efficiency of computations can be increased by exploiting normal basis (NB) representation of finite fi eld elements as squaring of an element represented in NB amounts to mere cyclic shift of the components of its Cartesian representation with respect to that basis. A class of functions where the theory of GSFs can be immediately applied is the class of k -variable Boolean functions (BFs), since they are a subclass of the general class of GSFs, where

the mapping is from GF(2 k) to GF(2). It is shown that any k - variable BF has a Frobenius polynomial (FP) representation, ie., its GP coefficients satisfy conjuga cy constraints, allowing the terms in its GP representation to be grouped into Frobenius cycles. A study of the BFs as members of a monoid algebra over GF(2) is carried out, and standard classes of BFs like the linear and β-self dual (SD) / anti self dual (ASD) BFs are characterized in the transform domain. Spectral domain study of linear Boolean functions (LBFs) reveals the fact that they are ideals in monoid algebras over GF(2). This result is then applied to the class of generalized Reed - Muller (GRM) cod es to show that they can also be described by ideal structures in appropriate monoid algebras over GF(2), as they are constructe from LBFs. Although transform domain studies on β- SD/ASD BFs do not show any specific algebraic structures in moniod algebra, the transform coefficients are shown to satisfy certain constraints which help in their identification. Characterization of β- SD/ASD BFs for 2, 3 and 4 variables is carried out in terms of their GP coefficients and constraints on the coefficients are deriv ed. Classification problem of BFs is considered and the existing equivalence relations for classification of BFs (commonly known as the five invariance operations) and their effect on the coefficients of GPs representing BFs are studied, as a consequence of which a class identification procedure for 2 and 3 variable BFs by verification of their GP coefficients is formulated and a finite model which synthesizes and BF of a class from a prototype function of that class is proposed. Alternately, an attempt is made to see whether certain operations connected with the monoid algebra model of BFs would be suitable for classification purposes of the same. The case of 2 and 3 variable BFs is examined and it is shown that each of these classes have members from diff erent ideals in appropriate monoid algebras. A finite field model for BF synthesis, which sums up elements from ideals, is propsed. This is a Frobenius sum computer which can make use of NB for implementation purposes. Traditional transform domain charact erization of linear block codes adopts the practice of representing individual code vectors in the spectral domain by finite field DFT techniques. But, as pointed out earlier, this is not possible for all code lengths since DFT of all lengths does not exis t in the finite field case. A possible way to over come this limitation is to regard linear block codes as mappings from the k - tuple vector space to the n - tuple vector space and view them as signals over multiplicative cyclic monoids M(2 k) which assume val ues from a finite field GF(2 n), thus making all linear block codes amenable to transform domain studies, and allowing them to be characterized by single variable Gps over an appropriate extension field. It is shown that any linear (n,k) block code is a lin earized GSF (LGSF) which represents a one – to one mapping, and that the linearized Galois polynomial (LGP) representing this mapping has, in general, k coefficients belonging to GF(2 L), where L = L.C.M. of n and k. these LGPs representing linear mappings constitute a subclass of the general class of GPs. Depending on whether conjugacy relations among the LGP coefficients are non trivial or trivial, the corresponding polynomials are called linearized Frobenius polynomials (LFPs) and linearized polynomials (LPs) respectively. The fact that any one to one linear mapping is representable by a LGSF admits the possibility of any general linear mapping, which is not necessarily one to one, also, to be represented by a LGSF. Thus a study of the general class of L GSFs which also includes those which represent linear block codes as a subclass, is taken up and an isomorphism between linear (n,k) transformations (linear transformations from the k - tuple vector space to the n - tuple vector space where k is not necessaril y equal to n) and LGSFs represented by LGPs over GF(2 L), is established. It is further shown that the class of LGSFs constitutes an ideal in the corresponding monoid algebra over GF(2 n), out of which the subclass of LGSFs representing one to one mapping s (and hence linear (n,k) block codes) have LGP representations whose coefficients satisfy certain nonzero determinant property. Classes of LGSFs are studied in terms of the nature of the mappings generated by them. The algebra of LGPs is studied with s pecific reference to linear block codes in terms of an operation of composition known as symbolic multiplication of LGPs. The class of LGSFs represented by single terms LGPs is examined in detail. It is shown that any single term LGP representing a linear (n,k) transformation, where k divides n, always represents a one to one mapping and hence a linear (n,k) block code. Groups of single term LGPs are shown to have the structure of finite fields isomorphic to GF(2 n) with the operations of additions and symbo lic multiplication. Coefficients of a LGP representing a linear block code are obtained from the basis vectors of the code. Consequently, there are as many LGP representations of a linear block code as

the number of ways a basis can be chosen for the same . Thus given two LGPs which are known to represent linear block codes, it would be desirable to know whether they represent the same code or different codes. Results in this direction are achieved for codes generated by single term LGPs which are members o f the finite fields mentioned earlier. A study of distinctness of the codes in these fields is conducted and the number of distinct codes in each field is computed. It is shown that when n and k are relatively prime, all the codes in the respective finite field are distinct. A study of the roots of LGPs representing linear (n,k) block codes is conducted next. It is observed that the roots of LGPs need not necessarily belong to the same field. Further, it is shown that they characterize groups of codes rath er than individual codes. It is also shown that they cannot assume nonzero values from GF(2 k). Standard basis and normal basis LGP representations of cyclic codes are derived from a canonic form of their basis vectors. It is shown that for some (n,k) cyc lic codes whose k divides n, the NB LGP representation is simply a q - polynomial over GF (q), ie., a LGP with coefficients from the ground field (if the ground field under consideration is GF (p), then the LGP is denoted as p - polynomial). Standard array d ecoding problem of linear block codes is considered. Since the standard array is essentially a two dimensional (2 - D) truth table, it has been possible to compactly represent standard arrays using 2 -D GSFs, on lines similar to those for representing the usu al one – dimensional (1 - D) truth tables as 1 - D GSFs. It is shown that a wide variety of options are open for both 1 - D and 2 - D GSF implementation of standard array decodes depending on whether the received vector is to be decoded into a k - tuple message vecto r or an n - tuple code vector. It is shown that any 1 - D GSF which maps the received vector into a k -tuple message can be implemented by a Frobenius sum computer and hence NB representation and parallel processing techniques can be used to advantage in such situations for fast decoding of linear block codes. GP representation of syndromes is considered and it is pointed out that any syndrome table has a linearized Frobenius polynomial (LFP) representation, ie., a LGP whose coefficients satisfy conjugacy constr aints. In general, the roots of these polynomials belong to an extension field of GF(2 n). however, those roots which lie in GF(2 n) are shown to be the code vectors of the corresponding linear block code. Possibility of characterizing linear block codes by the roots of appropriate LGPs leads to an alternate characterization of linear block codes by means of syndrome polynomials (SPs). A SP is a LP degree 2 k over GF(2 n) whose roots are non repetitive and constitute the code vectors of a linear (n,k) block code. They represent special types of LGSFs characterizing many to one linear mappings from GF(2 n) to GF(2 n) of a particular kind: these mappings are such that any element of GF(2 n) which is a member of a given k - dimensional subspace of GF(2 n) gets ma pped into the '0' element of GF(2 n) whereas any other element which is not a member of that subspace gets mapped into a member of an (n - k) dimensional subsapce of GF(2 n) which constitutes the root space of another SP called its dual polynomial which also represents a similar mapping. In other words, every SP of degree 2 k has associated with it a k - dimensional subspace as its root space and an (n - k) dimensional subspace as its range space which constitutes the root space of a dual SP of degree 2 n - k and vi ce versa. Except the fact that the roots of a LP have the structure of a subspace, very few results are available on these polynomials (SPs) as far as characterization of the subspaces are considered. An investigation of properties of SPs is carried out an d it has yielded fruitful results. It is shown that any LP in x of degree 2 k over GF(2 n) with the coefficient of x nonzero, and which divides x 2n – x, uniquely characterize a linear (n,k) block code; the code vectors being the roots of the polynomial. Usin g this property of LPs and the associated duals, it is proved that SPs can be used for decoding of linear block codes which they represent as root spaces. It is shown that they in fact can be used for computation of syndromes of the respective codes, thus accounting for the name SP, the syndromes being members from the root space of the dual SP. Thus these syndromes are n - tuples in contrast to the syndromes usually associated with a standard array, which are (n - k) tuples. Reference to representations of fi nite field elements with respect to NB so far has been from the point of view of certain implementational advantages. Their role in the characterization and study of linear block codes using SPs has turned out to be even more significant. SPs represnting l inear block codes whose code vectors are considered as

elements with respect to some NB of GF(2 n) have been called normal basis syndrome polynomials (NB SPs). Such representations are noteworthy because of the following facts: First, it is shown that it is possible to identify codes of the same weight distribution from their NB SPs. Secondly, NB SP representation helps in the characterization of t - cyclic codes (quasi - cyclic codes which are closed under t cyclic shifts, t ≥ 1>. Specifically, it is shown that any linear (n,k) t - cyclic code has a NB SP representation whose coefficient belong to a subfield GF(2 n) of GF(2 n), and conversely, any SP with coefficients from GF(2 t), which divides nx 2 - x, represents a t - cyclic code. The th ird fact which goes in favour of NB representation follows from the second. For t=1, we get the characterization of the important class of cyclic codes which has a NB SP representation in the form of a p - polynomial. A different proof of this result on cycl ic codes is also which to emphasize the fact that a cyclic subsapce has the structure of a modulus when represented with respect to a NB. The dual of the SP of any linear block code, in general does not represent the SP of the corresponding dual code. Howe ver, in the case of cyclic codes represented in NB, the dual polynomials and the SP repreessneting the dual cyclic code are shown to be the same. This follows from the theory of p - polynomials where conventional polynomials arithmetic and symbolic aritheme tric are related through the notion of q - associaties. The NB p - polynomial representation of a cyclic code is easily derivable from the generator polynomials of its dual cyclic code and is shown to be equal to the linearized q - associate of the same. The fi nal point in favour of NB representation is a new approach to the study of weight distribution of cyclic codes. This is based on factorizing their NB p - polynomial representation. An algorithms for factorizing polynomials over finite fields, based on DFT over finite fields, is developed. This algorithm is particularly efficient if there are no repetitive roots and if the field in which the roots lie are known; both of these conditions are satisfied by a SP. It is shown that the number of cycles in a cyclic code is equal to the number of irreducible polynomials in the factorization of its NB p - polynomials, the number of members in each cycle is equal to the degree of each irreducible polynomial in the factorization and a cycle represntative of the code is gi ven by a representative root of each irreducible polynomial. Examples of NB p - polynomial representations. Self dual (n,k) cyclic codes are characterized in terms of their NB p - polynomial representations and it is shown that these polynomials split in GF(2 k), as a consequence of which the study of their weight distributions reduces to finding the number of Frobenius classes in GF(2 k), the order of each Frobenius class, and the weight of a representative member of each class expressed in NB Cartesian form i n GF(2 n) . this respectively gives the number of cycles in the code, number of members in each cycle, and information about its weight distribution.

For more details click here   Back

Title   *:*   *Wireless VLF/ELF Mine Communication*
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Abstract

Communication between personnel on the ground surface and people working in under ground mine is very important for normal operational work as well as for emergency rescue operations. Cables are prone to get damaged in the event of a mine disaster. A wireless communication system which can transmit and receive signals through the earth region over the underground mine area plays a crucial role for rescue operations. Normal radio frequency electromagnetic (EM) waves get attenuated very rapidly in the earth medium while every low frequency EM wave can propagate sufficient distance with moderate power requirement. The makes VLF/ELF systems attractive for mine communications. For transmitting voice or other signals from the surface of the earth to underground mining area, a wire loop antenna may be laid on the earth surface. The loop should be sufficiently large to cover a wide mine area. In such a case thee may be considerable variation of current distribution in the loop. A receiver operation at VLF/ELF is subjected to atmospheric noise which is very much impulsive in nature. Besides various machineries used in mining operations introduce strong interfering signals which adversely effects the receiver performance. The objective of this thesis is (a) to analyse loop antennas on the earth surface, and (b) to study performance of PSK receivers in mine environment. A brief description of the work follows. Chapter 1 gives a brief account of the work in the areas of wire antennas for through the earth wireless communications, and performance study of receivers in mine environment. Chapter 2 describes the derivation of vector (magnetic) and scalar potential due to a horizontal current element radiating over the lossy earth. Fourier transform technique has been used for obtaining integral representation for the magnetic vector potential. The magnetic vector potential has both horizontal and vertical components. By applying larentz gauge to the vector potential, the scalar potential for a charge doublet is obtained from which scalar potential for a point charge associated with the current element is derived. Both the vector and the scalar potentials are represented as Summerfield type integrals. The horizontal components of vector potential for the special case of the source and the observations point being located on the air/earth interface has been obtained in a closed form. This component of the vector potential and the scalar potential due to a point charge are the necessary potentials for analyzing wire antennas on the earth surface. Chapter 3, describes the formulation of the antenna problem. A mixed potential integral equations formulation has been employed. The scalar potential does not lend to a closed form representations we have used a quasi static approach to obtain a closed form expression for the scalar potential. The method of moments has been used for obtaining current distribution in the loop antenna. From the current distribution in the surface loop the field inside the earth has been computed. Chapter 4 describes the derivation of a closed form expression for the self impedance of a circular loop antenna on the earth surface by considering an uniform current distribution for the whole loop. Neumann's formula which is usually used for inductance computation has been suitable modified for the computation of the self impedance. In chapter 5 a method has been presented for studying performance of PSK

receivers in atmospheric noise which contains an impulse-like component superimposed on a homogeneous background. This noise has been modeled as a two component random process. One component is Gaussian in nature which represents the background noise. The other component is assumed to be a stationary poisson arrival process of pure impulses. A conventional PSK receiver can not perform satisfactorily in presence of strong interfering signals which may be generated from different machineries. The effectiveness of spread spectrum receiver for such situation has been studied by considering an interfering tone at the carrier frequency in addition to atmospheric noise.

For more details click here   Back

Title   : *Study Of Signals And Systems In The Framework Of Morkov's Constructive Mathematical Logic*
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Roll No   : *8410464*
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Abstract

This thesis is concerned with the problem of formulating within the framework of Markov's constructive mathematical logic, certain structural concepts of a theory for signals and systems defined over monoids of finite alphabets. Markov's normal algorithms play a dominant role in this theory. The central idea on which the work reported in this thesis is based is that of treating a signal space as a free monoid of a an alphabet, and a system as normal algorithm over the alphabet. With signals treated as works from a specific alphabet A, our first step is to consider the realization of various signal processing operations in terms of string manipulating normal algorithms. The signal space in this context is a subset of the free monoid, Aˇ, of A (i.e., the monoid consisting of all possible finite words from the alphabet A, together with the associative binary operation by concatenation of words). A normal algorithm N over a given alphabet A is in essence a mapping that recognizes a subset X of words in Aˇ and maps in onto another subset Y of words in Aˇ. With the subsets X and Y treated respectively as input and output signal spaces, our next step is to examine on the lines of the theory of formal languages, the signal processing normal algorithms as rewriting systems described by a grammar and then as automata. The third step in our work is concerned with the formulation of a theory for the study of signals and systems in the framework of Markov's constructive mathematical logic. The constructive logic introduced by Markov is built on a hierarchy of languages (ßα), whose main constituents are alphabets, words and normal algorithms. Here the term theory refers to a set of constructive logical sentences written in a particular language belonging to this hierarchy (ßα). We introduce in this thesis a theory consisting of five constructive logical sentences in addition to those of the axioms of monoids, for which the class of signal processing normal algorithms constitutes a model that we refer as C , we present two clusters of results, one pertaining to its first order properties and another pertaining to its higher order properties. The notion of a first order property of a normal algorithmic signal processing system belonging to the model C is defined here as a property that is expressible by a constructive logical sentence in which no normal algorithm is quantified. This notion is analogous to that of a first order property of a classical algebraic system. For a classical algebraic system A, a characterization theorem due to Lyndon states that if P is a first order property then P is preserved in a homomorphic image of A if and only if P is expressible by a positive sentence of the first order predicate calculus. In this thesis we present an analogous characterization theorem of the Lyndon type in the framework of the languages of (ßα). According to this theorem a first order property P of a normal algorithmic signal processing system is preserved in a homomorphic image of the system if and only if P is

described by a constructive logical sentence that does not contain the negation symbol. In the classical system theory certain properties like continuity and connectedness are called high order properties because they cannot be described by sentences of the first order predicate calculus. Analogously the notion of a higher order property of the model C refers to a property that cannot be described by a constructive logical sentence without quantifying one or more normal algorithms. In the classical sense higher order system properties are usually studied with the help of various concepts of general topology. In the case of C however, these topological notions are not very appropriate to use because of the fact that they are primarily meant for infinite spaces whereas the basic spaces of our concern in the study of the model C are finite. We find that it is more appropriate in our case to use Hammer's extended topology. Following Hammer, we introduce the concept of constructive extended filters and discuss their relationships with normal algorithms. The major result of the thesis maybe summarized as follows: (i) With signals represented as words from certain finite alphabets consisting of non-numerical symbols we demonstrate a technique by which some of the traditional signal processing operations such as cyclic shifting and linear convolution could be implemented in terms of string manipulating normal algorithms. Further with signal processing operations in mind we propose a particular basis set of elementary substitution formulas using any normal algorithm can be constructed. (ii) Fitting has outlined a string manipulation language EFS(str(L)) based on the notion of Elementary formal system (EFS) due to smullyan. On the same lines, we present another string manipulations languages EFS(spl(A)) which is suitable for signal processing purposes. In this context we show that a signal processing operation which is realized by means of a system of normal algorithms, could also be realized by a system of procedures in EFS(spl(A)). Further, with signals treated as languages of a free monoid we introduce a grammar called M-grammar that finitely specifies potentially infinite subsets (languages) of the free monoid. This M-grammar formalizes a specific type of rewriting system for normal algorithms just as the phrase structure grammar of the Chomsky hierarchy does for Turing machines. A rewriting system corresponding to a Turing machine consists of a finite set of letter-to-letter substitutions of semi-thue type that operate on post words. Similarly we replace every word-to-word substitution formula of a normal algorithms by a finite set of letter-to-letter semi-Thue substitutions that operate on post word of specific kind. Since the resulting system of semi-Thue substitutions is essentially a post-Turing rewriting system obtained from end justified substitution formulas of the normal algorithm, we have chosen to call it end justified post-Turing (EPT) rewriting system. Using the notion of EPT rewriting system we outline a procedure for the realization of normal algorithms by Turing machines and of Turing machines by normal algorithms. (iii) The notions of automata and codes are closely associated with each other in the sense that a subset of a free monoid is not only known as a language, but also as a code and the finite state machine which recognizes it is known as an automaton. With this in mind we show that the transcriptions i.e. the coded forms of normal algorithms are strings consisting of words from a thin biprefix code set X = O‖ÆO, which is a a subset of the free monoid Ao˘, where Ao = (O 1). In addition we introduce a special class of automata termed as cyclic normal automata that characterize EPT rewriting systems. Our study of automata in this connection has led us to formulate the principle of normalization of automata as an alternative version of Markov's principle of normalization of algorithms. (iv) In the framework of a constructive logic which is built on the system of languages (ßα) we present a constructive theory Th(K) for the structural study of signals and systems. Th(K) consists of five constructive logical sentences. The first sentence is a version of Markov's principle of constructive choice. The second sentence states that if a signal processing

algorithm is applicable to a signal representation then the process of applying the normal algorithm terminates. The third sentence describes the functional equivalence between two signal processing normal algorithms having identical input-output relationships. The fourth sentence is about the admissibility of the operation of composition of normal algorithms and the fifth is about the admissibility of their union. These five sentences together describe the essential characteristics of a class of normal algorithmic signal processing systems belonging to the model CK. Within the theory Th(K), we establish a homomorphism theorem analogous to one given by Lyndon for classical systems. Let us consider two signal processing system K1 and K2 belonging to the model CK, and let $\Delta 1$ and $\Delta 2$ denote the two sets of constructive sentences corresponding to first order properties of the two systems respectively. Further, let LF denote the set of constructive sentences of $\Delta 1 \cap \Delta 2$ that do not contain negation. Then our homomorphism theorem asserts that every constructive sentence in LF that holds for K1 also holds in K2. (v) For the study of the model CK, we formulate the notion of a constructive extended filter analogous to that of a extended filter given by Hammer. Hammer's work deals with classical sets whereas we are concerned with constructive sets. A point to note here is that the concept of a set is not unique in constructive mathematics for it depends on the languages chosen from (ßα) to interpret the concept. Following Shanin we interpret the notion of a constructive set in the following manner: a set is decided by a property and a set property is described by a special type of formula known as one-parameter formula from a languages of (ßα). We outline procedures for constructing two specific types of normal algorithms, where a normal algorithm of the first type decides the normal algorithms, where a normal algorithm of the first type decides the membership of an element with reference to a given set property and a normal algorithm of the second type eliminates duplication of elements in the set. normal algorithms of these two types are conjointly represented as a word from a specific alphabet. The transcription of this word in association with the one parameter formula that describes the set property is viewed here as a constructive set. based on this notion of a constructive set we describe a technique of formulating different types of extended filters over constructive sets. We show that a normal algorithm over an alphabet A is an ordered sequence of pairs of extended filter bases over a set of words from A. normal algorithms are thus seen to have a direct relevance in all potential applications of Hammer's topological techniques in signal processing. Erlandson has defined the following measures for between two filters. The same measures are redefined here in terms of normal algorithmic operators mapping a metric lattices of extended filters over a constructive set into the metric space of constructive real numbers

For more details click here   Back

Title : *Investigation of Symmetry in Multi-phase Systems, etc Consequences and Analysis*
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Abstract

The power system network, which consists of three balanced sub-networks, viz. generation sub-network, transmission sub-network and distribution sub-network, possesses certain special kinds of symmetries. This is true not only of three-phase conventional power system networks but also of multi-phase (order of phase higher than three) networks in general. The symmetries involved are rotational and reflection symmetries in space and translational symmetry in time (or phase advances).The study of symmetry in three-phase and multi-phase electrical machines and group theoretic techniques dealing with them help us to develop general methods for simplifying their analysis. The group theoretic technique have been extensively used in the past to study the implications of symmetry in molecular structures, atomic spectra, symmetric physical structures, waveguide junctions and linear networks and systems. However, the importance of these techniques has so far not been recognized in the area of electric machines analysis. This is perhaps best exemplified by the fact that the symmetrical, Clark's and Park's components at present are regarded as three independent transformations whose derivations make use of the machine symmetries only implicitly. As shown in this thesis, these transformations are in fact members of a general family of transformations for multi-phase 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 dynamic equations of electric machines possessing symmetries can be put into a diagonal or atleast a block diagonal form so that the original machine network can be replaced by a set of smaller disjoint sub-networks whose analysis is considerably simpler. There are in all three different aspects of analysis considered here,i) steady state and transient analysis of three-phasesynchronous machines ii) steady state and transient analysis of six-phase(multi-phase) synchronous machines iii) steady state and transient analysis of three-phaseinduction machines.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 and transient analysis of three-phase electric machines but also for multi-phase electric machines. Multi-phase power system are also examined in detail in this thesis because of increasing the demand of electrical energy.The multi-phase transmission system has the advantage of acquiring new rights-of-way efficiently and effectively. The general feasibility of multi-phase lines has been investigated and the six-phase line appears to be more suitable than the other multi-phase lines. The feasibility studies of six-phase line obtained by converting double circuit three-phase lines are also reported to have been

carried out.The various elements of six-phase systems for the purpose of steady state analysis have been mathematically represented. The model of six-phase sychrronous machines in phaser co-ordinates is reported for the analysis under balanced as well as under unbalanced conditions.The mathematical model of three-phase/six-phase transformers with different primary and secondary connections with and without leakage impedances are available in the literature, and based upon these models, the three-phase and the single-phase equivalent of a six-phase transmission line integrated with two three-phase/six-phase transformers have been developed.It is not only the multi-phase transmission (HPOT) system, but also the six-phase (multi-phase) synchronous machines have been examined for higher rating, employing different types of stator winding arrangements since a long time. The steady state analysis of six-phase machine is reported to have been studied with the help of an orthogonal transformation, derived using group theoretic techniques exploiting the symmetry of six-phase synchronous machines which is named Park's transformation for six-phase machine.Although, a considerable amount of work on multiphase transmission and generation system has been reported in the literature, yet the other aspects of investigations, such as dynamic and transient stability study including modelling for the purpose of such studies have not been under taken in detail so far. These aspects have been dealt in detail in the present work.The salient features of the work reported in the thesis are as follows s1. examine/investigate symmetry inherent in 3-phase synchronous machines and using group theoretic technique, develop the Park's transformation from the fundamental and extend this feature to the multi-phase synchronous machine in order to obtain the generalized Park's component transformation 2. develop, exploiting symmetry and using group theory, orthogonal transformations viz. symmetrical component and Park's component transformation for 3-phase induction machines, using different basis of representation3. develop a detailed dynamical modelling of a six-phase synchronous machine4. investigate the dynamic stability of a six-phase synchronous machine and its comparision with that of three-phase machine5. investigate in detail the load flow, transient stability and dynamic stability with a view to examine the performance of mixed 3-phase and 6-phase systems and completely six-phase systems, with that of the conventional three-phase system; and,6. develop mathematical representations for various multiphase elements, such as n-phase synchronous machine, 3-phase/n-phase transformer, n-phase transmission lines, ■of power system networks under steady state conditions.A brief account of the work reported in the thesis is presented in the following paragraphs.The symmetry inherent in three-phase synchronous machine has been discussed. This symmetry can be observed from the coefficient matrices of the machine dynamic equations which possess rotational symmetry in space in addition to translation one in time, i.e. skew or screw symmetry. Based upon the symmetry considerations, and using the group theoretic techniques, linear power invariant real transformation similar to Park's transformation for three-phase synchronous machine has been developed. And considering the rotational symmetry alone, with the help of representation theory, linear power invariant, complex transformation similar to symmetrical component of three-phase synchronous machine, has been also developed.The symmetry in six-phase (multi-phase) synchronous machine has also been investigated. This type of symmetry is named screw symmetry or six-axes screw symmetry [C,j2-n;/6] which satisfy the space group axioms. The translation group is also discussed, and with the help of the Brillovin zone and time reversal theory, the irreducible representations of the group [C, j2tc/6] has been derived. Based upon these symmetry, a linear power invariant, real transformation similar to Park's transformation for six-phase synchronous machine has been derived.The symmetry in three-phase induction machine also has been discussed. Two transformations for three-phase induction machine has been derived using group theoretic techniques, depending on the winding being stationary or moving as in one case the resolution angles are time

invariant and in the other case it is time dependent. These transformations are Clarke's and Park's transformation for induction machines.Also the difference between the Park's transformation for induction and synchronous machines has been clearified with the help of the magnetic properties of symmetrical polyphase winding and time sequence reference.The dynamical equations of a six-phase synchronous machine have been developed with the help of the orthogonal Park's transformation. Starting with the inductance calculations of the machine right from the fundamental. Further, a linearized model in terms of current variables has also been developed.The load flow study has been carried out to investigate the impact of converting double circuit three-phase lines to single circuit six-phase or twelve-phase lines under two voltage conditions, namely l) when the phase to ground voltages of the multi-phase line and the double circuit three-phase line are equal and 2) when the phase to ground voltage of the multi-phase line is f3 times that of the double circuit three-phase lines. The single-phase representation of a n-phase transmission line connected via two 3-phase/n-phase transformers has been obtained on the same base quantities as three-phase transmission line.The dynamic stability of a sample network for its different system configurations and voltage conditions has been investigated employing eigenvalue technique based on a linearized model. The two-axi model and the classical model of the synchronous machine have been used. The performance of a mixed 3-phase and 6-phase system also with 12-phase with different system loading has been compared to that of a completely three-phase system.Also, the dynamic stability of a completely six-phase and twelve-phase system has been examined with the same system loadings as the conventional three-phase system and also with the increased system loadings.The direct and the quadrature axis transient and sub-transient inductances of a six-phase (multi-phase) synchronous machine have been calculated from the fundamental. The various time constants of a six-phase synchronous machine have also been obtained. The transient stability investigation has been carried out on another sample network for the various system configurations and voltage conditions. In this analysis, the synchronous machine is represented as a constant voltage source behind a direct-axis transient reactance, and the loads as constant impedance. The mixed 3-phase and 6-phase system, and a completely six-phase system have been investigated and compared with conventional three-phase system from the transient stability point of view.

For more details click here   Back

Title : ***Transform Domain Study Of Cyclic And Abelian Codes Over Residue Class Integer Rings***
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Abstract

Linear block codes for error control have been widely studied over the last four decadesunder the assumption that the symbols to be transmitted have the structure of finite field.This assumption restricts the size of the alphabet to a power of a prime number. Forarbitrary alphabet size an appropriate mathematical structure to consider is the class ofresidue class integral rings Zm. Several have investigated linear block codes over Zm. Likethe case of codes over finite fields most of these studied have considered only thespecial class of linear cyclic over Zm. Very few results are available for the generalclass of Asbelian codes over Zm. Studies for the class of linear cyclic codes over Zm havecomprise of; (I) derivation of cyclic codes over Zm, for m equal to a product of distinctprimes from cyclic codes over finite fields (ii) derivation of parity check matrices forcodes over Zm analogous to parity check matrices of hamming and Reed

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For more details click here   Back

Title : ***Effect Of Morphology And Mineralogy On Compressibility Of Sands***

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Supervisor(s) : ***Yudhbir& Gokhale K V G K***

Abstract

Mechanical behaviour of a granular material is controlled by its constituent particle characteristics. The particle size, gradation, shape and angularity together with the relative density play an important role in the deformation characteristics of sands. Although classification of a sand fro engineering purposes is based on the size attributes the presence of mineral constituents with compositional differences such as quartz, feldspar, mica and carbonates results in significant changes in the engineering behaviour of the system. While the importance of all these parameters in understanding the behaviour of granular material has been recognized earlier, adequate attention has not been bestowed to study in detail the influence of all these parameters on the system behaviour. Further not enough attempts have been made to quantify some of these aspects. There is also a need to study the particle modification at low stress levels prior to particle crushing especially with reference to the liquefaction potential of sands. Available literature on this aspect is scanty. In the present study an attempt has been made to investigate all these aspects. Three natural sands of differing mineral composition and an artificially prepared quartz sand were chosen. In addition six more samples have also been prepared using these four sands through size fractionation, mineral separation and selective mixing. Seven samples of sands as obtained from RPI New York were also used in the study. All these samples have been characterized in terms of their sphericity shape factor and angularity. The quantification of particle shape has been achieved using these three parameters. Compressibility tests were carried out for the ten samples under differing relative density conditions and varying stress levels. A scheme for classification of sands on the basis of compressibility was evolved using the results from the present study and test data available from different sources in the literature. For the different classes of compressibility as proposed in the present work, studies on constrained modulus (M) have enabled the estimation of coefficients in the constrained modulus expression. In addition the modification in particle size and shape have been systematically monitored for specimens subject to compression. The stress levels within which the particle modification takes place for different sands, prior to crushing have been established. Role of particle size, angularity, shape relative density and mineral composition on compressibility constrained modulus, modification and crushing has been established. Predictions of cone penetration resistance (q_C) for sand of different compressibility on the basis of results in the present study and available theoretical models (Janbu 1974) are shown to be in complete agreement with the trends reported. The work contained in the thesis has been organized into six chapter. In chapter one, the topic has been introduced and the scope of the present study has been outlined. The available literature on the characterization of shape of particles, its influence on stress strain dilatancy behaviour, compressibility characteristics, and mechanism of grain modification as well as crushing under different stress conditions has been reviewed in chapter two. The materials and methods involved are described in detail in chapter three. The four sands (Ganga, Calcareous, Kalpi and Standard samples) have been characterized for their mineralogical composition using X-ray diffraction. Particle shape analysis has been carried out using in image analyzer system. Details of this equipment and procedures of measurements are presented in this chapter. The various expressions used for the quantification of particle shape such as sphericity shape factor and angularity are explained. Sample preparation and the test procedure for compression test has also been outlined. Chapter four deals with the experimental data concerning mineralogical composition, physical character-

is tics, morphology compressibility and crushing. While the Ganga sand is composed of quartz (60-65%), feldspar (20-25%) and mica (8 to 10%) with minor amount (upto about 3%) of chlorite and kaolonite kalpi sand has calcite upto around 18% with quartz and feldspar in equal proportion (40% each) together with minor quantity of mica (upto 2%). The calcareous sand has carbonate upto 95% with subordinate quartz (upto 5%). Aragonite and calcite are the main minerals. The standard sand is a pure quartz sand. Grain size distribution and morphological characteristics for all these sands have been presented. Data on compressibility for dry sands with loose and dense relative densities were obtained upto a confining pressure of 176.32 kg/cm2 and deformation characteristics are presented. Grain size distribution for sand samples on completion of compression tests are contrasted with the original gradation. In chapter five, the test data obtained are interpreted in terms of various operative parameters and the details are presented on morphological classification and role of grain modification and crushing on compressibility and constrained modulus. The role of mineralogical composition in the behaviour of sand under stress has also been brought out. Interrelationships between various parameters used for the description of surface characteristics are established. It has been brought out that for the classification of sands in addition to the usual tests (emax, e, emin, grain size distribution etc). Shape and angularity characteristics of sand grains should also be evaluated and this has been accomplished using a technique proposed in the present study. It is shown that based on grain size, shape angularity mineralogy gradation and relative density natural sands experience particle degradation to a varying degree under stress. On the basis of particle gradation characteristics before and after compression, an expressions for total potential for particle degradation as related to d50 has been established. It has also been brought out that there exists a critical stress level at which the grain modification of an alluvial sand is initiated. This stress is much less that the stress level required for actual grain crushing. It has been indicated that critical stress value is of the order of 8-9 kg/cm2 for Ganga and calcareous sands whereas it is around 16 kg/cm2 for Kalpi sand; the standard sand showing no modification at all even upto stress level of 176 kg/cm2. It has been indicated that the compressibility of sands is strongly controlled among other factors by mineralogy and angularity. At a low stress level, the stress-strain behviour of sands with significant amount of mica and or carbonates is mainly governed by grain inter-locking. At high stresses the stressstrain behaviour is significantly different from that at low stress due to grain modification and crushing. Depending on mineral composition, particle size shape angularity and gradation, grouping of sands into three broad categories sands of low moderate and high compressibility has been propose don the basis of their compressibility characteristics. The power laws governing variation of constrained modulus with effective confining stress and relative density as reported in the literature, tacitly assume that the sand remains unchanged during loading to high stress. It has been established in the present study that particle modification and crushing at high stress level (grater than the critical stress) influence the stress strain behviour of sand. Hence these power laws are strictly applicable for stress levels less than the critical stress. The power laws of the type proposed by belotti et al. (1985) between qc and effective stress as well as M and effective stress, for a given relative density has been observed to be strongly controlled by the compressibility of sands. The coefficients in these power laws have been quantitatively correlated with grain mineralogy and angularity. The predicated trends for qc are in agreement with those reported by Robertson et al. (1983). Based on these relationships for qc and M, the value of α=qc/M is shown to vary between 3 and 11 as generally reported. The conclusions arrived at on the basis of the present study are highlighted in chapter six.

For more details click here   Back

Title   :   *Digital Protection Of EHV/UHV Transmission Lines*
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Abstract

The phenomenal growth in size and complexity of modern power system and economic considerations, necessity the location of large generating stations in remote areas, thus indispensability the emergence of EHV /UHV transmission lines, and their interconnect ions fro bulk power transfer over long distances. For the successful operation, the primary and basic objective of all power system is to maintain a high level of continuity of service at normal operating condition and when intolerable condition occurs, to minimize the outage time. The security reliability, durability and the stability of power system network greatly depend on how fast and efficiently the fault can be cleared. Though the EHV /UHV lines are capable to transfer the bulk power, any type of fau lts, which may occur on them, are considered as major problem to the system transient stability. If the faults persist for a longer time, the whole power system network may endanger the system security. High speed fault clearance is an effective method of improving system transient stability and increasing its power transfer capability. The fault clearing time is dependent upon the speed of protective relay as well that of the circuit breaker and with the development of ultra high speed (UHS) circuit break er, the need for developing UHS protective relay has become utmost essential. It is feasible to obtain UHS protective relay for the protection of EHV /UHV transmission lines with the exploration of traveling wave phenomena. The development of digital comp uter has real thrust for great innovations in transmission line relaying. In 1969, Rockefeller proposed a hypothetical centralized digital computer system for the protection of all the equipments in power system. Since then, more and more digital computer based software oriented relaying schemes are being developed. The used of digital computer for relaying purposes, permitted several distinct advantages such as desired flexibility sophistication, accuracy and also its self checking ability. However, the ap plications of digital computers for relaying purposes was restricted due to the high cost of digital computers. With the advent of micro processor and mini computer which are cost effective and highly flexible in nature, tremendous attention has been rende red towards their applications in protection schemes. A micro processor based relay has its applications for almost all the components of power system network such as m/c's, transformers. Bus bars and EHV /UHV lines etc. the further research and the develo pment work in micro processor technology, makes it possible to develop digital protection on the basis of new principles. The relaying schemes reported for the protection of transmission lines can be broadly classified into two major categories viz: the d istance relaying schemes and traveling wave relaying schemes. In recent years, the search for the improved performance of the transmission lines protection schemes,

has led to the development of new ideas based on the traveling wave principle. In 1976, th e first traveling wave relay was proposed and developed by ASEA (Sweden) and was installed on Bonneville Power Administration (USA). Since then, a number of traveling wave relaying schemes have been proposed. Almost all of these schemes necessitate the use of fast communication channel between and terminals for the detection of faults. Therefore, there is a need for a traveling wave based relaying scheme which is directional in nature and which can detect on internal fault without the aid of carrier communi cation channel so that operating time of the carrier communication equipment is automatically eliminated and which also incorporate a simple fault locating feature. The recent attention has been towards the development of traveling wave based relaying sch emes for the protection of EHV /UHV long heavily lines on account of fact that high frequency electromagnetic transients contained in the post fault waveforms during the short interval time after the occurrence of fault can be used for relaying purposes. F or this purpose, an accurate computation of the relaying quantities during a very short interval of time immediately after the occurrence of fault is essential. Modeling of the power system network for this purpose needs to consider the distributed paramet ers to describe the transient phenomena after fault initiation, the frequency dependency of the line parameters along with the nature of earth return, John and Aggarwal have developed techniques for the analysis of power system components during fault cond ition incorporating exact models of transmission lines. However, this could be applicable with ease, only to simple power system network. It is no longer necessary to suppress the fault generated transients by means of time consuming filtering. If the trav eling wave principle can be successfully used in the power system protective relaying, it would represent one of the ideal methods of protecting power system components. However, the detailed study of the literature available reveals, that most of the deve lopment of the traveling wave based relays reported so far are tested through computer simulation. Hence, there is a need for developing on line micro processor based relaying scheme based on traveling wave phenomena. The primary objectives of the thesis have been detailed in the following Para. 1. to realize any type of complex threshold characteristics for distance protection with micro processor based on line protection schemes. The relaying scheme has been designed, fabricated and tested in the lab for on line protection of EHV /UHV transmissions lines using the fundamental components. 2. to present a simple and an accurate model of EHV /UHV transmission lines and to develop fault analysis techniques incorporating frequency dependency phenomena of the transmission lines parameter in order to compute transients in complex multimode power system. 3. to develop UHS relays based on traveling wave phenomena and to implement this using on line micro processor which incorporate the important features of d etection of the direction of faults and which can also detect internal faults without the aid of any communications channels. 4.to proposed a method of estimating distance to the fault by using the traveling wave discriminant functions and their voltage a ngle of fault inception. The important features of the work reported in the thesis is organized in the following five chapters. Chapter 1 on introduction presents a brief and critical review of the important literature pertaining to the evaluation and dev elopment of protection relaying scheme

chronologically. Chapter 2 deals with an overview of some important aspects of distance and traveling wave algorithms. Chapter 3 presents a novel on line micro processor based relaying scheme, which has been designe d, developed and tested in the lab. It gives the mathematical theory along with the hardware and the software description. In Chapter 4 an accurate Pi model of transmission lines and frequency domain nodal formulation, suitable for the analysis of faulted multimode power system are developed. The fault analysis techniques are illustrated by computing the voltages and currents in time domain for symmetrical three phase and also for one phase to ground faults. The results are used later for the traveling wav e relaying scheme and these are incorporated with microprocessor based scheme to detect the direction of the fault for on line protection using three phase thyristorised fault simulator to simulate three phase and one phase to ground faults at various ince ption angles. Later, correlation technique is detect distance to the fault by computer simulation using the traveling wave forward and backward discriminant function. Finally, the thesis concludes with chapter 5, where, a brief review of the work carried out in this thesis and suggestion for further scope of work are given.

For more details click here   Back

Title   :   *Control Of Static VAR Systems For Improvement Of Dynamic Stability And Damping Of Torsional Oscillations*

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Abstract

With the growing requirement of transmitting bulk power to expanding load centres over restricted right of ways, the need for optimum utilization of existing transmission facilities is being increasingly recognized. The power transfer capability of long transmission lines is limited from both steady state and transient stability considerations. An inadequate level of available system damping may further aggravate the situation. The inherent ability of Static Var Systems (SVS) to provide rapid, continuously controllable reactive compensa tion in response to changing system conditions, has been shown to result in addi tion to many other advantages, an enhancement of these stability limits and increase in system damping. An SVS connected at the midpoint of a long transmission line and actuated by a control signal derived from terminal voltage improves the power transfer capability of the network [1,2]. Any method of design of SVS controller for this purpose must consider the appropriate model of SVS and the system. The knowledge of adequate system model is also essential for predicting the SVS performance. There is however not much literature available on the adequacy of these models. In literature, the reported models range from the most simplistic representations of both ac system and SVS [2] to a detailed representation of generator, transmission network and the SVS [3]. However, the effect of an individual component model on the integrated system performance is not clearly observed. A pure voltage control of SVS is often not adequate for the damping of power swings in the system. A significant contribution to system damping is achieved when auxiliary feedback is introduced in the SVS control system. This leads to a further improvement in the power carrying capability of the network. The signals which can be employed for supplementary control of SVS include deviations in rotor velocity, voltage angle, bus frequency, line active and reactive power or their derivatives. No detailed analysis is however available on the comparative effectiveness of different auxiliary signals which would enable the selection of a specific signal for enhancement of dynamic stability in a given application. Series compensation is an alternate means of enhancing power transmission on EHV systems, economically. Although, series capacitors exercise a positive influence on both the steady state and transient stability, they have been identi fied to cause torsional oscillations which may be negatively or lightly damped. These subsynchronous oscillations occur when the electrical resonant frequency set up between series capacitance and network inductance is in close vicinity or coincident with the complement of one of the torsional mode frequencies of the turbine-generator system. If uncontrolled, these oscillations may lead to severe generator shaft failures. There are several methods for mitigating the problem of torsional oscilla tions or subsynchronous resonance (SSR). Reactive power modulation using a TCR is one of the recently proposed and successfully implemented countermea-sures to this problem. A TCR connected at the generator terminals which modu lates its inductance in response to a signal derived from rotor

velocity is shown to damp all torsional SSR modes in the IEEE benchmark system [4]. The use of SVS at sites other than generator terminal for the same objective of control ling torsional oscillations alone, or possibly in conjunction with other objectives such as improvement of power transfer, has not been investigated. The analytical methods for the study of dynamic stability and subsynchro nous resonance in power systems due to series compensated lines are well esta blished. Analyses based on computation of eigenvalues of the system matrix and frequency scanning technique which utilize linearized system models, are widely employed. The use of damping torque method has been reported for the study of torsional interactions between turbine-generator and HVDC systems. For these investigations the network transients need to be modelled. The exten sion of this method for the evaluation of benefits of reactive power modulation for damping subsynchronous oscillations has not been reported. While linear models are used for analytical prediction of dynamic stability and design of controllers, validation using system simulation is usually necessary. This is because the actual systems are complex and nonlinear and phenomena such as harmonic generation by SVS is neglected in linearized analysis. The physical simulators such as TNA with appropriate models of generator and SVS are commonly used because of ease in real time simulation and as they provide an "unforgiving model" for testing new control concepts. The parity simulation concept is also attractive and has been used for designing a compact dc simula tor [5]. A successful attempt was made for development of parity simulation of a TCR. However, because of the large effort involved in putting together a system simulator, this work was discontinued. The objectives of this thesis are: i. to develop models and methods for the analysis of dynamic stability and performance of systems incorporating SVS for improving power transfer capability. ii. to study the improvement in dynamic stability through effective use of auxiliary SVS control. iii. to investigate into the combined application of both series and shunt compensation schemes wherein an SVS connected at the midpoint of a long transmission line is used both for improving the power transfer capabi lity and damping of torsional oscillations. iv. To examine the applicability of frequency domain methods (damping torque and frequency scanning) in evaluating the effectiveness of SVS control in damping subsynchronous frequency oscillations. v. To validate the analytical prediction of SVS performance using detailed (nonlinear) system simulation. In pursuance of these objectives the thesis has resulted in following major contributions : i 1) The influences of modelling SVS delays, Thyristor controlled reactor (TCR) transients, network transients, AVR and the generator on the dynamic stability of power systems incorporating SVS with pure voltage control, have been highlighted. An overall model is proposed which adequately describes the system performance for small signal perturbations. Even though this analysis is conducted for a specific system, the models developed and techniques employed are general enough to be applied to any system configuration. 2) The effectiveness of various control signals for reactive power modulation of an SVS installed at the midpoint of a long transmission line is investiga ted with the objective of damping low frequency oscillations which are critical in limiting power transfer. A new auxiliary signal is proposed which synthesizes the frequency of generator internal voltage from locally available bus voltage and transmission line current. It is found that this computed internal frequency (CIF) signal is far superior than any other conventional signal, in that, it allows full utilization of the network transmission capacity. 3) Supplementary control strategies have been developed employing which, a midpoint located SVS in a long series compensated line can be used to damp all the torsional oscillation modes in addition to enhancing the system dynamic stability. This is shown for two levels of series compensa tion: one, when the transmission line is compensated at a nominal level and the other at which a torsional mode is critically destabilized. 4) The methods of damping torque and frequency scanning analyses have been extended to examine the dynamic stability

of power systems compen sated by 5VS. 5) The analytical prediction of SVS performance as described in 1) is validated by tests on a physical simulator at Central Power Research Institute (CPRI), Bangalore. It is found that the analytical results match very well with those obtained on the simulator. An outline of the work reported in this thesis is given below. The first chapter introduces the various aspects studied and reviews in brief the literature available in this area. Chapter 2 is concerned with development of linearized models with varying levels of complexity for the different subsystems involved in an SVS compensated power system. The study system comprises a generator connected to infinite bus through a long distance transmission line which is compensated at its midpoint by an FC-TCR type static var system. The SVS which is assumed to operate on voltage control alone is modelled both with and without TCR transients to gether with an option to include various control system delays. The network representation also allows a choice of modelling the line transients. The generator model in its most simplified form is represented by a constant voltage source behind subtransient reactance. In the detailed form it is represented by a 6th order model including flux decay and AVR. The overall system model is developed by a systematic interconnection of different component models through appro priate interconnection variables. Different subsystem models are analyzed with respect to their effects on the region of stability in the SVS controller parameter plane, predicted values of power transfer limit and step response. Based on these studies an adequate system model is derived. The improvement in power transfer obtained with simple voltage control of SVS is exemplified. Chapter 3 deals with the analysis of auxiliary control of a midpoint located SVS for improvement of power transfer capability. For a prespecified auxiliary controller configuration various conventionally used supplementary signals such as voltage angle, bus frequency, line current and reactive power are examined with respect to their effectivenss in enhancing the power transfer limit. The system model derived in Chapter 2 is augmented to include SVS auxiliary control ler. As dynamic stability essentially relates to the low frequency rotor mode oscillations it seems natural to expect that a signal derived from generating source frequency would have a more beneficial impact on the stability limit. The frequency of internal voltage of the generator is therefore computed utilizing locally available voltage and line current and this synthesized CIF signal is fed to the auxiliary controller. It is shown from eigenvalue analysis that CIF signal is far superior than any other conventionally employed signal. The optimal values of auxiliary controller parameters are determined on the basis of root loci and power limits. For increasing the power transfer capability of a very long line (say, 1200 km), more than one appropriately located SVS will be required if no series compensation is used. A combination of series and shunt compensation is a tech nically viable solution where the series capacitor compensates for the line reac tance and SVS provides voltage support. In addition, by providing suitable auxiliary controller on SVS the torsional oscillations together with the low frequency rotor oscillations can also be damped. This concept is investigated in Chapter 4 to determine the best control strategy in attaining a stable high power transfer. The system model derived in Chapter 2 is modified to incorporate series capa citors and turbine mechanical system together with the auxiliary SVS controller. A simple lead-lag circuit configuration is assumed for this controller. Different auxiliary stabilizing signals, viz., bus frequency, line current, reactive power, CIF and a combination of reactive power and CIF are now investigated in respect of their ability to damp all the torsional modes. These studies are performed at a power transfer level which is much higher than that attainable with pure voltage control of SVS in the uncompensated case. It is observed that an auxiliary signal derived from line reactive power alone is sufficient to achieve the desired objective when transmission line is non-critically compensated. However, when the degree of compensation is such that one of the torsional modes is critically undamped, reactive power in conjunction with CIF is

successful in stabilizing all the torsional oscillation modes. Eigenvalue analysis is employed to predict the system stability. The design of auxiliary controller is based on a study of the loci of critical system eigenvalues. Chapter 5 reports on the use of two heuristic, though widely employed, frequency domain techniques for the prediction of dynamic stability of SVS compensated power systems in the subsynchronous frequency range. The damping torque method is applied to determine the electrical damping contributions of both uncompensated and series compensated systems. Damping torque is obtained as real part of the transfer function defining the change in electrical torque with respect to that in the generator rotor speed. The synchronizing torque component is also evaluated. In the frequency scanning method expressions are computed for the equivalent frequency dependent admittances of the genera ting unit and SVS using state space equations in D-Q variables. The mechanical shaft dynamics and induction generator effect are considered while calculating the admittance of generating unit. The system stability is assessed from the net equivalent admittance of the system as viewed from SVS terminals. While damping torque method is utilized to study both voltage and auxiliary control of SVS, frequency scanning method is employed to investigate the voltage control alone. The stability results obtained are compared with those of Chapters 3, 4 and the efficacy of these methods in determining stability of systems incorpora ting SVS, is examined. Chapter 6 is concerned with the simulation of static var systems using parity simulation technique and a physical simulator. The principle involved in parity simulation alongwith results for the simulation of a thyristor controlled reactor (TCR) using this technique, are described. The study system of Chapter 2 is finally simulated on the HVDC simulator at CPRI, Bangalore. The scaling procedure and the setting up of various system components such as infinite bus, synchronous generator, AVR, transformers, transmission lines, SVS on the simulator, are illustrated. Load flow studies are conducted for varying levels of generator power. SVS responses are obtained for a step change in the reference voltage input using different integrator gain (Ky) settings. Based on these studies the stability range of K is determined together with its optimal value which results in fastest response. The power transfer limits both with and without the optimized SVS are evaluated. It is found that the results obtained on HVDC simulator correlate well with those predicted from eigenvalue analysis and digital simulation based on linearized models in Chapter 2. The SVS performance is then studied for a single line to ground fault at the generator terminal and its expected behaviour is verified. Chapter 7 summarizes the conclusions derived from this thesis and indicates the possibilities for further work in this area. REFERENCES [1] J.D. Ainsworth, C.B. Cooper, E. Friedlander and H.L. Thanawala, "Long Distance AC Transmission Using Static Voltage Stabilizers and Switched Linear Reactors", CIGRE Paper 31-01, 1974. [2] H.E. Schweikardt, G. Romegialli and K. Reichert, "Closed Loop Control of Static VAR Sources (SVS) on EHV Transmission Lines", IEEE PES 1978 Winter Meeting, New York, Paper No A 78 135-6, Jan 29-Feb 3, 1978. [3] S.C. Kapoor, "Dynamic Stability of Long Transmission Systems with Static Compensators and Synchronous Machines", IEEE Trans, on PAS, Vol PAS-98, pp 124-134, Jan/Feb 1979. [4] N.C. Abi-Samra, R.F. Smith, T.E. McDermott and M.B. Chidester, "Analysis of Thyristor Controlled Shunt SSR Countermeasures", IEEE Trans, on PAS, Vol. PAS-104, pp 584-597, Msrch 1985. [5] R. Joetten, T. Wess, J. Wolters, H. Ring and B. Bjoernsson, "A New Real Time Simulator for Power System Studies", IEEE Trans, on PAS, Vol. PAS-104, pp 2604-2611, SepU 1985.

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Abstract

Forced-commutation techniques are now being applied to improve the performance of the conventional ac-dc converters. With this, better power factor at source side, less distortion of the line current and reduced ripple in the output current are achieved. However, the requirements of large number of auxiliary power devices and LC elements for the purpose of forced commutation of SCRs, make these converters heavy, expensive and less reliable. Recently the availability of Gate Turn OFF Thyristors (GTOs) with improved reliability and high ratings have made them attractive for use in PWM ac-dc converters. As a GTO requires no commutation arrangement in the power circuit and can be turned OFF by a negative gate signal, its use as a power device, in place of an SCR with forced commutation arrangement, greatly simplifies the converter configuration. In this thesis, new GTO based PWM ac-dc converters have been proposed and their detailed study is carried out. Following converter configurations have been considered: (i) A two quadrant PWM GTO converter. (ii) A four quadrant converter using a single PWM GTO converter with a static reversing switch. (iii) A PWM GTO dual converter. A number of PWM schemes for ac-dc converters are available in literature. To have a proper choice based on quantitative analysis, a comparative study is carried out as regares to performances offered at source as well as load side by various PWM schemes. Equal, triangular, stepped, sinusoidal and inverted sinusoidal PWM schemes have been considered fro the comparative study. Equal Pulse-Width Modulation (EPWM) scheme has been found to offer best over-all performances among these PWM schemes. Therefore, this has been employed in the proposed PWM ac-dc GTO converters. Kataoka et al [1] have described a GTO converter containing six GTOs and employing optimal PWM scheme. Firing/extinction angles are chosen such as to minimize one or more lower order harmonics. However, this requires more switching operations per ac cycle as compared to that with EPWM. The width of the output pulses is controlled to achieve output voltage variations. Therefore control to very low values of the output voltage is not possible as pulse-width can not be reduced to zero due to finite switching times of the GTO. An EPWM ac-dc converter which uses only three GTOs and three converter grade SCRs has been discussed by in a et al[2]. Control to almost zero output voltage is achieved by shifting the position of the pulses with respect to source voltage when minimum pulse-width is attained. However, in both of the above mentioned converters the smooth control of the output voltage is limited to only one quadrant. Firing pulses are to be resettled for a different gating sequence whenever the operation has to change from rectification to inversion or vice versa. An EPWM ac-dc GTO converter which offers smooth transfer of operation from rectification to inversion and vice-versa is proposed in this thesis. The converter contains six GTOs and makes use of a combination of pulse-width control and phase-angle control to achieve continuous and smooth control in the two quadrants. Unity fundamental power factor is maintained in most part of the control range. The

proposed GTO-converter has been analyzed, constructed and tested in the laboratory. In the EPWM ac-dc converters reported so far in the literature, half of the power switches having forced commutating capability are made to conduct several times in a cycle while the remaining half conduct only once during a cycle. This is an unsymmetrical type of gating and can also be implemented on the proposed converter. A symmetrical type of gating which is not reported so far is worked out to implement EPWM on the proposed GTO converter. This requires equal number of switching operations per cycle for all the GTOs in the converter. For the same number of output pulses per cycle, the total number of the switching operations per cycle required by the symmetrical gating are found to be less than that required by the unsymmetrical gating. Thus the symmetrical gating results into less switching losses and these losses are distributed uniformly among all the GTOs in the converter. A digital firing scheme which can produce both symmetrical as well as unsymmetrical gating patterns to implement EPWM is worked out. The control of firing/extinction angles is so designed that a linear relationship between the converter output voltage and control voltage is obtained. The proposed GTO converter feeding a separately excited dc motor load has been simulated on a digital computer taking also into account the presence of source inductance. The speed-torque characteristics are calculated and experimentally verified. Four quadrant operation of a separately excited dc motor requires a bi-directional armature current. But a single PWM GTO converter produces only unidirectional output current. A static reversing switch consisting of four converter grade SCRs can be used at its dc terminals to achieve operation in all the four quadrants. Functionally this is equivalent to a conventional non-circulating current dual converter. However, because of PWM control it offers better power factor at the source side, reduced ripple in the output current and very small discontinuous current conduction area on speed-torque plane as compared with the conventional non-circulating current dual converter where phase control is used. A closed loop speed control drive using such a four quadrant PWM GTO converter has been designed and tested in the laboratory. Current limiting features and back emf correction at the time of armature reconnection are incorporated in the closed loop scheme. Four quadrant operation may also be obtained by a dual converter which is a combination of two converters connected back to back. A new PWM GTO dual converter is proposed in this thesis. The firing pattern is such that no circulating current flows between the two converters when they are fired simultaneously. The load current has full freedom to flow through any one of the two converters at any moment hence the possibility of discontinuous conduction is not there. In addition, it offers good performance at source side as well as load side because PWM control is used. Compared to conventional circulating current converter, the proposed dual converter has a number of merits. The most important among them are absence of circulating current reactor, better power factor at source side, reduced ripple in the output current and higher efficiency due to absence of circulating current and circulating current reactor. A closed loop speed control scheme is designed with the proposed dual converter and tested for various speed change operations. The above mentioned four quadrant converters namely: (i) the single PWM GTO converter with a static reversing switch and (ii) the PWM GTO dual converter are compared. Their relative merits are brought out.

For more details click here   Back

Title : *Standard Cell Placement And Routing*
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Abstract

The acute need for automating the VLSI design process has led to the emergence of design methodologies that lend themselves to total automation, even at the cost of some overheads . The Standard Cell design methodology is one such, which is based on using 'cells' or certain predefined collection of logic functions. The hundreds of such cells that constitute of logic functions. The hundreds of such cells that constitute a VLSI circuit have got to be assigned to proper positions on the chip, and then interconnected according to circuit specifications. The former process is called Placement and the later Routing. The NP-completeness of the placement problem demands the use of heuristics; and we use here a heuristic for graph partitioning to efficiently identify clusters of modules which have strong interconnectivity. The inherent non convexity of the objective function chosen for partitioning (viz., the crossing count of wires across a plane between two groups of cells) leaves scope for a better solution. The placement improvement phase uses the total wire length as the objective function and can be called 'relaxation algorithm', because it relaxes one randomly chosen cell at a time and by constructing two 'force vectors' , identifies the best location for it. The process is repeated for a small number of randomly chosen cells. The algorithms work in $0(n2)$ time. Next, the number of feed through required per row determined and placed. A net list, or a net based description of the circuit interconnectivity is used for routing. The aim here is to minimize the number of tracks. Nets which do not have any overlap and which do not have any constraints from other nets are placed first, and as many such nets as possible are packed into a single track. Two layer wiring is used and vias are placed at points where a transition occurs from one plane to another.

For more details click here   Back

Title : *Direct Stability Evaluation And On-Line Dynamic Security Asstssment Of Power Systems Using Structure Preserving Energy Functions*

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Abstract

Successful operation of modern interconnected power systems depends largely on itsability to maintain stability during the transients. Transient stability evaluation assumestherefore greater significance in the planning design assumes therefore greatersignificance in the planning design and operation of large-scale powder systems. Powersystem stability is in essence single concept; but for the purpose of analysis it is classifiedas transient; but stability and steady state stability .The former refer s to the stability ofthe system under large disturbances such as faults on transmission network. Steady statestability refers to the ability of the system to remain in synchronism under smallperturbations caused by random changes in the load. System security may be considered as the ability of a power system in normal state toundergo a disturbance without going into emergency condition .The static securityassessment is widely used in modern energy control centers to predict the system securitywhen subjected to a set of contingencies. It is assumed here that the system remain sstable following a contingency. This assumption is relaxed inn considering dynamicsecurity. While the objectives and methodologies of dynamic security assessment are yetto be clearly defined there is a general consensus that the system model is similar to thatused in transient stability studies just as static security assessment employs models usedin load flow studies. The transient stability analysis deals with nonlinear mathematical models describingthe dynamic behabiour of the system. Digital simulation involving explicit evaluation ofswing curves is a versatile tool for stability assessment but the method is time consumingand hence unsuitable for on-line applications. Direct methods based transient energycalculations are recognized to be useful as screening tools in evaluating critical situationsin the system .The transient energy margin (TEM) which is defined as the differencebetween the critical energy and the energy at the clearing time has been suggested as anindex for checking the stability of system following a disturbance. This index also servesto indicate the severity of the disturbance. The energy-integral criterion first proposed by Aylett was later generalized in the use ofLyaspunov functions by a number of researchers. The application of the Lyapunovmethod for transient analysis lead to conservative results in the computation of theregions of stability. Later efforts using the energy in the certain of inertia (COI)variables and the concept of controlling unstable equilibrium point (u.e. p) have removedmuch of the conservativeness of the results. Approximations in evaluating the up's andthe application of the Potential Energy Boundary Surface (PEBS) technique havesimplified the computation of stability regions. Hi therto the application of direct methods using energy functions is based onreduced model of the system eliminating load buses. This is possible for constantimpedance type loads. Devin if such a load representation is accurate it will be desirableto preserve the structure of the network for on-line dynamic security assessment .Therecent work on the structure preserving energy function (SPEF) (defined on structurepreserving models) has removed this limitation and made it possible to consideredarbitrary voltage dependent load model [1-3]. The problem of transfer conductance

isalso overcome by the use of structure preserving models. Some attempts have been madeto include detailed models. Some attempts have been made to include detailed machinemodels [4] where the results are conservative. While the concept of SPEF is undoubtedly appealing its application to on-line dynamicsecurity assessment requires further developments. First of the computationalrequirements with nonlinear load models are much more than with reduced models. Thiscan be a severe limitation for on-line applications. Secondary there is a need to improvethe system models used. Finally the user must have the tools for the stability evaluation(both in planning and operation) that can be readily used for large systems. Another drawback of the present state of direct methods is the problem of accuratedetermination of the critical energy. While the PEBS method has overcome thecomputation of u.e.p, the energy accuracy of the method in multi-machine system isgoverned by the fact that not all the kinetic energy (even with respect to center of inertia)is responsible for system separation .The kinetic energy that is responsible for the systemseperararation depends on the mode of instability and can be approximately calculatedbased on heuristic arguments [5]. However and exact deveration of the energy function tobe used in such cases is not available in the literature. This thesis is aimed at trying to overcome some of the limitations mentioned above.Specifically the objectives are:1) Incorporation of the computation of SPEF in transient stability program tosimplify the stability evaluation.2) Development of methods and efficient algorithms for the fast and accurateevaluation of transient stability of power system thereby making the applicationof direct methods to on-line dynamic security analysis much more promising.3) Development of SPEF for more realistic power system models for the evaluationof system stability. The major contribution of the thesis are listed below:i) An existing simulation program [6] modified to include thecomputation of SPEF. The use of SPEF can speed up the calculation ofcritical clearing time (Tcr) or the stability limit thereby avoiding thetime consuming simulation runs. Both classical and detail Ed machinemodels alongwith voltage dependent loads are used in the computationof SPEF.ii) A new SPEF is derived considering the mode of instability where asingle group of machines separate from the rest. This energy functionfrom the previously derived energy function [3] in the kinetic energyterm. The new energy function gives more accurate results.iii) Utilising the information on the mode of instability an algorithm ispresented to speed up the computation of TEM by solving algebraicequations. This procedure eliminates the need for determining thefaulted trajectory and can make the on-line assessment of dynamicsecurity using the energy function much more attractive.iv) A SPEF is derived to include the resistance of transmission lineswhich ha not been done so far. Derivation is based on the assumptionthat conductance to susceptance ratios (G/B) of all the networkelements are equal which permits network to be transferred into a lossless network [7]. This assumption is not found to be restricting as thenumerical examples show that the use of an average value for G/Bgives reasonably accurate.]v) A new SPEF is derived with realistic model of generators consideringwinding on the quadratureais. This is an extension of the workreported in [4]. However the energy function derived here is constanton the post-fault trajectory with the time derivative as zero. This leadsto more accurate results than that reported in [4] in the computation ofstability region using PEBS method. A simplified and general methodfore the calculation of SPEF is also presented where the use ofclassical model becomes a special case The following is An outline ofthe work reported in this thesis;1) Chapter 1 introduce the various aspects of energy based direct methods forstability analysis of power systems and the application of these methods toon-line dynamic security assessment .The state of the are in this area ispresented and the scope and objective of the thesis are outlined alongwiththe chapter wise summary.2) Chapter 2 deals with the modification of a dynamic simulation programby pod more [6] to include the computation of SPEF .The existing programprovides time domain simulation of reduced powder system networks. It iswritten in

Fortran and is composed of a main routine and a number ofsubroutines beside two supporting programs for base load flow andnetwork reduction eliminating the load buses. The following modificationsare incorporated in the existing program to develop the new transientstability program: A The structure of the original network is retained to enable arbitrary voltage loadrepresentation. This is done byi) Replacing the supporting program for network reduction by theprogram YMAT to construct the network bus admittancematrix.ii) Modifying the subroutine NWSOL used for the networksolution to include voltage dependent nonlinear loads. B. The program is augmented to compute SPEF. Adding two new subroutinesdoes this:i) PFSOL for solving the post-fault network equations at the end of eachintegrating step to obtain voltages and their angles at all the buses to beused in the computation of the energy function. Internal voltage of thegenerators to be used in the network solution is the same as that obtained bythe integration of the machine equations.ii) TEF to evaluate the SPOEF and its components for each time step of thenetwork solution. The modified program can thus handle the power system stability problem using I) timedomain simulation and ii) direct assessment via the SPEF .The analysis of the programoutput during the faulted can be used to predict the critical energy and the criticalclearing time. After the initial development the transient stability program was testedwith three realistic power system examples. The validation test confirms s that directsmethods provides results comparables to that of simulation. 3) Chapter 3 ids devoted to the systematic development of a mathematical modelfor the direct stability evaluation of multimachine power system based on theassumptions that I) instability results from a single machine or a group of machineseparating from the rest and ii) the generators in each groups swing together .A newenergy function is then derived and it is shown that the function has a time derivativewhich is zero. Structure preserving model of the system is used and the classical modelrepresents the generators. Loads are modeled as arbitrary functions of respective busvoltage .The system equation s and the energy is evaluated using are formulated in COIvariables. Critical energy function is formulated in COI variables. Critical energy isevaluated using the PEBS method .The procedure has been applied to three systemexamples considering in Chapter 2. The resulting indicate that I) the inclusion of themode of instability in the energy function gives consistently a better estimate of thecritical clearing time compared to that obtained using the energy function of ref. [3]which does not considerate mode of instability and ii) the effect of voltage dependentaction power loads on the region of stability is quite significant and thus cannot beignored. The voltage dependent active power loads introduce path dependent terms inthe energy function, which is computed by numerical integration using trapezoidal rule.4) A efficient method for assessing the dynamic security of power systems on-line basedon the concept of TEM is presented in Chapter 4 .The system model and the energyfunction of Chapter 3 are again used for the development of the method. A deterministicestimation of the transient energy margin involves the computation of the energy functionI) at criticality and ii) at clearing. It is shown that for a given mode of instability (as described in Chapter 3) thepotential energy reduces to a function of single independent variable corresponding to therotor angle (s) of then machine (s) going out-of-step with respect to the remainingmachines. It is also shown that the critical and the clearing energies can be obtained bythe solution of algebraic equations thereby completely eliminating the simulation of thefaulted system. This leads to a substantial reduction in the computation required forstability evaluation using SPEF. The proposed method is illustrated buy considering the three system examples givenin Chapters 2 and 3 .The predicted value of the critical energy and that at clearing are inclose agreement with those obtained using the faulted trajectory simulation .The proposedmethod can also be used for accurate ranking of the contingencies as illustrated in 1O-machine system example.5) Structure preserving energy functions have so far been developed withoutaccounting for the transmission line

resistances. An attempt is made in Chapter 5TO develop a valid energy function including the line resistances .The method isbased on a network property which states tat a network having the same G/B ratiofor all its elements is equivalents to a loss less network with a new set of powerinjection [7] .The use of the proposed energy function illustrated with numericalexamples. Results indicate that I) inclusion of line resistances improves transientstability in terms of a larger region of stability and a higher of critical declaringtime and ii) predicted critical clearing time obtained using the average value ofG/B for the network elements compares well that obtained by digital simulationusing the actual resistance of these elements .The components of the energyfunction accounting for the transmission line resistances is path dependent and isevaluated by trapezoidal rule. 6) The principal aim of Chapter 6 is to extend the work reported in ref. [4]considering more detailed models of the generators. The topological energy function ofref. considering the same model as in [4], a new SPEF is developed the time derivative ofwhich is zero. Moreover this model is improved upon by the addition of a damperwinding on the quadrate axis and a new energy function is derived winding on thequadrate axis and a new energy function is derived .The time derivative of the energyfunction is again shown to be zero. Simpler expression for the energy function is thanderived thereby increasing the speed of calculation. Investigations are carried out on a 4-machine and 10-machine system examples. Critical clearing times obtained by directmethod and by simulation are compared and are found to be in close agreement. Theresults shows that i) the variation of the field and the generator voltages havepredominant effects on the system energy during a transient and ii) the inclusion oftransient saliency AVR and damper winding is beneficial in improving the transientstability. 7) A brief review of the major contributions of this thesis And the suggestion forfurther work from the seventh and the concluding chapter.

For more details click here   Back

*Title   : **Finite Dconvolution Data Recovery Schems For Block Data Communication Over Dispersive Channels***

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*Supervisor(s) : **Siddiqui M U***

Abstract

Studied several data recovery (DR) schemes for block data transmission (BDT) over finite impulse response channels in the presence of noise. With the aim of understanding various the detail and schemes methods like maximum likelihood decision feedback and least squares the deconvolution of various DR schemes two criteria for good channel are considered namely maximum minimum distance channels and maximum dista nce channels maximum distance channels. The maximum likelihood recursive deconvolution algorithm (ML - RDA) is derived based on Mitters lemma. It has been shown that the recursive algorithm reduces to the Gaussion elimination algorithm if the data values are assumed to be real variables. It has been shown that the recursive algorithm if the data values are assumed to be real squares (LS) solution and the conventional discrete Fourier transfer (DFT) approach are particular cases of square conventional discrete Fourier transfer (DFT) approach are particular cases of square completions of the channel convolution matrix. The performance of some computer simulation and the performance of curves given for a wide range of block lengths and typical channel examples. B DT has been shown to limit error propagation to almost a block length in the worst care and to provide better trade - off between performance processing complexity and data rate.

For more details click here   Back

Title : *Optimal Control Systems Design With Vector-Valued Performance Index*
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Abstract

Ever since Zadeh proposed the use of vector-valued performance index as a performance criterion m optimal control theory in 1963 attempts have been made to define and evaluate vector-valued performance indices suitable for the design of optimal control systems A general performance index defined as the sum of the pth power of the deviations of the k perfor mance index elements from their ideal values which represents a class of distance functions has been in existence since early 1970s The performance index so defined forms a metric in the k-dimensional performance index space for each value of the performance index parameter p varying from one to infinity Xll Minimisation of the performance index defined yields a class of non-inferior systems corresponding to a class of compromise solutions The possibility of choosing one solution out of the class of solutions provides the possibility of using the vector-valued perform nee index as a flexible design criterion The use of vector-valued performance index in the design of optimal control systems however remained unexplored due to the nonavailability of 1 a general method for the evaluation of the vector-valued performance index for any value of p and 2 a basis for choosing a particular value of p to select the appropriate system out of a class of non-inferior systems The objective of this thesis is to overcome these two difficulties In order to make the evaluation of the vector-valued per formance index considered amenable to a solution a set of weighting constants has been defined in a manner such that the minimisation of the vector-valued performance index becomes equivalent to the minimisation of a linear combination of its elements The method of evaluation presented avoids the difficult task of selecting the weighting constants m advance and computes instead the weighting constants corresponding to Xlll each value of the performance index parameter p This offers no complexity for larger values of p and computes the compro mise solutions for all finite values of p with equal ease A method has also been presented for computing the compromise solution for p = «> representing an end point of the class It has also been shown that for many problems this solution can be obtained analytically and/or graphically These two methods together compute the entire class of compromise solutions A method has been presented to select a single system out of the set of non-infexior systems corresponding to the class of compromise solutions choosing an appropriate value of the performance index parameter p It has been shown that by making the choice of the performance index parameter p dependent on one of the k performance index elements of the vector-valued performance index the performance index can be made a flexible criterion for the design of optimal control systems The method for the computation of compromise solutions for values of p other than infinity has been simplified for XIV two classes of control problems (1) the steady-state regulator problem and (2) the parameter optimisation problem for which close form methods for optimisation are available Numerical examples have been included to demonstrate the applicability of the vector-valued performance index m the design of optimal control systems

For more details click here   Back

Title : *Multi Phase (II-PHASE) Systems: Dynamical Modelling And Analysis*
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Abstract

The local area demand of electric energy was previously met by a locally constructed generating station known as urban system. However, gradually the power stations with higher capacity were installed which have been supplying the electric energy covering a wider area. Steadily with the installation of bigger plants, such as superhydel and super thermal plants near the source of energy for economic considerations, the electric energy is now being transmitted to the load centers far off from the generating stations. Thus the problem of electric utilities has been to transmit large amount of power economically and efficiently. Although the solution to this problem has been achieved to some extent by increasing the transmission voltage which ensures greater economy reduced losses and improved regulation yet the three-phase transmission system at the increased transmission voltage, for example, at EHV/UHV levels, presents certain drawbacks, such as difficulty in acquiring new rights-of-way, high surface voltage gradient on conductors, strong electric field on the ground surface with possible biological effects, increased audible noise and radio interference, switching surge over voltages which cause problem to air gap insulation, problem in insulation co-ordination, increased short-circuit currents and possibility of Ferro-resonance conditions. Because of these factors increasing the transmission voltage seems to have also reached a point of saturation. Further, HVDC transmission emerged as an alternative which has some advantages, such as increased stability limit, lower losses and costs than the equivalent a.c. lines; it has the advantage of its use as an asynchronous connections which does not raise the fault level appreciably, and it can also be used as a link between a.c. system having different frequencies. But, it has some disadvantages too, namely higher terminal costs, introduction of harmonics resulting in greater losses and communication interference, and also difficulties in providing adequate protection scheme. The other alternative may be multi-phase i.e. high-phase order transmission (HPOT) systems. The concept of the multi-phase system was initiated during the year 1972 and various studies have been conducted and reported since then. The multi-phase transmission system has the advantage of acquiring new rights-of-way efficiently and effectively. The general feasibility of multi-phase lines has been investigated and the six-phase line appears to be more suitable than the other multi-phase lines. The feasibility studies of six-phase line obtained by converting double-circuit three-phase lines are also reported to have been carried out. The installation and the field testing of some experimental six-phase and twelve-phase lines are reported to have been undertaken. The over voltages and insulation requirements for six-phase lines have also been studied. The various elements of six-phase system for the purpose of steady-state analysis have been mathematically represented. The model

of six-phase synchronous machines in phaser co-ordinates is reported for the analysis under balanced as well as under unbalanced condition. The mathematical model of three-phase/six-phase transformers with different primary and secondary connections with and without leakage impedances are available in the literature and based upon these models, the three-phase and the single-phase equivalents of a six-phase transmission line integrated with two three-phase/six-phase transformers have been developed. The load flow study is reported to have been carried out on mixed 3-phase and six-phase, and completely six-phase systems under balanced as well as under unbalanced conditions. The impact of converting double-circuit 3-phase lines to single-circuit six-phase lines at the same line to line (i.e. adjacent phase) voltage on the load flow performance has been investigated. It has been concluded from these studies that, the mixed three-phase and six-phase system and a completely six-phase system have the advantage of better voltage magnitude, improved phase angle and increased efficiency even for the higher system loadings than that of the conventional three-phase systems. The short circuit analysis an important study for the purpose of designing protection scheme, is reported to have been carried out in order to investigate the effect of six-phase line in comparison to double-circuit three-phase lines with equal line to line (i.e. adjacent phase) voltage, by deriving appropriate six-phase transformations, such as symmetrical component transformation and Clarke's component transformation. It is not only the multi-phase transmission (high phase order transmission i.e. HPOT) system, but also the six-phase (multi-phase) synchronous machines have been examined for higher rating employing different types of stator winding arrangements since a long time. The steady state analysis of a six-phase machine is reported to have been studied with the help of an orthogonal transformation conceptualizing it as a combination of two sets of Park's transformation. Although a considerable amount of work on the multi-phase transmission and generation system has been reported in the literature, yet the other aspects of investigation, such as transient and dynamic stability studies including modeling for the purpose of such studies have not been undertaken in detail so far. These aspects have been dealt in detail in the present work. The salient features of the work reported in the thesis are as follows: 1. to develop a detailed dynamical modeling of a six-phase synchronous machine; 2. to develop mathematical representations for various multi-phase (n-phase) elements, such n-phase synchronous machine, 3-phase/n-phase transformers, n-phase transmission lines, of power system networks for steady-state condition; 3. to investigate the dynamic stability of a six-phase synchronous machine and its comparison with that of three-phase machine; and 4. to investigate in detail the load flow, transient stability and dynamic stability with a view to examine the performance of mixed-phase 3-phse and 6-phase systems and completely six-phase systems, with that of conventional three-phase system. A brief account of the work reported in the thesis is presented in the following paragraphs. The dynamical equations of a six-phase synchronous machine have been developed with the help of an orthogonal transformation starting with the inductance calculations of the machine right from the fundamentals. Further, a linearized model in terms of current variables has been developed, and employing the eigenvalue technique the dynamic stability of a six-phase machine has been investigated and compared to that of a three-phase synchronous machine.

Generalized mathematical representations of the various components of multi-phase (n-phase) power system elements for steady-state condition have been developed. A mathematical model of a multi-phase (n-phase) synchronous machine has also been developed in phasor co-ordinates from which the model of a six-phase machine has been derived. The mathematical models of 3-phase/n-phase transformers for various connections viz., 3-phase star/n-phase star, 3-phase delta/n-phase star, have been developed with tappings on the primary as well as on secondary side taking leakage impedance of the transformer into considerations. The three-phase equivalent of a n-phase transmission line has been developed in terms of impedance and ABCD parameters for pi representation. This representation is helpful in analyzing the system on completely three-phase basis. The equivalent single-phase representation has also been obtained with the help of the three-phase equivalent in terms of ABCD parameters representing pi-circuit to analyze a fully balanced system. The n-phase equivalent of a three-phase line connected with a 3-phase/n-phase equivalent representation with be needed to carry out the analysis of the mixed system completely on n-phase basis (i.e. if the interest of investigation lies on the n-phase part of the system). The load floe study has been carried out to investigate the impact of converting double circuit three-phase lines to single circuit six-phase or twelve phase lines under two voltage conditions , namely 1) when the phase to ground voltages of the multi-phase line and he double circuit three-phase lines are equal and 2) when the phase to ground voltage of the multi-phase line is √3 times that of the double circuit three-phase lines. Two types of cases have been taken into consideration: 1) for a given slack bus voltage; and 2) for a given reactive generation at the slack bus. The single-phase representation of a n-phase transmission line connected viz two 3-phase/n-phase transformers has been obtained on the same base quantities as three-phase transmission line. The direct and quadrature axis transient and subtraient inductances of a six-phase (multi-phase) synchronous machine have been calculated from the fundamental. The various the constants of a six-phase synchronous machine have also been obtained. The transient stability investigation has been carried out on a sample network for the various system configurations and voltage conditions. In this analysis the synchronous machine is represented as a constant voltage source behind a direct-axis transient reactance, and the loads as constant impedances. The mixed 3-phase and six-phase system and a completely six-phase system have been investigated and compared with conventional three-phase system from the transient stability point of view. The dynamic stability of a sample network for its different system configuration and voltage conditions has been investigated employing eigenvalue technique based on a linearized model. The two-axis model and the classical model of the synchronous machine have been used. The performance of a mixed 3-phaes and six-phase system with the different system loadings has been compared to that of a completely three-phase system. Also, the dynamic stability of a completely six-phase system has been examined with the same system loadings as the conventional three-phase system and also with the increases system loadings.

For more details click here   Back

Title   :   Power Factor Improvement Harmonic Reduction In Thyristor
*   Converters*
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Abstract

Rapid progress in thyristor control technology has given rise to increasing uses of thyristor converters (ac-dc converters and ac-controllers) for power control in ac and dc applications. They offer numerous advantages such as higher efficiency, better reliability, fast time response and compact size. Although, most of the applications employ naturally commutated phase-controlled converters because of their reliability and simplicity they suffer from the limitations of generation of line current harmonics and poor power factor at low output voltages. Line current harmonics cause interference with communication lines and adversely affect the performance of other devices operating on the same lines. Similarly, the operation of the system at low power factor results in reduction of power transfer capability of the transmission lines and increase of system losses. These problems are most vital in electric traction systems die to relatively weak lines. As a consequence of ever increasing demand of thyristor converters, the problems associated with the converter-utility interfacing are of primary concern in order to maintain the quality of the supply and the efficiency of power transmission. Although, the problem posed by the thristor converters may be overcome by employing harmonic filters and reactive power compensator externally, their uses have been restricted due to increase in system cost. Hence, in recent years, attempts are being made to improve the converter performance through the use of better and sophisticated converter controls. A number of improved methods of converter control, based on natural as well as forced commutation, have been developed for the harmonic reduction and power factor improvement of the converters. However, the use of improved phase-control scheme (controlled flywhelling) in a ac-dc converters and ac-controller are not fully explored. In the recent years, the static compensators using thyristor-switched capacitors (TSC) and thyristor-controlled reactors (TCR) find extensive use for dynamic compensation of load reactive power. They have all the advantages listed above for the thyristor converters. Like the converters, the static VAR compensators employing thyristor-controlled reactor also suffer from the problem of generation of line current harmonics. Though the operation and applications of static VAR compensators are well covered in the literature details of the control circuits and the harmonic control in TCR have not been emphasized. The objective of the work reported in the thesis are: 1. Detailed evaluation of existing control schemes both in ac-dc converters and ac-controllers. 2. Development of sequence control scheme for ac-dc converters employing controlled flywheeling technique. 3. Development of control schemes for selective harmonic elimination in ac-dc converters and ac-controllers. 4. Development of control schemes for static VAR compensators for power factor correlation and harmonic reduction in thyristor-controlled reactor. The major contributions of the thesis are as follows: 1. Comparative study of existing control schemes of single-phase ac-dc converters and ac-controllers is carried out for determining the relative merits of one scheme over the other. 2. Improved sequence control scheme for single-phase line-commutated converter is proposed which reduced the reactive power consumption as well as line current harmonics. 3. Selective harmonic elimination methods

for ac-dc converters and ac-controllers are proposed. Power circuit for ac-controller and control circuits for ac-dc converter and ac-controller are developed. 4. control schemes for TSC and FC-TCR compensators are developed for power factor improvement. Two control strategies for thyristor-controlled reactor are proposed for minimization of reactor current harmonics. An outline of the work reported in the thesis is given below: 1. Chapter 1 introduced the various aspects studied and reviews the literature in this area. 2. Chapter 2 deals with a comparative study of control schemes for natural – and forced-commutation control of single-phase AC-DC converters. Assuming a smooth load current and an ideal commutation, the comparison is carried out on the basis of system power factor, fundamental reactive power, distortion factor, voltage ripple in the output voltage, dominant line current harmonics etc. further, the influence of two modulation schemes, namely symmetrical pulse width modulation and asymmetrical pulse-width modulation, on the motor performance and on the source is investigated for their comparison. 3. An improved sequence control for series connected bridges with graded ratings is described in Chapter 3. A generalized method for selecting the rations of the bridge converters and two control strategies for minimizing the reactive power are described. Converters are operated with the half-controlled characteristics. 4. Chapter 4 deals with the selective harmonic elimination in the forced-commutated single-phase ac-dc converts. A pulse-width modulation scheme is described for the elimination of one or more unwanted line current harmonics. In that, the pulses are of equal widths and they are arranged symmetrically around pi/2 axis of the supply voltage for a unity displacement factor. The locations of the pulses depend upon the harmonics to be eliminated. A generalized algorithm is developed for determining the pulse positions. 5. Chapter 5 presents a comparative study of different control schemes for single-phase ac-controllers feeding a resistive load. Comparison is based on the performance criteria such as line current harmonics, system power factor distortion factor and displacement factor. 6. Chapter 6 deals with selective harmonic reduction in ac-controllers feeding resistive load, making use of pulse-width modulation scheme. To keep the displacement factor unity pulses in a half-cycle are arranged to be symmetrical about the pi/2 axis. To reduce the undesirable line current harmonics, suitable pulse-positions are determined. Power variation is achieved by varying the pulse-widths symmetrically around the pulse positions. A general method of eliminating M number of harmonics is discussed. An algorithm relating the pulse positions and the harmonics to be eliminated is presented. Power and control circuits to implement the scheme are discussed. The harmonic elimination method is not applicable for the elimination of any one harmonic, excepting the triplen harmonics. However, with the assumption of flat-topped current waveform, pulse positions are determined for minimization of any one line current harmonics. 7. Chapter 7 deals with static VAR compensators for power factor correction. Principles of transient free switching of capacitor bank are described and a control scheme for thyristor-switched capacitor compensator is presented. Operation of mixed capacitor-thyristor-controlled reactor (FC-TCR) type compensator is described. A digital control scheme for FC-TCR compensator for power factor correction is described. To reduce the harmonics generated by TCR, two sequence control schemes for thyristor controlled reactor are developed. 8. The concluding chapter outlines the conclusions drawn from the thesis and gives suggestions for further work.

For more details click here   Back

Title : *Analysis And Of Simulation HVDC-Turbine Generator Torsional Interactions*
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Abstract

The application of HVDC transmission for transmitting power from remotely sited fossilthermal generating stations is on the increase .One of the attractive features of the DCtransmissions the fast and reliable control of current through the control of the delayangle of the converter bridges .The design of adequate control system must take intoaccount the nature of DVDC –ac system interactions many of which are quite wellunderstood. For example the adverse interaction leading to harmonic instability ledto the development of equidistant pulse control (EPC) scheme. The possibility ofHVDC-turbine generator torsional interactions was discovered recently .The firstexperience of such interaction occurred at the Square Butte DC project during themonth of October 1977 when the dc link connected to the generating stationoperated radially [1] It was found that there is potential for torsional instabilitywhen a turbine –generator has a torsional mode whose frequency is within thebandwidth of HVDC regulators and the ac system in the vicinity is relatively weak. The field tests and studies on HVDC simulator were carried out to understandthis phenomenon and to identify the parameters affecting it . modification in theHDVC control has been suggested for inhibiting subsynchronous frequencyoscillations. The analytic tool used to study the torsional interactions is based onthe calculation of electrical damping contribution from AC/DC power systems. The phenomenon of subsynchronous resonance (SSR) in series compensated acsystems ahs been studied in depth and the analytical tools for study ofsubsynchronous resonance (SSR) in ac power system due to series compensatedlines are well established .Analysis based on computation of eigenvalues of thesystem matrix or frequency scanning techniques are widely used and utilize thedevelopment of linearised system models. The time response of the system particularly armature currents torques on rotorshafts caused by the major disturbances is obtained by digital simulation. In suchsimulation apart from representing the turbine-generator in detail the networktransients are also modeled. There is little analytical work reported on HVDC-turbine-generator torsionalinteractions and consequently this phenomenon is not satisfactorily explained in theliterature .Partly this is due to the problem being of recent origin. In additions themathematical modeling of AC/DC system is quite complex due to discrete nature ofconverter control and difficulty in exact mathematical description of conversionprocess in converters. The digital dynamic simulation of AC/DC system is still in a nascent stage andhas been applied for the study of torsional interactions. Recently Padiyar et al [2]have reported on the development of linear models for AC/DC systems based ondiscrete model of a 6-pulse converter .however this

does not includerepresentation for 12-pulse converter and generating units .It is also possible todevelop efficient models for the converter simulation using graph theoreticapproach[3] . The work reported in this thesis is directed at developing models andanalytical techniques for the prediction and simulation of torsional instability inAC/DC systems. Event though the models and techniques developed are generalenough to be applied to any system configuration the analysis of the HVDC-torsionalinteractions is carried out with the case study of a turbine generator supplyingpower to an infinite bus through an AC and DC line in parallel . The majoremphasis in this thesis is to develop an understanding of the phenomenon and studythe factors that influence it .Hence the design auxiliary subsynchronous dampingcontrollers (SSDC) is not investigated . The major contributions of the thesis are gives below: 1) A discrete time model for a 12 pulse converter is developed along the linesgive in [p2] .This is based on neglecting ac and dc harmonics and is used indeveloping linearised system model of AC/DC systems for the study of torsionalinteractions. Continuous time representation of dc system has also been consideredfor comparison. The system model developed is a detailed one including statortransients damper circuits ac and dc network transients and torsional representationof mechanicals system. 2) A converter model representing 6/12 pulse operation and based on equivalentcircuit approach using graph theoretic analysis has been developed for efficientdynamic digital simulation. Considering a modular approach to system simulation acomputer program is developed top include detailed representations of synchronousgenerator and converter control.3) The method of frequency scanning technique has been extended to study tensionalinteraction between HVDC system and turbine-generator shaft dynamics. Theequivalent frequency dependent admittance of the generator (viewed fro itsterminals) at subsynchronous frequencies taking into account both the rotor shaftdynamics and induction generator effect is calculated .An expression for theequivalent admittance of the dc system is developed. A detailed study of the HVDC- tensional interactions is carried out usingeigenvalue and frequency scanning analysis . An explanation of the phenomenon I givenand the measure for overcoming the tensional instability are indicated . A brief description of the work reported in this thesis is given below; The first chapter introduce the various aspects studies and gives a brief review ofthe literature in this area .The objectives and the scope of the thesis are given alongwith a brief outline of the subsequent chapters. Chapter two deals with the formulation of a linearised mathematical model ofAC/DC systems for the study of torsional interactions between the HVDC system andturbine –generator shaft dynamics. The system considered consists of a synchronousgenerator driven by steam turbine which feeds power to an infinite bus through a dcand an ac line in parallel. The inverter of the dc system is represented by a constantdc voltage. The converter model used is as given in [4] .The system model has beenderived by first developing component models and interconnecting them throughappropriate interface variables. The frequency domain method is employed todetermine the electrical damping contribution of AC/DC systems which is obtained asa real part of the transfer function defining the change in electrical torque to changein the generator rotor speed .The system models includes details representation of thegenerating unit converter and its control ac and dc network transients. The effect ontorsional interaction of various system parameters

such as dc line loading converterfiring angle the firing scheme employed i.e. individual phase control (IPC) orequidistant pulse control)(EPC) and the ac line strength is investigated .The resultsobtained are compared with those available in the literature [4]. The model developed in chapter two augmented for eigenvalue analysis byincorporating the mechanical system in chapter there. Both continuous and discretetime representation of the dc system are considered .The discrete time model for a12-pulse converter is developed .The stability predictions are carried out througheigenvalue analysis .The results are compared with those given in Chapter 2. Theeffects of dc line length controller parameters and machine rating on the torsionaslinteraction are also investigated .Based on a detailed study explanation of thephenomenon of HVDC –torsional interactions is given which is along similar lines asthe explanation of SSR in series compensated AC. Systems. Chapter four describes the converter model for six or twelve pulse operationand presents its application for dynamic digital simulation of HVDC systems. Thesimulation is simplified by representing the converter as a time varying equivalentcircuit on the dc side which derived from graph theoretic formulation .The convertermodel developed has a modular structure and hence can be used to simulate a converterterminal with any number of bridges connected in series .The forward voltage dropin value is include in the model. Te expression for value currents and voltages acrossnonconducting values all the normal and abnormally modes of converter operation arealso given . Chapter five reports on the detailed dynamic digital simulation using the convertermodel developed in the earlier chapter. The ac system model include detailedrepresentation of the generator and the shaft dynamic ac and dc network transients.The available computer program which incorporates simplified ac systemrepresentation is suitably augmented to include this detailed ac system representationis suitably augmented to include this detailed ac system model . The computerprogram is used to study the time response of various quantities when the system issubjected to disturbance .the disturbances considered are I) change in the dc currentreference and ii) change in the dc voltage at the inverter .The time variations in shafttorques dc and ac current and voltage following the disturbance are used to indicatethe stability of the operating point. Chapter six deals with the frequency scanning technique for the production ofstability of AC/DC systems in subsynchronous frequency range .The expressions foradmittances of the generating unit and dc system are developed using the state spaceequations in D-Q variables .The mechanical shaft dynamics and induction generatoreffect are considered while calculating the admittance of the generating unit. Using theadmittance of various subsystems a method to calculate electrical dampingcontribution AC/DC power systems is also given .The results obtained arecompared with those obtained in Chapter 3 .It is found that the frequency scanningmethod predicts and can be used for fast evaluation of torsional interactions underdifferent system conditions. The detailed study frequency scanning method offers aninsight into the phenomenon of HVDC torsional interaction and indicates the possib;lesolutions o the problem of torsional instability . The seventh chapter outlines the conclusions drawn from this thesis and givessuggestions for further work in this area.

For more details click here   Back

Title   *:   Investigations Into The Design Of Power System Stabilizers*
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Abstract

With increasing size and complexity of modern power systems stability investigations areassuming greater significance in system planning design and operation. Transientstability of power systems is improved by incorporating fast acting and high gainexcitation systems with synchronous generators. However such excitation systemsintroduce negative damping in the system impairing dynamic stability. Oscillations ofsmall magnitude and low frequency in the range of 0.2 to 2.0 Hz can perist for longperiods of time and in some case present limitations to the power transfer capabilityPower System Stabilizers (PSS) are developed to damp-out these oscillations .PSS aredynamic compensators which receive a feedback signal from rotor speed angular positionfrequency or electrical power and provide a corrective input to the excitation system. The basis for the design of PSS explained in the classic paper by deMello andConcordia [1] .The PSS is designed as a dynamic compensator using input derived fromlocal control signal with the objective of increasing the damping torque whilemaintaining the synchronizing torque. The model given in [1] is a simplified one wherethe power system is represented by a single generator feeding infinities bus throughtransmission line. A third order model neglecting damper windings represents thesynchronous machine. This simplified model of the power system permits application ofclassical control theory for the design of PSS. Since then there has been much work on power system stabilization reported in theliterature using classical and modern control theory. In the latter approach the PS designis based on the objective of assignment of closed-loop poles or minimizing aperformance index. In spite of the extensive literature on PSAS there are still some gaps,which are described below: (1) It is observed that a simple model of a power system (that of signal machineconnected to infinite bus) is not adequate in many situations and coordinated applicationof PSS using multimachine system model is essential [2] .The design based on theconcept of damping torque utilizing classical control theory is not adequate here.However the direct application of modern control theory is also not feasible due to thepractical constraints of having to use only local control signals. While some theoreticalwork on decentralized control in large systems has been carried out its application fordesign of PSS in a large power system is not reported. It PSS are to be equipped on the generators that are already installed in a system for thepurpose of improving dynamic stability there arises the question of selecting appropriatelocations for PSS in order to provide an effective control. This question has not alsobeen satisfactorily answered. (2) The objective of PSS design given in [1] is to increase

the damping torque in thegenerators .It can shown that this is equivalent it shifting the complex pair of eigen-values corresponding to electromechanical oscillations to the left in the complex plane[3]. This indicates that pole assignment is a suitable objective for PSS design. Howeverthe design freedom (in the selection of parameters) is not fully utilized in the workreported in this area; for example with a second in the dynamic compensator using asingle input it is possible to assign upto five closed-loop poles to their desired locations.With more complex compensators (multi input) it may be possible to assign more closed-loop poles. Generally for the purpose of stabilization it is adequate to specify the region in thecomplex plane where closed-loop poles should lie rather than specifying exact locations.However unique compensators cannot be obtained unless exact locations are specified.This problem can be avoided if a suitable performance index is chosen as an objective inconjunction with the application of optimal control theory.(3) While there is some work reported on the choice of control signals [4] a details studycomparing their relative merits is not available .The comparison should be Based onsatisfactory performance of the controller under varying conditions of operating pointand system strength. Interaction between two or more parallel-connected generators in a power stationcomplicates the choice of control signals for PSS. A detailed analysis is not available inthe literature.(4) Third order synchronous machine model is widely used for PSS design. Adequacyof this model needs to be tested. The work reported in this thesis is directed at trying to fill the gaps mentioned above.The major contributions are as follows:(1) Study of decentralized control for the design of PSS in large power systems byconsidering application to a particular large power system.(2) Determination of effective PSS locations in a large multimachine system througheigenvalue sensitivity analysis and validation of the results.(3) A detailed investigation on the effectiveness of various feedback control signals(viz.rotor speed, electrical power and bus frequency) for PSS design includingconsideration of interaction between adjacent machines in the choice of signal.(4) Application of modern control theory for the design of dynamic compensators(to be used as PSS utilizing full design freedom. Comparison of the performanceof PSS designed using pole assignment techniques parameters optimizationtechnique and classical control, method.(5) Verification of the adequacy of using simplified model of synchronous machinein PSS design. An outline of the reported in the thesis is given below:(1) Chapter 1 introduces various aspects of dynamic stability and design of PSS inlarge multimachine power systems and reviews the literature in this area.(2) Chapter 2 details with design techniques for PSS .The techniques developed hereare general enough to be applied to multimachine systems. Pole-assignment inclosed-loop system is a well accepted design objective for PSS is used in the firsttwo techniques presented .In the first technique model control theory is utilizedfor PSS design. Only accessible states are used as feedback signals to PSS. Poleassignment technique given by Munro and Hirbod [5] with dynamic outputfeedback is utilized for PSS design in the second techniques. Electromechanical oscillations of machine rotors with respect to one another causepower surge between machines and limit power transfer capabilities particularly insystems having long transmission lines. Damping of these oscillations can be achieved byminimization of power fluctuations in generators output .The third design technique isbased on parameter

optimization with the objective to minimize power fluctuations ingenerator outputs due to disturbances. The three design techniques presented in thischapter are compared with the classical design technique used in the power industry. (3) The main study in chapter 3 is concerned with the adequacy of simplified machinemodels neglecting the effect of damper circuit for the design of PSS. This is done byemploying the PSS designed for lower order machine model to the machine representedin detail considering the effect of damper circuits. Comparison between the performanceof the stabilizers designed using simplified and detailed models of the machine ispresented based on time-domain analysis of the closed-loop systems.(4) Chapter 4 presents a case study on the evaluation of the effectiveness of variousfeedback signals that can be used for PSS design. Three control signals namely rotorspeed electrical power output and terminal bus frequency are considered .PSS for thethree control signals are designed and the effectiveness of signals is judged bydetermining stable regions in the P-Q domain. The influence of ac system strength on thedesign of PSS utilizing the three control signals is studied. Analysis of interactionbetween two generating units equipped with PSS in a power plant is also carried out .Theresults indicate the importance of using average speed instead of individual speeds ascontrol signal.(5) Chapter 5 deals with the development of a sate-space model for large power systemssuitable for dynamic stability analysis and the selection of proper locations of PSS .Thesystem model of the multimachine system is obtained systematically by developing themodels of various machines and their interconnections through the network .The networkis represented by its Jacobian matrix. Two analytical techniques are presented for the choice of effective locations of PSS .Acase study of a 13-machine system is presented for the selection of PSS locations. Loci ofeigenvalues are obtained to validate the results obtained through the analyticaltechniques. .(6) Chapter 6 presents the application of two design techniques for PSS in amultimachine system using decentralized feedback control. The first technique isbased on the algorithm given in [6] .Pss for the selected machines are designedneglecting the interconnection between machines to assign closed-loopeigenvalues. Parameters of the stabilizers are then update by introducing theinterconnections in discrete increments keeping the closed-loop eigenvaluesunchanged. The algorithm is found to be not suitable when the constraint ofproviding PSS on limited number of machines is considered .In the second technique a performance index on minimization of fluctuations in thepower outputs off relevant generators is used to design PSS using parameteroptimization technique. Two examples of power systems one with 3 machines and the other with 13 machinesare considered to illustrate the techniques. (7) The concluding chapter summarizes the research results and indicates possibilities forfuture work.

For more details click here   Back

Title : *Linear Sequential SystemS Over Residue Class Polynomial Rings: Theory And Applications*

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Abstract

This work introduces as a generalization of linear sequential systems over finite fields the notion of linear sequential systems over residue class rings of polynomials over finite fields and gives theory and applications of these systems. Structural properties, implementation and analysis of such systems and their applications in error control coding and generation of sequences over residue class rings of polynomials are presented. Properties of the sequences and their application in modulation and multiplexing of data sequences over finite fields are considered. Study of linear sequential systems (LSS) over the finite field GF(2) was imitated by Huffman, which was later generalized by several investigators to systems over GF(p) and GF(pn). LSS over GF(pn) are described by input space, output space and state space, which are vector spaces of appropriate dimension over GF(pn), and characterizing matrices A, B, C and D of appropriate sizes over GF(pn). Finite field GF(pn) is a specific case of residue class ring of polynomials, denoted by)]([aWP np where W(a) is the modulus polynomial of degree n over GF(p);)]([aWP np becomes GF(pn) when W(a) is irreducible. LSS over)]([aWPnp , denoted by)]([aWPnp - LSS, are thus a generalization of LSS over GF(pn). In)]([aWP np -LSS the sets of inputs, outputs and states are free modules over and the characterizing matrices A, B, C and D are over . By appropriate definition of addition and multiplication operations it is possible to obtain rings of n-tuples and nxn commutative matrices over GF(p), which are isomorphic to)]([aWPnp -LSS which can be viewed as LSS which process n-tuples or nxn matrices from the respective rings. A)]([aWPnp -LSS can be implemented over GF(p) using the isomorphism between)]([aWPnp and the ring of n-tuples. LSS defined over tensor product of residue class polynomial rings over GF(p) give rise to additional families of LSS. In this case also isomorphisms can be established between tensor product residue class polynomial rings, rings of n-tuples, and rings of nxn commutative matrices over GF(p). using these isomorphisms LSS over tensor product of residue class polynomial rings can be implemented over GF(p). In finite fields the operations of addition subtraction, multiplication and division are all defined. However in a ring the operation of division is not defined. As a consequence the generalization considered in this thesis is not trivial. It is known that finite fields of a given order are all isomorphic to each other. However, in a ring this is not true. The set of all isomorphic residue class polynomial rings of a given order pn constitutes an equivalence class and LSS defined over these rings constitute a distinct class of LSS. Number of such distinct classes of LSS is equal to the number of non-isomorphic residue class polynomial rings of order pn; LSS defined over GF(pn) constitute one of these classes. Enumeration of nonisomorphic residue class polynomial rings of a given order, or equivalently of the distinct classes of LSS is carried out. It is shown that the number of nonisomorphic residue class polynomial rings of a given order pn and hence the number of distinct classes of -LSS depends on the partition function of n and the number of irreducible polynomials of degree 1, 2,…, (n-1) over GF(pn). Since the properties of LSS depend on the ring over which it is defined,

LSS over offer in comparison to the conventional LSS over finite fields, a wider choice of systems. The analysis and applications of LSS over residue class polynomial rings discussed here are based mainly on the decomposition of rings into external direct sum of primary rings or internal direct sum of ideals generated by orthogonal idempotents. LSS defined over rings can, therefore, be decomposed into component systems defined over primary rings which are either finite fields or local rings. The decomposition of into primary gives rise to implementation of)]([aWPnp -LSS using subsystems over primary rings. Likewise decomposition of)]([aWPnp into internal direct sum of orthogonal ideals gives rise to implementation of)]([aWPnp -LSS using subsystems over orthogonal ideals. In the study of the response of)]([aWPnp -LSS the characteristic matrix A plays a prominent role. The conditions for A to be singular nilpotent and nonsingular are derived. It is shown that when A is singular but not nilpotent, the response is either periodic or ultimately periodic depending on the initial state. When A is nilpotent, the response is ultimately a zero sequence and when A is nonsingular the response is periodic, irrespective of initial state it is shown further that if A is nonsingular and hence periodic with period say, T, and input is periodic with period J, then the output of)]([aWPnp -LSS is also periodic with a period which divides pJT. The maximum possible period of a state cycle is equal to the period of A. if the initial state has components from an ideal then all the states in the state cycle will have components from the same ideal. The number of state cycles is thus at least equal to the number of ideals in)]([aWP np over which the LSS is defined. The structure of state cycles of)]([aWPnp -LSS is obtained in terms of the structure of state cycles with respect to the direct sum components of the characteristic matrix A of the LSS. Under autonomous operations the output sequence of a -LSS is affixed linear transformation of the state sequence and the set of all output sequences constitutes a module. For the single output canonical system the autonomous response is a linear recursion sequences, i.e., the output sequence satisfies a linear recursion relation over)]([aWPnp , and the set of all such sequences constitutes a free module. Hamming correlation properties of linear recursion sequences over are studied. Bounds on the values and number of levels of correlation functions are derived. It is shown that sequences over orthogonal ideals generated by distinct orthogonal idempotents are point wise orthogonal. Since an arbitrary sequence over a somisimple or semi local ring can be decomposed into an internal direct sum of component sequences over orthogonal ideals these component sequences are inherently point wise orthogonal sequences. An arbitrary sequence over a finite field or a local ring can be first mapped into a sequence over an appropriate semical or semi simple ring and then decomposed into sequences over orthogonal ideals. Such orthogonal sequences can be used for modulating and multiplexing data sequences with elements from finite fields. For this purpose source sequences over finite fields are transformed into orthogonal sequences over orthogonal ideals in an appropriate semi simple ring. Each orthogonal sequences then modulates a maximum length sequence over the same ideal. Modulated sequences corresponding to different sources are added and transmitted as a single multiplexed sequence over the semi simple ring. The orthogonality property of sequences over orthogonal ideals is used for separating (demultiplexing) the component sequences at the receiver. Each individual sequences is then Hamming cross-correlated with the reference sequence for demodulation. Applications of LSS over residue class polynomial rings in the generation of nonsystematic and systematic linear polynomial and cyclic over)]([aWPnp and decoding of these codes are considered. In the polynomial and cyclic codes every codeword, expressed as a polynomial over)]([aWPnp , is a multiple of a fixed polynomial called generator polynomial. These codes are encoded by polynomial multiplications employing appropriate)]([aWPnp -LSS. An (N, K) polynomical

code over)]([aWPnp is a free sub module of rank K and order pnK. It is shown that the set of all autonomous responses of a nonsingular single output canonical)]([aWPnp -LSS has the structure of a linear cyclic code which is an ideal in the residue class polynomial ring modulo (xN-1) over)]([aWPnp . Decoding of polynomial and cyclic code is done by employing LSS which perform polynomial division. If the remainder is nonzero error is detected. If the error is within the correcting capability the remainder is uniquely related to the error polynomial which is obtained from the decoding table and subtracted from the received polynomial. In the case of cyclic codes it is shown that the decoding can be done by computing the Hamming cross-correlation between the received codeword and a set of reference codeword available at the receiver. The reference work which gives the maximum cross-correlation value and the shift at which this occurs are utilized for decoding the received word. For the case of systematic cyclic codes permutation decoding can be employed on the lines similar to permutation decoding of systematic cyclic codes over finite fields.

For more details click here   Back

Title : *Selection Of Nominal Point For LQSF Regulator And Determination Of Parameter Range For A Specified Suboptimality*
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Abstract

The design of a LQSF regulator for a linear time-invariant dynamical system is based on nominal values of the state and input matrices. These values correspond to the nominal values of the parameters of the system. The performance of the nominal closed-loop system is designed to be optimum. However, even when a single parameter varies, the performance of the closed-loop system for the off-nominal values of this variable parameter may deviate from that of the nominal closed-loop systems. In such as situation it is expected that the performance of the closed-loop system for off-nominal values should be satisfactory. The most important requirement is the asymptotic stability of the closed-loop system for the range of parameter variation. Additionally some other performance criterion may be sought to be satisfied. When a single parameter varies, some or all elements of the state and input matrices may vary. Corresponding to a range of variation of the parameter ranges of variation of these matrices can be obtained. In that case the overall performance of the closed-loop system for all values of the parameter in the range may vary depending on the nominal point chosen. Thus a problem exists to select a nominal point. Then can the nominal point be so selected that the performance of the closed-loop system in the whole range is best in terms of some criterion of performance (in addition to the asymptotic stability) compared to that for any other choices of nominal point in the range? Consider a closed-loop system as obtained using a LQSF regulator the design of which is based on the nominal value of the parameter. When the parameter value is different from the nominal the performance of the closed-loop system may deteriorate. In such a situation it is of interest to identify a range of the parameter around the nominal value for which the deterioration of performance of the closed-loop system as quantified by some measure is known. Such a range can given some idea about the robustness of the LQSF regulator. This thesis is addressed to the above aspects and problems connected with a LQSF under parameter variation. A single parameter variation is considered. A chapter-wise summary of the work reported in this thesis is given below. The first chapter provides a literature survey of different approaches and methods available to design a control system in case of parameter variation. The objectives and scope of the thesis are also outlined. In chapter 2 the asymptotic stability of a closed-loop system corresponding to a range of variation of a single parameter is considered. Corresponding to the variation of a single parameter, a convex variation of the state matrix and an identical convex variation of the input matrix are assumed. Two methods are developed to test the asymptotic

stability of the closed-loop system in the range of parameter variation. The second method can be applied only to the case for which the closed-loop matrix is in companion form. In chapter 3, the problem of selection of a nominal point to design a LQSF regulator is investigated. Two different performance criteria are used. The first criterion is the sensitivity of a closed-loop system as measured by the comparison sensitivity. Corresponding to the variation of a parameter a convex variation of only the state matrix is considered. It is shown that one of the end points of the range of parameter variation can be selected as the nominal point if the concerned sufficiency condition is satisfied. The amount of trajectory variation is considered as the second criterion. For this both the convex variation of the state matrix and an identical convex variation of the input matrix are considered. Based on the above criterion, a method is proposed to select a nominal point. The problem of identifying of range of the variable parameter for two different measures of sub optimality is studied chapter 4. Corresponding to the variation of a single parameter, both the convex variation of the state matrix and an identical convex variation of the input matrix are considered. The two measures of sub optimality are (i) deterioration of optimality and (ii) s-sub optimality. Algorithms are developed to identify a range of the parameter for a specified value of either of these measures. The iterative nature of the algorithm allows to obtain a close estimate of the range for a specified measure. In chapter 5, the problem of identifying a range of the parameter for known gain margin phase margin gain reduction tolerance and tolerance to sector-bounded nonlnearity is considered. The variation of only the state matrix is considered. The variation is assumed to be convex. It is shown that the phase margin, gain reduction tolerance and tolerance to sector-bounded nonlinearity of a sub optimal system can be expressed in terms of a real positive scalar β_1, if sufficient conditions is satisfied. Based on this a method is proposed to identify a range of the parameter for a specified phase margin. The specified phase margin determines the gain reduction tolerance and tolerance to sector-bounded nonlinearity. Finally the results of the thesis are summarized in chapter 6.

For more details click here   Back

Title   :   *Reactive Power Control And Security Analysis Of Power*
                                Systems
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Abstract

In the present context of energy crisis all over the world, system improvement by reducing the transmission losses is significant, This can be achieved by proper planning and "optimal operation of the systems. A proper control of reactive power flow leads to the reduction in power losses, improved voltage profile, reduction in line and equipment loading, increased power transfer capability and improved system security.An optimal power flow problem considering active and reactive power dispatch is a very demanding nonlinear programming problem due to the large number of variables and constraints. Hence, separating the real and reactive power optimization problems is appropriate for on-line applications. The optimal reactive power control problem can be stated as the problem of determining control variables, (the generator terminal voltages, transformer tap ratios, and static var systems or switchable shunt capacitors/reactors) to minimize systei losses subject to the constraints on the control variables load bus voltages, reactive power outputs of the generators etc. This problem is a nonlinear optimization problem. Fast and accurate methods for the solution of this problem are required. The nonlinear programming methods may cause convergence problems. Linear programming (LP) methods are more suitable for on-line applications and have been applied for security constrained economic dispatch. However, not much work has been' reported on their application for the reactive power control.One of the major functions of modern energy control centers is security assessment, which involves the simulation of contingencies that can occur, by solving the power flow equations for each contingency. Speed, accuracy and reliability are important for solution methods. The distribution factors and D.C. load flows are not applicable for evaluating voltage problems during a contingency. Fast decoupled load flow and Iterative linear power flow methods are useful for this purpose but may require a number of iterations for an accurate solution of load flow equations for each contingency. Under certain conditions it is possible to decouple the power flow equations exactly. Also the reactive power flow equations (in bus voltage variables) become linear with parameters which are functions of the phase angles. Once the phase angles are computed from the decoupled real power flow equations, the voltage magnitudes can be computed exactly without iterations. However, the solution of linear equations with variable parameters can be time consuming in security assessment. An investigation of various approximations that can be introduced to simplify the solutions is in order.Conceptually, there are two approaches for security assessment (1) deterministic contingency evaluation with a list of next-contingencies to be considered, (2) using pattern recognition techniques. In the first approach, it is recognized that if the contingencies can be ordered in relation to their severity the computational effort involved in security assessment can be saved to a large extent. Automatic contingency selection is a new direction of research and is concerned with developing efficient algorithms which rank the contingencies in terms of their impact on system performance. An automatic contingency selection method requires a performance index for determining the severity of the outage and an efficient method to compute this performance index for each contingency. Most of the work reported relates to the ranking of contingencies based on overloading of lines in which the reactive power and voltage problems

are not considered.The scope of this thesis covers the two areas of reactive power optimization and security analysis. The reactive power control problem is treated as a linear optimization problem and detailed investigations are carried out to evolve an algorithm that ensures speed and convergence to make it feasible for real time applications.In security analysis, the emphasis is placed on the solution of reactive power flow equations which become linear when the load is considered to be constant current type. The various typos of approximations that can be used to simplify the solutions are investigated with the objective of determining the best method for security analysis. The work also covers the aspects of developing an automatic contingency selection algorithm.The major contributions of this thesis are listed below :1) An exact formulation of the reactive power optimization problem based on sensitivity matrix is given, which can be solved using successive linear programming. Detailed investigation with case studies is carried out to simplify the formulation with the objective of reducing the computational effort.2) Application of dual interval programming technique for reactive power optimization.3) Comparative study of various approximate methods for the solution of reactive power flow equations for security analysis.4) Development of an efficient and accurate method for the solution of reactive power flow equations. 5) Development of an automatic contingency selection algorithm based on the performance index which is a function of reactive power losses in the network.An outline of the thesis is given below :Chapter 1 introduces the problems of optimum control of reactive power flow and security analysis. A brief review of the state of the art is presented. The scope and objectives of the thesis are described.Chapter 2 deals with the optimum control of reactive power flow for minimization of real power losses in power systems. The control variables are the generator terminal voltages, transformer tap ratios and controllable reactive power sources. All real power generations except that at the slack bus are assumed to be fixed. The constraints on the control variables, generator reactive power outputs, load bus voltages and line flows are considered. By utilizing the sensitivity matrix computed from load flow equations a linear optimization problem is formulated which is solved by revised simplex method. In order to improve the accuracy and achieve feasibility of the optimal solution, the procedure is repeated until convergence is obtained. Approximate formulations of the method for reducing computer memory and time are studied. Results obtained for 6 bus, 30 bus and 57 bus systems are presented. Chapter 3 presents the use of dual interval programming technique for loss minimization instead of the standard LP. The objective is to minimize computations for real time applications. In an interval programming method, double sided constraints can be handled directly while in a standard LP they have to be converted into two sets of single sided constraints. The results obtained for the 6 bus, 30 bus and 57 bus systems are compared with those obtained using standard LP technique.In Chapter 4, an investigation of various approximations for the solutions of reactive power flow equations is presented. Under certain conditions the power flow equations can be decoupled exactly and the load bus voltage magnitudes can be computed by solving a set of linear equations. However, these equations contains phase angles as parameters and are not convenient to use directly in security assessment. Various approximations are investigated to simplify the solution of these equations. These are tested on 30 bus and 61 bus systems and compared with the solution methods using fast decoupled and iterative linear power flow.Chapter 5 deals with an automatic contingency selection algorithm. A performance index to measure the severity of an outage based on the reactive power loss is proposed. This index is a combination of line loading and voltage deviation factors. An efficient algorithm to compute the performance.

For more details click here   Back

Title   *: On The Phoshorus Diffusion In Silicon In Oxidising And*
        Chloro-Oxidising Ambients
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Abstract

The performance of a silicon device/I.C. is dominantly influenced by the impurity distribution in the active regions of the device. These impurities are introduced into silicon by diffusion/ion implantation. In the device/I.C. fabrication process sequence, this impurity deposition is invariably followed by other high temperature processes such as drive-in, oxidation etc. the deposited impurities redistribute themselves during these processes and the final impurity distribution is rather a complicated function of he initial distribution and the parameters such as ambient, temperatures etc., of the later processes. To accurately relate the process parameters with device performance, therefore, a precise knowledge of the effect of process parameters on the impurity diffusion is essential. The recent years have been considerable activity in this area, primarily motivated by two factors. (i) As the I.C. complexity increases, the computer aided design methods are to be used, in order to reduce the time required for the development of new product. This is turn needs accurate mathematical models for process variable-impurity profile relationship, besides the models for devices/circuits. (ii) it is recognized that the process-profile relationship is still not adequately known and remains a major limiting factor in out capability to accurately relate the process variables with device/circuit performance. The objective of this work is to study the effect of oxygen and chlorine (in diffusion ambient) on the diffusion of phosphorus in silicon. It is now well established that the thermal oxidation of silicon causes an injection of excess self interstitials into the bulk silicon, which cause an enhancement in impurity diffusion coefficient. The study of this oxidation-enhanced diffusion (OED) has been reported by several workers [1-3], who estimated OED by evaluating the redistribution of impurities, deposited by ion implantation/CVD, during oxidation. The extraction of the diffusion coefficient in these experiments is tedius and the finer details of the experimental profile vis-à-vis its theoretical counterpart are likely to be overlooked due to the approximations made for initial distribution. The effect of chlorine on phosphorus diffusion has been reported in detail only by Nabeta et al. [4]. Their experimental results, however, cover only a narrow range of temperature and have been questioned due to the high surface concentrations (> 1020 cm-3) involved in the experiment [5]. In the present work, the effect of ambient has been studied by carrying out constant source diffusion using pH3 in different ambient, under intrinsic diffusion conditions. This experimental situation is amenable to simple mathematical analysis. In addition the large segregation coefficient of phosphorus in SiO2-Si system, allows the diffusions to be carried out in strongly oxidizing ambient, thus permitting the observation of OED of nearly the same magnitude as observed during oxidation in dry O2. A mathematical model for impurity diffusion in oxidizing ambient from a constant source is presented. The diffusion equations in dopant silicate glass (DSG) and silicon are solved for impurity distribution in the two mediums. A reaction rate limited flux boundary conditions, instead of that of thermodynamic equilibrium, has been assumed at the interface. The general solution for impurity distribution in silicon is found to be a series, which converges reasonably fast only for small diffusion or large values of reaction rate

constant/1diffusion time, the model yields solutions identical to those reported by Smits [6] Grove [7]. Phosphorus was diffused in <111> and <100> silicon using pH3 source (1000 ppm pH3 in Ar) at various temperatures in the range 9500C-12500c, in three different ambients; (i) 95.5 V% N2+1.5 V% O2 + 3.0 V% (PH3+Ar), (ii) 90.1 V% O2 +9.9 V% (PH3+Ar) and (iii) 94.5 V% O2 + 0.5 V% (PH3+Ar) + 5.0 V% N2 bubbled through TCE at room temperature. The impurity distribution in each sample was determined from sheet resistivity measurements made after successive removal of silicon by anodic oxidation. The diffusion parameters were then calculated by comparing the experimental profile with the appropriate theoretical profile derived in the model. In agreement with the theoretical predictions for diffusion in oxidizing ambient, the surface impurity concentration is observed to be a strong function of the ratios of the PSG thickness to impurity diffusion lengths of PSG and silicon respectively. For identical diffusion ambients, the oxidation rate is seen to cause the surface impurity concentration to vary by two orders of magnitude. On the basis of the model predictions and the experimental results, it is concluded that the desirable process features for low concentration phosphorus diffusion are high temperature and strongly oxidizing ambient. In strongly oxidizing ambient, the observed OED is in good agreement with the data reported by Antonia is et al. [3], for OED during dry O2 oxidation. In the present work the surface impurity concentration was of the order of 1018 cm-3. At these concentration, the OED was observed to be independent of crystal orientation and diffusion time. Various models proposed for the kinetics of excess-self interstitials generated during oxidation are examined in the light of the observations of this work coupled with the observation on other oxidation related phenomena, such as growth oxidation induced stacking faults (OSF), reported in literature. It is shown that only the model proposed by Hu [8], satisfactorily explains all the experimental observations reported so far on OED and OSF growth in silicon. It is suggested that the surface regrowth process in Hu's model depends upon the impurity type (through its segregation property in SiO2-Si system) and concentration at the interface. The presence of chlorine in diffusion ambient is observed to cause a reduction in diffusion coefficient at all the temperatures. This effect is significantly larger on <111> than on <100> silicon and decreases with temperature, becoming negligible at 9500C. The reduction in diffusion coefficient is consistent with the observation of retarded growth of OSF in Cl2-O2 ambient [9], reported in literature and is a pointer to the fact that the presence of chlorine in the oxidation/diffusion ambient reduces the net generation of excess self interstitials at the interface. The experimental data of this work have been correlated with the reported segregation properties of chlorine in SiO2-Si system during chlorine-oxidation [10-11] and it is confirmed that the chlorine containing interface acts as a sink for self-interstitials. Hu's model is extended to take into account the effect of chlorine in diffusion coefficient. The last but important observations is the reduction diffusion coefficient in chloro-oxidising ambient below its value in inert ambient (by about 35% at 1250C) in <111> a direct evidence to the fact that in inert ambient, phosphorus diffusion proceeds via partial/pure interstitialcy mechanisms, thus ruling out the possibility of a pure vacancy mechanism

For more details click here   Back

Title : *Novel Distance Relaying Schemes For The Protection Of Ehv/Uhv Transmission Lines Using Digital Techniques*
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Abstract

The demand of the electrical power in many countries of the world, has been increased manifolds during the last two decades due to the rapid growth of industries and also agricultural commercial and domestic needs. Thus, large thermal Hydro and Nuclear pow er plants were installed, generally for away from the load centers. This necessitated the transfer of bulk power over long distances by means of transmission lines and interconnections. The reliability, durability and the stability of the power system netw ork depends how fast and efficiently, the fault can be cleared. The transmission line voltages, in the past was limited to 220kV and hence, the protection schemes based upon the 'lnduction Cup Relay' were satisfactory as the fault detection within 2 to 3 c ycles did not create any serious stability problem. The increase in the system voltages to 400kV and above necessitated the detection of the fault in less than one cycle (20 msec). Which is beyond the capabilities of electromechanical relays. This gave ris e to the development of static relays and finally, to the solid state relays. Solid state relays have distinct advantages over electromechanical and also other types of static relays that , they are fast in operation sensitives accurate, compact and immume to vibrations and shocks due to external causes. Absence of moving parts and contacts makes them more reliable and also long lasting. Negligible maintenance is needed once they are put in service, their burden is low and also they do not require high vol tage supply. All these factors make them economical in the long run. The distance relays used so far, for the protection of EHV/UHV transmission lines (400kV and above) use discreate components like, diodes transistors TTL logic gates and analogue techniq ues. Some of them use digital components also but they all suffer from the serious drawback of having different operating time depending upon the reach of the relay and the phase difference between the selected input signals. This can create serious time c oordination problem between different relaying schemes as the operating time various between 10 to 50 msec, (2 12 1 2to cycles). Most of the relays generate classical threshold characteristics which could be prone to power swing in the case of long, heavily loaded transmission lines. Quadrilateral characteristic is most compatible to any type of line faults having high arcing resistances. Hence, modern trend is to use relays having quadrilateral pick up characteristics. A relay, once designe d for a specific characteristics cannot produce a different polar characteristics which may be required for some applications. The same relay may not function, both, as since an cosine comparator. The protection schemes for the transmission lines are quit e complex and at the same time, they are not flexible and their prime cost also is quite high digital relays using Microprocessor and Minicomputer for 'On Line' distance protection of EHV/UHV transmission lines are much faster

and also free from many drawb acks. But, their long time durability and reliability is not yet ascertained and at the same time, they are not accepted by 'Protection Engineers' as a primary means of protection. The distances relaying schemes based upon traveling waves phenomena have b een designed and fabricated and the first of its kind is in used on 500kV system of Bonneville Power Administration, U.S.A. this scheme seems to be the best of all but, is highly sophisticated and uneconomical for small power systems. Hence, there is an am ple scope for developing a protection scheme which is free from the most of the existing drawbacks. Accordingly he primary objectives of this thesis have been: 1. to present critical review of some important relaying schemes with respect to simplicity circu it ability, reliability and flexibility in generating the various types of pick up characteristics in the complex B - plane (i.e. R - X plane). 2. to develop novel high speed, reliable relaying schemes for single phase, single zone operation which could be used to produce any desired pick up characteristic with constant operating times and can be used both, as sine and cosine comparators with minimum of hardware. 3. to design, develop and fabricate a 3 - zone single phase relaying scheme, using CMOS logic gates and di gital IC's,capable of producing any desired threshold characteristic with constant operating time (15 msec) for fault at any point within the reach of the relay, by the use of 2 input comparators. 4. to design, and fabricate a 3 - zone poly phase relaying schem e with a new operational strategy, using multi input comparators to produce modified who characteristic using blinders and a quadrilateral characteristics with 3 input signals only, and 5. to design, and fabricate a 'Dynamic Test Bench' with 'point on wave s elector' and to test the performance of the various proposed relaying schemes on it, with respect to operating time, accuracy transient reach verses switching angle of fault current and range. The salient features of the work reported in this thesis are a s follows: Chapter 1 presents a brief review of the important literature pertaining to the development of the distance relaying schemes chronologically. It also describes the need of better and faster schemes and gradual change from electromechanical relay to static and them finally to the solid state relays. Chapter 2 gives the critical review of some of the important relaying schemes which could be used for the protection of heavily loaded long transmission lines. A detailed study of these schemes is done and their merits and demerits are brought out. It is revealed from the close examination, that , all these schemes suffer in one way or the other. Thus, there is a scope for the design and development of a relay which is free from the drawbacks of the ex isting schemes. Chapter 3 starts with the proposed novel relaying scheme. It describes the theory, development and testing of the digital phase comparator relay using CMOS logic gates and digital IC's which could be used both as sine and cosine comparator and generators many important pick up characteristics used for distance protection. The relay uses 2 input transient free, block average symmetrical coincidence comparator and its hardware is kept to a minimum thereby giving economy fast response and reli ability. Chapter 4 deals with the design and development of a 3 zone single phase relaying scheme using logical techniques. It presents a new operating strategy and a novel way of automatic zone changing and a novel way of providing signals for 3 zone ope ration. The present work is an improvement and simplification over the relay proposed earlier. CMOS logic gates and digital IC's are used to give

getter noise immunity. The relay uses 2 input transient free, 90 o block average coincidence comparators with c onstant operating time of 15 msec. Any where upto the balance point. Variable angular criteria can be used by the change of clock frequency and thereby shaping the characteristics. Scheme - I provides the classical characteristics in zone I and zone - 2 but el liptical characteristics in zone – 3. The same relaying scheme is extended to work as a 3 - zone polyphase relay by the triplication of single phase units. Multi input comparators are used to produce modified mho characteristics as proposed by scheme – II. Th e scheme III proposes a 3 zone polyphase relay which produces a quadri lateral characteristics by using 3 signals only. All these 3 schemes are effective for all types of shunt faults on 3 phase lines. The steady state and dynamic performance of these sche mes is tested phase wise, and operation of 3 zone polyphase relay is found to be satisfactory. Chapter 5 describes the design, development and the fabrication of a single phase Dynamic Test Bench which is used to predict the performance of the proposed r elays. It represents the scaled down model of the power system, with built in pint on wave selector' and digital time interval meter. Any type of fault condition can be simulated on it and, the relay performance with respect to range and switching angle of fault current, can be checked. The overall accuracy of the dynamic test bench is better than +5% and each unit has an accuracy of +2%. Finally, the concluding chapter 6 gives a brief review of the work reported in the thesis and suggestions for further s cope of work.

For more details click here   Back

Title   :   *Application Of Topological Energy Functions For The Direct Stability Evaluation Of Power Systems*
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Abstract

With the increasing growth of modern interconnected power systems, the stability investigations assume greater significance in planning, design and operation of these systems. Power system stability is a single entity; but for the purposes of analysis, it is classified as 'transient stability' and 'dynamic stability'. The former refers to the stability of the system under large disturbances such as faults and the latter to the stability under small perturbations caused by random load changes. The transient stability analysis deals with non-linear mathematical models. The conventional methods of stability analysis rely on digital simulation and explicit evaluation of swing curves. However, this approach can be time consuming, particularly for real time dynamic security analysis. Hence 'direct' methods for stability analysis have been developed based on Lyapunov functions. Although much work has been reported in this area, the application of this method is limited by (i) the computational burden in computing stability regions, (ii) conservativeness of results, (iii) the problem of transfer conductance's, and (iv) the use of simple (classical) models of generators and loads. Recent work is directed in removing some of these limitations. The use of energy functions in Centre of Angle (inertia) variables and the concept of controlling unstable equilibrium points (uep) has eliminated much of the conservativeness of the results. Approximation in evaluating uep's the application of Potential Energy Boundary Surfaces (PEBS) method have simplified the computational effort required in determining the stability regions. The problem of transfer conductance's can be reduce using the 'Structure Preserving Model' in which the topology of the system is preserved. This also facilitates the use of more detailed load models and is also convenient from the point of view of real time dynamic security assessment. The energy functions using structure preserving model can be termed a 'Topological Energy Functions'. There is not much work reported in this area. The objectives of this thesis are: 1) Development and application of topological energy functions for direct stability analysis of power systems, considering more realistic models for generators and loads; 2) Extension of the structure preserving energy function and its application for direct stability evaluation of AC/DC systems. The major contributions of the thesis are listed below. i) Topological energy functions are developed and applied for the direct stability analysis of power systems with non-linear voltage dependent loads, a) Considering classical model for generators, b) Considering flux decay, the transient saliency in generators along with excitation system and voltage regulator. ii) A fast method of solving power flow equations during transient has been developed and applied for the direct stability analysis of a class of power systems. iii) Direct stability evaluation using topological energy function has been extended to power systems with D.C. links, with realistic models. An outline of the work reported in the thesis is given below. 1) The first chapter introduce the various aspects of direct stability analysis of pure A.C. and AC/DC power systems and presents the state of art in this area. 2) The chapter 2 presents the

development along with the application of topological energy function for the direct stability evaluation of power systems. Classical model for the generators has been assumed. The loads are modeled as arbitrary functions of respective bus voltages. The system equations are formulated in Center of Angle (COA) reference frame. PEBS method is used to determine the critical transient energy. Procedure proposed here has been demonstrated on two multimachine power system examples. The results indicate that (i) even for constant impedance type of loads, the topological energy function gives better results than those obtained with reduced network, (ii) the effect of voltage dependent active power loads on the region of stability is quite significant and thus cannot is ignored. The voltage dependent active power loads introduce path dependent term in the energy function. Approximations in evaluating the critical energy by ignoring this term appears to be sufficiently accurate. 3) A fast method for evaluating the transient stability of power systems using topological energy function is presented in Chapter 3. With non-linear voltage dependent loads, the computation of faulted trajectory requires iterative solution of network equations, which is time consuming. In this chapter, a non-iterative method for solving power flow equations is introduced. This is applicable to the case when the load buses are uncoupled and for a class of non-linear voltage dependent loads. Unlike in earlier methods. The problem of convergence in the network solution algorithms can be avoided. A power invariant transformation, which leads to the decoupling of load buses in a practical system with connected load buses, is presented. Although load characteristics become more complex under this transformation, approximation can be introduced which facilitates the analysis. The method is illustrated by numerical examples and encouraging results are obtained. 4) The principal aim of the chapter 4 is to investigate the stability of power systems considering higher order models for generators with excitation systems. Using COA formulation, a topological energy function is developed to incorporate flux decay, transient saliency, AVR and exciter. The investigations are carried out on a 4-machine system example. The critical clearing times predicted are in close agreement with those obtained from digital simulation. The prediction from the energy function corroborates the results obtained from digital simulation that the saliency and the inclusion of controlling devices increase the region of stability. 5) The extension of energy function for evaluating the transient stability of AC/DC systems has been attempted in Chapter 5. A performance model for d.c. Link is assumed, where the dynamic complex load at the converter terminals is obtained from algebraic equations governing the converter operation. The D.C link current is determined as the output of dynamical system representing power and auxiliary controllers. Two types of controllers have been considered: (a) an auxiliary controller which modulates D.C. power in response to bus frequency signals from the a.c. system; (b) an emergency controller in which the reference current is changed in a ramp-fashion when a disturbance in the a.c. system is sensed. The dynamic loads due to d.c. link introduce time dependent integral term in the energy function. This is numerically integrated using trapezoidal rule in evaluating the energy. Stability analysis is illustrated with a 3-machine power system example. 6) The concluding chapter summarizes the research results and indicates the directions for further work.

For more details click here   Back

Title   : *Analysis of Subsynchronous Resonance And Its Control Through Excitation System*

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Abstract

Everincreasing power demand is forcing electrical utilities to search for 'economical methods of transmittinglarge blocks of electrical power from generating stationsto load centres. Series capacitor compensation of transmission lines offers an economical proposition to increase power transfer ¦ capability of the'existing lines* ,"When' compared'to other alternatives of'increasing'transmission capability,viz• additional transmission lines, higher ' voltages and H»V*D«C»'. transmission, the initial capital cost using 'Series capacitor is much lower* Series capacitor compensation is also better^ from the point of •overall economics,' system performance, and envirormental intact..:'Series capacitor application in long distance transmission lines, however, may result in subsynchronous resonance• Subsynchronous resonance got great attention during the last decade because of the two incidents of turbine-generator shaft failures at Mobave on Dec*9> 1970 and Oct* 26, 1971* Both the incidents had .resulted from the self excited torsional¦frequency oscillations of the turbine-generator shaft caused by unstable bilateral coupling between the series capacitor compensated electrical system and the generator shaft mechanical system*While the problem of subsynchronous oscillations dueto series capacitor was envisaged as long ago as 1943 by Concordia et,al«, adequate attention ^as .not paid to include the generator shaft dynamics which was mainly responsible for subsynchronous resonance, until the incidents of shaft failure at Mohave took place. Since then the research has been done to investigate the,factors responsible for subsynchronous resonance ami',means to mitigate it. , Shaft torsional modes and induction generator effect of the synchronous machines have been found responsible for subsynchronous resonance* 'Filters and supplemental excitation damping coMrol , have been used'to mitigate subsynchronous resonance* .Feedback signals such as'reactive, power, active power'and'field current have'been suggested ,,' In^; designing, the,'contr,oller.'¦¦'.'While there are several publications on subsynchronous resonance,a detailed study of the control problem of SSR based on modern control theory is not reported* Also the general formulation of a detailed system model, that is suitable for investigation of subsynchronous resonance in multimachine system is lacking• While the frequency scanning technique has been used for prediction of subsynchronous resonance instabilities in large systems, it utilizes simple models of generators and very approximate determination of the influence of shaft torsional modes.. There is a need for evaluating the relative contribution of the induction generator effect and shaft torsional'system to subsynchronous resonance to get an insight into the phenomena and suggest countermeasures to

overcome su'b-synchronous resonance instability.The objectives' of '^the work reported in this thesis are ':1. ¦ A systematic development of a mathematical model' for'the study of 'the phencmenon of subsynchronous .resonance in the system which is easily adaptable to large multi-machine ¦ systerns•"2«. Development:of suitable controllers using .complete' state feedback... signals .or,'output ..feedback signals' . through'"ejc citation, system,, of the generator to ¦mitigate •', ^the ,:adverse: effects ¦of,'., subsynchro^nous re.scnance..'^3. Investigation for the use of frequency response techniques as a quick check of subsynchronous resonance instability and in determining the part played by the various components 'in this*Major contributions reported in this thesis are as follows :1. A mathematical model of the electrical power system . has been developed through building blocks of its subsystems* models? This permits readily its extension to large systerns• The model has been utilized to highlight the various factors contributing to the subsynchronous resonance in the system,2m Suitable controllers using complete state feedbacksignals and output feedback signals have been designed. The selection of the control signals for the outputfeedback has.been achieved through eigenvalue sensitivity analysis.' A technique has been developed for the optimization of the perforoance index'through'linear programming method in the design of optimal controller using output feedback.3. The method of frequency scanning technique has been •extended .to investigate the stability of. the .system incorporating all the details -of the generator models which brings out the part;played by'the various ¦ cOTip'Ononts 'in; the "subsynchronous' instability.. 'An outline of the work reported in this thesis is given below.The first chapter introduces the various aspects ofthe problem of subsynchronous resonance in series capacitorcompensated long distance transmission systems and gives a brief review of the literature in this area* The objectives and the scope of the thesis are given alongwith a briefoutline of the subsequent chapters.Chapter %mo deals with the foriHulation of suitable mathematical model of the power system for subsynchronous resonance studies and, investigates the various factors which can lead to the subsynchronous resonance in the system* The formulation of the mathematical model of the system has been made in such a way.that'.it can be easily• adapted for large systems^ The development of the mathematical model has been achieved by modelling various subsystems separately •.and interconnecting, through interface variables• The sta-, bility studies of the" system are'carried out through eigenvalue analysis^ The influence of the compensating capacitor, series resistance, exciter gain, pcwer system stabilizer gain ,and the mechanical damping on the subsynchronous resonance oscillations has been brought out» .Possibility of excessive' shaft .'torques due^ to,•.•subsynchronous ¦o,scilla-. tions^, even', when.• the • system is 'Stable, Is investigated^ ¦Chapter three O'^utlines the design of an auxiliary feedback controller in the excitation system to mitigate the problem of subsynchronous reso^nance. P61e assignment technique has been used in'designing the•controHers• Two types of controller design have been investigated, one based on the complete state feedback and the other based on output feedback* The complete state feedback controller is designed based on modal control theory* As the complete state feedback is not feasible in practical system, the use of partial state feedback signals that^are locally available-are investigated. The selection of control signals is based on

eigenvalue sensitivities* The. results obtained from stabilization scheme using partial state feedback are compared to those obtained using modal control*Chapter f o^'ur deals with the application 'of linear regulator theory for the design of controllers* Two controllers have been designed, one using the complete state feedback and the other using"the output feedback, . The feedback controller design based .on minimizing the 'integral of the squared, ' transient shaft torque- deviations gives ¦ satisfactory results* Optimal control using output feedback is equivalent to, parameter op timiz at ion* A technique based on .sequential.linear •programming is proposed for•the selection.' of; controlle.r .gains to, minimize'the ¦porformance index.Chapter five describes the use of frequency response methods in studying the stability of the system and in investigating the part played by various subsystems insubsynchronO'Us resonance instability^ Two methods of frequency response technique have been used^i) Generalized Nyquist criterion for multivariable system for studying the stability of the system*ii) Frequency scanning technique based on the calculation of cc-axis impedances has been used to investigate the stability of the system and the part played by various components of the system* A method has been given to determine the accurate a-axis impedance of the generator represented in full datail• It is based upon the total power input to the generator at different frequencies. The part played by the torsional modes of the shaft system and induction generator effect has been investigated*.The sixth Chapter outlines the conclusions drawnfrom ttiis thesis'and gives suggestions for'further ¦ work In' this area*.

For more details click here   Back

Title : *Analysis Of New Types Of Waveguide And Microstrip Discountinuity Structures And Their Practical Applications*
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Abstract

Coaxial lines rectangular waveguids and microstrip lines are the most widely usedmicrowave transmission lines while coaxial lines and waveguids have been in use sincelong and still continue to be an integral part of a typical microwave ate up the emergenceof microstrip line (and other MIC's) is a corporately recent phenomenon. The MIC'Soffer advantages like reduction in volume and weight and improved reliability and lowcost of production when produced in mass .The interest in waveguids and coaxial lines isbeing sustained by factors like their higher power handling comparability comparativelylow power loss etc. An abrupt change in the configuration of a transmission line is trend 'discontinuity'.The discontinuities are either deliberately created or are necessitated by some otherconsiderations. In the first category one can mention elements in the line changes in oneor more dimensions or in the medium of the line so as to match it to a given load or termnation etc. In the second category fall discontinuities like beads needed to support theinner conductor in a coaxial line metallic posts needed to mount an active device across awaveguide microstrip gap used for D.C. blocking etc. Besides the above-mentioned discontinuities the junctions of similar/ dissimilar linesconstitute another very important class of microwave transmission line discontinuityproblems. The junctions of similar lines are used primarily for the production of non-reciprocal components like isolators circulators tees directional couplers etc. The junctionof dissimilar lines are needed to serves are a means of launching the electromagneticenergy from, one line into the other. The objectives of this thesis are:i) To present the electromagnetic analysis of some new types of discontinuityproblems involving coaxial-waveguide and coaxial-microstrip junctions and toinvestigate their practical applications andii) To investigate both theoretically and experimentally the case of a microstriop lineloaded in the transverse plane with a than cylindrical metallic post and suggestareas of application of this new configuration. A brief chapter wise description of the work reported in this thesis is given below;1. The first chapter briefly traces the origin and growth of the field ofmicrowave transmission lines and their discontinuities. This chapter alsohighlights the salient features. From the point of view of partial application ofthe work reported in the thesis.2. The second chapter besides introducing in brief the basic concepts anddefinitions used in the gives an overview on microwave transmission linesand their discontinuities on microwave transmission lines and theirdiscontinuities. Various discontinuities in coaxial waveguide and microstripforms are discussed. The junctions of similar /dissimilar lines are alsodiscussed. Particular attention is paid to problem s that are relevant to thework reported in this thesis .A section on methods of experimental evaluationof microwave transmission line discontinuities is also included.3. The junction formed by a coaxial line entering the broad wall of rectangularwaveguids has been and continues to be, a subject of study (see, e.g., [1]-[3]).This junction is used mainly for coupling the electromagnetic energy from thecoaxial line into the wavelength or vice versa .A useful modification of thisjunction results if we a mobable short-circuit were present in the coaxial linei.e. if we let the coaxial line be tunable. The junction of a tunable coaxial lineand a rectangular waveguide has some well-known uses e.g. for matching

thecoaxial line to the waveguids and the by maximizing the power coupled [4]as a power combining element [5] etc. The utility of this junction wassignificantly enhanced when it was successfully used fir experimentalevaluation of complex permittivity of dielectric samples [6] .The thirdchapter of the thesis examines this junction from one more different angle i.e.from the viewpoint of its applicability to microwave filtering .Two differentversions of the junction are analysed. The first called the 'short-circuitedcaser is the case when the tip of the probe is allowed to touch the bottominner wall of the waveguide. The second called the air-gap case is the casewhen an air-gap is allowed to exist between the tip of the probe and thewaveguide wall. The analysis of these configurations is complicated by theadditional boundary condition that the movable short impose at the junctionplane. The analysis is done under some suitable simplifying assumptions,which help in obtaining a closed-from expression for the transmissioncoefficient between the waveguide ports [7] –[10]. Both the short-circuited and air-gap cases exhibit a sharp transmissionminimum, which can be tuned all over the operating band of the waveguide byvarying the position of the movable short. Consequently these structures will findapplication as new types of prototypes for developing waveguids notch filters andwill be especially useful when one is interested in achieving a large continuousmechanical tenability. The third chapter also presents the results of the experimentation that was takes upon the filtering behaviour of the above-mentioned configurations. It is seen that theundesirable pass band ripples that these configurations exhibit can be brought down to anacceptable level thought the use of an extremely thin (electrically) probe. Detail theoretical results describing the dependence of the filtering parameters (i.e. thepeak indentation loss Q's and the skirt selectivities) on the physical parameters (e.g.waveguide dimensions probe radius characteristic impedance of the coaxial line etc.) arepresented graphically. One of the crucial assumptions made in the above mentioned analysis was theneglect of higher-order waveguide modes while writing the total excitation field along thelength of the probe. In the last section of the third chapter an attempts is made toincorporate the effects of the first higher-order mode in the analysis. Only the short-circuited case considered .It is seen that although in principle it is possible to go onrefining the analysis for more and more higher-order modes he tremendous increase inthe amount of algebra involved with the inclusion of each new mode (and still moreheavy work for the air-gap case) make this effort rather impractical. Also it should benoted that for obtaining a partially acceptable performance of the above-mentionedconfigurations use of extremely thin probes is in any case mandatory in which case theanalysis presented in the earlier sections is sufficiently accurate. The analysis reported inthe last section may thus be viewed as a rather revealing academic exercise. 4. Thejunction of a tunable coaxial line and a rectangular waveguide, which was examined inthe third chapter for its filtering aspects, has been re-examined in the fourth chapter. Theemphasis now is on its applicability as methods of experimental evaluation of waveguidemounts. Lewin's formulated for a singly-loaded E-plane waveguide metallic post [11] hasbeen extended to the configuration under consideration .The advantage of thisformulation is that unlike the analysis presented in the third chapter the effects of allhigher-order waveguids modes excited in the velocity of the post can easily incorporatedin the analysis .A comparison between this formulated and the one presented in the thirdchapter is made .As expected the results given these two different appropriates tally forthinner posts . Analysis reveals that the positions of the movable short for minimum and maximumtransmission between the waveguide ports can be correlated to the parameters of the postby means of simple explicit equations .As a result a very useful method for experimentalcharacterization of waveguide posts results .In Comparison with the existing methodsof this kind the present method is superior in the following respects;i) No electrical measurements are needed thus the error s encountered in electricalmeasurements, e.g. unwanted reflections at various junctions poor instrumentsensitivity etc., are completely eliminated.ii)

An explicit measurement of the unknown parameters is possible.iii) The configuration used is simple and easy to implement.iv) The working equations are quite simple thus obviating the need ofgraphical/semi graphical/computer-aided analysis of the measured data. The above-mentioned method is applied to there different posts [12]. Agreement with thetheory id good .An extension of the method for characterizing doubly loaded posts isformulated. Application of the method for characterizing broad wall coaxial-waveguidsjunctions is discussed.4. In the fifth chapter the junction formed by a tunable coaxial line entering amicrostrip line through the ground plane is analysed .The planar waveguidsdispersion model [13] is used for the analysis as this model suits thegeometry of the problem involved, The analysis runs along lines similar tothose followed in the third chapter. This configuration also exhibited acontinuously tunable sharp transmission minimum, which can be exploitedfor developing micro strip notch filters with large continuous mechanicaltunabilities. Of the various methods that are used to feed a micro-strip line from a coaxial input thebroad-well launching is an important method. This method becomes especially useful ifsmall ground-plane spacing is involved and if frequencies above S-band are not used .Inthis method the coaxial is mounted on the ground plane of the microstrip line. And theinner conductor of the coaxial line penetrates the substrates through a cylindrical hole tofeed the strip. Although some discussion on this type of launchers is available in theliterature [14], no directly usable results on the input impedance seen by the coaxial line(which is a very important parameter in the design /analysis of any coaxial-microstriplauncher) in such a launcher seem to have reported so far .The fifth chapter of the thesisreports an investigation on this impudence .The aforementioned analysis of the broad-wall junction of a tunable coaxial line and a microstrip line is used for this investigation.The theoretical resonance condition (which is also experimentally verified for twodifferent sets of parameter values) obtained by the analysis establishes after properinterpretation that the feed-wire in a broad-wall coaxial –microstrip launcher can beassumed for the purpose of writing its input impudence to act as a thin wire antennaradiating in an unbounded homogeneous dielectric-filled space [15].6. The sixth chapter analysis the case of a microstrip lines loaded in the transverse panewith a thin cylindrical conducting post. Once again the planar waveguide model [13] isused for the analysis .As expected it is found that the post offers an inductive reactanceacross the microstrip line .The mathematical expression for this reactance ids worked out.Theoretical results describing the dependence of this reactance on the various parameters(i.e. aspects ratio of the microstrip post diameter and dielectric constant of the substrate)of the configuration are presented graphically .The experimental verification of thetheory is done by forming a resonant structure consisting of a microstrip open-end/gap(which can be characterized by available methods) and the unknown post and noting thefrequency of resonance of the resulting configuration] 16] . The configuration analysed in the sixth chapter provides one with an easy means ofsimulating parallel reactances in a microstrip/stripline and will find an extensiveapplication in the design of the microstrip /stripline filters impudence-matching sectionsetc. Where parallel reactances are required .The analysis reported in this chapter will alsohelp in the design of some microstrip-slot line transitions which involves the use of atransversely placed metallic wire [17]). 7. The seventh chapter of the thesis concludes the work by highlighting the variousimportant results obtained and their potential for practical applications.

For more details click here   Back

Title   *: Origins Of Excess Forward And Reverse Currents In Silicon Diffused Junction Solar Cells*
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Abstract

For more details click here   Back

Title   :   *Ultra High Speed Protective Relaying Schemes For EHV/UHV Transmission Lines Based On Travelling Wave Phenomena*

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Abstract

It has long been recognized that the ultra high speed(UHS) clearing of faults on a transmission line improves the transient stability. .The fault clearing time being dependent on the speed of the protective rel.ay as¦ well as that of the associated circuit breaker^ and with the emergence of. UHScircuit breakers, the need for developing UHS protective rela.ys has become' imperative* The realization of UHSprotective relays,, for the protection of EHV/UHV transmission lines, has been.possible with the utilization of the travelling wave characteristics^'The development of protective relays^ based on travelling wave phenomena, is of very recent origin. Thefirst tr.avelling'wave relay was' developed by'ASEA^ Sweden, and was ,installed on .Bonneville-, power Administration's (US.A) ¦500' KV', system in April 1976. Since..then,' a few othertravelling wave relay schemes have been proposed* Almost,all of these schemes necessitate the use of a fast communication channel for internal fault detection. And, two of these schemes possess the fault locating feature, but involve in cumbersome computational procedures* Therefore, there is a need for a travelling wave relay scheme, vv'hich can detect an internal fault without the aid of a carrier communication channel so that the operating time of the carrier communication equipment is eliminated, and which incorporates a simple fault locating feature*For the development of high speed and UHS protectiverelay schemes,, an accurate determination of the complex post-fault current and voltage waveforms'is essential* For this purpose, accurate modelling of power .systems and fault analysis techniques, suitable for digital simulation, are necessary* So far,, only Johns and Aggarwal have developed techniques for the analysis of faulted power systems incorporating exact models of teansmission lines* However, these techniques would be applicable, with ease^ only to simple power systems*It is well-known that the 'use of digital computers, for protective relaying purposes, offers several advantages* The digital distance algoritlms, proposed fox the ¦protection .of 'tra.nsmission lines,- require the elimination, of d*c. offset. and also a wide spectrum of non-fundamental frequencycomponents with the help of digital filtering and data fitting techniques, a task that entails considerable time delay if adequate accuracy were to be achieved^ On the other handy the adoption of travelling wave techniques, for the digital protection of transmission lines, needs the elimination of only the profault components, since the travelling wave relays use only the fault-generated compo-nentSi, Also, only a short data window is required, and this leads to a higher speed of fault detection* Very few papers have dealt with the development of digital travelling wave relay algorithms* Takagi et al» have proposed a digital travelling wave relay, which involves in the exchange of .quantitative information between the ends of the protected line and consequently, imposes demanding requirements on the communication channel# Hence, thero is a need for, developing simpler digital travelling wave relay .algorithms*Accordingly, the primary objectives of this thesis have been as given below*1* To generate a simple mathematical model, for a longEHV/UHV transmission line and to develop fault analysis techniques, which are•suitable for frequency domain methods of computing transients in complex

multinodo pQwer systems^2ii To propose a new and simple travelling wave relaying scheme for the protection of EHV/UHV transmission lines#3» To develop a new travelling wave relaying scheme^ for the protection of EHVA^HV transmission lines, which can detect internal faults without the aid of a communication channel and vihich embodies a simple fault locating technique, and4.» To develop simple digital relgiying algorithms, 'based on travelling wave phenomena^i^An outline of the work reported in the thesis is given below»Chapter 1 presents a brief and critical review of .the important literature pertaining to the evolution of distance, travelling-wave and computer relaying schemes developed for the protection of transmission lines*Chapter 2 starts with an overview of some importantaspects of generating the distance relay characteristics, suitable for the protection of long and heavily-loaded EHV/UHVtransmission lines, which are given in the literature.. The theory, principles of operation, d-?'tails of hardware implement* tation and test results of two new distance relaying schemes, fabricated with Integrated Circuits and capable of generating a suitable threshold characteristic, are also presented in this.'chap ter%'In Chapter 3, an accurate frequency-domain Pi model of a transmission line and frequency-domain nodal analysis techniques, suitable for the analysis of faulted multinodepower systems, are developed. An important feature of the fault analysis techniques is the use of frequency**domain bus admittance matrix* These form an important basis for the digital simulation of faulted EHV/UHV neta^/orks* The utility of the Pi model of the line and the application of the fault analysis techniques are illustrated by computing the voltages and currents at a chosen point in tvw sample power systems for symmetrical three-phase and also for one phase to ground fault$¦•Chapter 4 presents the development of^ and testresults pertaining to, two new travelling wave relay schemes* In one relay scheme, the amplitude comparison ofeach of the three pairs of modal relay input signals is utilized to distinguish betv/een, the reverse and forward faults* Tripping is initiated only^ if the fault is found to be forward at both the ends of the protected .line.In the other scheme,, one relay input signal, (for each mode) is usGd for detecting reverse faults? Under reverse fault conditions, tripping is blocked at the remote end^ with the aid of a fast communication channel, and also at the local end directly^ By making use of the first, and if necessary the second, time derivatives of the other inputsignal, (for each mode), the instants of the first andsecond incidences of the backv/ard travelling waves, at the relaying point, are determined* The time interval betv^een these two instants is equal to twice the travel time of the waves between the fault and relaying points* Thus, the detection of an internal fault as well as its location are accomplished v^ithout the aid of exchanging information between the two ends of the protected line*Both the relaying schemes cater to all types of faultsand hence, can be regarded as a novel type of polyphaserelays* The underlying principles of^both the schemes are validated by the results obtained through digital simulation studies conducted on .sample pov/er systems for various conditions and two types of faults^In Chapter 5, the algorithms for the digital computer application of the amplitude-comparison and fault-*locating relay schemes, described in Chapter 4, are developed* The cycle-to-cyclG comparison method, proposed by Mann and Morrison, is adapted as a simple digital filter for remeving the prefault components* The viability of these algorithms is tested on the digital computer, DEC System 1090- at I*I*T«, Kanpur, by using realistic fault data obtained from^ the digital simulation of sample power systems# The results of these tests have demonstrated the viability of theproposed algorithras* In the beginning of the chapter,a brief overview of digital distance algorithms is presented in order to bring out their relative meritsand demerits*The thesis concludes with Chapter 6y wherein ibrief review of the work carried out in this thesis"and suggestions for further v^/ork are given*spectrometer interface which has

Title   : Fully Cntrolled Converters With Controlled Flywheeling
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Abstract

Single-phase half controlled converter system has many advantages over the fullycontrolled converter system expect that it cannot operate in the inversion mode. Theadvantages of half controlled converter can be combined with two quadrant operation byemploying the technique of controlled. Flywheeling in fully controlled converter [1,2].In the three phase case the performance of half controlled system is inferior than that offully controlled converter because of the larger load current ripple and percentages ofsource current harmonics. However the technique of Controlled Flywheeling in the fullycontrolled converter makes the system performance better than both half controlled andfully controlled converter [3]. In the present thesis the details of advantages of employing controlled flying invarious single phase as well three phase converter circuits for a dc separately excitedmotor load are examined and compared with conventional technique). The technique(which is termed as Normal Control technique) .The various converter circuits underconsideration are listed below.i) Single phase converterii) Single phase two stage sequentially controlled converteriii) Three phase converteriv) Single phase circuiting current dual converterv) Three phase circuiting current dual converter. The study covers various aspects of system performance, which includes speed-torque characteristics armature current ripple overall power factor system efficiencysource current distortion factor and source current harmonics. It has been observed that in comparison with the normal system efficiency andpower factor reduces the armature current ripple. /The percentage of source currentharmonics increases with controlled flywheeling though the increase in thepronounced in the higher frequency range. However in the case of circulating currentdual converters it has been observed that the lowest of the source current harmonics(third harmonic in the single phase case and fifth harmonic in the three phase case)actually decrease with controlled flywheeling. A noted observation in the case of single phase dual converter is that in spiteof the reactor being very large the system efficiency is very low for both controlledflywheeling and normal control waveform both the converters do not conduct as thetime but conduct alternately. Since two halves of the reactor is tightly coupled thearmature current is forced to alternate in direction when the two converters conductalternately. This results in unusually large r.m.s. Values of armature current as wellas circulating current to obtain a relatively small value of average armature current.Therefore the copper loss in the system becomes very high reducing the systemefficiency. In the systems considered above the armature current ripple is an importantfactor as it the system efficiency machine commutation and derating of the motor aswell as thyristors. Also when the current becomes discontinuous the speed-torquecharacteristics get adversely affected. Therefore a method is described to chosen

anoptimum value of filter inductance so that the armature current remains continuous inthe entire range of motor operation and that the magnitude of armature current rippleremains within the permissible limits. Normalised nomograms to choose an optimumvalue of filter inductance are provided for case controlled flyweeling and normalcontrol techniques for case (I), (ii) and (iii) listed above .In each case the optimumvalue of filter inductance for controlled flywheeling is substantially lower than thatfor normal control technique. Firing circuits for the technique of controlled flywheeling are developed andthe analytical results are experimentally verified for the cases (I), (ii), (iii) and (v)listed above.

For more details click here   Back

Title : *Broadband Microstrip Antennas Using Coupled Resonators*
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Abstract

Microstrip antennas usually employ two-dimensional microstrip-like resonator structures* They are light in weight, have small volume and low-profile planar configura tions which can bo made conformal* The major shortcoming of these antennas is their narrow bandwidth. A commonly used definition for bandwidth is the frequency range over which input VSWR is less than two* A rectangular patch antenna has a bandwidth of the order of 4 percent at 3 GHz (substrate thickness h =» 0*318 cm and er » 2#55). Bandwidth of the antenna can be increased proportionately either by increasing the substrate thickness or by reducing the dielectric constant* However, the increase in substrate thickness is generally limited by excitation of surface waves and there are practical limitations in XX decreasing the value of dielectric constant* Thus,, the bandwidth realized is not sufficient for many purposes* A few configurations for improving the bandwidth have been reported in the literature* An improvement of 20 percent in the bandwidth has been obtained by using trapezoidal structures instead of commonly employed rectangular structures* The bandwidth of the antenna can be nearly doubled by placing quarter wavelength short circuit parasitic elements adjacent to the radiating edges of rectangular patch element or by placing parasitic strips parallel to the non-radiating edges of a patch antenna. Single food has boon used in those antenna structures* The bandwidth of the antenna can bo increased manyfolds by employing multi-fed microstrip antenna arrays in log-periodic or quasi-log-periodic configuration* In the present thesis, various configurations yielding broader bandwidth, from single fed antennas arc proposed* Those are t radiating edges coupled, non-radiating edges coupled, and four edges coupled microstrip antennas• The mechanism of the coupling between the resonators can be either gap coupling (two resonators being placed in close vicinity) or direct coupling (two resonators are connected by a short line section)* These antenna stru ctures arc analyzed and optimized using Green1s function approach with segmentation method* In segmentation method, XXI a structure is divided into segments for which impedance Green1s functions are known* In gap coupled configurations• the gap between the coupled resonators is modelled as a capacitive n;-network* The value of these capacitances is calculated by using formulas available for asymmetric coupled microstrip lines * This capacitive network model for the gap becomes one of the segments in the segmentation procedure, All series capacitances are shunted by condu ctances to account for the radiation from the gap* Based on these designs, extensive experiments have been carried out around 3 GHz frequency by fabricating more than fifty antennas on polystyrene substrate (e « 2*55)• In radiating edges gap coupled microstrip antennas, two resonators of slightly different lengths (approximately half wavelength) and widths equal to that of rectangular patch antenna* are placed adjacent to the radiating edges of rectangular patch element. Lengths of the parasitic elements, gap-width between the resonators, and location of the feed-point are optimized to yield maximum bandwidth* The bandwidth of the antenna obtained experimentally is 330 MHz (« 10 percent) for h «

0*159 cm and 510 MHz (w 16*9 percent) for h » 0*313 cm* which is 4*2 times the bandwidth of rectangular patch antenna (BW - 121 MHz)* XXLL In the non-radiating edges gap coupled antennas, two resonators of different lengths (nearly half wavelength) arc gap coupled to the non-radiating edges of rectangular element. The experimental bandwidth of the antenna is 225 MHz for h = 0.159 cm. and 480 MHz for h = 0.318 cm. In this configuration, the gap-width between the resonators is found to bo much smaller (*~ 0.2 to 0.3 mm) than that of radiating edges gap coupled antennas. Because, in the non-radiating edges couplod case, field varies along the coupled edges, so coupling will be less for any specified gap-width as compared to the radiating edges coupled case where the field Is nearly uniform along tho coupled edges. Four edges gap coupled antennas consist of four parasitic elements which are gap coupled to all the four edges of a rectangular patch element. The lengths of the parasitic elements placed along the non-radiating edges are taken equal. Experimental bandwidth of the antenna is 815 MHz (= 25*8 percent) for h = 0.318 cm, which Is 6.7 times tho bandwidth of rectangular patch antenna. In radiating edges directly coupled antennas, two resonators of different lengths arc directly coupled to tho radiating edges of rectangular patch element through a short microstriplino section. Tho parameters optimized are s lengths of the parasitic elements, location of the xxili food-point, length and width of the connecting strip* Bandwidth of the antenna is 550' MHz (» 17*1 percent) for h = 0*318 cm. In case of non-radiating edges directly coupled and four edges directly coupled antennas, additional resonators arc directly coupled to non-radiating edges and all the four edges of rectangular patch element respectively* In the latter case, the resonators placed along the non-radiating edges are of equal lengths* As the field varies along the non-radiating edgesf the coupling will be more if the connecting strip is located at higher field point* So* the locations of the connecting strips along the non-radiating edges become additional design parameters along-with the other parameters of the radiating edges directly coupled antennas* Experimental bandwidths of the two antennas are 600 MHz (« 18*2 percent) and 810 MHz (« 24 percent) respectively for h = 0*318 cm* A comparative study of those antenna structures points out that the 'four edges gap coupled and directly f coupled antennas yield largest bandwidth* These designs help in overcoming the narrow bandwidth limitations of microstrip antennas.

For more details click here   Back

Title : *Digital Simulation And Stability Analysis Of Multiterminal HVDC Systems*

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Abstract

In recent years, high voltage direct current transmission technology has made rapid strides and is continually advancing. Although the operation of two terminal HVDC systems is fairly well established. Attempts are being made to improve its performance through use of better and sophisticated converter controls. Also, there has been increasing interest in the planning of multiterminal DC transmission schemes as this provides more flexibility and advantages than its two terminal counterparts that are in existence. The system planning and design for AC/DC systems require analytical tools to study the operation and control of HVDC systems. The steady state operating point in a HVDC system is determined from the load flow calculations of the integrated AC/DC system. The performance of the HVDC system depends to a great extent on the converter control system. In order to evaluate the control response, it is necessary to investigate the dynamic behaviour of the system and HVDC simulators have been traditionally used for this purpose. Undoubtedly much insight into the system performance can be gained through DC simulator, but it has been limitations of flexibility and cost in representing a wide variety of system configurations and control alternatives. Thus, digital simulation is being considered to supplement HVDC simulator. However, this requires a detailed representation of the converter, its associated control system and AC and DC networks. While dynamic simulation is useful for control optimization, it is necessary to investigate the operating point stability of the DC poser system for the design of the controller. This led to the development of linearized DC system model to describe the system dynamics about a steady state operating point following small disturbances. The AC system representation should also be considered in the stability analysis to account for the interaction between the ac and dc systems as it influences the controller design. The above studies have been reported in the literature mainly with reference to two terminal systems. Although, load flow analysis and digital simulation of multiterminal systems have also been attempted, it has not received considerable attention. A general formulation of the system model for stability analysis of multiterminal systems is not available in the literature. The objective of the work reported in the thesis are: 1) Development of methods and models for the load flow analysis, digital simulation and steady state stability analysis of multiterminal HVDC systems. 2) Investigation of the AC system influence on the dynamic behaviour and stability characteristics of HVDC system to evaluate the control strategies. The major contributions of the thesis are as follows: 1) A simplified analysis of the dc system for the load flow studies of integrated AC/DC power system. 2) A technique for the detailed digital simulation of HVDC systems using a novel converter representation based on graph theoretic framework. Considering a modular approach to system simulation, a computer program is developed which includes a detailed representation of the converter controls and the AC system. 3) Development of a systematic procedure for operating point stability analysis of HVDC systems both in time and frequency domains. A now discrete time converter model is proposed for this purpose. A suitable model of the AC system feeding the converters is also derived alongwith that of the controller which allows a detailed investigation of the various aspects of stability

even for multiterminal systems. A brief description of the work reported in the thesis is given below: 1) The first Chapter introduce the various aspects studied and reviews the literature in the area. 2) The chapter two deals with the load flow analysis of the multiterminal HVDC/AC systems. In the DC system representation unknown variables are assumed as DC current, transformer tap ratio and firing angle for each converter except when the converter is operating at either constant current control or constant angle control. While the dc network equations are used to determine the current, the transformer tap ratio and the firing angle are determined from the operating constraints at each converter. For the load flow solution of integrated AC/DC system, the equations for the respective system are formulated and solved separately and interfaced at the dc terminal buses. The computer program developed for the purpose is tested on some sample systems. 3) A novel converter representation based on graph theoretic analysis is introduced in Chapter three for digital simulation of HVDC systems. The approach leads to an efficient formulation of the converter state equations corresponding to all possible modes using simple cutest matrices. For the representation of the multiterminal systems, the approach employed is to model each component separately and in a modular fashion. These models are interconnected using appropriate interfacing variables. The dynamics of the converter controls are represented in detail. Both individual phase control and equidistant pulse control firing schemes are considered. the results of the various test simulations under steady state and transient conditions for two terminal and three terminal HVDC systems are presented to illustrate the capability of the computer program developed. 4) The chapter four reports on the development of the state space model of the AC system ad harmonic filters for digital simulation. In the formulation of the system model the effect of the converter is represented by the current injection into the ac network. The converter ac bus voltages are derived as the output of the AC bus voltages are derived as the output of the ac system. The computer program developed in the previous chapter is suitably augmented and its capability is demonstrated through test simulations of two terminal and three terminal HVDC systems. 5) The chapter five describes the operating point stability analysis of HVDC systems using a new discrete model of the converter based on average system quantities. In the formulation of the overall system model, while the dc transmission network and converter controls are treated as continuous time subsystems, the firing pulse generator is represented as a discrete time subsystem with its output effective only at discrete time instants. The development of the linearized state space system model proceeds systematically with the development of individual subsystem models and their interconnection through appropriate interfacing variables. The analysis of the system model is based on linear, discrete time control theory. Both, the frequency response technique and eigenvalue analysis are employed to investigate the stability characteristics of a single rectifier system and two terminal HVDC systems. The results obtained from stability analysis are validated by detailed digital simulation reported in the earlier chapters. 6) The chapter six deals with the development of the state space model of the AC system for stability analysis of DC power system. The DC system models, described in the previous chapter, are augmented to include the effect of the ac system. The stability analysis of two terminal and three terminal HVDC systems is presented to illustrate the approach. The results are checked by performing detailed digital simulation to validate the predictions. 7) The seventh and last chapter outlines the conclusions drawn from this thesis and gives suggestions for further work.

For more details click here   Back

Title   :   *Microwave Measurements Of Complex Dielectrfic Constant Of Solod And Liquid Films*
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Roll No   :   *7710470*
Supervisor(s) :   *Dasgupta C*

Abstract

Dielectric materials have widespread application in present day microwave system. Theyenable relationsation of a variety of activity as well as passive microwave devices .Knowledge of the dielectric properties of these materials and their dependence onvarious physical and electrical parameters like temperature and electric fieldrespectively is very much essential for accurate design and acceptable performanceof the devices. So far a large number methods have been reported for microwavemeasurement of electric properties of bulk samples. Today thin film technique plays an important role in MIC technology .Variousdielectrics are being used as the film or the substrate in MIC circuit .In cases of plannercircuits it has been found that the properties of a thin film of a material could bedifferent from those of the corresponding bulk sample. This phenomenon has beenstudied at radio frequency only .A systematic study has been studied at radio frequencyonly .A systematic study of this has not been possible so far due to lack of a suitablemicrowave measurement technique which could of a suitable microwave measurementtechniques which could measure the dielectric properties of a film on a substrate. Recently an increased interest has been observed in the microwave dielectricproperties of liquid crystals are not available reported in this field use either acylindrical resonance cavity or a multiplayer slab loaded waveguide . Thin films of biological sample contain various amounts of water .Somebiophysical interacting mechanisms of RF fields with biological systems can beinferred from tissue permittivity. It is desirable hat a small quantity of a biologicalsample should be measured . Objective of this is to study the well established methods of microwave dielectricmeasurement to illustrate their infectiveness in measuring the complex dielectricconstant of a solid dielectric film on a dielectric substrate and a liquid dielectric filmand witched between two dielectric walls forming a cell and to development newtechniques based on the principle of Roberts and Von Hippel [1] to meet the abovepurpose .A brief description of the work reported in the thesis is given below;1. The first chapter introduces the role of dielectric materials in electrical andradio engineering .It discusses the need for the characterization of dielectricmaterials their behaviour with respects to frequency and also how the study ofmacroscopic behaviour of dielectric can predict the microscopic phenomena inthem .2. The second chapter present the basic principles and an overview of the wellestablished methods for dielectric measurements. The methods have beendivided into groups i.e. Resonant cavity Free space and Transmission line.Emphasis has been given on transmission line techniques and their effectivenessin measurement ? *of thin foils biological samples and semiconductors. Inrelevance to the present thesis special emphasis has been given on existingmethods of measurement of

dielectric constant of a film on a substrate .So farthere have been only two methods and the limitations of those methods havebeen discussed in detail . All the methods discussed in this chapter have been referenced. The referenceperiod extends upto January 1982 .Measurement errors have been analysedwherever appropriate. 3. The third chapter discusses the method of measurement of solid film on a substrateby input impedance method. The method is an extension of Roberts and Von Hippel'stechnique to a two layered sample where the complex dielectric constant of thesubstrate layer is known .Working equations have been developed for three types ofsubstrate termination short circuit open circuit and matched load or infinite substrate.the working equations have been solved numerically for the complex dielectricconstant of the film for each case of substrate termination .Analytical solutiontechnique using combined data from both short-circuited substrate and open-circuitedsubstrate cases has also been shown [2] .Analytical solution technique for electricalthin film is presented [3,4]. Effect of subtract thickness on the measurementuncertainty has been discussed in detail [2]. The theory development in the present chapter has been experimentally verified atX-band measuring the complex dielectric constants of a ferroelectrics films of a solidsolution of $BaTiO_3$ and $BaZrO_3$, and a semiconductor film of p-type Germanium onpolystyrene substrate . An analysis of the method shows that the measurement principle can be used over awide frequency band from 1 GHz to 100 GHz using a proper transmission lineand impedance measuring technique for a film of any thickness and dielectric constantif a dielectric substrate of proper dielectric constant and thickness is chosen . Measurement uncertainty due to film thickness measurement has been removedby using a short circuit-open circuit technique.4. Chapter four presents the extension of Roberts and Von Hippel's technique to thecase of three layered samples. In this methods the complex dielectric constant of a thinliquid film is measured .The film is sandwithed between two dielectric walls forminga dielectric cell as sample holder terminating a waveguide .Information on thefrequency behaviour of the tested substance can be obtained from the input impudenceof the sample holder while the required sample volume is of the order of fewmicroliters .Feasibility of the method has been samples. The methods is suitable forthin biological films and liquid crystal films .The principle can be extended upto GHz.This chapter also shown how the thickness of the cell-wall affects the measurementuncertainty .For optimum cell-wall thickness the uncertainty in ? * is principallylimited by the volume of the liquid sample used. This limitation has been overcomeby using a combined short-circuit open-circuit method [5] . 5. The fifth chapter presents a resonance methods for measuring the complex dielectricconstant of electrically thin films. The resonance frequency and the standing waveratio at resonance are the information's necessary for computation of ? ' and tan? ofthe film[6] .6. Chapter six of the thesis high-lights the contributions to the field of dielectricmeasurements by the thesis and the scope for further work .

For more details click here   Back

Title   *:*   *Mathematical Modelling And Analysis Of Six-Phase (Multi-*
                       Phase) Power Systems
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Abstract

Because of everincreasing power supply requirements, electric utilities are facing the pressing need to transfer more and more power from generating stations to load centers. The most common solution of increasing power transmission capability by increasing transmission system voltages seems to have reached the point of saturation. High-voltage transmission lines present strong electric field at the ground surface with possible biological effects, visual pollution, audible noise and increasingly difficult problems in acquiring new rights-of-way etc. as a result, several alternatives for the purpose are being considered. recently, the concept of multi-phase (high phase order) transmission was pioneered by Barnes and Barthold in place of convectional three-phase systems. Multi-phase transmission utilizes difficult to obtain rights-of-way in a better manner and offers a very appealing and unique solution to the problem of increased demand for electric energy. Since the initiation of the concept in 1972, the investigation on the use of multi-phase transmission has received growing interest. In addition to multi-phase transmission, the use of multi-phase windings in generator construction has also been considered for the last several years. A six-phase generator (with associated six-phase/three-phase transformer) has been proposed for high power applications in several recent publications. Such generators have been found to be effective in reducing the effects of high armature circuit currents with the added advantage of reduced generated phase voltages and thus reduced insulation requirements in armature slots. The potential benefits of multi-phase system accrue from the smaller phase angles between the phases resulting in lower adjacent phase-phase voltages. Thus in a multi-phase transmission, the interphase insulation requirements, spacing, conductor surface gradient and noise levels are reduced considerably. As a result, a multi-phase line with smaller dimension can be used to transmit a larger amount of power covering the entire range of transmission voltages. The general feasibility of multi-phase systems has been investigated in U.S.A. and the efforts have been made to unify the definitions of system voltages. At present, the six-phase system appears to be very promising among the multi-phase systems. In addition to investigation involving the steady state and transient operation of six-phase systems, overvoltages and insulation requirements, feasibility studies for converting certain existing double circuit three-phase lines to six-phases have been carried out. The construction of experimental lines and their testing for six-phase and twelve phases are reported to be undertaken by certain research establishments such as P.T.I., NY (USA). Fault analyses form an important step in the design of adequate protective schemes. A detailed fault analysis program employs symmetrical and Clarke's component transformations. Such transformations for multi-phase system, particularly

the six-phase system are available in the literature. Employing these transformations, fault analysis of six-phase system has been discussed in several papers considering either a six-phase line conceptually in isolation or by focusing attention on a specific line in the system with the rest of the network represented by Thevenin's equivalent on either end of the line. From practical view-points, it would be desirable to include such details viz. proper fault impedances/admittances, the interfacing transformer for six-phase conversion and adequate representation of the rest of the network so that the performance of the overall system during fault may be investigated. Suitable, techniques for handling more complex faults and their combinations need to be developed since the transformation methods become unwidely for such cases involving unbalanced network. Multi-phase transmission systems, particularly the six-phase lines have been modeled by their phase impedance/admittance matrices and ABCD-parameters. The associated transformers (three-phase/six-phase) have been represented without considering the leakage impedances of the windings. Employing this simplified transformer representation, equivalent three-phase representations of six-phase lines and loads were obtained for carrying out the steady-state analysis of a composite three-phase and six-phase system on three-phase basis. In similar fashion, the three-phase lines and loads were treated for the analysis of composite system entirely on six-phase basis. However, detailed modeling and realistic analytical tools are needed to effectively analyse and evaluate the performance and also the advantages of multi-phase systems which could meet many of the needs that have developed for the power systems in recent years. The objectives of this thesis are: 1. To develop suitable mathematical models of various multi-phase elements with special emphasis on phase parameter descriptions so that a six-phase (multi-phase) and a composite three-phase and six-phase power system may be represented in adequate details under balanced as well as under unbalanced conditions. 2. detailed investigations of load flow, short circuit and transient stability problems employing the mathematical models developed in this work. The methods employing positive sequence as well as phase coordinate representations have been used. An outline of the work reported in this thesis is given below: 1. An overview of the feasibility of multi-phase systems mainly based on the findings reported in the literature is presented to bring out the relative merits, demerits of multi-phase system and its compactibility with the conventional three-phase system. 2. The mathematical models of various multi-phase elements, viz., six-phase generator, three-phase/six-phase and six-phase transformers, six-phase lines and loads are developed. The transformers required for conversion from three phase to six-phase are represented to include the leakage impedances and off nominal tappings. An alternative model of the transformers (such as wye/star, delta/star and star/star) suitable for unbalanced network analysis is developed making use of the symmetrical lattice equivalent circuits. Employing the improved transformer models, equivalent circuits. Employing the improved transformer models, equivalent three phase descriptions of a six-phase line in terms of phase impedance/admittance matrix and ABCD-parameters are also derived. Similarly, the six-phase equivalent of a three-phase line is developed. Representation of multi-phase equivalents of three phase loads in terms of phase and sequence parameters are obtained. Employing the element models, a six-phase (or composite

three-phase and six-phase) power system is then modeled: in balanced conditions on an equivalent single-phase basis and in unbalanced conditions as an equivalent three-phase system; and also as a composite three-phase and six-phase system retaining the physical identities of different elements. 3. the procedure for load flow analysis for balanced as well as unbalanced conditions are developed for a completely six-phase and also for a composite three-phase and six-phase systems. One of the aspects studied in detail is the impact of converting certain existing double circuit three-phase lines to six-phase lines. The studies carried out on sample system indicate that multi-phase system, in general, have potentiality to maintain better voltage magnitudes, phase angle, and efficiency even for higher phase loadings than that of conventional three phase systems. 4. the fault analysis technique using symmetrical component transformation and bus impledence description of the network for three phase systems is generalized to handle completely six-phase or a composite three-phase and six-phase system. In addition, to investigate the behaviour of the system under unbalance and simultaneous faults, the method of phase coordinates is developed. One of the salient features of the study is a detailed ground fault investigation of a six-phase transmission system connected to the three-phase network via wye/star, three phase/six-phase transformers at both ends. 5. several alternative schemes for transient stability analysis of six-phase and a composite three-phase and six-phase system are developed depending upon the interest of investigation either in three phase or six-phase or both three-phase and six-phase part of the network. Based on several case studies, performance of six-phase system is compared with the conventional three-phase systems.

For more details click here   Back

Title : *Reliability Evaluation And Planning Of Bulk Power Systems*
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Supervisor(s) : *Padiyar K R*

Abstract

The long term planning of bulk power systems involves the selection of the generation and transmission system additions at appropriate intervals to minimize the present worth of the total investment and operational costs subject to the constraints of relia bility and security. Thus, the planning problem is a complex multistage decision problem. Simulation methods have been traditionally used to identify the optimal expansion plan from a set of viable alternatives. As the system size is increased the number o f alternatives to be considered grow exponentially and the use of mathematical optimization techniques becomes attractive. However, for practical utility these techniques should be simple. A review of literature shows that in recent years much attention h as been focused on the following problem: 1. Development of mathematical optimization techniques for the solution of single stage and multistage decision problems. 2. Reliability evaluation of bulk power systems using probabilistic analysis. The methodology of the optimization methods is similar. Given the future loads and right of ways the least cost expansion problem is formulated. The transmission line loadings are determined using approximate models for simplicity. Both transportation network model and DC load flow model have been used. The former is less accurate than the latter model as Kirchhoff's voltage law need not be satisfied for the network flow model. However, the computations using network flow model are faster and may be considered for planning purposes. The optimization problem can be simplified if the system planning is viewed as a single decision problem. Linear programming, branch and bound integer programming nonlinear programming with exterior penalty functions have been used as single st age optimization methods. Reliability evaluation of bulk power systems is difficult as the criteria of failure must incorporate line overload constrains. Explicit enumeration of all the system states is not feasible even for moderate sized systems. Doulli ez and Jamoulle have presented a method based on decomposition principle for finding the probability that all the flow requirements are satisfied for a transportation network with random are capacities. The expected value of unsupplied flow is computed by identifying a set of states having the same minimal cut. However, the extension of this method to DC load flow is not straight forward. The objectives of the work reported in this thesis are, 1. A comparative study of the various static optimization techni ques that can be used for the single stage expansion of bulk power transmission system. 2. Reliability analysis of bulk power systems using decomposition principle. Both the network flow and DC load flow models are considered in the above studies. The major contributions of the thesis are as follows: 1. The applications of the out of kilter algorithm for transmission planning

and optimal generation sitting, using the network flow model. 2. The development of a non linear programming technique utilizing DC load fl ow equations for the expansion of transmission systems. Main feature of this technique is elimination of penalty functions using the interchange of control and dependent variables. 3. Development of a computer program to calculate the probability of loss of l oad (LOLP) and expected demand not supplied (EDNS) in bulk power systems utilizing the decomposition principle given by Doulliez and Jamoulle. The program has been applied to the IEEE reliability test system. Sensitivity analysis of EDNS and its applicatio n for the system expansion in planning is also studied. 4. The development of reliability analysis of bulk power systems using DC load flow. The decomposition principle is used for implicit enumeration of generation states. The criteria for failure is based on the load supplying capability of the system. Both independent and correlated bus loads are considered. An outline of the thesis is given below: 1. The chapter one gives brief literature survey in the area and introduces the various aspects studied. 2. The chapter two deals with the application of transportation network model for planning of bulk power systems. The planning problem is treated as single stage static optimization problem, with linear constraints on the power flows in the network. The right of ways and load demand at various buses are specified and the objective is to minimize the total investment and operational costs. The out of kilter algorithm (OKA) is applied to solve the optimization problem. The OKA is computationally efficient as it inv olves only integer additions and subtractions. The mathematical formulations permits the investigation of optimum locations of generation and its impact on the expansion of the transmission system. Illustrative example are given to demonstrate the applicab ility of the method. 3. The chapter three presents a comparisons of various optimization technique that can be used for the automated expansion of transmission systems, using DC load flow equations. With the choice of line susceptances as control variables, D C load flow equation are nonlinear. For small changes in the control variables the equations can be linearlized using sensitivity matrix, thus permitting the use of successive linear programming as in optimization method. Zero one integer linear programmin g can also be used since the actual control variables (line additions) are discrete. This chapter also presents a non linear programming technique to consider directly the load flow equations. The structure of these equations is utilized to eliminate t he cons rate on dependent variables by interchange of the control and dependent variables when the limits on the dependent variables are exceeded. This approach avoids the use of penalty functions. A representative example is used to compare the three tec hniques. The results indicate that non linear programming takes less computational time, although the solutions obtained by three methods are not much different. 4. The chapter four presents the reliability evaluation of bulk power systems using the network flow model. The load is assumed to be deterministic, while the generation and transmission capacities are treated as discrete random variables. The decomposition principle enumerated by Doulliez and Jamoulle is used to classify the system states into thre e non overlapping subsets of success, failure and unclassified states. The set of unclassified states is further decomposed and this process is continued until the probability of remaining unclassified states becomes very small. This is an efficient proced ure for the implicit enumeration of system states. The computational efficiency of the algorithm is improved using contingency network flow method. An extension to the decomposition principle is also considered where all the failure states are exhausted a t each level of contingency. The algorithm is used to determine two reliability indices; 1. Probability of loss of load (LOLP)

and 2. expected demand not supplied (EDNS). The sensitivity of EDNS with respect to the generation or line capacities of individu al elements is also computed and can be used to locate the weak links in the system. A method for incorporating the reliability constraints using the sensitivity analysis in the planning problem is suggested. Computer program has been developed for the re liability evaluation and is applied to, two sample systems including the IEEE reliability test system. 5. the chapter five extends the reliability analysis of bulk power systems using DC load flow model. The method of analysis is similar to that used in t he previous chapter except that the transmission system states are considered separately. The reliability evaluation considers two operating policies, 1. with fixed generation schedule and 2. with rescheduling of generation to alleviate line overloads and loss of generation. The consideration of the second policy requires optimal load flow using linear programming. This involves the computation of load supplying capability (LSC) for various system states. The analysis is performed with the bus load treated as, 1, in dependent and 2. correlated. A six bus 11 unit system example is considered to illustrate the methods proposed in this chapter. The results are compared with those obtained in chapter four. 6. the sixth and the last chapter presents the conclus ions drawn from this thesis and gives suggestions for further work.

For more details click here   Back

*Title   : **Desegmentation Method And Its Applications To Circularly Polarized Microstrip Antennas***

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*Supervisor(s) : **Gupta K C***

Abstract

Two-dimensional microstrip-like components find applications in microwave integrated circuits (MICs) and in' planar microstrip antennas• These components have their' lengths and widths comparable to, or greater than, the wavelength at the frequency .of operation but the height is much smaller than the wavelength* . The methods for .analysis and design of two-dimensional components, that have been proposed in the literature, include the Green's function approach, the count our integral method, the spectral domain analysis, and the finite element method* The &reenfs fun ction approach is based on the availability .of the impedance Green1s functions for certain regular shapes such as rectan gles, circles, annular rings, circular and annular sectors, and'three types of triangles, viz.*, equilateral, right-angled isosceles, and 30° - 60 right-angled* Segmentation method is available for shapes which can be partitioned into these regular shaped segments* Some of these techniques, namely, the finite element method, the Green's function approach* and the spectral domain technique have been used for the analysis of micros trip patch antennas also,. The use of segmentation method for analysis and design of microstrip patch antennas is proposed in this thesis* A complementary technique called desegmentation method is proposed for analysis of two-dimensional components in MICs and in microstrip antennas• The proposed techniques are used in the design and optimization of three types of singly fed circularly polarized microstrip antennas* The Green1s function approach for analysis and design of planar microstrip antennas, as used in this thesis, employs impedance Green1s functions for segments with magnetic wall boundaries. In this method, the antenna is modelled as a multiport resonator with the magnetic wall boundary located slightly outside the physical periphery to compensate for the fringing reactive fields* The periphery of this resonator, is divided into a discrete number of sections of small widths* Bach of these sections is considered as a port of the' multi-port network* The Znnatrix for this multiport is evaluated using Green's function(s). For antenna configurations of irregular shapes (i.e. those for which Green1s functions are not available), the segmentation and the desegmentation methods are used* The ports on the periphery,of" the antenna are terminated by conductances to account for the radiated power* The element Z^. of the Z-matrix of the resultant loaded multiport network gives the input impedance at the ith port* The radiation characteristics are evaluated in terms of the magnetic current equivalent to the voltage distri bution along the periphery • In the desegmentation method (proposed in this thesis) one or more regular shaped segments are added to the given irregular shaped segment such that the resultant shape is either a regular shape or a combination of regular shapes. The segment(s) added and the resultant shape are analyzed by Green1s function approach

and segmentation method. The characterization for the given circuit is obtained in terms of the character!zation of the addedsegment(s) and that of the resultant circuit configuration* This method has been formulated both in-terms of Z-parameters and in.terms of S-parameters* The validity and applications of the method have been illustrated by several examples of lumped circuits, transmission line circuits, and planar circuits* The de-segmentation method has also been used to evolve a generalized method for de-embedding of multiport networks* Two different design philosophies have been proposed in the literature for obtaining circular polarization from micro-strip antennas. In the first case, one uses structures (e.g. squares and circles) with two spatially orthogonal modes which are excited in phase quadrature by two separate feeds* This arrangement requires a 90 -hybrid for feeding the antenna• The other philosophy makes use of two spatially orthogonal modes which are resonant at slightly different frequencies and the antenna is excited at an intermediate frequency by m a single suitably located feed point• In this case the 90°-hybrid is not needed* Several configurations of the latter category have been suggested in the literature* However, detailed analysis and designs have not been reported, In this thesis, three types of such antennas (viz«f a nearly square patch with diagonal feed, a corners chopped square patch* and a square patch with a diagonal slot) have been analyzed and optimized« Desegmentation method outlined above has been used for this purpose * The results are veri fied experimentally* 1 nearly square patch circularly polarized antenna (for which an axial ratio of about 1*4 dB has been reported ear lier) is optimized using Green's function approach* The . optimum ratio of length to width of the rectangle that gives the best axial ratio is found to depend on the thickness and dielectric constant of the substrate* Antennas on substrates having different thickness and values of dielectric constant have been optimized for axial ratio and input VS¥E. with respect to a 50 ohm coaxial line* Axial ratio as. good as 0*45 dB with input V8WB. equal to U73 (substrate thickness = 1/8"M, e = 2*52)f and in another case an axial ratio of 0.17 dB with input V8WR equal to t.33 (on t/l6,f • thick substrates with e =s 2.52 and 2*49) have been realized in 8-band* A corners chopped square patch antenna has also been analyzed and optimized* The antenna configuration is a square patch with two right-angled isosceles triangular segments from opposite corners removed* The method of ^segmentation is used for analysis• The optimum value of truncation for the best axial ratio is determined* Axial **atio of 0*02 dB (input V8WR = 2,2 on l/8?t substrate) and 0.12 dB (input V3WR = 1.6 on 1/16I! substrate with £r =2.51) have been achieved for S-band operation* A square patch antenna with a diagonally located slot lias also been optimized by desegmentation method* The dimen sions of the slot for the best axial ratio and the feed location for the best input VSWR are optimized* An axial ^atlo equal to 0.2 dB with input VSWR about 2*2 has been obtained. A comparative study of the three structures, outlined abovef reveals that a square antenna with a diagonal slot has the best axial ratio bandwidth whereas a diagonal fed Nearly square antenna has best input Y8WE values.

For more details click here   Back

Title   :   Analysis Of Power System Dynamic Stability InFluenced
*   Loads And Thyristor Controlled VAR Compensators*
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Supervisor(s) :   Padiyar K R

Abstract

Dynamic stability is an important aspect in the design and operation of power system. While the previous investigations have considered the generator representation in detail, the load representation has not received much attention and the load characteris tics have uniformly been assumed to be of constant impedance type. The main reason for this lacuna is perhaps the non availability of load characteristics. However, attempts are being made to determine these characteristics by field and analytical tests. L oads can have either static, dynamic or combined characteristics dependent on voltages and frequency. Knowledge of effects of load characteristics is useful for system planning, operation and control. With the advent of EHV transmission, the requirement of rapidly adjustable reactive compensation is becoming a necessity. Synchronous condensers which are the traditional means of providing this are being replaced by thyristor controlled var compensators. Static var compensators have a number of advantage. The important among them are fast response, absence of inertia, low losses and little maintenance requirements. The use of these devices can not only stabilize the voltage and increase the power transfer capability but also improve the system damping. Power s ystem stabilizers (PSS) receiving signal from either rotor velocity, accelerating power or frequency are presently used to damp out the oscillations in the system. Likewise a properly designed var compensator actuated by bus frequency deviation could be ef fective in damping the chosen modes of oscillation. In a multi machine system the proper choice of location of var compensator is important. Methods for optimum selection and the effect of location on system damping have not been reported in the literatur e. Thyristor controlled var compensators can also be connected to distribution lines to keep the load bus voltage within limits and also to improve power factor. The per formance of induction motor loads is affected in the presence of these compensators. This thesis is concerned with the effect of static and dynamic loads and the influence of static var compensator on dynamic stability of power systems. The concept of improving system damping using auxiliary control signal derived from bus frequency devia tion for the thyristor controlled reactor is investigated in detail. Influence of the location of var compensator on the system damping is investigated using an analytical technique. OBJECTIVE OF THE THESIS The objective of this research work is to repor t detailed investigations on the following: 1. Effect of voltage and frequency dependence of static loads on dynamic stability in single and multi machine systems. 2. Influence of induction motor loads on system stability. 3. Effect of thyristor controlled var co mpensation on dynamic stability and determination of optimum location of var compensator in a multi machine system. 4. Dynamic performance of induction motor load with var compensation. An outline of the work reported is given below: 1. The first chapter gives a brief literature survey in the area and introduces the various aspects investigated. 2. The chapter two deals with the application of parameter plane technique for the dynamic stability study of a single machine infinite bus system with voltage and frequen cy dependent loads. The power system is modeled as a multi variable system with load representation in the feed back path. The stability domains in load parameter

plane are plotted and analyzed. The influence of PSS, machine and line parameters are conside red in the study. 3. In Chapter Three a third order induction motor model is developed and applied for stability studies. The induction motor is represented by a matrix transfer function with the voltages magnitude and frequency as input variables and active and reactive power as output variables. This model is used in conjunction with the system model developed in Chapter Two Multivariable Nyquist criterion is used for stability analysis. 4. Chapter Four deals with the dynamic stability analysis of multi machine systems. After developing a state space model, effects of voltage and frequency dependency of loads are analyzed by root locus technique considering a 3 machine system example. 5. The Chapter Five presents the development of a state space model for a thyrist or controlled var compensator. The control signals considered for the var compensation are terminal voltage and frequency deviation. The influence of control characteristics of var compensator in conjunction with static and dynamic loads is investigated. 6. The Chapter Six deals with the analysis of multi machine systems with var compensation. A method based on eigenvalue sensitivities is employed for determining the influence of location of the compensator on the system damping, when the static var compensato r are equipped with auxiliary controllers using bus frequency deviation signals. The case study of a 3 machine system is used to illustrate the technique. 7. In Chapter Seven dynamic and steady state performance of induction motor load is discussed. A detaile d 3 phase model and a simplified third order model are compared for the prediction of the starting performance. It is observed that the simplified model gives reasonably accurate results. The influence of var compensation is investigated with a simplified model. 8. The Eighth and last chapter presents the conclusions drawn from this thesis and gives suggestions for future research in this area.

For more details click here   Back

Title   *:   Analysis And Design Of Vlf Antennas*
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Abstract

The main aim of the present work is to analyze large VLF antenna systems. The results obtained can be used for designing VIF antennas. In the first chapter, the reasons for using VIF are discussed. Then the chapter surveys the history of VIF antennas and the various aspects which have been studied by various researchers. The nature of VIF antennas is discussed followed by the review of basic equations applicable to electrically short antennas. The principle of top loading is also discussed. As the analyse s of VIF antennas is based on the method of moments, the mathematics of this technique are studied in details in the second chapter. The various antenna integral equations are derived. It is shown that an antenna integral equations can be expressed as a fu nctional equations in term s of an operator. Methods to solve the functional equation are discussed. The antennas problem is a boundary value problem and it is practically not possible to solve the problem exactly. It has to be solved approximately with th e help of computers. Two approximation methods namely the variation method and the method of moments are studied and the basic differences between he two is brought out. Various type soft basis and weighting functions are discussed. Since the equations ar e to be solved numerically the relevant aspects of numerical solutions are discussed. VIF antennas can be seen as wire structures. Therefore, the antenna integral equation and the corresponding operator equation can be greatly simplified by suitably modify ing the equations for thin wire geometry. The second chapter is concluded after discussing the various applications of moment's method in electromagnetic and other allied fields. In the third chapter various approaches an computational techniques are disc ussed. Since a VIF antennas is electrically very short a static method can be usefully exploited. The static method is simple and economical. However, it has its own limitations, which can be overcome by going for a time varying or a.c. solution. An a.c . solution which is used later to analyse various VIF antennas is discussed in detail. The various aspects discussed are about the choice of basis and weighting functions, modification of the potential equation and details about the development of the impe dance matrix. It is shown that segments of different lengths can gives correct results provided that proper limits are applied while evaluating the elements of the impedance matrix. Thus it is also possible to choose the length of the input gap arbitrarily . The antenna is fed at this gap. The computer program was checked with known results for simple antenna structures. In all cases, the agreement was good. Computational aspects such as convergence, relation between the segment length and diameter are stud ied and the results are presented. These results can be used while designing an antenna. Also input impedances for various input gap widths are computed to show that it is possible to compute the input impedance for various gap widths (or gap width /segmen t length ratio) while

also assuming that the voltage across the input gap is one volt. In Chapter 4, umbrella type antennas are analyzed. Various aspects covered are the effect of wire diameter, top loading grounded parts etc. on the input impedance. The figure of merit which is defined as the band width efficiency product has been studied as a function of various parameters. In addition to the input impedance current distributions for various part of the umbrella antenna are also determined. In Chapter 5 , a large VIF antenna similar to the ones at Anthorn (UK) or Cutler, Maine (USA), or North West Cape (Australia) is analyzed. The dimensions of the antenna system are similar to those of the one at An thorn. In this chapter is has been shown that the symme try of the structure can be exploited to reduce the size of the matrix. If the symmetry considerations are not taken into account then the size of the matrix would become so large that is would be almost impossible to solve even with the biggest modern com puters. The antenna is analyzed in various stages. First an ideal case is considered where there are only down leads and top hat. The effective height is then very close to the physical height of the top hat. The grounded masts are included next and their effect on the input impedance and current distributions is shown. At the third stage guy wires are connected to the inner and outer masts and their effect on the input impedance and current distribution is again studied. Finally, the actual antenna system, where the guy wires are also connected to the center mast in studied. Economics aspects such as the height of towers, sag and tension in the cables of top hat and their relationship from the point of view of structural engineering are discussed. In Chap ter 6 various other aspects likely to affect the performance of the antenna system are discussed. These aspects are the various losses, ground systems corona, insulators etc. In addition two other types of VIF antenna viz. horizontal antenna and hall on t ype antennas are discussed and their applications are indicated.

For more details click here   Back

Title   : A Study Of Over Voltage Problems In EHV Systems
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Abstract

With the increase in power demand, the present trend is to transmit large amount of power over long distance lines at extra high voltage (EHV). In EHV systems, the insulation level is decided by over voltages caused due to switching and / or faults rather than lightening. A poor choice of insulation level will either increase the cost of the system or will increase risk of failure due to faults initiated by flashovers. Therefore a proper insulation level should be chosen which requires the knowledge of the nature and magnitudes of various over voltages caused by different system conditions. Since the magnitude and time duration of various over voltages is different, therefore, they stress the insulation in different manner. There are three distinct periods d uring which the over voltages occur, viz., a) A surge period during which the traveling wave effects predominate and in which the line is represented by its surge characteristics. The transient (surge) over voltages are caused by line energisation/ re energis ation or fault initiation. b) A dynamic period which is transitional between the surge period and the steady state and is characterized by the voltage variation contained in an envelope which varies a periodically with time. c) A steady state period during which the voltage is periodic but usually is distorted due to various harmonic components. Then the power system is terminated by a transformer, steady state over voltages may occur at the transformer terminals due to switching operation. The transformer non li near characteristic plays a dominant role in this phenomena and the system is said to be in a 'ferro resonant mode. The objective of this thesis is to study all the above mentioned over voltages. Suitable techniques for digital simulation have been evolve d for their evaluation which consider more detailed system representation than reported before in the literature. Steady state over voltages are studied first. The field investigation of an electromagnetic voltage transformer (EMVT) failure while being de energized by a circuit breaker (CB) fitted with grading capacitors across the contacts is described. This phenomena has been analyzed using the principle of 'Harmonic Balance' and it is shown that the failure was due to ferro resonance phenomena. Also the analysis for the pre steady state period is carried out using state space techniques. This is to give insight into initial conditions which might give rise to the steady state over voltages. Based upon the data collected for several makes of EMVTs and CBs fitted with grading capacitors, remedial measures have been suggested to avoid such incidents. Dynamic over voltages following load rejection have been considered next. The methods reported in the literature for the evaluation of such over voltages are approximate. Usually the digital simulation is employed to predict the variation in magnitude and frequency of the internal voltage of the machine and this information is used subsequently on the transient network analyzer (TNA) to predict ferro resonant ov er voltages. The digital simulation ignores the network transients but can predict the phenomena of self excitation. In this thesis, this two stage computation is combined in a single digital simulation program, which incorporates not only the network tran sients on a 3 - phase basis but also the synchronous machine representation in details. The prime mover governor is also considered along with the exciter and voltages regulator. The non linear ties due to transformer and machine saturation are included. It is believed that this is a more

accurate approach, and can be used to determine if the phenomena of self excitation and / or ferro resonance can occur in a single simulation. This is illustrated with the help of the case studies of both hydro and thermal machines feeding a load through a long EHV line. The effectiveness of the voltage regulator in controlling the over voltages due to ferro resonance is also demonstrated. Transient over voltages are considered next. The method of characteristic as given by Dommel is recognized to be most efficient for the calculation of the transmission line transients, since the equations involved are algebraic rather than differential. However this method requires iterative solution at each time step if nonlinear ties are present in the network. The state space techniques are more efficient in handling non linear ties. In this thesis the alternative of (1) employment of state space techniques for both the network and the transmission line and (2) the combined used of state space techniques for the network and the method of characteristics for the transmission lines, have been examined. It is found out that the second approach is usually superior in terms of computation time. The transient over voltages caused by fault initi ation are also considered. The transmission line model using the method of characteristics due to Dommel is extended to simulate the initiation of a fault at nay point of the line. The generator dynamics is represented and the results are compared when the generator is represented by a constant voltages source. It is demonstrated that the over voltages are greater if the generator dynamics is included in the simulation. It is found that the opening of the CB at the receiving end in trying to clear the fault aggravates the over voltages problem and it can be controlled through the use of CB opening resistors. It is also found in this case that the over voltages are higher at receiving end when the fault is closer to the receiving end. Finally, the thesis con cludes with the high lights of the work reported in the area of over voltages in EHV systems and project the scope for further work.

For more details click here   Back

Title : ***Synthesis Of Active Filters, Oscillator And Delay Networks***
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Abstract

Active filters have widespread application in present day electronic systems. They enable realisation of a variety of network functions for different applications. A large number of papers are available on active filters using operational amplifiers (OA), resistors and capacitors* These filters have two main limitations. First is the hig:h frequency limitation due to the finite gain-bandwidth products of the OAs used. Second limitation is due to difficulties in incor porating capacitors during IC fabrication. To overcome these limitations a new class of active networks using only OAs and resistors, termed active R networksf have been developed. In recent years a number of active R circuits that realise different network functions have been reported. However, xvii synthesis techniques are not available for many of these circuits* This thesis presents systematic synthesis techniques for active R filters [band pass (BP), low pass (LP), high pass (HP)f all pass (AP) and notch (BE)], oscilla tors and delay networks* A number of new circuits have been realised. The first chapter of the thesis introduces the concept of active 5. networks. The works reported in literature and this thesis are discussed. The second chapter deals with OA modelling and parameter measurement relevant to active R networks* Characteristics of existing OA models are discussed* A new OA model is pro posed that takes into account OA second pole effects without complicated analysis This new pole-zero model enables easy design of active B. networks for wide frequency range appli cation* Available methods of OA parameter measurement are also described in this chapter* Band pass and low pass filters form part of practically every electronic system BPPs with high a> and Q values are particularly useful. Though a number of active R BP and IP filters have been reported in literature synthesis techniques for most of them have not been developed. In the third chapter synthesis techniques for inverting and non~ inverting BP and IP filters are given* A circuit with multifunction capability [l] has been realised* It provides inverting BP, non-inverting LP, AP* BE and oscillator functions. It can xviii also provide non-inverting BP response if the polarities of both the OAs in the circuit are reversed* The circuit has been designed, based on pole-zero model for the OAs, and tested* Experimental results show the validity of this pole-zero model. Modifications of the synthesis technique lead to other reported BPF circuits; The synthesis techniques for IPFs realise nth order inverting and non-inverting LPPs. All pass filters find application in phase shifters, delay equalisers and delay networks . Only few first and second order active R APFs have been reported in literature, Synthesis techniques for active R APPs and higher order active R APPs have not been realised till now* In the fourth and fifth chapters two new synthesis techniques to realise active R APP of any given order, both with real poles and zeros and with complex poles and zeros are proposed [2]. All circuits are realised with an attenuation constant due to resistive summation. This is because, an ideal active R summer circuit is not known. The effect of OA second pole on APP performance has been analysed and experimentally verified. The synthesis technique proposed in the fifth chapter leads to circuits

with larger signal handling capacity The sixth chapter presents synthesis techniques for first and second order high pass filters and second order xlx notch filters* These circuits are also realised with an attenuation constant due to resistive summation. A symmetrical notch filter has been designed based on pole-zero model for high a) and Q values and experimentally tested• Sinusoidal oscillators with wide timing range, constant amplitude and low distortion with independent frequency control either by resistance variation or by voltage variation are re quired in many applications. A few active R oscillators have been reported in literature. Only some of them have independent frequency control facility In the seventh chapter a synthesis j technique for active R oscillators is proposed to realise a two OA six resistor oscillator circuit [3] In this circuit condi tion for oscillations is maintained by one grounded resistor while its frequency is controlled by another grounded resistor. Replacement of the frequency controlling resistor by a JFET leads to a voltage controlled oscillator. Both resistance and voltage controlled oscillators give constant amplitude, low distortion oscillations over a wide frequency range. Delay networks are required to provide improved transient response in pulse communication systems. Till now no active R delay network has been realised. In the eighth chapter an active R circuit to realise the fourth order Pade all pass " sT approximation for has been synthesised [4]. The realised circuit has been designed and tested for a delay of 30 \is. XX The synthesis techniques presented in this thesis are general* Hence, they can also realise active EC filters, oscillators and delay networks.

For more details click here   Back

Title : *Determination Of Effective Device Parameters Of Silicon Juncition Field Effect Transistors*
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Abstract

Most of the circuit parameters of semiconductor devices under normal operating conditions can either be obtained by direct measurements or be calculated from the knowledge of the device parameters (geometrical and material) by using the relationships betwe en the circuit parameters and the device parameters. The value of such parameters are published by the device manufacturers and are freely available to circuit designers, whereas the values of the device parameters are generally far less accessible. In fac t, even if the design values of these parameters are furnished, there is a certain amount of uncertainty in the actual device parameters that result during the fabrication process. Hence, I, for any extended application of a device a circuit designer is in need of extrapolating the value of certain circuit parameters of interest, he is left with two options: (1) To measure the relevant circuit parameters under actual conditions of operations, (2) To infer the value of the device parameters from measurements done u nder normal operating conditions and to used this knowledge for calculating relevant circuit parameters under extended conditions of operations. The former option, though seemingly straight forward may present considerable practical difficulties. The objec tive of this thesis is to established a methodology for the second option, specifically for the JFET. Before one can actually select the two sets of parameters viz. device and circuit parameters one must exercise caution to ensure that the relationships li nking the chosen parameters are not mutually contradictory. One such inbuilt anomaly, which seems to have gone unnoticed by earlier workers arises out of the expressions for the channel conductance G do and the gate channel capacitance c g in the voltage var iable resistance (VVR) region of operation. This anomly becomes evident from the following considerations. (1) experimental measurement of c g for different values of the gate source bias V GS give a linear plot of 21cvs V GS indicating an ab rupt P - N junction with uniform doping. (2) Experimental measurement of the conductance g go of the residual channel left after the formation of the gate channel depletion layer show that g do varies linearly with the applied gate source bias. (3) If the gate channel junction is indeed an abrupt P - N junction with uniform doping, g do should be proportional to the square root of the applied gate source bias. Clearly, the three observations made above are not consistent. A conjecture for resolving this anomaly has been p roposed on the basis of a parasitic transistor formed with the gate, channel and substrate of the JFET as its emitter, base and collector respectively. The generation of carriers in the gate channel as well as the substrate channel depletion layers is show n to be capable of causing the width of the residual channel to vary linearly with the applied gate source bias. Device parameters for a planar JFET consist of channel dimensions (length, width and height) and the impurity profile. In the case of most co mmercially available JFETs the doping is uniform and as such the impurity profile is given simply by the constant impurity concentration. One thus has to select a set of four circuit parameters whose value can then be used to set up four independent equati ons involving the four device parameters. The selection of these four circuit parameters out of the various possible choices is carried out in the following manner. (1) the first considerations is the reliability of the relationships between the chosen circui t parameters and the device parameters. One thus

makes the first short list consisting of those circuit parameters which are related to the device parameters by well accepted and preferably explicit relationships. (2) A priority list is now prepared out of the short listed circuit parameter son the basis of the convenience and accuracy of the necessary measurements. (3) The first four parameters in the priority list are used in actual evaluation of the device parameters while some of the remaining are used in prov iding cross checks. This sequence of steps represents a general approach to the evaluation of the device parameters of any device from measurement of its circuit parameters. In case of JFET, this procedure is considerably simplified because of the nature o f its models in the different modes of operation. The parallel channel behavior of JFET is well understood and reliable, explicit relationships exist for the following three circuit parameters characterizing this made of operation. 1) open channel conductanc e g o 2) pinch off voltage U p 3) reverse bias gate channel capacitance c g it has been observed that not other independent relationship is available from the circuit parameters in the gradual channel model. The common source input capacitances c uss leads to an ex pression with device parameters which has been utilized later as a cross check. For the fourth parameter, which should be independent with respect to the previous three, post pinch off models have therefore to be considered for obtaining another independe nt relationship between the two sets of parameters. As no satisfactory post pinch off model is available for short channel JFETs, the methodology is restricted to long channel devices only. Thus, it becomes necessary that a method be developed to distingui sh long channel and short channel JFETs. Such a method has been developed on the basis of a property of the I D - V DS characteristic pointed out by Wedlock [1]. After a brief review of the different existing post pinch off models of long channel JFETs, the tw o models suggested by Grebene and Gandhi [2], and Lehovec and Miller [3] have been tested for their agreement with experimental results. Only the following two circuit parameters have been found to have explicit mathematical expressions in terms of the dev ice parameters which are verified experimentally . i) Drain source incremental conductance g ds ii) Gate source incremental capacitance c gs Of these two g ds has been selected form the stand point of the relative ease and accuracy of its measurement under pulsed bi asing condition. The four device parameter are determined uniquely from the measurements of the circuit parameters. The device parameters so obtained are the effective parameters in the sense that these are capable of predicting only the electrical charac teristics of the device and are not necessarily the parameters for the manufacture or design of the device. The validity of these effective device parameters has been established by the following checks done with the auxiliary measurements. i) the dependence of c iss on V DS and V GS has been derived for an experimental determination of the quantity azL where z = channel width; L = channel length and a = undeleted channel height. The device parameters have been directly substituted to obtain t his quantity which agrees within reasonable limits with the measured one. ii) The dependence of c gs on I D and V GS has been developed and the model has been tested for its validity through experimental measurements. A combination of the device parameters, N o 2 q 2 μo a 2 z 2 is directly obtained from the experimental measurements of this capacitance for different value of the bias currents and voltages. The value of this combination is obtained by a direct substitution of the device parameters and is compared with the one obtained from the measurement of gate source capacitance under post pinch off. The agreement within order of magnitude has been obtained indicating a fair validity of the model and the device parameters for long channel commercially packaged silic on JFETs.

For more details click here   Back

Title   :   *Analysis And Performance Of Chopper-Fed D C Motors Under Motoring And Regenerative Braking*
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Abstract

D. C. choppers provides an efficient and economic way of controlling d. c. separately and series excited motors supplied from constant voltage d. c. bus bars because of their low cost, high efficiency less space, fast response and their ability to regener ate down to very low speed. Chopper controlled d. c. motors find application in under ground traction and in battery operated vehicles. They have also been employed in 1500 V main line d. c. traction where resistance control was used previously. The other advantages of chopper control in relation to traction application are smooth acceleration better adhesion due to smooth and step less control of voltage, and less maintenance. This thesis presents analysis and performance of chopper controlled d. c. separa tely and series excited motors under motoring and regenerative braking. 1. performance and Analysis of Chopper fed D.C Separately excited Motor: 1.1 Motoring Operation: H. Irie et. Al. [1] and K. Nitta et. Al. [2] have described the methods of calculating the mot or performance and H. Barton[3] has derived the steady state transfer characteristics of chopper, for d. c. separately excited motor fed by a time ratio controlled (TRC) chopper with square wave output voltage taking into account the discontinuous conducti on. Parimelalagon and Rajagopalan [4] have presented four methods of analysis using various approximations for a now square output voltage TRC chopper with load current dependent commutation. Alexandrovitz and Zabar [5] have described analogue computer sim ulation and Damle and Dubey [6] have described a digital computer programme based on point by point solution of differential equations valid for each made of operation and using final conditions of the previous made as initial conditions for each made for a chopper with load dependent commutation. None of the methods of analysis reported so far have taken into account the effect of source inductance, armature reaction and discontinuous conduction in d. c. separately excited motor fed by a chopper with load dependent commutation. In the present work, methods of analysis have been developed which take into account the effect of source inductance discontinuous conduction armature reaction and commutation pulse effect. Steady state transfer characteristics of c hopper with load current dependent commutation have also been derived. The approach allows realization of analytical method involving much less computation time compared to exact solution of differential equations. A good correlation has obtained betwe en predicted and measured curves. The source inductance has considerable influence on the performance of the motor, and discontinuous conduction does take place in case of chopper with load dependent computation unless the chopper is operated at high fr equency. 1.2 Regenerative Braking: G.

Kimura and M. Shioya [7] have derived a method of analysis of TRC chopper controlled d.c. separately excited motor under regenerative braking assuming ideal square wave output voltage neglecting chopper commutation pulse and armature reaction of machine. The effect of source inductance on the performance characteristics of machine has not been investigated. In this part of the thesis, a systematic analysis has been carried out to predict the braking characteristics unde r regeneration. The analysis has been done both for square wave chopper and non square wave output chopper with load dependent commutation. Normalized boundaries have been obtained which separate the regions of continuous and discontinuous conduction on th e normalized speed torque plane for various value of aTT ratio. An approach has been presented for selecting a suitable value of armature circuit filter inductance with a view to reduce the area of discontinuous conduction to a small reg ion, to optimize the regenerative power, maximize the efficiency of regeneration and to keep the armature current ripple within low tolerable limits. The effects of chopper commutation pulse, armature reaction of machine and the effect of source inductance on the braking characteristics have been investigated. The predicated results agree well with the actual results. 2. chopper controlled D.C. Series Motors: 2.1 Motoring operation: The main problem in the analysis of chopper controlled d. c. series motor arise s due to non linearity of the magnetic circuit of the motor. The analytical methods of analysis of d. c. series motor fed by chopper with square wave output voltage have been described by P.W. Frenklin [8] for choppers with current limit control (CLC) and by Dubey and Shepherd [9], for chopper with TRC as well as CLC. B. Mellitt and M. H. Rashid [10] and Damle and Dubey [11] have described compute r based numerical methods of analysis for calculation of motor performance when fed by a chopper with load depe ndent commutation dubey [12] has developed an analytical method for this case by extending the method described in reference [9]. None of these methods account for the effect of eddy currents. T.Fujimaki et al [13] have developed a dynamic model of the mot or which takes eddy current effect into account. The relevant equations have then been employed to predict transient response. None of the above methods have taken the effect of source inductance into account. In this part of the thesis, a general method of analysis of a TRC chopper controlled d.c. series motor has been presented. First, a systematic modeling of a series motor has been done. The saturation of magnetic circuit, armature reaction and eddy current effects have been taken into account in this modeling. An empirical formula has been suggested to take into account the variation of field and armature circuit inductance with armature current. The machine back e.m.f. coefficient has been taken as function of average armature current and it takes int o account both saturation and armature reaction effect. To estimate the effects of eddy currents on the armature induced e.m.f. two approaches have been used. First a dynamic field circuit model based on field theory has been identified using transient res ponse. Secondly an empirical formulation based on extensive experimental results on typical d.c. machines having different designs of magnetic circuits has been developed to take into account the eddy current effect. The second approach being much simpler to implement in the analysis of chopper fed series motor, has finally been adapted. The effect of chopper commutation pulse has been taken in to account in the analyses. The influence of source

inductance on the machine performance and chopper commutation has been investigated. It has been shown that for reliable predication of ripple in armature current, incremental inductances should be used and eddy current effect should be taken into account .t he predicted results agree well with the experimental resul ts. 2.2 Regenerative Braking operation: The Regenerative Braking of chopper controlled d. c. series motor is some what complicated because of stability problems. R. Wagner [14] has reported that instability of operation occurs resulting in loss of current con trol, at high speeds he has suggested circuits to overcome these problems. Farrer and McLoughlin [15] and Loderer [16] have considered the circuit aspects Regenerative Braking The thesis describes a steady state analysis method of chopper fed dc series mo tor under Regenerative Braking taking into account the effect of magnetic saturation chopper commutation interval and the effect of source inductance. The effects of commutating capacitor armature circuit inductance and source inductance on the braking sp eed torque characteristics, braking power and stability of the drive has been investigated. It has been noted that an oversized commutation capacitor improved the stability and that the source inductance while improves the stability of braking characterist ics it reduces the regenerated power for the same values of speed and duty ratio. The predicated results corroborate well with experimental results. The last part of the thesis describes the effect of source inductance on the commutation in various choppe r circuits. A discussion has been given in the concluding part of the thesis. 2.1

For more details click here   Back

*Title   :   **Triangular Segments And Two Dimensional Analysis For Microwave Integrated Circuits***

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Abstract

The concept of two dimensional planar circuits is a generalization of one dimensional strip line or micro strip circuits to the case when the transverse dimensions are comparable to wave length. Thus, these circuits have dimensions comparable to (or greate r than) the wave length in two directions but have the third dimension much smaller than the wave length. Analysis of two dimensional circuits containing rectangular and circular segments by using impedance Green's functions is available in literature. Investigations reported in this thesis are aimed at (i) analysis of triangular planar segments and their applications in micro wave integrated circuits, and (ii) use of two dimensional analysis for the design and optimization of strip line and micro strip cir cuits. The thesis begins with the development of impedance Green's functions for the analysis of triangular segments. Three types of triangles (30 0 - 60 0 right angled, equilateral and right angled isosceles) are considered by placing additional image sour ces outside the triangular regions. The Green's functions satisfy magnetic wall condition all along the periphery of the segments. Green's functions for some triangular shapes with electric wall on one of the sides and magnetic walls on the other two sides are also obtained. Green's functions for circular sectors, annular rings, and annular sectors have been obtained by expanding these in series of eigen functions. As mutually orthogonal eigen functions are obtainable only for those sect oral angles which are submultiples of 180 o , the Green's functions are obtainable for only these sect oral shapes. Segmentation method for the analysis of planar circuits involves breaking up of a circuit pattern into segments for which Green's functions are known. S - matrix of the overall circuit is obtained form the S -matrices of the individual segments. This method is modified so that Z - matrices for individual planar segments are used to obtain the overall Z - matrix. The proposed method using Z - matrices is shown to be compu tationally more efficient than the earlier method. The Green's functions, for the equilateral triangular segments, derived in this thesis have been used to analyze rhombic and hexagonal resonant shapes by segmenting these into triangular shapes. Equilater al triangular, 60 0 – rhombic, and regular hexagonal shapes are analyzed and their resonance have been investigated. It has been pointed out that equilateral triangular shapes have odd modes of resonances in addition to the even modes reported earlier. For rhombic and hexagonal shapes, their resonance frequencies as well as the voltage variations around the periphery have been obtained for fundamental and some higher order modes. The resonance frequencies predicted have been verified experimentally for each of three shapes. Strip

line and micro strip T -junctions have been shown to exhibit lower parasitic reactance's when triangular geometries are used as compared to the junctions with rectangular geometry normally used. Two types of T - junctions with impedanc e ratios 1:1:1 and $(1 / \sqrt{2})$: 1:1 have been studied for this purpose. For T - junctions with impedance ratio 1:1:1, an equilateral triangle is used at the junction. For T - junctions with impedance ratios $1 / \sqrt{2}$): 1:1, a right angled isosceles triangle (in magn etic wall model) is used at the junction. Improvements using triangular shaped junctions have been verified experimentally for both the cases. The two dimensional analysis technique can be used in optimization of the design of the circuits whose performan ce is limited by the junction reactance's and the presence of higher order modes. This procedure has been used to obtain improved designs for 3 db in phase power dividers and 3 db branch line hybrids. Three types of power divider circuits that have been c onsidered are: 1) a circuit with single matching section $(Z = Z o / \sqrt{2})$ on the input side, 11) a circuit with single matching sections $(Z = Z o / \sqrt{2})$ on the output sides, and iii) a circuit with a matching section $(Z = Z o / \sqrt{2} \, 1/4)$ at the input side and matching sections $(Z = Z o / \sqrt{2} \, 1/4)$ on the output sides. Triangular geometries have been used at the T - junctions. The lengths of various matching section and position and value of isolation resistance are optimized for each of the three types of power dividers to mi nimize input and output VSWR's at the center frequency. Experimental results for a micro strip circuit with single matching section at the input side are included. For 3 db branch line hybrid also, right angled isosceles triangles are used at each of the T -junctions. Lengths of the quarter wave sections are optimized to minimize the input VSWR and to equalize the power division at the center frequency. These two circuit examples demonstrates the applicability of two dimensional circuit analysis for the de sign and optimization of strip line and micro strip circuits.

For more details click here   Back

*Title : **Optimal Control And Parameter Determination In Volterra Type Integral And Delay Differential Systems***

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Abstract

A wide variety of systems in science and engineering have a mathematical representation in the form of a system of Volterra type integral equations (VTIE). Dynamical systems represented through Delay-Differential Equations (DDE) are abundant in Chemical processes, Mechanical and Electrical systems etc.. Several researchers have studied the problem of optimal control and parameter determination in such systems. The first results on optimal control of systems described by VTIE were due to Friedman (1964) and were followed by the work of Vinokurov (1969). Huang (1972) considered a general variational problem in such systems* Das (1967) considered the problem of optimal control for a hereditary process with delay, in presence of unknown parameters* A Pontryagin's maximum principle for systems governed by DDE was derived by Kharatishvili (1961) • Numerical techniques for the determination of optimal control in DDE have been developed by several authors* Eller et alt (1969) have presented a technique, that generates an open-loop control, in the case of a quadratic cost functional. Slater and Wells (1972) have transformed the problem for a linear system, with the cost functional quadratic in control but not containing the state variables, into an equivalent non-delay problem* Sub-optimal controls have been obtained by Inoue et al,, (1971), Jamshidi et al. (1972) and Malek-Zavarei (1980) using a Maclaurin series expansion of the control. G-racovetsky and Yidyasagar (1972 ,1973) and Malek-Zavarei (1980) have endeavoured to obtain sub-optimal controls, by solving a sequence of optimal control problems defined for ordinary differential equations. In this work we consider some aspects of the above problems* A large portion of the work is devoted to the development of com putational methods, for the determination of optimal control and parameters, in systems described by VTIE and DDE, in a determini stic framework. Numerical algorithms, based on the quasilinearization tech nique, are developed for the determination of parameters in VTIE, minimizing a seminorm. The convergence proofs are given, under various system restrictions, for the two algorithms developed. As an application of these algorithms the problem of model reduction in dynamical systems is solved and various computational aspects are discussed. . Thn method is illustrated by a numerical example• Then a set of necessary conditions is developed for optimal control of systems described by VTIE with parameters. This special treatment results in a compact set of conditions to be satisfied by the optimal control and parameters. The problem of optimal control of systems described by DDE is then considered• An iterative scheme is proposed to determine a partly closed-loop and partly open-loop control for

problems with quadratic cost functional. The convergence of the algorithm is established with certain system restri ctions, As an illustration an optimal control policy, for a refining plant, to improve the system response is determined using the algorithm developed. Finally the determination of optimal initial function and parameters in a system of DDE is discussed• The initial fun ction is approximated to be contained in a finite dimensional subspace of the space of continuous functions and the problem is formulated as a parameter determination problem. Conditions for existence of a solution to the problem are discussed and a set of necessary conditions is developed. A steepest descent algorithm is proposed to determine a local solution of the problem. The method is illustrated by solving a model reduction problem.

For more details click here   Back

Abstract

Reflection-type hybrid coupled PIN diode digital phase shifters find several applications in microwave systems* Invest igations reported in this thesis are aimed at (i) evolving design procedures for various 180° and 90° phase shifter circuits of this kind for a given set of diode parameters, (ii) comparison of these circuits, and (iii) their optimization to attain best performance taking into account, various discontinuity reactances contributed by microstrip circuitry, The study reported here begins with exploring as to which parameters of the hybrid play critical role in phase shifter behaviour* The most important hybrid parameter for phase shifter performance is the directivity. It is found that a directivity of 20 dB in a 90° hybrid can cause, in the worst case, an input VSWR of the phase shifter to be 1*56* an insertion loss of 0215 c and a phase error as high as + 22*8°• An inequality of 1*0 dB in amplitudes of the two signals at the coupled ports of the hybrid can increase the input VSWR of the phase shifter to 1.26, but does not contribute to any phase error (0O) e ' xvii Performance of phase shifters using ideal 180° and 90° switches allows one to study phase shifter circuits independent of PIN diode characteristics and thus enables one to investigate the limitations in performance imposed by the characteristics of the hybrids* Five types of hybrids have been considered* Results of this study point out the need of designing the trans forming networks such that the two impedances, seen by the hybrid in the two bias states of the diode, are placed symmetri cally on two sides of the X=0 axis on the Smith chart. For 180° phase bits using two-branch and rat-race hybrids, this is achieved by inserting an interconnecting line length of V8 between the switches and the hybrid ports. This results in maximum bandwidth of the phase shifter. Corresponding line length for the 90° phase bit is X/16* Phase bits using three-branch hybrids are found to give maximum bandwidth for zero line length• The design of phase shifters using nonideal diodes is essentially the design of the transforming network to achieve the desired phase shift at the centre frequency and minimum phase error over the band of frequencies. Closed form design equations are derived for the design of three types of trans forming networks, namely; (i) single line length (to be used with impedance transf orating hybrid), (ii) quarter wave trans former and (iii) a single stub xviii Performances of phase shifters using three types of transforming networks with two-branch, three-branch and rat-race hybrids are evaluated* Bandwidths for various designs have been computed for two specifications of bandwidth and for wide range of diode reactances.

Insertion losses for the above designs have also been calculated. It is observed that in most of the cases wide bandwidth is obtained when the forward bias reactance of the diode X™ is large and the reverse bias reactance Xp is small* Circuits using two-branch impedance transforming hybrid give lowest loss and have smallest size when compared to the other circuits considered* Another aspect analyzed is the effect of variations in diode parameters on phase shifter performance* This study is useful in specifying the tolerances in diode parameters for given performance characteristics of the phase shifter. Sensi- j tivities of differential phase shift (A 0) with respect to diode reactances for 180° and 90° phase bits have been evaluated for the three types of transforming networks* It is found that I tighter tolerances in diode capacitances are needed for 90° ; bits than for 180° bits. It is observed that the effect of diode resistances R™ and RR on the phase shift is small as compared to that of the reactances* Hence* the design equationst derived by ignoring diode losses, may also be used for lossy ; xlx diodes• Phase shifter performance using mismatched diodes is more sensitive to the inequality of the phases of the two reflection coefficients of the phase shift networksf than that in their magnitudes. There is % significant effect of microstrip discontinuity reactances on the phase shifter performance* A 180° phase bit using two-branch hybrid and single stub type of transforming network (e = 2*53 and substrate height = 0,0625 inch) gives a differential phase shift of 190° instead of 180°. Compens^* tion of these discontinuities (mainly contributed by T-junctions) is carried out by an optimization process* The optimized phase shifter gives slightly wider bandwidth than an ideal circuit without discontinuities* Both 180° and 90° optimized phase bits have been fabricated* Diodes used were characterized experimentally• The theoretical and experimental results are found to agree within the specified tolerance of the diele ctric constant of the substrate.

For more details click here   Back