LARGE SCALE POWER SYSTEM DYNAMIC MODELLING AND SIMULATION : A GRAPH THEORETIC APPROACH

by

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- Dedicated to

MY BELOVED PARENTS

C E R T I F I C A T E

Certified that the research work "Large Scale Power System Dynamic Modelling and Simulation : A Graph Theoretic Approach' by L.N. Paliwal, has been carried out under our joint supervision at the Indian Institute of Technology, Delhi and that this work has not been submitted elsewhere for the award of a degree.

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-L.N. Paliwal

ABSTRACT

The dynamical solution of electric power systems has long been recognized as extremely important for system planning and operation. Increased size and complexity of present day power systems have changed the nature of the system dynamics, thereby demanding accurate and comprehensive dynamic analysis of such systems. Owing to the order of complexity of interconnected system in dynamic studies, it is uneconomical nay impractical to represent the entire system in detail. It is, therefore, frequently expedient to restrict the use of detailed mathematical description for each component model to that subsystem whose detailed dynamics are under study. The rest of the system, where internal performance is not of particular consequence, is then represented by appropriately simple dynamic equivalents so as to adequately capture the influence of the rest of the system on the performance of the study subsystem.

A practical and effective method for large scale power system dynamic studies requires the computer simulation of system response, with time, following a prescribed disturbance. The general superiority of state models for system dynamic studies over frequency domain and transfer function techniques is well documented. Most of the models used for system studies are based on conventional rotor d-q frame of reference, incorporating varying degree of model accuracy depending on the requirements

for specific system studies. Some authors [60,65] have developed power system dynamic models through the application of linear graph theory. Their models are based on direct phase quantities in either S-domain or in state-space form. However, for large scale power systems, the development of state models incorporating such details as saliency, amortisseur circuits, stator and network transients and shaft dynamics etc. in terms of direct phase quantities becomes highly cumbersome, involved and unmanageable. Thus, efforts made so far in using graph theory for large scale power system modelling have failed to attract the attention of practising engineers. The main thrust of the present work is to explore and demonstrate the practical applicability and effectiveness of the graph theoretic approach to large scale power system dynamic modelling with a view to highlighting the strong appeal of the technique to the power system engineers. Investigations have been made in the course of the evolution of the thesis to highlight the efficient application of graph theoretic approach in formulating a system state model which proves to be extremely systematic and vastly more general than mere manipulations of the matrix equations as pursued in conventional d-q frame [26].

The development of the stability equivalents for large scale power systems is of topical interest. In this context, an attempt has also been made to demonstrate the application of the graph theory in arriving at system dynamic equivalents which has hitherto remained unexplored in the literature. A novel approach based on a certain moment technique, in conjunction with the application of graph-theory, has been explored in the present work for developing stability equivalents of power systems. Transient stability studies for sample power system based on stability equivalents have been carried out using the new approach of moment technique as well as the conventional approach due to Brown et. al [35] and relevant comparison made in order to bring out the merit of the new approach vis-a-vis that of the conventional approach.

The research presentation in the thesis is organized in six chapters.

Chapter 1 gives a short review of previous work and broad outline of the present work in the area of system modelling and system equivalence. The philosophy and methodology of large scale system modelling through graph theoretic approach have been duly highlighted.

The second chapter is devoted to the development of state models for both large and small disturbances for a machine-infinite bus system through linear graph-theoretic component-to-subsystem-to-system modelling framework. In the process, the nonlinear and linearized state models of power system components/subsystems such as generator, transformer and double circuit transmission line etc., are formulated (conceptually, in isolation) and then combined with appropriate interconnection constraints to develop multi-terminal representations of the sub-assembly at various levels. The models incorporate saliency adequate damping effects of amortisseur circuits, and stator and network transients in addition to traditional electro-mechanical transients implied by machine rotor d-q frame of reference. The cases of degeneracy of first and second order are specially presented to bring out their contribution in reducing the number of states.

The third chapter demonstrates the powerfulness of the graph-theoretic approach in developing a linearized state model for a large scale interconnected multi-machine system from a basis of mathematical models of the component parts of the system and knowledge of the system structure. The linearized d-q state models of basic, repetitive components/sub-assemblies such as generator, transformer and transmission line are formulated (conceptually,in isolation) in synchronously rotating reference frame (as against conventional rotor frame for generator, and stationary frame for transmission network) which permits ease of interconnection without involving any intermediary of axis transformations. These subsystems are then recombined systematically via linear graph theoretic subsystem-to-system modelling construct to form the overall state model of the complete multi-machine system. The procedure clearly highlights a 'gradual growth process' that develops sub-network representation at the $(i+1)^{th}$ level by systematically adding only one component or sub-assembly at a time to the sub-assembly at the i^{th} level of representation, thereby demonstrating the generality in formulation for digital computer simulation.

An effective and systematic graph theoretic subsystem-to-system approach towards the development of linearized state models for typical hydro and thermal power systems feeding large load centres through series compensated long distance transmission networks, is presented in the fourth chapter. These small perturbation models incorporate such detailed dynamics as those of generator stator, shaft, controllers and long transmission system, necessary for accurate and precise stability-studies with particular reference to sub-synchronous resonance aspects. The generality in the formulation of the models, together with its ready amenability to digital simulation and applicability to multi-machine systems have been clearly brought out.

The fifth chapter deals with the development of dynamic equivalents of large scale power systems requiring reasonable computer memory and processing time. A highly systematic, machine implementable graph theoretic procedure for developing passive and active network equivalents for the external system at the boundary buses of the study-system, is presented. The efficient application of graph theory in realizing the Ward type distribution factors' [8,35] has been highlighted . The development of dynamic equivalents based on a new concept of moment technique has been attempted. A comparison of the dynamic equivalents based on the usual Ward-type distribution factors and the new approach based on moment concept has been clearly brought out by examining the equivalents in the context of transient stability studies of a sample 44-bus system. An attempt has also been made to look into some details regarding load modelling for stability equivalents.

Finally, chapter 6 brings out the detailed conclusions of the entire work and the scope for further studies.

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