ON SOME ASPECTS OF AUTOMATIC GENERATION CONTROL OF INTERCONNECTED POWER SYSTEMS IN CONTINUOUS AND DISCRETE MODES

by

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ELECTRICAL ENGINEERING DEPARTMENT

Submitted

in fulfilment of the requirements of the degree of

DOCTOR OF PHILOSOPHY

to the

INDIAN INSTITUTE OF TECHNOLOGY, DELHI

December, 1980

Dedicated to

the memory of my mother

Smt. Indira Devi

CERTIFICATE

Certified that the dissertation entitled, "On Some Aspects of Automatic Generation Control of Interconnected Power Systems in Continuous and Discrete Modes" which is being submitted by Shri M.L. Kothari for the award of Doctor of Philosophy in Electrical Engineering of the Indian Institute of Technology, Delhi is a record of the student's own work carried out by him under our joint supervision and guidance at the Indian Institute of Technology, Delhi. The matter embodied in this dissertation has not been submitted elsewhere for the award of any other degree.

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ACKNOWLEDGEMENTS

I have great pleasure in expressing my gratitude to Professor J. Nanda and Professor P.S. Satsangi, Department of Electrical Engineering for their constant encouragement, stimulating discussions and unceasing enthusiasm during the course of this work.

I am grateful to the authorities of the G.B. Pant University of Agriculture and Technology, Pantnagar for sanctioning study leave for this work. I am also grateful to the authorities of Indian Institute of Technology, Delhi for providing financial assistance.

I am grateful to the Head, Department of Electrical Engg and Head, Centre of Energy Studies, I.I.T. Delhi for providing the facilities for carrying out the research work.

I wish to thank the staff of the Computer Centre, Indian Institute of Technology, Delhi for the facilities provided for digital computation.

I should appreciate the care and interest taken by Sh. J.N. Saini, in typing this thesis.

Finally, I am grateful to my brothers, wife and children for their excellent understanding, support and cooperation during the course of this work.

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ABSTRACT

An electric energy system must be maintained at a desired operating level characterized by nominal frequency, voltage profile, and load flow configuration. It is kept in this nominal state by close control of the real and reactive powers generated in the controllable sources of the system. A mismatch in the real power balance affects primarily the system frequency, but leaves the bus voltage magnitudes essentially unaffected. Similarly a mismatch in reactive power balance affects mainly the bus voltage magnitudes but leaves the system frequency practically unaffected.

The regulation of the power output of electric generators within a prescribed area in response to changes in system frequency and/or tie-line loading, or the relation of these to each other, so as to maintain the scheduled system frequency and/or the established interchange with other areas within predetermined limits is known as the automatic generation control (AGC). Each control area should strive to match its generation to its prevailing load at scheduled frequency and should also assist in maintaining frequency and time error within acceptable limits.

A lot of work concerning AGC of interconnected power systems has been reported in the past using either classical or optimal control strategy. Although many studies pertaining to classical controllers for the thermal plants are available

in the literature, yet surprisingly in most of the cases the mathematical model has been oversimplified by ignoring the simultaneous presence of important system constraints like generation rate constraint (GRC), governor deadband (DB) and even the very reheat nature of the steam plants. Moreover, the investigations in all these studies mainly pertain to secondary control aspect of AGC based on Tie-Line Bias control strategy, leaving the primary control aspect practically untouched. Proper selection of governor speed regulation parameter R for the primary control loop is extremely vital, lest an arbitrary selection of small R may provide pretty poor dynamic response. Surprisingly, there has been no comprehensive attempt so far to suggest a systematic approach to the optimum selection of R in the simultaneous presence of GRC and DB. It is also not clearly known how the governor deadband plays its role in the AGC system in the presence of stringent GRCs. Moreover, none of the works dealing with supplementary controllers based on classical control strategy has considered for a modern thermal/hydro-thermal system, the optimization of these controllers in the simultaneous presence of both GRC and DB and hence the optimal classical controllers so arrived at may not behave properly in the actual systems.

Literature survey does not also provide any comprehensive sensitivity analysis to understand the performance of the AGC system to changes in system parameters under simultaneous consideration of GRC and DB.

All these intrinsic problems have been carefully investigated in the present work.

Further, literature survey shows that a good deal of attention has been paid during the last one decade to the application of linear optimal control strategy to AGC. Inspite of the powerfulness of the optimal control theory, the controllers so achieved have failed to appeal to the utilities because the realization of such optimal controllers is difficult, cumbersome and costly. In the present work the author demonstrates a new and logical approach for the synthesis of simple realizable centralized/decentralized suboptimal controllers through the use of powerful linear optimal control strategy and sensitivity analysis. Load demand estimators are essential to implement the optimal control strategy. However, the present work suggests a design procedure for optimal control strategy through the use of a new performance index that obviates the need of load demand estimators. Using this new optimal control strategy, studies are carried out to provide a systematic synthesis procedure for arriving at easily realizable and practically implementable decentralized suboptimal controllers based on local state variables.

Most of the earlier works in the area of AGC pertain to interconnected thermal systems. Surprisingly, hardly any rigorous and systematic work has been reported for AGC of an interconnected hydro-thermal system involving widely different characteristics for the hydro and thermal subsystems. The present work therefore aims at studying some of the important problems like optimization of the primary and secondary control loops of AGC of a hydro-thermal system considering GRC and DB.

So far all the problems mentioned in the present work have been examined considering the availability of area control error (ACE) as a continuous signal for AGC purposes. However, in a practical situation the ACE is available only in the sampled form. Therefore it is obvious that the more exact picture for the AGC for any system can only be achieved through discrete mode analysis. The work therefore is extended to investigate the AGC problems of thermal and hydro-thermal systems using discrete mode analysis in order to highlight the specific differences in the system performance with discrete and continuous control strategies.

Chapter 1 introduces the AGC problem of interconnected power systems in general and presents a critical survey of the past work concerning AGC. It clearly lays down the objectives and motivations of the research work presented in the thesis.

Chapter 2 presents a systematic approach to the selection of governor speed regulation parameter R and also the selection of optimum integral controllers for an AGC system comprising of two equal-area reheat steam plants in the simultaneous presence of GRC and DB. Sensitivity analysis is carried out to observe the performance of the AGC system to changes in certain system parameters in a more realistic manner by duly considering the presence of GRC and DB.

Chapter 3 provides a systematic and comprehensive approach for exploring simple practical suboptimal controller structures for automatic generation control of a two equal-area nonreheat thermal system in the simultaneous presence of GRC and DB using the powerful tool of the linear optimal control strategy.

Chapter 4 reports the development of an optimal controller based on a new performance index for AGC of two equal- area non-reheat system, which circumvents the need for a load demand estimator. The performance of such a new optimal controller has been compared with that of a Fosha-Elgerd optimal controller. Finally in this chapter decentralized suboptimal controllers based on 'Minimum Norm' and 'Minimum Error Excitation' concepts are worked out and their performances analyzed.

Chapter 5 deals with automatic generation control of a hydro-thermal system. A systematic approach to the optimum selection of governor speed regulation parameter R and integral controller settings for both the areas considering GRCs and DB is highlighted. An attempt is also made to explore the effectiveness of adding proportional feedback of the area control error to the integral controllers on the performance of the AGC systems. Studies are also carried out to understand

and examine the role of governor deadband on the dynamic performance of the AGC system. Sensitivity analysis is carried out in order to identify those significant system parameters that strongly influence the dynamic performance of the hydro-thermal system considering generation rate constraint and governor deadband.

Chapter 6 deals with some aspects of sampled-data automatic generation control of a two-area reheat thermal system provided with classical controllers. A linear discrete-time state space model is developed for the analysis. A systematic and comprehensive approach for optimization of such controllers in the discrete mode using margin of stability and integral squared error concepts have been attempted. The performances of the optimum integral controller settings achieved through continuous and discrete modes have been compared in the realistic discrete mode operation of the AGC. An approach to optimum selection of sampling period is discussed. Dynamic performances of optimum integral and optimum proportional-integral controllers in the discrete mode with and without GRC have been further examined. Attempt is also made to study the effect of change in frequency bias setting on optimum controller setting and system responses. Since in an integrated system, different control areas may have different rated capacities, an investigation is carried out to explore the condition of reducing a given two-area system to an equivalent one area-infinite bus system. Finally a sensitivity analysis is carried out to understand the effect of variation of significant system parameters on optimum integral gain settings and cost function in the presence of GRC.

Chapter 7 deals with some aspects of sampled-data AGC of a two-area hydro-thermal system provided with integral controllers in both the areas. A linear discrete-time state space model is developed for the analysis. An approach to systematic selection of optimum integral gain settings in both the areas is brought out with and without GRC. The optimum controller settings achieved through discrete mode analysis have also been compared with those obtained through continuous mode analysis. The effect of sampling period on optimum integral gain setting has been brought out. Selection of optimum sampling period is also discussed.

Lastly Chapter 8, brings out the detailed conclusions of the entire work and the scope for further research.

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