ROBUST POWER SYSTEM STABILIZER DESIGN BASED ON LMI OPTIMIZATION APPROACH

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JUDUL: ROBUST POWER SYSTEM STABILISER DESIGN BASED ON LMI OPTIMIZATION APPROACH

SESI PENGAJIAN: 2004/2005

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"I hereby acknowledge that the scope and quality of this thesis is qualified for the award of the Degree of Master of Electrical Engineering"

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NOVEMBER 2004

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بِسْمِ اللَّهِ الرَّحْمَٰنِ الرَّحِيمِ

In the Name of Allah, the Most Gracious, the Most Merciful

For my beloved family

ACKNOWLEDGEMENT

I am deeply grateful for the help that I received from my supervisor, Professor Dr. R. Jeeghathesan, during the development of this project

I would also like to extend my gratitude to all lecturers that has given me all the basic needed for completing this project, and also to my classmates and friend for their encouragement and help.

I could not have done this project without the unconditional support, active encouragement, complete cooperation, and honest sacrifice by my family. To appreciate their immense contribution, this thesis is lovingly dedicated to them.

ABSTRACT

Robust control theory considers a fundamental and practically important issue in control engineering plant uncertainty. It turns out that many of the simplest questions are very difficult to solve, but researchers have made considerable progress over the last twenty years. In this project, a robust control of power system stabilizer (PSS) for single machine infinite bus using LMI optimization approach is considered. In practical, power system stabilizers (PSS) are added to excitation systems to enhance the damping during low frequency oscillations. The main objective of this project is to design robust controller for PSS using H∞ technique based on LMI optimization approach. The nonlinear model of a machine is linearized at different operating points using Power System Dynamic simulation software. A robust controller is obtained using linear matrix inequalities approach. This method does not require state of the system for feedback and is easily implementable. A single machine infinite bus system is applied to demonstrate the efficiency and robustness of the approach. The results obtained from simulations validate the improvement in damping of overall power oscillations in the system. The simulation also shows that the optimized PSSs are robust in providing adequate damping for a range of conditions on the system. This method gives very good results for the design of PSS for single machine infinite bus system compared to NBO method.

ABSTRAK

Teori kawalan *robust* secara dasar dan praktikalnya merupakan satu asas yang amat penting di dalam kejuruteraan kawalan loji yang mempunyai pembolehubah yang tidak tetap. Hal ini telah menyebabkan kebanyakkan persoalan-persoalan mudah amat sukar untuk diselesaikan, namun para penyelidik telah menunjukkan kemajuan yang memberansangkan dalam penyelidikan sejak 20 tahun yang lalu. Di dalam projek ini, kawalan penstabil sistem kuasa yang *robust* direka untuk kegunaan sistem mesin tunggal yang mempunyai infinitif terminal menggunakan pendekatan pengoptimalan Ketaksamaan Matrik Linear (LMI). Secara praktikal, penstabil sistem kuasa (PSS) digunakan dalam sistem kuasa bagi tujuan penambahbaikan pengecutan denyutan yang berlaku ketika tempoh ayunan frekuensi rendah di dalam sistem. Objektif utama di dalam kajian ini adalah untuk mencipta pengawal yang tegar untuk kegunaan PSS menggunakan kaedah H_∞ ke atas pendekatan pengoptimalan LMI. Model mesin yang tidak linear dilinearkan pada titik operasi yang berlainan menggunakan perisian simulasi sistem kuasa dinamik (PSD). Satu pengawalan yang tegar diperolehi menggunakan pendekatan Ketidaksamaan Matrik Linear (LMI). Kaedah ini tidak memerlukan pengetahuan kepada keadaan sistem dalam proses suapbalik dan hal ini menyebabkan amat mudah diimplementasikan. Satu mesin tunggal yang mempunyai infinitif terminal digunakan bagi menguji kecekapan dan ketegalan pendekatan ini. Keputusan yang diperolehi daripada simulasi mengesahkan kemajuan dalam pengecutan denyutan dalam keseluruhan sistem ayunan kuasa. Keputusan simulasi itu juga menunjukkan PSS yang optimum adalah tegar dalam menyediakan pengecutan denyutan yang mencukupi dalam linkungan kondisi sistem. Kaedah ini memberikan satu keputusan yang baik bagi rekaan PSS utk kegunaan sistem mesin tunggal berterminal infinitif berbanding kaedah Pengoptimalan Tak Linear (NBO).

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CHAPTER I

INTRODUCTION

1.1 Problem background

The electrical power systems have been going drastic changes in the past decade. It constantly experience changes in transmission networks, load patterns and operating conditions. On the other hand, in the expansion of the transmission network, high demands on the load and various operating conditions, there are several limitations due to the environmental effect, economic constraints, and the system operations. These limitations will give pressure to the system to sustain their performances. Nowadays, fast developments in industries also contribute to the cause of the crisis with the issues of 'minimizing the breakdown'. The industries cannot tolerate with the failure of electrical power system that will effect their productions.

These days, there are many attempts by researchers to solved the problem arises by the stability of power system. There are very difficult to manage the power system with the high demand without any sufficient control system to co-ordinated the complex system. Therefore, the importance of robust power system control becomes even more visible with the deregulation of power systems and recent increase in the power demand. However, in order to operate power systems effectively, without reduction in the system security and quality of supply, new control strategies need to be implemented.

Today, in modern power systems environment, the operating conditions gradually closer to their control and operational limits. As stated before, this scenario has originated due to the increase in demand for electric energy coupled with economic and environmental restrictions on power system expansion. Modern power system, in a real world seen to be in a simplest form but in an actual world, there are large and nonlinear. For that reason, due to these properties, there are many challenges on theoretical and practical aspects need to be considered. Figure 1.1 shows the example of modern power system network with four generators in one system.

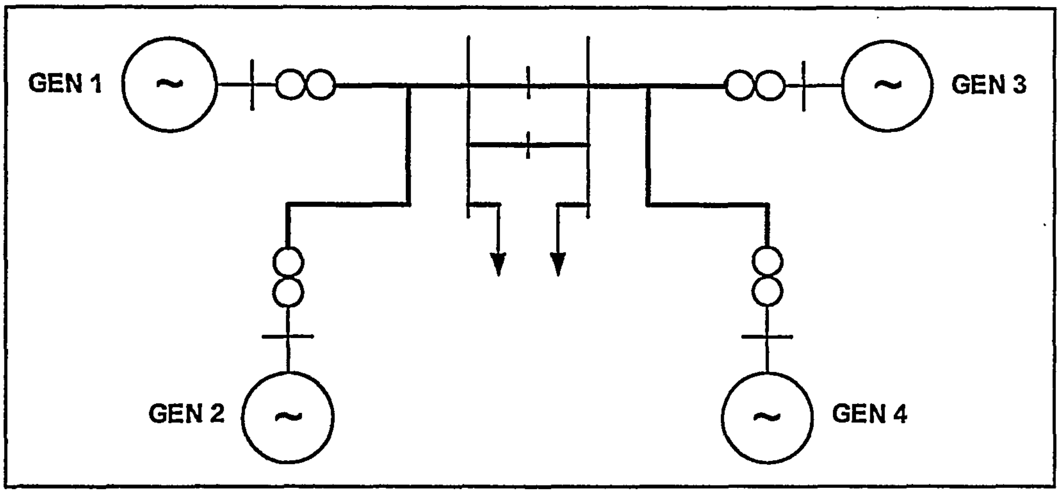

Figure 1.1 Power System Network

One of the main problems related with modern power system is the robustness issues. In the electrical terminology, it called the steady state stability, or in control terminology, the small signal stability around a system operating point. Robust control theory considers a fundamental and practically important issue in control engineering environment. The aim is to maintain overall system performance despite changes in the system. This idea has been around since the origins of control systems and any controller that cannot tolerate variations in the plant that will encountered in operation is simply a poorly designed controller.

Nowadays, there are many latest technology have been proposed to solve the problem related to the stability of power system [1]. However, before implementing any latest technology, it is necessary to certify these latest control schemas through simulation within an environment that allows accurate modelling of all power system components. The control system will have to regulate the system under various operating condition. This control system must have the ability to tolerate model uncertainty in the system, suppress potential instability, and damp the system oscillation that might threaten system stability when the system is operating under stressed conditions. Additionally, the main task in the design of control systems in power system is to evaluate the stability robustness. In history, before modern control system was introduced, most of the cases in the stability problems used classical model of controller.

1.1.1 Classical Power System Stabilizer

Classical model of controller are designed to make a system stable under a specific operating condition only [2]. Classical Power System Stabilizer (PSS) have been successfully applied for a long time. PSS are usually design one at a time, by classical control methods, which restrict the system modelling to low order single-input single-output linear models, whereas the power system oscillatory instability is actually a large-scale multivariable problem. The fact that the usual design of PSS is based on very simplified mathematical models has not prevented this to be a very effective solution to the damping of electromechanical oscillations in the past. However, modern control systems are designed to make a system stable for wide range of operating conditions. The basic concept of modern control system is to ensure whether the design specifications are satisfied even for the worst-case scenario.

1.1.2 LMI approach

An important feature of LMI based methods is the possibility of combining design constraints into a single convex optimization problem. LMIs have been involved in some of the major events of control theory. With the advent of powerful convex optimization techniques, LMIS are now about to become an important practical tool for feature control applications. It starts when Lyapunov invented Lyapunov equations. This history of LMI in the analysis of dynamical systems goes back more than 100 years. It began in about 1890, when Lyapunov published his seminal work introducing what we now call Lyapunov theory [2]. LMI will ensure the stability of the system if the physical system possibly translated into LMI format. LMI format is useful in many engineering issues related to control problems.

1.1.3 Modern Power Systems

Nowadays, the demand is focus on the stability issues, which the stability problem in electrical power system operations is the steady-state stability. The load demands at a certain bus can vary gradually, or even sharply, every hour throughout a day; disturbances of differing extents of severity could happen during the normal operation; and the topology of the system could change over time. The existence of uncertainties requires good robustness of the control systems. A control system is robust if it is insensitive to differences between the actual system and the model of the system that was used to design the controller. Oscillations of small magnitude and low frequency, linked with the electromechanical modes in power systems, often persist for long periods and in some cases present limitations on the power transfer capability[1]. Robustness means, 'the capability of the system to operate with various operating points/conditions.

Modern control system theories have been developed significantly in the past years. The key idea in a robust control paradigm is to check whether the design specifications are satisfied even for the worst-case scenario. Many efforts have been taken to investigate the application of robust control techniques to power systems. One of the popular methods is H optimization techniques that have many applications in power systems. In general, power systems must typically perform over a wide range of operating conditions. With the existence of uncertainty it will requires good robustness of the control systems. It is robust if the system insensitive to differences between the actual system and the model of the system that was used to design the controller. These differences are referred as model uncertainty.

1.1.4 Power system stabilizer

Power system stabilizer (PSS) unit has long been regarded as an effective way to enhance the damping of electromechanical oscillations in power systems. PSS controller design is a method of combining the PSS with the AVR. The main action of the PSS is to control the rotor oscillations; the input signal of rotor speed has been the most important signal. PSS is very important in the power system to maintain the stability of the system. PSS operate to improve the damping of the system by adding or subtracting signal to the exciter.

The action of a PSS is to extend the angular stability limits of a power system by providing supplemental damping to the oscillation of synchronous machine rotors through generator excitation. This damping is provided by a electric torque applied to the rotor that is in phase with the speed variation. Once the oscillations are damped, the thermal limit of the tie lines in the system may then be approaches. However, power system instabilities can arise in certain circumstances due to negative damping effects of the PSS on the rotor. The reason for this is that PSSs are tuned around steady-state operating point; their damping effect is only valid for small excursions around this operating point. During severe disturbances, a PSS may actually cause the generator under its control to lose synchronism in an attempt to control its excitation field. Figure 1.2 shows the example block diagram of power system stabilizer. However, in this thesis, the focus is to design LMI-PSS that will improve the classical method of designing PSS.

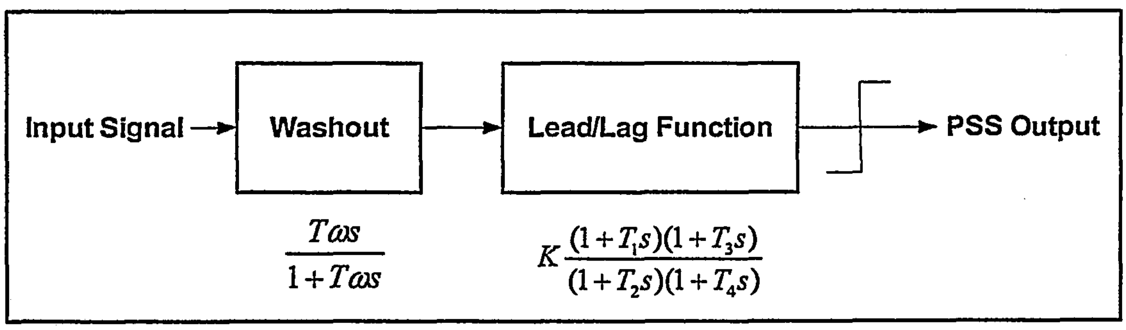

Figure 1.2 Conventional Power System Stabilizer Structure

1.2 Problem statement

Supplementary excitation control achieved by means of power system stabilizer is the most convenient and economical method of damping the electromechanical oscillations of a synchronous generator and enabling the operation of modern fast excitation systems. The power system stabilizer adds damping to generator rotor oscillations by adjusting the generator excitation so that it provides a component of electrical torque in phase with rotor speed. A power system stabilizer (PSS) designed to provide damping for a system with weak tie line by means of phase compensation at the rotor oscillation frequency will not provide adequate phase compensation for another situation, say a strong tie line situation. This is because the increase in reactance with a strong tie line will increase the synchronizing torque thereby increasing the natural frequency of oscillation and also the phase lead compensation requirement. Therefore a PSS, a well tuned for a particular operating situation is unable to provide the same sort of performance for other operating conditions.

Robust controllers were designed using advanced multi-variable control techniques like LQG, H_2, H_∞ and LMI based optimization in the last decade. The main aims of these robust control methods are to design controllers that are capable of handling modelling errors and uncertainties and produce control action that stabilizes the plant. Additionally, the controller designed should ensure stability and meet performance specifications for all possible plant behaviour defined by an uncertainty. Among the various multi-variable control methods the LMI based optimization technique is popular. It provides the design engineer a more flexibility freedom in handling a larger and more realistic set of design objectives both in frequency and time domains, unlike the others which cannot adequately capture all design specifications.

In order to analyze the suitability of the LMI theory for generator excitation systems, the design of a LMI optimization based power system stabilizer will be investigated in this thesis. The general theory and the formulation of the LMI based control problem will be presented along with the method of designing controllers using the LMI technique. The design procedure and performance evaluation of the

PSS designed with LMI optimization technique and the advantages and limitations of this control technique when applied to the field of excitation control will be investigated in detail for system power system models.