早稲田大学大学院理工学研究科

博 士 論 文 概 要

論 文 題 目

Studies on Robust Control for Power System Stabilization

(電力系統安定化におけるロバスト制御に関する研究)

申 請 者

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With the advancement of power technologies modern generators operate with reduced stability margins which make necessary more accurate knowledge of the limits of stable operation under dynamic conditions. However, the complexity of power system transients and cascade disturbance characteristics are beyond practical limitations of modelling techniques used in conventional generator control designs. Therefore a controller design based on a linearized model and fixed parameters may degrade because of drifts in operating conditions or uncertainties. Thus in order to provide reliable system operation the controller must be designed taking into account the various sources of uncertainties. The sources of uncertainties in generator control primarily include linear approximation, modelling errors, measurement errors, parameter errors and faults. In order to take the parametric uncertainties into account several researchers have applied the concept of variable structure to power system control design, and also various control techniques have been proposed for dealing with parametric uncertainties, which are complicated and difficult to implement. One of the approaches in the robust control design is the quadratic stability of systems with parametric uncertainties. The robust quadratic stability has been applied to power system control by some reaseachers. But in most cases, all the states of the system have to be measured or have to be available for measurements, which is practically impossible and limiter constraints are not considered. In order to solve the problems in this thesis the use of an observer based robust quadratic controller is proposed to stabilize power systems, where the parametric uncertainties considered can be time varying and the values of these uncertainties are considered to be bounded. It is known that robust controls have big overshoot in their control inputs. As a common method cutoff limiters are used to limit the control input. In that case the performance of the system can not be predicted and even may degraded. In this thesis an algorithm is introduced which the limiters are considered during the design. It is shown that with the limiter consideration during the design the performance of the system improves, while the stability of the system is guaranteed. It is shown that the proposed techniques in this thesis are effective in the presence of parameter variations and fault uncertainties and can enhance the stability of the power system.

The organization of the thesis and abstract of each chapter is as follows:

Chapter 1, 'Introduction'; This chapter includes a brief review of state of arts of power systems and robust control. The problems which electric utilities are encountered in the field of genereator and power system control are cited. Some other robust control techniques are briefly reviewed. The neccessity of application of the robust control schemes to power systems and its operational and economical

effects are described.

Chapter 2, 'Robust Generator Control for parametric uncertainties'; In this chapter first, the sources of parametric uncertainties in power system are reviewed in detail. Since the parameters of generator changes with different factors such as temperature and aging it is concluded that control strategies which do not consider these uncertainties during the design, may degrade. A full state robust quadratic control scheme is introduced. To make the application of the method clear first simulations are run for a simple power system. The system model includes one generator connected to infinite bus system, and has automatic voltage regulator (AVR) and a governor. The results are compared with that of linear optimal control (LQR). Parameters of the system are varied randomly. It is shown that the proposed method can stabilize the system under different system parametric combinations while the LQR fails. This chapter is conluded with the idea that the consideration of parametric variation of the system during the control design increases the reliability of the system and existing power plants can be operated with an increased stability margin.

Chapter 3, 'Robust Observer Based Generator Control for Typical Faults'; In this chapter an algorithm is proposed for robust generator control with robust observer, and the main source of uncertainty considered is one circuit line opening of double circuit lines and three phase to ground fault. Offline contingency analysis of these phenomena are currently carried out in real operation of power systems. Controls which are designed and tested for the kinds of faults could be applied practically with high degree of reliability. In generator control there are many states which are not measureable or if measureable are of considerable cost. Therefore it is necessary to design a controller which is based on the measureable state of system. Here the measureable state is considered to be the variation of speed of the generator shaft. This signal is used as input signal to the convensional power system stabilizer (PSS). The model studied is the detailed model of one machine infinite bus system. Nonlinear simularions are run with different fault senarios, it is shown that even if LQR fails for the fault cases the preposed method can stabilize the system.

Chapter 4, 'Robust Optimal Generator Control and Limiter Considerations'; In this chapter a generator control is designed which is not only robust against parametric uncertainties, but also is optimal in performance. Furthermore noise can be taken into account. Positive constants which had to be determined by the designer before can be determined systematically. Nonlinear simularions are run with different fault scenarios. It is shown that the robust optimal control provides the system with a better performance, but the controls usually suffer from a big overshoot in their control input. If the control is not limited a very large control signal may cause damage to the equipment. The servo devices may saturate and the performance of the system degrades. To overcome the problems, an algorithm is presented. In this algorithm first a lower gain control is designed, and then based on this control and using Lyaponuv stability theory another stabilizing control is designed. The two controls are added and satuarated. Through nonlinear simulations it is shown that the system with the constrained control is stabilized, while the cutoff limiter case degrades.

Chapter 5, 'Robust Output Feedback for PSS', This chapter is concerned with the design of PSS with robust output feedback control. To consider uncertainties existing in power systems, first a robust optimal control for PSS is designed and then the output feedback gain is derived by mathematical operations. To guarantee the stability of the system an eigen value technique is used to locate the poles of the closed loop system in a stable region. The control input signal consists of incremental shaft speed $\Delta\omega$ and electric power ΔP, which are easily measured in real operations. The main uncertainties considered in the design is one circuit line opening of double circuit lines, 15% variation in inertia constant and 20% variation in damping. The proposed control method is tested on a one machine to infinite bus power system, and numerical simulations are run using nonlinear equations for a three phase to ground fault near generator terminals followed by one circuit line opening. The results are compared with the conventional PSS and it is shown that considerable improvements are obtained by using the proposed robust output feedback control. One of the features of this research is the derivation of robust output feedback control to design a PSS without compensator. The concept of phase compensator has been develped for one machine to infinite bus system, but with the development of two signal output robust control method, generalization of the two input control has been achieved.

Chapter 6, 'Conclusions'; This chapter summarizes conclusion. It is concluded that: Robust control techniques for power system stabilization have been developed. The parametric uncertainties, and fault occurrences should be considered during the control design. It has been shown that the system with proposed robust control can stabilize the system under those uncertainties. The control constraints should be considered during the design otherwise the control may be overshooted which may damage the devices and the performance of the system will become unpredictable. It has been shown that with the proposed constrained control methods the control