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Polynomial based H_∞ robust governor for load frequency control in steam turbine power systems

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ABSTRACT

This work presents an approach to design a load frequency controller (LFC) for power systems with steam turbines. The goal is to damp the oscillations of the output frequency deviations as fast as possible. The design is based on the polynomial H_∞ robust control theory. The robust governor is synthesized by assuming parameter's variations, negligible dynamics, and a constant main steam pressure. The proposed controller will adequately ensure the internal stability and the robust performance of the closed-loop system. The closed-loop control system is tested by subjecting the system to different disturbance signals to show the robustness characteristics, and the well damping of the output frequency under parametric perturbations. The simulation results point out that the system performance is substantially improved.
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1. Introduction

Power system stability is the property that enables it to remain in a state of operating equilibrium under normal operating conditions and to regain an acceptable state of equilibrium after being subjected to a disturbance [1,2]. The quality of the power supply must meet certain standard requirements with regard to specific factors. These factors are the constancy of the frequency, the constancy of the voltage, and the level of reliability. Our main concern is regarding the first factor mentioned above.

The most universal method of electric generation is accomplished by the thermal generation using the steam turbine-driven generator units. The steam is produced in steam generators or boilers using either fossil or nuclear fuels as primary energy sources [2]. The poor balancing between the generated power and demands can cause the system frequency to deviate away from the nominal value, and create inadvertent power exchanges between control areas. To avoid such a situation, load frequency controllers are designed and implemented to perform automatically this balancing in each control area [1,3,4].

In [5], the speed governors have been designed based on PID techniques. Fuzzy sliding mode controller for LFC has been designed in [6] to account for the system's parameters variations and the governor backlash. The researchers in [7] used genetic algorithm GA for tuning the control parameters of the Proportional–Integral (PI) control subject to the H_∞ constraints in terms of linear matrix inequality LMI. Modern control techniques have been reported in [8,9], in which a load frequency controller for LFC has been designed using linear quadratic regulation LQR techniques. The work in [10] investigates the design problem or robust load frequency controller using LMI methods for solving the H_∞ control problem. The optimization by the sequential quadratic programming technique is utilized to design a robust load frequency control [11]. In [12], the design of a self-tuning for a PID behavior controller is investigated. An adaptive fuzzy control PID a like controller is designed for an isolated turbine speed control system. Another very interesting technique is the active disturbance rejection control ADRC, which solves the FLC problem by estimating the disturbance on-line, and determining an efficient nonlinear feedback control [13]. In [14], the ADRC is used to design a robust frequency load controller for interconnected power system. The ADRC-based FLC solution is developed for the power systems with turbines of various types, such as non-reheat, reheat and hydraulic.

The FLC problem is not only taken place in isolated power generator systems but also in interconnected electric power systems. Recent works consider the LFC problem in of several-area interconnected reheat thermal power system, where different control schemes are used. In [15], the decentralized LFC problem is solved by using robust optimal PID controller for two-area power systems. For four-area power system, in the work [16], the fuzzy logic technique is employed to solve the problem.

This paper presents a procedure to design a robust H_∞ governor based on the polynomial approach. The work herein considers

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parameters and model uncertainties, which are the main reason of causing the inefficiency of usual frequency load control such as PI and PID or even adaptive fuzzy control PID a like controller. Moreover, the robustness features can be attained within the framework of the linear theory. Therefore, in practice, the implementation of the obtained controller (or a reduced order one) will be easier than implementing the nonlinear feedback control usually used with the ADRC.

2. Steam turbines and speed governing system

A steam turbine converts the stored energy of a high pressure and high-temperature steam into a mechanical energy, which is in turn converted into electrical energy by the generator. The heat source for the boiler may be a nuclear reactor or a furnace fired by fossil fuel (coal, oil, or gas) [1,2].

Steam turbines normally consist of two or more turbine sections or cylinders coupled in series. Most units placed in service in recent years have been of the tandem-compound design. In a tandem-compound, the sections are all on one shaft, with a single generator.

A typical mechanical-hydraulic speed governing system consists of a speed governor (SG), a speed relay (SR), a Hydraulic Servomotor (SM), and a Governor-Controller Valve (CVs). In a steam turbine-generator system, the governing is accomplished by a speed transducer, a comparator, and one or more force-stroke amplifiers. Fig. 1 depicts a conventional block diagram of a closed-loop control system of a steam turbine generator [2]. Appendix 1 gives the detailing of the used symbols and the transfer functions of the individual components [17].

3. Polynomial robust governor

In this work, a different configuration for the problem of LFC of steam turbine has been proposed as shown in Fig. 2. In the proposed configuration, the controller (governor) is placed in the feed forward path in contrast to the conventional governor in which the controller is positioned in the feed backward path. Since the main purpose of the droop feedback is to provide the steady-state speed regulation, in the process of governor control system design, we will temporarily assume that the droop feedback is of unity gain. The proposed configuration will be used to set up the problem within the framework of the H_∞ design methodology. The polynomial methods will be used for design the desired controller.

To start, let us assume a mixed sensitivity configuration for the steam turbine plant as shown in Fig. 3. It includes the performance shaping filters $V(s)$ and $W_1(s)$, and the uncertainty filter, $W_2(s)$. The additive uncertainty is used to compensate for neglected dynamics, which are represented as unstructured uncertainty through $W_2(s)$.

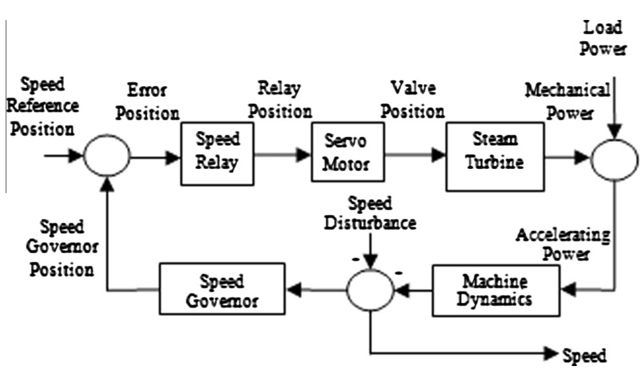

Fig. 1. Block diagram of steam turbine system.

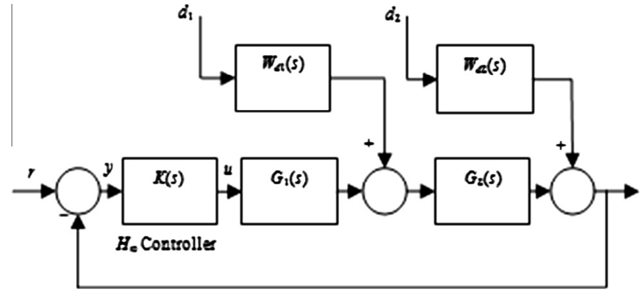

Fig. 2. Proposed configurations for LFC of a steam turbine power system.

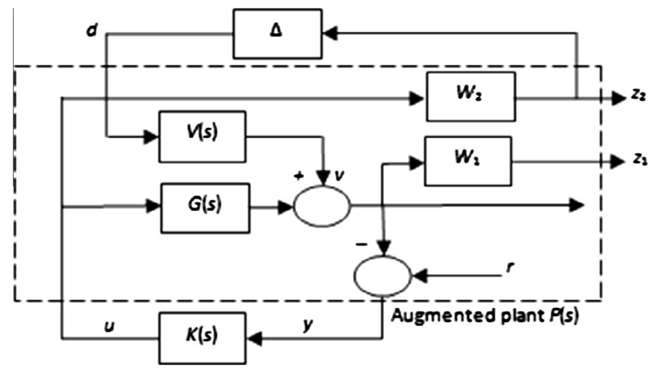

Fig. 3. A mixed sensitivity configuration.

The exogenous input d generates the disturbance v after passing through a shaping filter with transfer function $V(s)$. The control error z has two components z_1 and z_2, which are corresponding to the plant output and input respectively. The transfer functions of the different blocks are given by scalar polynomials as

$$G(s)=\frac{N(s)}{D(s)},V(s)=\frac{M(s)}{D(s)},W_1(s)=\frac{A_1(s)}{B_1(s)},W_2(s)=\frac{A_2(s)}{B_2(s)} \quad (1)$$

where the transfer function $G(s)$ is given by

$$G(s)=G_1(s)*G_2(s)=\frac{N(s)}{D(s)} \quad (2)$$

The design of the shaping filters is highly depended on the model at hand, and certain considerations have to be taken during the design of these shaping filters like uncertainty, high frequency roll-off, and integral control. The system dynamic is described by

$$\begin{bmatrix} z_1 \\ z_2 \\ y \end{bmatrix} = P\begin{bmatrix} d \\ u \end{bmatrix} \quad (3)$$

where the transfer function matrix P of the generalized plant is described by [18,19]

$$P=\begin{bmatrix} p_{11} & p_{12} \\ p_{21} & p_{22} \end{bmatrix}=\begin{bmatrix} W_1V & W_1G \\ 0 & W_2 \\ -V & -G \end{bmatrix}=\begin{bmatrix} \frac{A_1M}{B_1D} & \frac{A_1N}{B_1D} \\ 0 & \frac{A_2}{B_2} \\ -\frac{M}{D} & -\frac{N}{D} \end{bmatrix}=D^{-1}N=[D_1 \quad D_2]^{-1}[N_1 \quad N_2] \quad (4)$$

The mixed sensitivity problem schematized in Fig. 3 is the problem of minimizing the H_∞-norm of the closed-loop transfer function matrix

$$T_{zw}(s)=\begin{bmatrix} W_1SV \\ -W_2RV \end{bmatrix}, \quad \text{where} \begin{bmatrix} z_1 \\ z_2 \end{bmatrix}=T_{zw}(s)[d] \quad (5)$$

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