CONTROL OF THREE AREA INTERCONNECTED POWER SYSTEM USING SLIDING MODE CONTROLLER

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ABSTRACT

Multi-area power systems are growing rapidly due to deregulation, where several distant regions can share a scheduled amount of power via tie lines. Generally, a power system is considered to be a highly nonlinear and large-scale multi-input multi-output dynamical system with numerous variables, protection devices, and control loops. Power system controls are applied to keep the power system in a secure state, and frequency control is an important control problem in power system design and operation. Moreover, in view of the power supply-and-demand issues in multi-area power systems, load frequency control (LFC) is extensively applied to balance the tie line power and frequency despite of the load fluctuations. In the past decades, considerable efforts have been made to solve the LFC for multi-area power systems, and many different control strategies have been proposed to achieve the desired dynamic performance, such as PI and PID controllers, with diverse function, simple structure, and fixed control gain, have been widely applied. However, these conventional approaches do not work efficiently for all operating conditions, since multi area power systems contain a large number of nonlinearities and uncertainties, and the conventional controller parameters are always estimated from the model structure and parameters.

In addition, few new LFC based control techniques have been proven to be much more effective and robust, e.g., optimal control, robust decentralized control, adaptive control, and sliding mode control methods.

In this thesis, the design of an event-triggered DSMC algorithm is proposed for the LFC system by solving the sequential minimization problem with a MATLAB simulink.

INTRODUCTION

The quantification of system reserve has, until recently, been a relatively simple and largely deterministic process. The city's demand for electric energy is enormous, especially in areas where industrial and commercial activities have rapidly developed. However, finding a suitable site for a new substation or new transmission line is difficult because of protests by the residents of potentially affected neighborhoods. Expanding the capacity of a substation or transmission line is also difficult in urban areas. The system security of the substation is difficult to maintain when the substation suffers from capacity shortages or is in a state of emergency. A suitable load management scheme is, therefore, needed to preserve the reliability of the systems.

Frequency drifts, upwards or downwards, in a power system is the main indicator of the momentary imbalance between generation and demand. If, at any instant, power demand (taken in this thesis to be active power only) exceeds supply, then the system frequency falls. Conversely, if power supply exceeds demand, frequency rises. The system frequency fluctuates continuously in response to the changing demand and due to the practical impossibility of generation being controlled to instantaneously track all changes in demand.

The obvious challenge in including loads in frequency control is the large increase in the number of potential participants. Even in the largest control areas, at most a few hundred large generators contribute to frequency control. On the other hand, participation from the demand side might involve tens of thousands if not millions of consumers. Though this may appear technically daunting and economically unrealistic, it has to keep in mind that conventional primary frequency control is a distributed control system that relies on the availability of the frequency as a measure of imbalance between load and generation. Indeed, the response of each generating unit is determined by its droop characteristic and a local frequency measurement, not by a signal sent from a control center. Communication to and from the control center is used only in the slower secondary and tertiary control loops for better economic optimization and network security. A load or consumer thus does not have to be plugged into a communication network to take part in primary frequency control.

LOAD FREQUENCY CONTROL TECHNIQUES

- Load frequency control based on different techniques.

- Load frequency control with AC – DC parallel tie line.
- Consideration of communication delay in LFC
- Load frequency control of conventional sources integrated with distributed energy sources.
- LFC of hybrid power system integrated with renewable energy sources.
- Application of different learning techniques in LFC.
- Application of power electronics devices in LFC.

LOAD FREQUENCY CONTROL BASED ON DIFFERENT TECHNIQUES

In this category, different techniques used for implementation of LFC are discussed. The primary focus remains on the control strategies of parameters, which are generally the gains of controllers normally used in forward path where area control error is the input to the controller. In some cases governor speed regulation (R) and frequency bias (β) are also needed to be optimized. Depending on the different control scheme this group is further subdivided into following subgroups:

- LFC with different optimization Techniques
- LFC With Different Feedback Theory
- LFC with Application Of Observers
- LFC Using Internal Model Control

Load Frequency Control with Different Optimization Techniques

In the last three decades, different soft computing techniques have developed and successfully implemented to different complex optimization problem. Power system optimization is no exception to this trend. Soft computing techniques which are successfully used to solve load frequency control problem include Genetic Algorithm (GA), Particle Swarm Optimization (PSO), Bacterial Foraging Algorithm (BFA) and Differential Evolution (DE). In order to solve the optimization problem more effectively different artificial intelligence techniques are combined in hybrid manner. For instance a Fuzzy logic control scheme in combination with other optimization technique is very useful to ensure the robustness of the system.

Load Frequency Control with Different Feedback Theory

Development is a never ending process. Application of different development on feedback theory on LFC is also reported [26] – [30]. In fact different feedback theories were used as controlling tools in these LFC studies. A robust decentralized LFC in deregulated environment is presented in [26]. The LFC problem was solved as a multi objective control problem using H2/H∞ control technique. A robust controller was designed by reducing the LFC problem in static output feedback control.

Rakhshani et al. designed a linear quadratic regulator for load frequency control in a deregulated environment in [27]. The proposed optimal output feedback regulator overcame the necessity of measuring all the state variables of the system. In the proposed design only the measurable state variables within each control area were required to use for feedback. Comparison of the performance of the proposed regulator with the performance of full state feedback and state observer methods had also been carried out.

Role of novel robust decentralized controller had been demonstrated to solve the load frequency control (LFC) problem in a restructured power system [28], [29]. Quantitative feedback theory (QFT) was used here to construct the proposed controller. The main feature of this modified dynamic model of LFC was that in different contracted scenarios, the effects of the possible contracts behaved as a set of new input signal. Comparative study between the QFT based proposed controllers and the conventional controller proved the superiority of the first one. It had been proved that for a large variation in system parameters proposed QFT based controller is superior [29]. Proportional – integral (PI) state feedback controller to solve the load frequency problem. This study was aimed to find the proper governor speed regulation parameter (R) and participation factor in AGC for each generator. The study was carried out on the system which consists of hydro, thermal and gas generating units [30].

Load Frequency Control Using Observer

Load frequency control monitors a lot of component of power system which are directly or indirectly related to LFC. Hence observer takes a vital place in LFC as it observes minute to minute condition of every component that ensures frequency deviation remains within the prescribed limit. The advantages of observer concept were successfully used to solve load frequency control problems [31] - [33].

Rakhshani et al constructed a reduced order observer controller to eliminate the problem of measuring and monitoring all the state variables at all time. This proposed scheme was found effective when the system runs with lesser numbers of sensors than numbers of states. With the help of reduced order observer multi area LFC problem was solved with improved dynamic responses in deregulated environment. LFC of a two area power system using a global proportional – integral (PI) state feedback controller based on quasi – decentralized functional observers (QDFOs) theory was presented in another work [32]. Unlike conventional observers which were used as a centralized one for all areas in LFC, a low order observer was used for each area. Though they are completely decoupled from each other some outputs were shared between them to get a global control. The overall complexity of the system was reduced by using the proposed method.

Moreover, a decentralized sliding mode control scheme was also used [33] to solve LFC problem of three area interconnected power system. The robust controller was based on reaching law method to achieve better performance and to make frequency deviation zero after any load variation or any system variation.

Use of Internal Model Control in Load Frequency Control

Internal model control is another control method which provides a new methodology for solving load frequency control problem. The primary concept of this control method is similar to that of observers. This control scheme is employed in LFC to reduce the complexity of the problem. Recent trends towards restructuring of power system and interconnected system makes the load frequency control more complex. As the area increases order of the system also increases which in turn increases system complexity. Hence internal model control (IMC) scheme is applied in LFC to reduce the order of the system. Internal model control (IMC) was successfully applied in AGC [34] - [37]. Successful application of IMC based on two – degree of freedom concept in load frequency problem is presented in [34], [35] in which second order plus dead time (SOPDT) is used instead of full order system [35]. In a model predictive control scheme for LFC [36], focus was on neural network model predictive controller. The performance of the proposed controller was investigated over a wide range of system parameters. Another model predictive control (MPC) scheme for AGC [37] was used for a large control area. Each sub area consists of its own MPC controller.

Consideration of Communication Delay in LFC

In restructured power system, the competitive open access strategy makes the load frequency problem more complex and its performance worse. To overcome this unwanted situation open communication infrastructure is needed. Unlike the traditional closed communication network, time delays are not fixed for the new open communication network. Hence, automatic generation control achieves more perfection with the consideration of communication time delay. Automatic generation controls with delays are also presented. Again some studies are done by considering a limit of delay where some are without any margin. Hence LFC study in this group is further subdivided as follows:

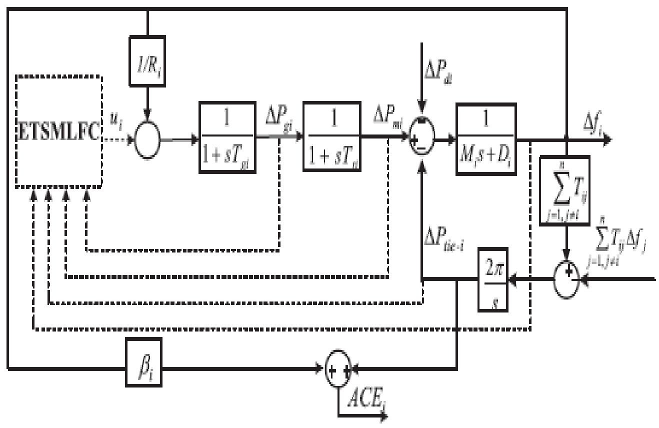
- Communication delay with no margin.
- Communication delay with margin

SIMULATION RESULTS

INTRODUCTION

In order to show some important features of the proposed LFC model, the results of several different simulation studies are reported in this Chapter for a three-area power system. In order to make a fair comparison, design procedure has been employed for controller design for both systems. In order to validate the proposed topology, simulation is carried out using the Matlab/Simulink.

PROPOSED TOPOLOGY

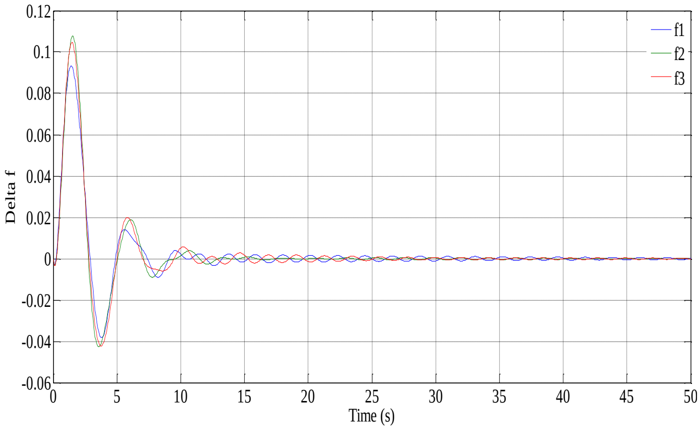


Block-diagram representation of an i[th] area power system model

The dynamic model of the multi area power system as is shown in Fig.5.1. According to the LFC scheme, both the frequency of the control area and the interchange power through the tie-line should be kept in the nominal values. Consequently, the measure of area control error (ACE) is proposed.

We solved the LFC problem in multi-area power system under the event-triggered SMC scheme, in which the corresponding networked sliding mode dynamics are given. First, sufficient conditions of performance analysis are proposed to guarantee the networked sliding mode dynamics to be asymptotically stable with a prescribed energy-to-energy performance. Then, the discrete-time sliding mode controller is designed for each subsystem. SMC law is synthesized to guarantee that each subsystem trajectories can be kept in the pre-specified sliding mode region within a finite time.

SIMULATION RESULT ANALYSIS



Frequency variation of three area interconnected power system

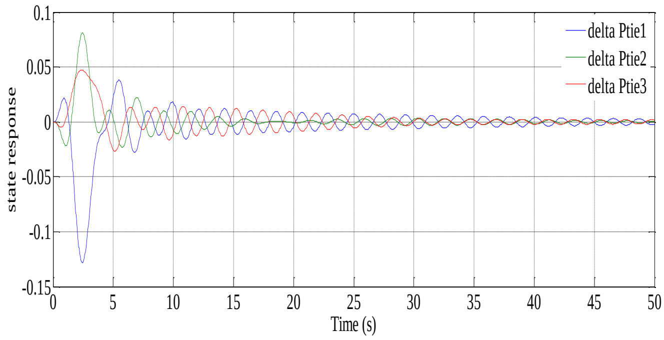


Fig.5.3: Tie-line response of three area interconnected power system

The responses of Δf_i and ΔP_{tie-i} in the three areas are shown in Figs. 5.2 and 5.3. It can be seen that the frequency deviation and tie line power deviation reach to zero with the designed event-triggered sliding mode controller.

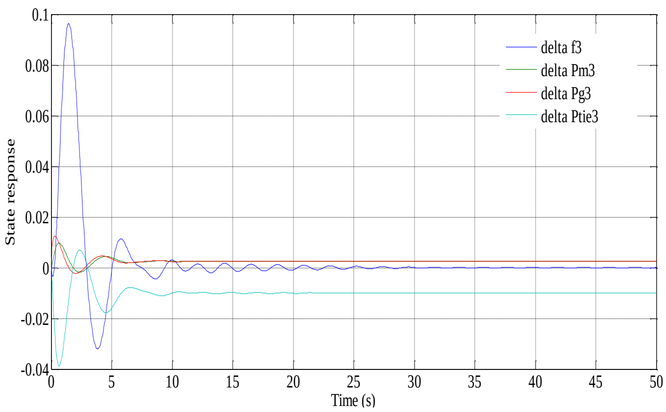


Fig.5.4: State responses of LFC scheme with ε = 0.1 for Area 3

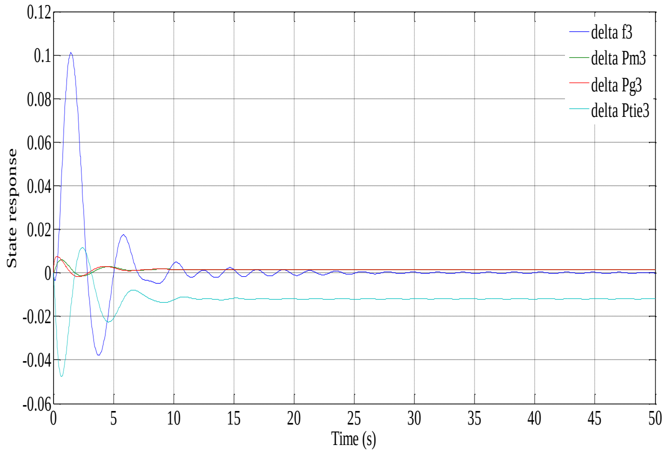


Fig.5.5: State responses of LFC scheme with ε = 0.6 for Area 3

Figs.5.4 and 5.5 are given to show the different responses of the state responses and the release instants and release intervals for Area 3, under the conditions that event-triggered parameters ε = 0.1 and ε = 0.6, respectively.

CONCLUSIONS

A sliding mode controller was designed to ensure that the each subsystem in the multi-area power system was stable and robust to external disturbance, including load variation and frequency fluctuation. Finally, the feasibility and effectiveness of the proposed design techniques were illustrated by example and simulation. Further research in this area could further improve the proposed algorithm, such as extending the present methods to LFC of power systems against delayed input cyber-attack, and handling the case where some of the LFC system state components

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