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Sliding Mode Load Frequency Control for Multi-Area Power System

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Abstract- **In case of a co-related power system, any load change in any area of the system causes the variations or deviations of the frequencies and also change in power in tie line. Frequency problems dose exist in all sectors of the power system. From the load point of view, frequency sensitive devices require quasi constant frequency to work properly. Whereas in the transmission system, power losses like hysteresis loss, eddy current loss in transformers are depends on the frequency. In system, load frequency control has been considered a bottom line issue. To maintain the equilibrium or stability between generated power and load demand without causing any change in frequency and tie-line power flow is the main objective.**

Index Terms- **Power system, load frequency control, sliding mode.**

I. INTRODUCTION

A modern power system involves so many control areas connected to each other by tie lines. One area is connected to another by either high-voltage direct current transmission links or alternating current tie-lines. The load frequency control of an interconnected power system plays most important role in adjusting the output of the generator according to load changes [1]. The main motive of LFC is to maintain the frequency and inter area tie line power at the scheduled value and within the acceptable limits when the disturbances take place [2]. Electrical power systems are critical nonlinear fluctuating systems. Since a power system exposed to small changes in load during its normal operation, the linearized model can be used and will be sufficient to represent the power system dynamics around the operating point [3]. The load frequency control is used for maintenance the frequency of the systemand scheduled interchanges to their scheduled values. The Olle Elgerd and C. Fosha are the main discoverer of the work and named it 'Megawatt Frequency Control'[4]. The power systems are nothing but the interconnection of more areas through tie lines. The generators in a control area all time vary their speed together for maintenance of frequency and the relative power angles to the predefined values in both static and dynamic conditions. If there is any sudden load change occurs in interconnected power system then there will be frequency changes and tie line power changes. Different control theories have been introduced in the literature for suburbanized LFC. A classical PI controller has easy structure and is very easy to apply. So it is a typical LFC used in power industry. However, the PI controller can produce a very long settling time and more overshoot in the transient responses of errors of the frequency [5]. In general, the conventional design approach for a load frequency controller employs the linear control theory to derive control law for the linearized plant model with invariant system parameter.

In co-related power systems, the control areas are supplied by each area and the power flow is allowed over tie lines among the areas. Whereas, the output frequencies are affected because of the small change in load in any of the areas so as the tie line power flow make the differences. So the temporary situation information of all other areas are required by the control system of each area to restore the pre-defined values of tie line powers and area frequency. Each output frequency finds the information about its own area and the tie line power deviation finds the information about the other areas.

II. OVERVIEW OF LFC

The initial try in case of LFC has to control the frequency of the power system by the governor. This skill of governor control was insufficient for the stabilization of the system. So, more supplementary control skills were introduced to the governor with the help of variable directly proportional to the deviation of frequency and it's integral. This technique includes classical approach of Load Frequency Control of power system. Cohn has done previous research in the important areas of LFC. Concordia et al [6] and Cohn [7] have proposed the basic values of frequency and tie line power also tie line bias control in case of co-related power system. Excessive frequency diversion can degrade the equipment, degrade the behaviour of network loads, establish lines of connection and stimulation overload prevention equipment on the network and network collapse may result in bad conditions. Hence, it is very necessary to keep the frequency at scheduled value.

The revolutionary abstraction of optimal control for LFC of an interconnected power system was early initiated by Elgerd [8]. North American Power Systems Interconnection Committee suggested that, each and every control area should have its frequency bias coefficient equals to the Area Frequency Response Characteristics (AFRC). But Elgerd and Fosha argued on the basis of frequency bias and presented that there is wider stability margin and better response by the help of optimal control methods. They have also demonstrated the truth that a state variable model on the basis of optimal control method can upgrade the stability margins and dynamic reply of the problem of load frequency control. Fig. 1, shown demonstrates four area power systems which have four control areas and six interconnections called tie line. So it is shown that each area donate some of its power to other area. Here the four areas are assumed to be identical and each has thermal non reheat turbines.

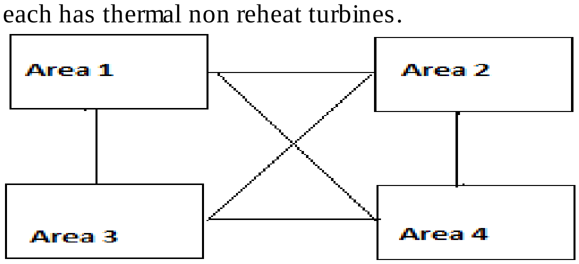

Figure 1: Multi area interconnected power system

The frequency diversions in all areas are severely putting effect on the quality and production of frequency sensitive industries such as petro chemical industries, weaving industry, pulp and paper industry etc. So the apparatus life time is reduced on the load side. The frequency and the tie-line power flow make differences by the load variations. Hence, the frequency and tie line power flow of each area should have to be hold.

III. LITERATURE REVIEW

Over a long period of time, different optimization theories are discovered as well as employed on the study of AGC of power system. The author S. Kumari, G. Shankar has described the differential evolution optimization technique to optimize the gains of the conventional PI and PID controller for the frequency stabilization. The system performance are improved by using DE-PI and DE-PID in comparison to results obtained using other optimization techniques. Pan and Liaw proposed an adaptive controller using proportional-integral (PI) adaptation. The controller worked quite well except with generation-rate constraint (GRC). From the simulation result, it seems that the incremental frequency deviation *Af(t)* was not very well damped. For LFC control in co-related power system, Kouba et al. in [5] have developed a proportional-integral-derivative (pm) controller design based on fuzzy logic (FL). Mandour et al. in [6] have proposed a tough LFC using genetic algorithm (GA) and H-infinity. Performance analysis of LFC based on artificial neural network technique is discussed in [7]. It is noticed from the reported final score that the presentation of optimized conventional controllers in LFC study using various investigated evolutionary algorithm is found to be good as compared to score obtained using optimal control theory. Elsisi et al. have employed BAT algorithm based model predictive control for frequency stabilization in nonlinear interconnected thennal-hydro system [9]. The LFC control of co-related power system with HVDC link using PSO optimized controller is achieved in [10]. The research says that the basic PSO has some disadvantages like converging slowly and easily plunging into local optimal. To reduce this disadvantages a new raised version of PSO is developed in [11]. While dealing with LFC problems EOA may appear to be very helpful. From the various EOA skills, genetic algorithm (GA) [9], differential evolution (DE) [1], particle swarm optimization (PSO) [10], ant colony optimization [12] and bacteria foraging optimization algorithm (BFOA) [13] have been used for the design of controller to be used in LFC. However, these skills suffer from moderate convergence, delicate ability in local search and also may result in entrapment in local minimum solutions which gives no updating in result and get stuck at intermediate point [2].

The more work by numbers of engineers of control engineering has originated links between the closed loop transient and frequency response. The research is continued over different classical control methods. It is revealed that it will result comparatively large transient frequency deviation and overshoots. Moreover, generally the settling time of frequency deviation for the system is relatively long (10 to 20 seconds). The LFC optimal regulator design techniques using optimal control theory stimulate the engineers of control engineering to design a control system with optimal controller, in reference to given performance criterion. Fosha and Elgerd were the two persons who first presented their work on optimal LFC regulator using this process. A power system of two same areas connected through tie line is considered for research. R. K. Cavin et al has assumed the difficulty of LFC for connected power system from the theory of optimal stochastic system. An algorithm based on control strategy was proposed which gives raised outputs of power system for both small and large signal modes of operation. The special attractive feature of the control scheme discussed here was it required the newly used variables. Those are change in frequency and scheduled inter change deviations taken as input.

$ACE = (P_{tie} - P_{sch}) + B_f \Delta f = \Delta P_{tie} + B_f \Delta f$ .... (1)

Where P_{tie} and P_{sch} are tie-line power and scheduled power through tie-line respectively and the constant B_{f} is called the frequency bias constant.

Figure 2 shows the model representation of single area system, consists of governor, turbine and generator load blocks.

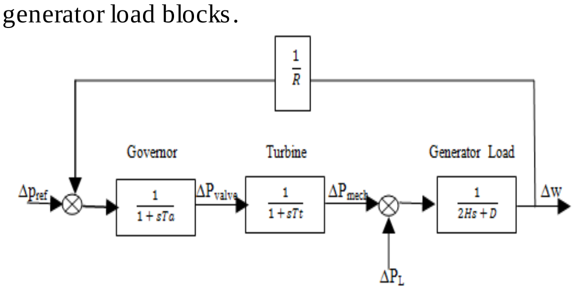

Figure 2: LFC for single area system

IV. SLIDING MODE CONTROL

The sliding mode control (SMC) is a system in which the structure is intentionally deviated with a discontinuous control and it pushes the phase trajectory to a plane. This technique is known for its toughness to deviation and parameter changes. Conventionally, the sliding mode control is based on state space approach. That is nothing but one first develop a Lyapunov function and then struggle to find a control law to make the derivative of the Lyapunov function negative definite.

There are two important phases for SMC design:

(i) To select an suitable switching surface for the system to ensure that the sliding motion on the plane possesses the required properties

(ii) To design a switching controls law which is able to push the system towards the sliding surface and stay on it [1].

The motion of the system which is limited to the switching surface is called as sliding. Sliding motion or sliding mode may be explain as the slow production of the state trajectory of a system limited to certain heights in a specified non-trivial sub-manifold of the state space with stable dynamics. When the state velocity vector moves towards the sliding surface then only sliding mode will exist. If these state trajectories are surrounded by the sliding surface, then these trajectories collides switching surface to keep it on. Any graph starting on the surface and stays there if surface σ(x) = 0. Any graph initiates separately and move toward sliding surface asymptotically. Thus, it is applicable to sliding motion. Sliding motion or sliding mode may be defined as the development of the state graph of a system confined to a specified plane of the state space with stable dynamics. The hyper plane in state space where the switching function is zero is called switching surface. The design of sliding mode controller includes selecting a proper sliding surface by applying SMC algorithm. The second step is to establish appropriate control law which force the closed loop system towards the sliding plane and ensure that system [14].The sliding mode control is developed to solve the matched and unmatched uncertainties.

V. EXPECTED RESULTS

The expected results are discussed as given below. The case of nominal parameter without considering load disturbances and parameter uncertainty is shown in fig. 3.

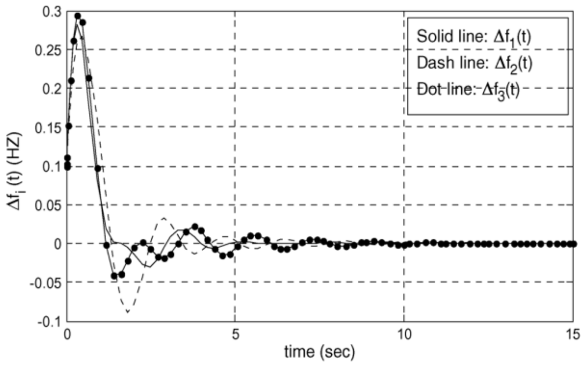

Figure 3: The $\Delta f_i(t)$ for each area

It shows that the $\Delta f_i(t)$ of each area can reach to zero within 10 sec. fig. 4 and fig. 5 results are for the case of matched parameters without and with sliding mode load frequency control respectively. According to fig. 5 the system with SMLFC can have faster response than the system in fig. 4.

Further under the different unmatched uncertainty such as $\Delta P_{d1}(t) = 0.02$ pu, $\Delta P_{d2}(t) = 0.015$ pu, $\Delta P_{d3}(t) = 0.01$ pu. From fig. 6 it can be seen that $\Delta f_i(t)$ without SMLFC, it can be seen that $\Delta f_i(t)$ cannot approach to zero after disturbances.

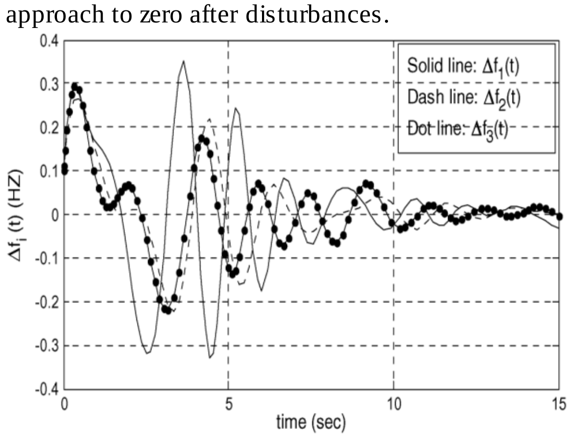

Figure 4: Without the SMLFC for the matching uncertainty

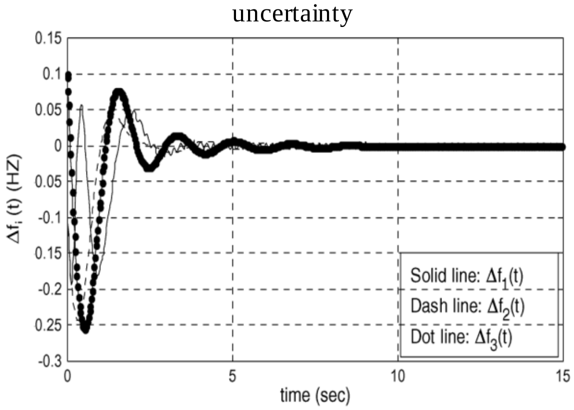

Figure 5: $\Delta f_i(t)$ with the SMLFC for the matching uncertainty

Fig. 7 and fig.8 shows $\Delta f_i(t)$ and tie line power deviation respectively approaches to zero with the sliding mode load frequency control. These expected results shows that the sliding mode load frequency controller can be effective to control the matched and mismatched parameter uncertainties of multi-area power system.

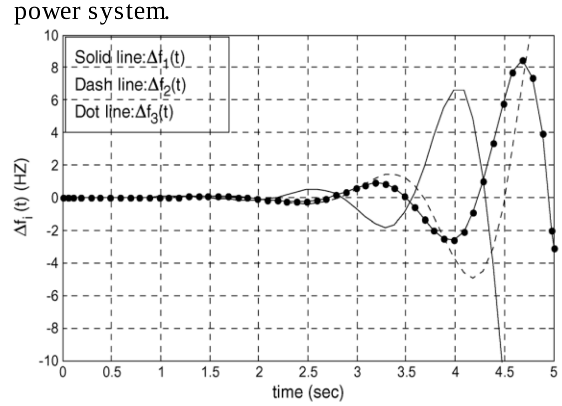

Figure 6: $\Delta f_i(t)$ without the SMLFC

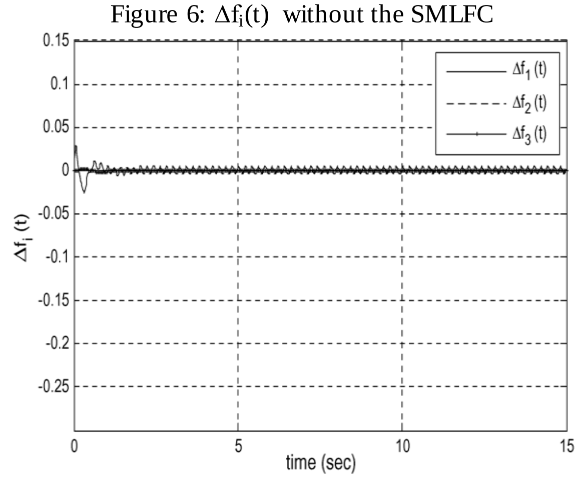

Figure 7: The. $\Delta f_i(t)$ with the SMLF

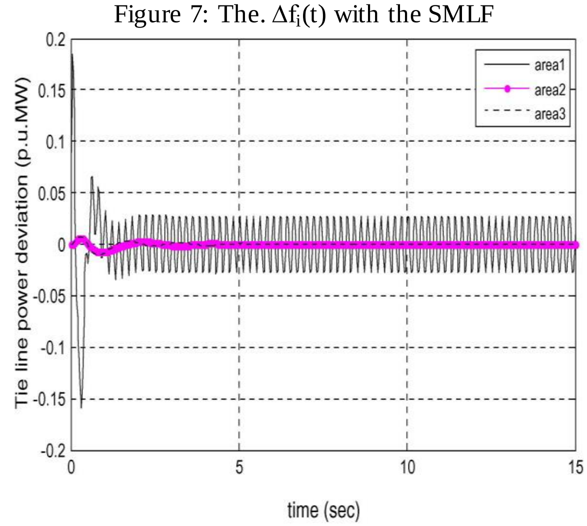

Figure 8: Tie line power deviation for Case 3 with the SMLFC.

VI. CONCLUSION

Optimal control technique has a huge application over control engineering. In this paper a Load Frequency Control algorithm based on some general concepts has been studied. A new adaptive Load Frequency Control method for multi-area power system under parameter uncertainties is presented in this paper. The expected results shows that the decentralized sliding mode load frequency control can reduce the overshoot and improve the response of the power system and can also limit the deviation of frequency to zero. This method has potential to be applied in the real environment besides its simple architecture. The results also prove the roughness of the control method in opposite to the external disturbance and system uncertainties. However, from the simulation results, we can see that the chattering behaviour of SMC is evident in the time response of tie-line power errors.

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