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LMI-BASED ROBUST CONTROLLER FOR LOAD FREQUENCY CONTROL OF THREE AREA INTERCONNECTED SYSTEM

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ABSTRACT

The purpose of this research is to create a robust predictive load frequency control (RPLFC) for power systems with unpredictable parameters and temporal delays in communication networks. The study looks closely at the communication of delay constraints across the various control regions as well as the relationship between delay restrictions and control gains. In addition, the usage of delay restrictions as a new performance index to steer controller design is discussed, along with the regulation of the controller for a trade-off between delay tolerance and dynamic reaction, and opting for the upper bound of the sampling period of a discrete realization of the controller, and the upper bound of the fault counter of the communication channel. All of these topics are brought up in the context of determining how to steer controller design. To determine whether or not the proposed technique is useful, simulation studies have all been outfitted with PID-type controllers and have been run for both single-area and three-area LFC schemes. MATLAB/SIMULINK served as the platform upon which the simulations were carried out.

Keywords: ACE, LFC, PID, RPLFC.

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1. INTRODUCTION

Controlling the frequency of the load is essential to the design and operation of electrical power systems. There is never an instance in which a power system's loading remains unchanged. It is required to construct a load frequency Management system to ensure that the quality of the power supply is maintained. This system deals with the control of loading on the generators based on the frequency of the power supply. In the context of a power system that serves multiple areas, each area must be furnished with at least one local load-frequency controller.

The design of a resilient decentralized load-frequency Controller makes use of a decentralized control idea that is robust [13-16]. Consequently, the RDLFC is composed of N different local load-frequency controllers (i.e. no measurements from other areas are required). In the new method that we have developed for the design of controllers, the RDLFC is achieved by solving N sets of decoupled Riccati equations. The N Riccati equations that were first calculated are interrelated; but, using the method that we have proposed, they can be separated. The asymptotically stable operation will be achieved across the entire power system when the RDLFC is utilized, taking into account all permissible parametric uncertainties. The process of managing the real power output of generating units in response to variations in system frequency and tie-line power interchange within prescribed limits is referred to as load frequency control (LFC) [1]. This is a challenge that must be solved to achieve the desired results. Advanced control methods were proposed in LFC as a response to the growing complexity of today's power systems. Some examples of these methods include optimal control [2]-[4]; variable structure control [5]; adaptive and self-tuning control [6], [7]; intelligent control [8], [9]; and robust control [10]-[14]. Recent topics that have garnered a lot of attention include LFC in a market that has just undergone deregulatory changes [16], [17], LFC with a communication delay [18], and LFC with new energy systems [19], [20]. For an exhaustive discussion of modern philosophies in AGC, please refer to [21] and [22]. The advanced control methods may result in improved performance; nevertheless, these methods call on either knowledge of the system states of an effective online identifier or; as a result, it may be challenging to put these methods into practice. In this presentation, we will explore a unified strategy for designing and tuning PID load frequency controllers that can be used to power systems with non-reheat, reheat, and hydro turbines.

2. LOAD FREQUENCY CONTROL

An interconnected power system presents a well-defined challenge when it comes to the topic of load frequency control. The power supply is segmented into different groups of generators that are linked together by tie-lines. Each cluster of generators is referred to as an area, and each area is responsible for ensuring that it can fulfill its load changes as well as any import or export targets that were established in advance by the controllers. Each region possesses its unique reaction characteristics, which connect the region's frequency to the total generation in response to changes in load on that region specifically. This curve illustrates the regulation of an area and indicates the gain of the region (measured in MW per Hertz). The area gain, also known as regulation, is a direct measurement of the impacts that all of the governors have on the prime movers inside the area. It plays a vital role in the system's ability to function both in a steady state and dynamically.

Constructing a linear system model with specified parameters is the standard approach that is followed when the design of L.F.C. functions is being carried out. This is accomplished by linearizing the system around an operational point. However, this strategy is not entirely accurate because the response characteristics of the system tend to be non-linear. The operating point has a direct influence on the parameters of the power system. As a consequence of this, the computed operating point will no longer be ideal as the operating conditions continue to change. A method of tracking the operating circumstances of the system is required to maintain system performance that is close to optimal. This method must also permit the continual update of system parameters to fulfill its purpose. After then, the control signal can be computed based on an optimal strategy by making use of the parameters that have been recently changed.

The amount and timing of load variations in the system are completely arbitrary. To successfully manage the transient response and take into account the sensitivity problem of L.F.C. in interconnected power systems, the utilization of self-tuning controllers is being contemplated as a potential solution. It makes more sense to think of the system as a stochastic one, and if you want better control performance, you should develop an adaptive stochastic controller rather than the fixed schemes that were employed before.

3. MULTI-AREA POWER SYSTEM MODEL

In a two-area power system that is interconnected, the control area is supplied by each area, and the power flow between the areas is enabled by the tie lines connecting the two areas. In this configuration, the two areas are connected using tie lines. Whereas, the output frequencies of all the regions are influenced because of a tiny change in load in any of the areas, which in turn affects the flow of power through the tie lines. Therefore, the control system of each area requires the transient situation information of all other areas to successfully restore the previously established values of the tie line powers and the area frequency. Each output frequency gathers information specific to its area, while the tie line power deviation does the same for the information about the remaining locations. For instance, the information in a power system with two areas can be expressed as $B_i$fi+P_{tie} if there are two areas. P_{tie} is the power in the tie line, B stands for frequency bias, and f is for predetermined frequency. This is the Area Control Error, also known as the ACE, which serves as the controller's input. Thus the load frequency control of a multi-area power system generally incorporates a proper control system, by which the area frequencies could bring back to their predefined value or very nearer to its predefined value so as the tie line power when the sudden change in load occurs.

When applied to a minor perturbation, the swing equation of a synchronous machine looks like this:

$$\frac{2H}{\omega}\frac{d^2\Delta\delta}{dt^2} = \Delta P_m - \Delta P_e$$

Or in terms of minor speed variations

$$\frac{d\Delta\frac{\omega}{\omega_s}}{dt} = \frac{1}{2H}(\Delta P_m - \Delta P_e)$$

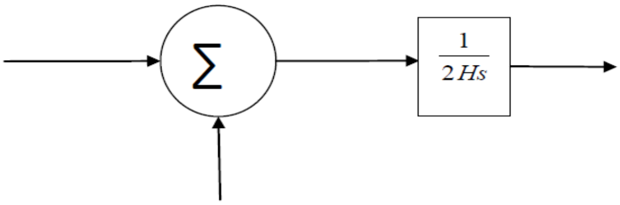


Figure-1. Generator mathematical modeling block diagram.

Figure-1 is the generator mathematical modeling block diagram. The load that is being placed on the power system is made up of many different types of electrical drives. The apparatus that is utilized for illumination is, for the most part, of a resistive character, whilst the rotating devices are, for the most part, a combination of inductive and resistive components. The following expression gives the speed-load characteristic of the composite load:

$$\Delta P_e = \Delta P_L + D\Delta\omega \quad (1)$$

Where ΔPL is the non-frequency-sensitive load change,

$D\Delta\omega$is the frequency-sensitive load change, and D is expressed as the percent change in load by the percent change in frequency. Block Diagram Representation of the Mathematical Model for Load is illustrated in Figure-2.

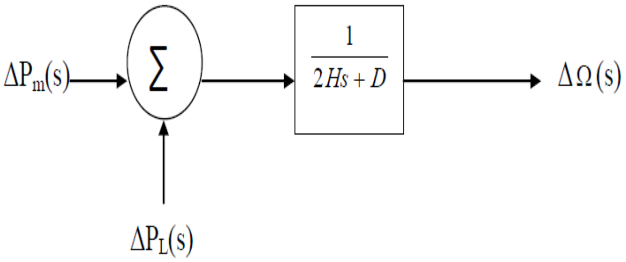


Figure-2. Block diagram representation of the mathematical model for load.

The source of power is commonly referred to as the prime mover. It could be hydraulic turbines at waterfalls or steam turbines whose energy is derived from the combustion of coal, gas, and other fuels. The model for the turbine establishes a relationship between the variations in the mechanical power output, denoted by ΔP_m, and the variations in the steam valve position, denoted by ΔP_V.

$$G_T = \frac{\Delta P_m(s)}{\Delta P_V(s)} = \frac{1}{1+\tau_t s} \quad (2)$$

Whereτ_t, the turbine constant is, in the range of 0.2 to 2.0 seconds.

When there is an unanticipated rise in the electrical load, the result is that the electrical power output is higher than the mechanical power input. As a direct consequence of this, the energy that is produced by the rotating turbines is used to compensate for the deficit of power on the load side. Because of this factor, the kinetic energy of the turbine, also known as the energy that is stored by the machine, is decreased. As a result, the governor sends a signal to supply more volumes of water or steam, or gas, which adds to the speed of the prime mover to compensate for the lack of sufficient speed.

The gradient of the curve is a representation of the speed regulation R. The normal difference in speed regulation for governors between no load and full load is between 5 and 6 percentage points.

$$\Delta P_g = \Delta P_{ref} - \frac{1}{R}\Delta f \tag{3}$$

Or in s- the domain

$$\Delta P_g(s) = \Delta P_{ref} - \frac{1}{R}\Delta f(s) \tag{4}$$

The command ΔPg is transformed through a hydraulic amplifier to the steam valve position command ΔP_V. We assume a linear relationship and consider simple time constant τ_g we have the following s-domain relation:

$$\Delta P_V(s) = \frac{1}{1+\tau_g}\Delta P_g(s) \tag{5}$$

Combining all of the previous block diagrams for a single system yields Figure-3.

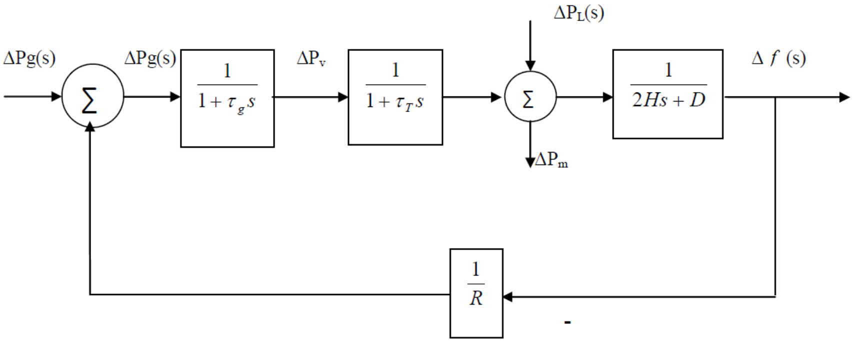


Figure-3. Generator, load, prime mover, governor system block diagram.

Figure-4 shows a multi-area power system's ith area control block diagram. The linearized approach is acceptable in the load frequency control problem since power systems are nonlinear and dynamic [21].

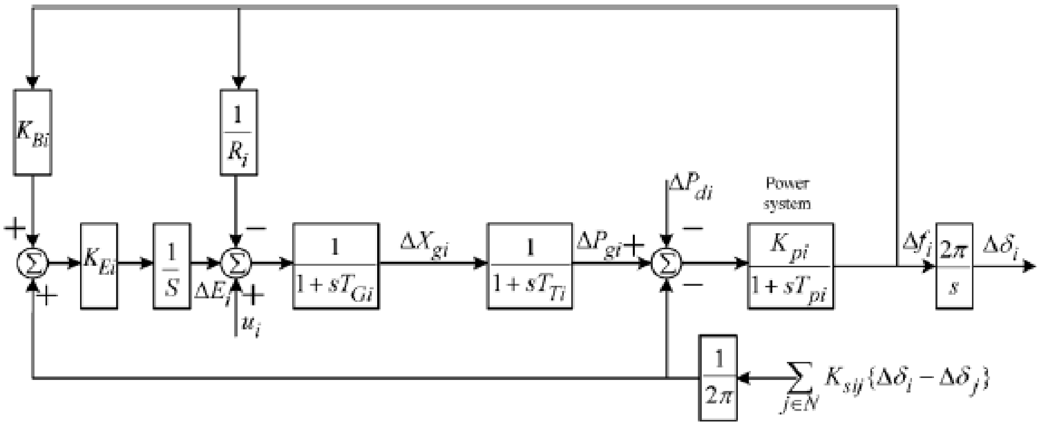


Figure-4. Multi-area power system's ith area block diagram.

A multi-area power system's ith area's dynamic equations are:

$$\Delta\dot{f_i}(t) = \frac{-1}{T_{Pi}}\Delta f_i(t) + \frac{K_{Pi}}{T_{Pi}}\Delta P_{gi}(t) - \frac{K_{Pi}}{T_{Pi}}\Delta P_{di}(t) - \frac{K_{Pi}}{2\pi T_{Pi}}\sum_{\substack{j\epsilon N \\ j\neq 1}} K_{sij}\{\Delta\delta_i(t) - \Delta\delta_i(t)\} \tag{6}$$

4. LFC PID CONTROLLER

The electrical market has suffered significant failures in its efforts to deliver on the promise of deregulation. In theory, deregulating the energy market would make the business more efficient by allowing producers to generate electricity at lower costs and then passing on those cost savings to end users. When it comes to electricity production, deregulation indicates that the production component of the energy supply will be opened up to market competition. However, the control of the power distribution and transmission will continue, and the local service firm that we use will continue to be responsible for the distribution of electricity on our behalf as well as the provision of services to customers. Since the generation of energy is about to become deregulated, it will soon be possible for us to select the electricity generation source of our choosing after having the opportunity to shop for it.

P-I-D controllers make up the bulk of the control strategies employed in industrial settings. It is utilized for a wide variety of control issues, including automated systems and factory operations. The fact that a PID-Controller is composed of three distinct principles is the primary reason why it is sometimes referred to as a three-term controller. The acronym PID can also be expanded to refer to proportional control, integral control, and derivative control.

PID control is something that may be put into action so that the system can meet all of its distinct design requirements. These may include the amount of time required for the system to settle and rise, as well as the precision and overshoot of its step reaction.

The tuning of the PID controller is done to increase the performance of the load frequency control in the power system. The design control law u = -K(s) Δf, where K(s) has the form

$$K(s) = K_p(1 + \frac{1}{T_i s} + T_d s) \tag{7}$$

In most situations, the PID controller is utilized as a method for mitigating the influence of noise. So, for this case, K(s) can be written as:

$$K(s) = K_p\left(1 + \frac{1}{T_i s} + \frac{T_d s}{N_s + 1}\right) \tag{8}$$

In this equation, N is known as the filter constant.

$$K(s) = K_p\left(1 + \frac{1}{T_i s} + T_d s\frac{1 - e^{-Ts}}{N_s + 1}\right) \tag{9}$$

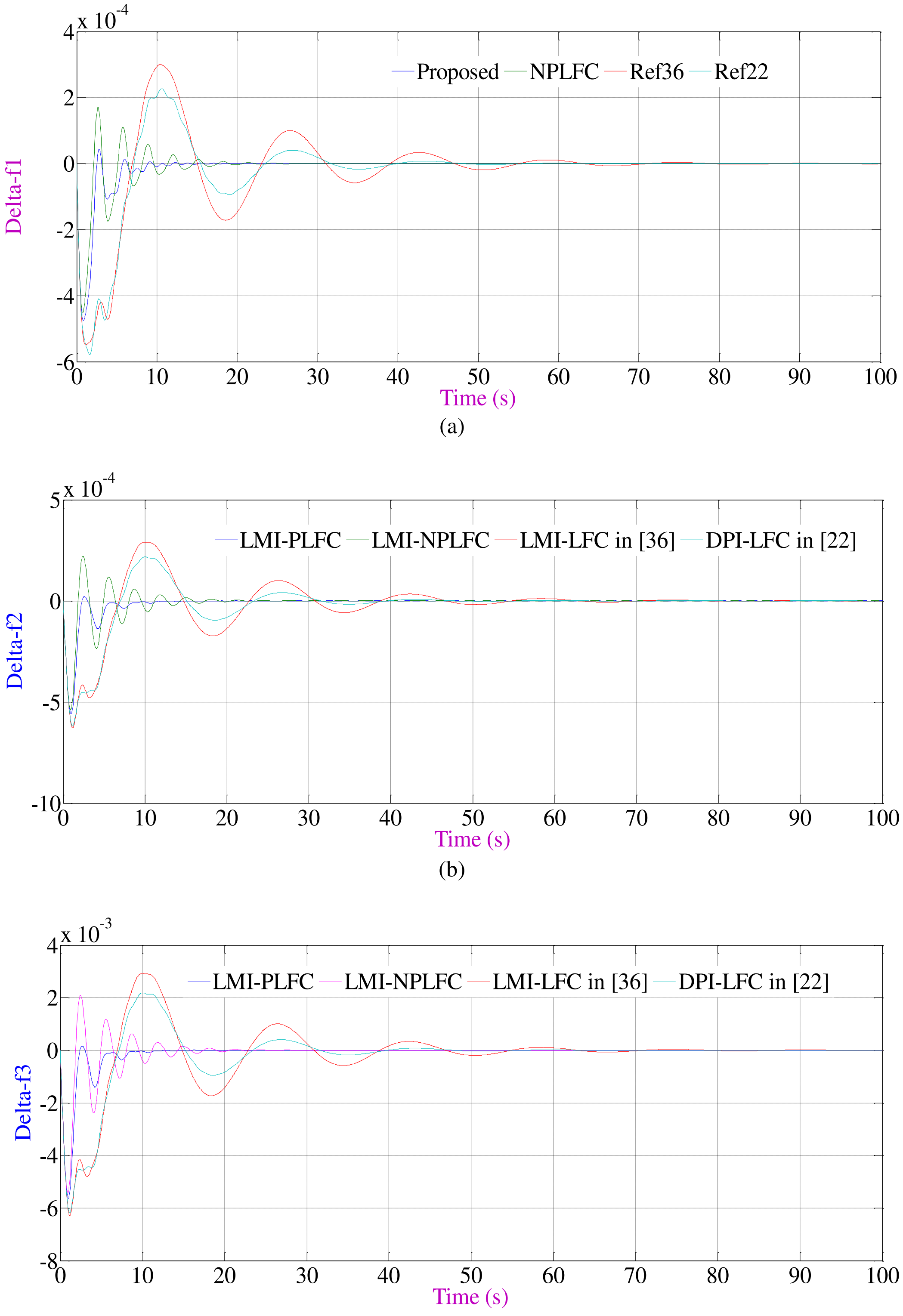
Where ‘T’ is an incredibly little sampling rate

Because the power system load frequency regulation takes into consideration only minor shifts in load, it is possible to conceptualize it using the single-area model.

5. SIMULATION RESULTS

The effectiveness of the suggested control strategy is demonstrated by conducting an analysis of both a single area power system and a three-area interconnected power system. Matlab/Simulink is used for the simulation work that needs to be done so that the suggested topology may be proven correct. The simulation is carried out utilizing the findings from [35], which looked at an LFC system with one area. Fig.5 illustrates the responses of the load frequency control system that was equipped with a PI controller [24], the load frequency control method that was based on linear matrix inequalities and was presented in [35], as well as the proposed LMI-based robust predictive and non-predictive controllers. This reveals that the suggested LMI-based LFC techniques have well-time responses, lower fluctuations, and better resilience.

Consider a three-area power system reported in [35], where the first area is modeled by two generators and the other areas have single generator equivalents. For performance studies, the decentralized LMIPLFC and LMI-NPLFC are compared with the decentralized LMI-based LFC approach in [35], and the decentralized PI controller (DPI-LFC) in [21]. The time responses of frequency deviation, Δ*f*, and Δ*E* for all areas are depicted in Figure-5 and Figure-6. The applied control inputs at each area are also shown in Figures 5.6. The results show two aspects of advantages for the proposed LMI-PLFC scheme in comparison with the other decentralized LFC approaches. First, its responses in Fig.5 have very good time specifications such as lower settling time and overshoot. Second, this good performance is obtained with better control efforts as shown in Figure-6. Imagine, for example, a three-region power system described in [35], where the first area is modeled by two generators, and the other areas have the equivalent of a single generator in each of their models. When it comes to performance studies, the decentralized LMIPLFC and LMI-NPLFC are put up against the decentralized LMI-based LFC technique described in [35] as well as the decentralized PI controller described in [21]. In Figure-5 and Figure-6 we can see a depiction of the temporal responses of frequency deviation, Δf, and ΔE for all of the different locations. In comparison to the existing decentralized LFC methods, the results demonstrate that the proposed LMI-PLFC scheme has two distinct benefits. First, its reactions are very good in terms of time specifications, as shown in Figure-5. These time specifications include a lower settling time and an overshoot. Second, the improvement in control efforts required to achieve this level of performance is illustrated in Figure-5.

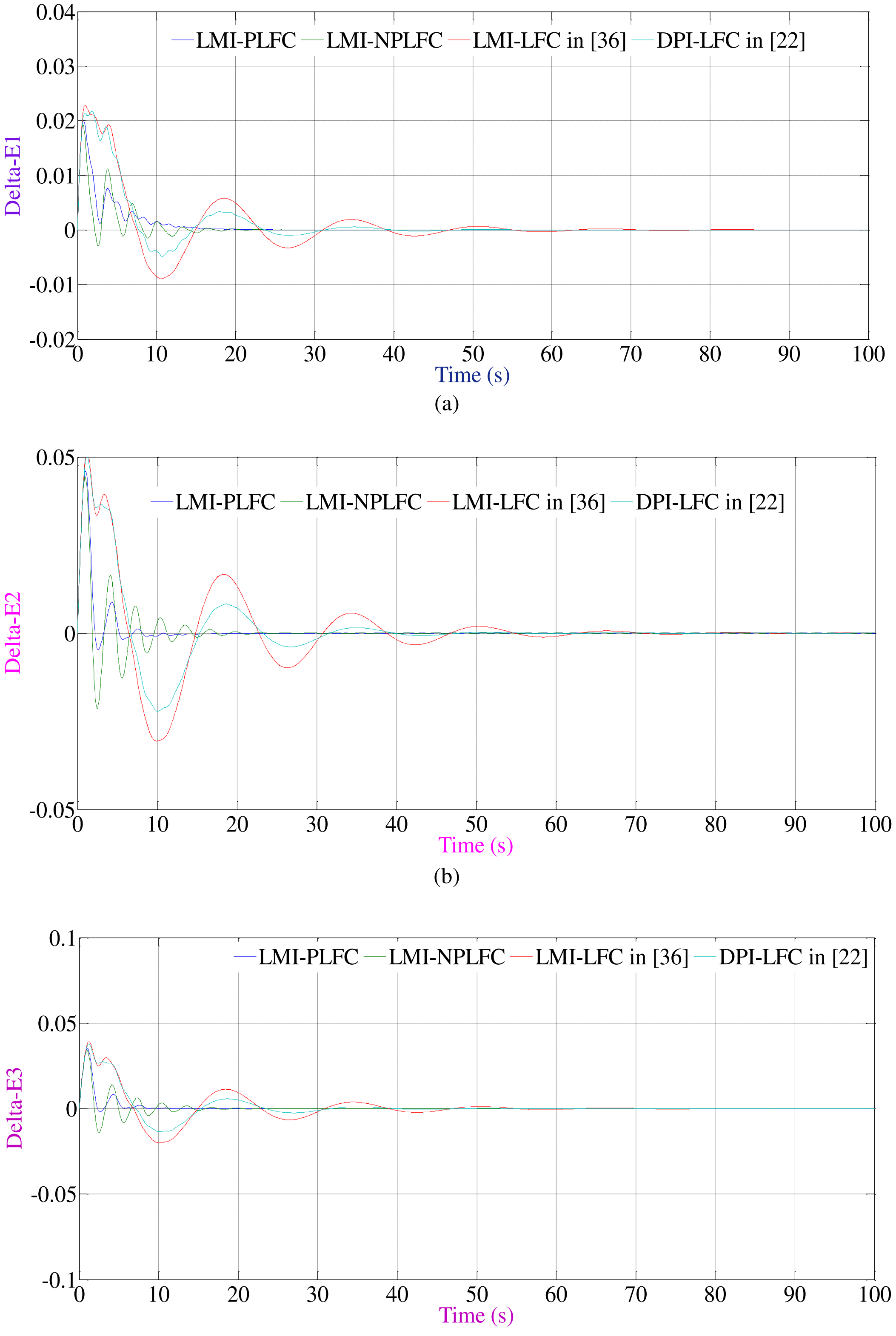


(a)

(b)

(c)

Figure-5. Responses of all of the regions in a multi-area LFC scheme using a variety of approaches.



(a)

(b)

(c)

Figure-6. Responses of all of the regions involved in a multi-area LFC scheme using various approaches.

6. CONCLUSIONS

To evaluate how well the suggested robust predictive LFC technique works, both one-area and multi-area power systems that have communication delays are taken into consideration. For an LFC system with a single coverage area, the proposed control technique demonstrates superior performance in comparison to the two LFC methods that are currently in use. It is important to highlight the fact that taking into account the communication latency along with uncertainty and time-varying parameters in the LFC system are crucial elements that set this system apart from certain previously published research. In addition, the suggested decentralized predictive LFC method is superior to the existing decentralized LFC approaches when applied to a system that covers many areas of responsibility for LFC. The other significant aspect that goes beyond the scope of those earlier works is the consideration of a decentralized control structure for a multi-area LFC system with time delays, uncertainty, and time-varying parameters.

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