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Extended state observer based load frequency controller for three area interconnected power system

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ABSTRACT

In this paper, we develop a new extended state variable observer based load frequency controller (LFC) scheme for three-area interconnected power systems. The extended state observerbased load frequency controllers are developed which utilize disturbance estimation techniques. The propose control approach assures that the fluctuating things of the load frequencies reaches to a safer range and the load frequencies can also be made at a very minimal not to have an effect on power quality and power flow in multi-area interconnected power system. The results of the simulations using MATLAB/SIMULINK done did not only address that the proposed newly control method works effectively but also change powerfully the parameter variations of the interconnected areas of the power system. Especially, it works very well to limit disturbances impact on interconnected areas in the system. Therefore, the performance of interconnected power system under different multi-conditions is simulated with the new control method to demonstrate the feasibility of the system.

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1. INTRODUCTION

In multi-area interconnected power system, stability of frequency is a very signify indicator of power quality as the loads of the tie-line multiple areas keep increasing and changing progressively. Meanwhile, load disturbances can occur suddenly which can cause deviations in tie-line power area exchange and nominal frequencies instability [1, 2]. Load frequency control for years now has been one of the basic robust control mechanisms in larger scale power electric systems with interconnected area and the main criteria of the load frequency control is to keep and maintain the system frequency uniform at its nominal value during and when there is load change. A large power electric system can be divided and separated into several load frequency area control that is interconnected by tie-lines and it relates to operational procedures to be followed in the event of major faults or of tie-line power. Generally, the main goal and duty of load frequency control is simply to adjust the frequencies of the separated areas and to simultaneously modulate power flowing across the tie-lines according with the agreement of an inter area power system. Moreover, load frequency control normalizes frequency, maintains dynamics, and makes quality assurance of the power supply, requires the use of load frequency controller (LFC) scheme in [3-6].

Load frequency control is also greatly significant in power electric system operational for delivering reliable and efficient power without poor quality. Therefore, a novel control technique needs to be developed in other to achieve LFC aims, thereby, maintaining and sustaining reliability of the electrical power system in multi-areas. In order to solve above problems, researchers and control engineers have proposed wide range of methods of state-of-the-art load frequency controllers to be applied in multi-area interconnected power system [7-15]. That is, the method of adaptive control proposed to take care parameter variation in [7-9]. But it cannot lead strongly to a general solution to the problem faced by LFC in power system. Many kinds of control technique such as proportional integral (PI) or proportional integral derivative (PID) controller for LFC were used. In the prescribed environment, some factors like uncertainties make it difficult to apply the above-mentioned LFC techniques in practice, which implies [10-12] to introduce some internal model control to design PID type LFC controllers. In [10] proposed fuzzy Proportional Integral controllers for LFC of power electric systems. While the different methods show that it is possible to enhance the performance of LFC in specified environments. The PID controller proposed in [11] combined with new structure shown to be robustly and to enhance the damping of the power electric system tracing with a small significant step changes in load. The strategy of tuning is based solely on the maximum peak resonance of the system specifications in [12]. However, most conventional PID controllers with gains fixed was designed under nominal system operating conditions, the selected mode of its gains is usually always on trial and error with no analytically methods of determining its parameters optimally which sometimes fails to give out the best and accurate control schemes and performance over a wider range of system operating conditions and exhibits, thereby, a poor dynamic response and performance during operations. Some of the control methods need to apply the full-state of the control area as feedback input while some will lead to higher-order controllers, these factors were too complex to be understood and comprehended by control and electrical engineers in [13, 14].

Among various control techniques mentioned, the optimal control with state feedback technique is one of the best options. Also, a robust decentralized linear controller was applied in [15-19]. Another control technique to look at is the "sliding mode control (SMC)". Sliding mode control techniques is another better way and approach to solve LFC problem. SMC has ofcoursed been applied for LFC in power electric system in [19-25] to achieve fast response and robustly performance in the power network, this method is a nonlinear control strategy with a famous rule. It is also insensitive perhaps to changes of the plant parameters and as well improves system transient control performance. The above approaches are achieved under assumption that all system state variables are to be measurable and readily available for feedback. In fact, not all system state variables are measurable for feedbacks, and then we need to estimate the state variables that are not unmeasurable. Estimating unmeasurable state variables is often called observation in [21-25]. This scheme can adapt the unknown upper bounds of matched nonlinearity and disturbance. It gets not only the system state trajectories accomplishment but also satisfies in parameters of the system state errors. The work illustrated above, achieve a significant result related to LFC's of interconnected power systems applying various control techniques.

However, there are some limitations of the above approaches. Firstly, the disturbances are not truncated from the output points in steady state. Secondly, the controller gains are not set to be extremely high to attenuate disturbances of unknown boundaries. Thirdly, the controller is designed in accordance to the nominal transfer function of the plant when a no-load disturbance is considered. In order to solve the above limitations, in the paper we develop newly extended state observer-based LFC scheme for three-area interconnected power electric system. The main contributions of the paper are as following:

- Extended state observer is first design to estimate the unmeasurable system state variables and also the load uncertainties.
- The extended state observer-based load frequency controllers are developed which utilize disturbance estimation techniques. Thus, the controller gains are not set to be extremely high to attenuate disturbances of unknown boundaries, which is very useful in load frequency controller design.
- The simulation results indicate that the proposed newly method improves the system dynamic response which provides a system control to adapt and meet up the LFC requirement.

The other parts of the proposed paper are structured in the following. A mathematical dynamics model of three-area power electric system is presented in section 2. The following proposed extended observer controller is showed in section 3. The results of the various simulations of three-area power system applying the proposed newly based control approaches are described in section 4. Lastly, conclusions are discussed in section 5.

2. THE MATHEMATICAL MODEL OF THREE-AREA INTERCONNECTED POWER SYSTEM MODEL

At first, we analyze LFC of power system of multi-areas. Figure 1 illustrates three-area interconnected systems [16] as desmostrated. The sole mission in the research work is simply to examine the various tie-line areas in power systems in other to control the frequencies of the following multi-area and to regulate simultaneously power flowing throught the tie-lines according to an inter-area operating agreement. In three-area networks, each control area is indicated by a turbine, generator, and governor system. The tie-line power in the interconnected three-area must be considered to generate the increment power stability equation of each power system area, since there is power flow in each area through the tie line.

From [3, 4], the tie line power increment that is out of area is:

$$\Delta P_{tie_i(p.u)} = 2\pi \sum_{\substack{j\in N \\ j\neq i}} T_{ij}\left(\int \Delta f_i \, dt - \int \Delta f_j \, dt\right) \tag{1}$$

To achieve balance between interconnected control areas, the frequency deviation and tie-line power fluctuation are detected in other to determine the area control error (ACE) of each control area. The ACE can be expressed for each control area as a linearity combination of tie-line power flunctuation and frequency deviation.

$$ACE_i = \Delta P_{tie_i} + K_{B_i}\Delta f_i \tag{2}$$

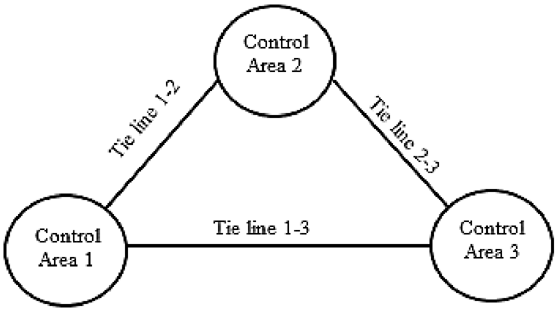

Figure 1. A simplified sketch of 3-area interconnected power system

A power network is stable if and only if ACE$_i$ = 0. In other words: Δf_iandΔP_{tie_i}tend towards zero over a short time frame. In practice, a typical interconnected generation system is nonlinearity and also dynamics; application of the linearity model is allowable in the LFC power problems that is, in modern's power system, small changes in load is always anticipated under normal operations in [18, 26-28].

$$\Delta \dot{f}_1(t) = -\frac{1}{T_{P_1}}\Delta f_1(t) + \frac{K_{P_1}}{T_{P_1}}\Delta P_{m1}(t) - \frac{k_{ps1}}{T_{ps1}}\Delta P_{tie1}(t) - \frac{k_{ps1}}{T_{ps1}}\Delta P_{tie3}(t) - \frac{k_{ps1}}{T_{ps1}}\Delta P_{d_1} \tag{3}$$

$$\Delta \dot{P}_{m1}(t) = -\frac{1}{T_{T_1}}\Delta P_{m1}(t) + \frac{1}{T_{T_1}}\Delta P_{v1}(t) \tag{4}$$

$$\Delta \dot{P}_{v1}(t) = -\frac{1}{R_1 T_{G_1}}\Delta f_1(t) - \frac{1}{T_{G_1}}\Delta P_{v1}(t) + \frac{1}{T_{G_1}}u_1 \tag{5}$$

$$\Delta \dot{E}_1(t) = B_1\Delta f_1(t) + \Delta P_{tie1}(t) + \Delta P_{tie3}(t) \tag{6}$$

$$\Delta \dot{P}_{tie1}(t) = 2\pi T_{12}\Delta f_1(t) - 2\pi T_{12}\Delta f_2(t) + 2\pi T_{13}\Delta f_1(t) - 2\pi T_{13}\Delta f_3(t) \tag{7}$$

$$\Delta \dot{f}_2(t) = -\frac{1}{T_{P_2}}\Delta f_2(t) + \frac{K_{P_2}}{T_{P_2}}\Delta P_{m2}(t) - \frac{k_{ps2}}{T_{ps2}}\Delta P_{tie1}(t) - \frac{k_{ps1}}{T_{ps1}}\Delta P_{tie2}(t) - \frac{k_{ps1}}{T_{ps1}}\Delta P_{d_2} \tag{8}$$

$$\Delta \dot{P}_{m2}(t) = -\frac{1}{T_{T_2}}\Delta P_{m2}(t) + \frac{1}{T_{T_2}}\Delta P_{v2}(t) \tag{9}$$

$$\Delta \dot{P}_{v2}(t) = -\frac{1}{R_2 T_{G_2}}\Delta f_2(t) - \frac{1}{T_{G_2}}\Delta P_{v2}(t) + \frac{1}{T_{G_2}}u_2 \tag{10}$$

$$\Delta\dot{E}_2(t) = B_2\Delta f_2(t) + \Delta P_{tie1}(t) + \Delta P_{tie2}(t) \tag{11}$$

$$\Delta\dot{P}_{tie2}(t) = 2\pi T_{12}\Delta f_2(t) - 2\pi T_{12}\Delta f_1(t) + 2\pi T_{23}\Delta f_2(t) - 2\pi T_{23}\Delta f_3(t) \tag{12}$$

$$\Delta\dot{f}_3(t) = -\frac{1}{T_{P_3}}\Delta f_3(t) + \frac{k_{P3}}{T_{P_3}}\Delta P_{m3}(t) - \frac{k_{ps3}}{T_{ps3}}\Delta P_{tie2}(t) - \frac{k_{ps3}}{T_{ps3}}\Delta P_{tie3}(t) - \frac{k_{ps3}}{T_{ps3}}\Delta P_{d_3} \tag{13}$$

$$\Delta\dot{P}_{m3}(t) = -\frac{1}{T_{T_3}}\Delta P_{m3}(t) + \frac{1}{T_{T_3}}\Delta P_{v3}(t) \tag{14}$$

$$\Delta\dot{P}_{v3}(t) = -\frac{1}{R_3 T_{G_3}}\Delta f_3(t) - \frac{1}{T_{G_3}}\Delta P_{v3}(t) + \frac{1}{T_{G_3}}u_3 \tag{15}$$

$$\Delta\dot{E}_3(t) = B_3\Delta f_3(t) + \Delta P_{tie2}(t) + \Delta P_{tie3}(t) \tag{16}$$

$$\Delta\dot{P}_{tie3}(t) = 2\pi T_{23}\Delta f_3(t) - 2\pi T_{23}\Delta f_2(t) + 2\pi T_{13}\Delta f_3(t) - 2\pi T_{13}\Delta f_1(t) \tag{17}$$

The matrix form shows in the dynamic equations from (3) to (17), the there-area interconnected power system described by Figure 2 which can be written and expressed in state-space representation below:

$$\dot{x}(t) = \tilde{A}x(t) + \tilde{B}u(t) + \tilde{F}\Delta P(t) \tag{18}$$

where $x(t) \in R^n$ is the state vector, $u(t) \in R^m$ is the control vector, and $\tilde{A}, \tilde{B}, \tilde{F}$is constant matrix equivalent i[th] of each area. ($\tilde{A} \in R^{n\times n}$, $\tilde{B} \in R^{n\times m}$, $F \in R^{n\times k}$).

$$\tilde{B} = \begin{bmatrix} 0 & 0 & \frac{1}{T_{G1}} & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & \frac{1}{T_{G2}} & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & \frac{1}{T_{G3}} & 0 & 0 \end{bmatrix}^T$$

$$\tilde{F} = \begin{bmatrix} -\frac{K_{P1}}{T_{P1}} & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & -\frac{K_{P2}}{T_{P2}} & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & -\frac{K_{P3}}{T_{P3}} & 0 & 0 & 0 & 0 \end{bmatrix}^T$$

$$\tilde{A} = \begin{bmatrix} -\frac{1}{T_{ps1}} & \frac{k_{ps1}}{T_{ps1}} & 0 & 0 & -\frac{k_{ps1}}{T_{ps1}} & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & -\frac{k_{ps1}}{T_{ps1}} \\ 0 & -\frac{1}{T_{T1}} & \frac{1}{T_{T1}} & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ -\frac{1}{R_1T_{G1}} & 0 & -\frac{1}{T_{G1}} & \frac{1}{T_{G1}} & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ B_1 & 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 \\ 2\pi(T_{12}+T_{13}) & 0 & 0 & 0 & 0 & -2\pi T_{12} & 0 & 0 & 0 & 0 & -2\pi T_{13} & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & \frac{k_{ps2}}{T_{ps2}} & -\frac{1}{T_{ps2}} & \frac{k_{ps2}}{T_{ps2}} & 0 & 0 & -\frac{k_{ps2}}{T_{ps2}} & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & -\frac{1}{T_{T2}} & \frac{1}{T_{T2}} & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & -\frac{1}{R_2T_{G2}} & 0 & -\frac{1}{T_{G2}} & \frac{1}{T_{G2}} & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 1 & B_2 & 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 \\ -2\pi T_{21} & 0 & 0 & 0 & 0 & 2\pi(T_{21}+T_{23}) & 0 & 0 & 0 & 0 & -2\pi T_{23} & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & -\frac{k_{ps3}}{T_{ps3}} & -\frac{1}{T_{ps3}} & \frac{k_{ps3}}{T_{ps3}} & 0 & 0 & \frac{k_{ps3}}{T_{ps3}} \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & -\frac{1}{T_{T3}} & \frac{1}{T_{T3}} & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & -\frac{1}{R_3T_{G3}} & 0 & -\frac{1}{T_{G3}} & \frac{1}{T_{G3}} & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & B_3 & 0 & 0 & 0 & 1 \\ -2\pi T_{13} & 0 & 0 & 0 & 0 & -2\pi T_{23} & 0 & 0 & 0 & 0 & 2\pi(T_{31}+T_{32}) & 0 & 0 & 0 & 0 \end{bmatrix}$$

$$\dot{x}(t) = [\Delta f_1(t) \quad \Delta P_{m1}(t) \quad \Delta P_{v1}(t) \quad \Delta E_1(t) \quad \Delta P_{tie1}(t) \quad \Delta f_2(t) \quad \Delta P_{m2}(t) \quad \Delta P_{v2}(t) \quad \Delta E_2(t) \quad \Delta P_{tie2}(t) \quad \Delta f_3(t) \quad \Delta P_{m3}(t) \quad \Delta P_{v3}(t) \quad \Delta E_3(t) \quad \Delta P_{tie3}(t)]^T$$

Because it is tedious to determine the values of the system exact parameters of $\tilde{A}, \tilde{B}, \tilde{F}$due to nonlinearity and dynamics of a power electric system, the dynamic model (18) is revised to the nominal parameters and parameter variations separations in the following:

$$\dot{x}(t) = [A + \Delta A(x,t)]x(t) + [B + \Delta B(x,t)]u(t) + \tilde{F}\Delta P_D(t) \quad = Ax(t) + Bu(t) + f(x,t) \quad y(t) = Cx(t) \tag{19}$$

where A, B is the exact values of $\tilde{A}, \tilde{B}$; the unknown matrices $\Delta A(x,t)$ and $\Delta B(x,t)$ denotes by their time-variant system of parametric variations; and $f(x,t)$ is called the lumped uncertainties and we can also denote by (20).

$$f(x,t) = \Delta A(x,t)x(t) + \Delta B(x,t)u(t) + \tilde{F}\Delta P_D(t) \tag{20}$$

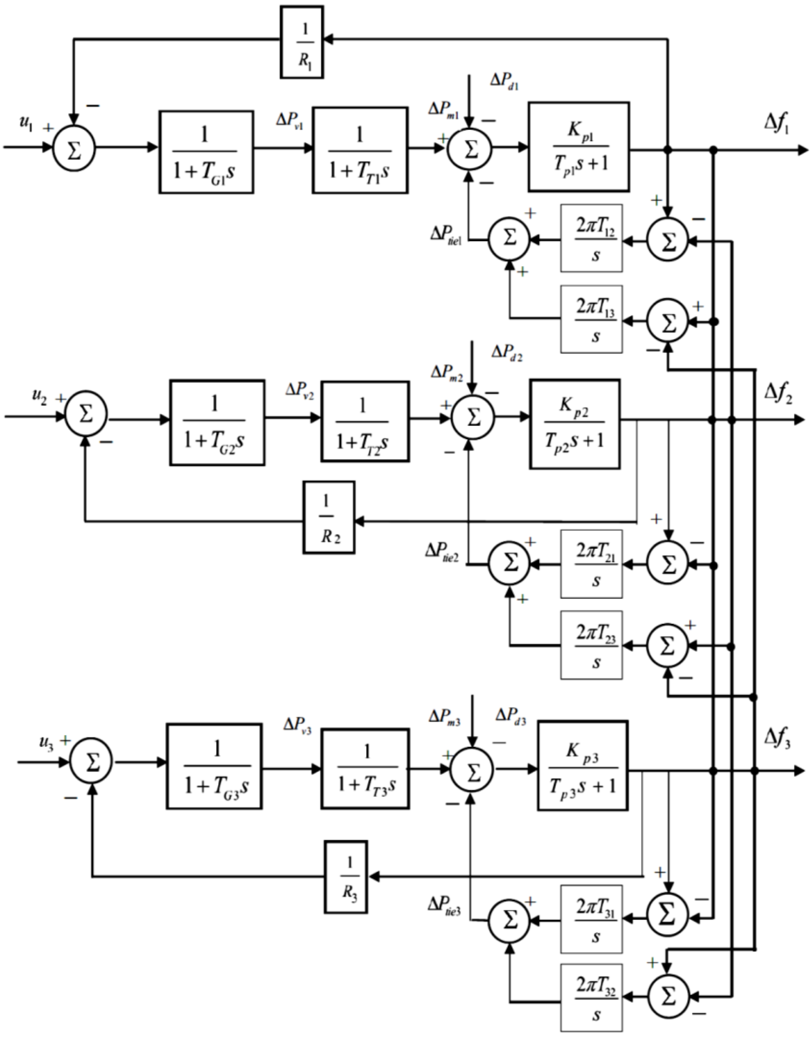

Figure 2. Block diagram of 3-area LFC system

3. PROPOSED EXTENDED OBSERVER-BASED LOAD FREQUENCY CONTROLLER

The proposed newly control technique that is, states observer performs the functions by estimating the state variables of the systems typically the output and control variables. State observers can be designed and applied only when the observability required condition is satisfied. First, we extend lumped uncertainty as an additional state variable to design and initiate an extended observer-based load frequency controller in the system as (21).

$$x_{n+1}(t) = f(x,t) \tag{21}$$

Then, the three-area power system in (19) can be written as:

$$\dot{\bar{x}}(t) = \bar{A}\bar{x}(t) + \bar{B}u(t) + Eh(t)\bar{y}(t) = \bar{C}\bar{x}(t) \quad (22)$$

$$h(t) = \frac{df(x,t)}{dt} \quad (23)$$

where: $\bar{x}(t) = \begin{bmatrix} x(t) \\ x_{n+1}(t) \end{bmatrix}$; $\bar{A} = \begin{bmatrix} A_{n\times n} & I_{n\times n} \\ 0_{n\times n} & 0_{n\times n} \end{bmatrix}$; $\bar{B} = \begin{bmatrix} B_{n\times m} \\ 0_{n\times m} \end{bmatrix}$; $E = \begin{bmatrix} 0_{n\times n} \\ I_{n\times n} \end{bmatrix}$; $\bar{C} = [C_{r\times n}, \quad 0_{r\times n}]$.

With regards to the state observers discussed, we will apply the notation $\hat{\bar{x}}$ to indicate the vector observed state. The vector $\hat{\bar{x}}$ of the observed state is used and applied in the state feedback to initiate the desired and required control vector. If we call the state$\bar{x}$is approximated to state, $\widehat{\bar{x}}$ the dynamical model:

$$\dot{\hat{\bar{x}}}(t) = \bar{A}\hat{\bar{x}}(t) + \bar{B}u(t) + L(\bar{y}(t) - \hat{\bar{y}}(t))\dot{\hat{\bar{y}}}(t) = \bar{C}\hat{\bar{x}}(t) \quad (24)$$

The states observed have u and $\bar{y}$ as the input and output signal. The gain L of state observer is chosen so that the eigenvalue of $\bar{A} - L\bar{C}$lie in the desired locations in the left-half s-plane. The control input is chosen as;

$$u(t) = -K\hat{\bar{x}} = [\widetilde{K} \quad \widehat{K}]\hat{\bar{x}} \quad (25)$$

where, $\widetilde{K}$is the feedback control gain to be chosen so that the eigenvalues of $A - B\widetilde{K}$lie in specific locations in the left-half s-plane and the lumped uncertainty compensation gain $\widetilde{K}$is designed:

$$\widehat{K} = [C(A - B\widetilde{K})^{-1}B]^{-1}C(A - B\widetilde{K})^{-1}F \quad (26)$$

Combine (22) and (24), the estimation error of state observers $e(t) = \bar{x}(t) - \hat{\bar{x}}(t)$ can be revised by:

$$\dot{e}(t) = \bar{A}e(t) - L(\bar{y}(t) - \hat{\bar{y}}(t)) + Eh(t) = (\bar{A} - L\bar{C})e(t) + Eh(t) \quad (27)$$

Denote $Eh(t)$ by $u(t)$ and using final-value theorem, we have:

$$\lim_{t\to\infty} e(t) = \lim_{t\to\infty}(s(sI - (\bar{A} - L\bar{C}))^{-1}U(s) = \lim_{t\to\infty}(sI - (\bar{A} - L\bar{C}))^{-1} \times \lim_{s\to\infty} sU(s) = \lim_{s\to\infty}(sI - (\bar{A} - L\bar{C}))^{-1} \times \lim_{t\to\infty} u(t) \quad (28)$$

Sine$\lim_{s\to\infty}(sI - (\bar{A} - L\bar{C}))^{-1}$is bounded and $\lim_{t\to\infty} u(t) = 0$. Therefore, estimation error of state observers is: $e(t) = \bar{x}(t) - \hat{\bar{x}}(t)$ is asymptotically stable.

Remark 1: If the system states are not measurable, then the estimation of the lumped uncertainty and the parameters of system states can be applying in the design control. Therefore, the composite control law will be designed as in (21).

Remark 2: It is noted that the lumped uncertainty cannot be attenuated completely and totally from the state equation no matter what controller was designed. In this approach, one of the most recent achievable objectives is simply to truncate the disturbances at the output point in steady state by the application of the composite control law. Therefore, the limitations recorded by other control strategies in this paper [21-25] has been solved.

4. SIMULATION RESULTS

In the case to evaluate the newly extended state observer approach, two simulations by using the MATLAB/SIMULINK software are given as following:

Simulation 1: The parameters of the three-area interconnected power system were seen as given in [16, 17].

Case 1. For the simulation at this instance in case 1, the parameters with there nominal values of the 3-area power network are applied. At this point, we assume zero disturbances occuring on the given system, i.e., $f(x,t) = 0$. Therefore, the frequency flunctuation or deviations of the 3-area interconnected power network according to the instance of case 1 whereby, applying the newly extended state observer controller are displayed in the results of simulation in Figure 3 to Figure 4. In Figure 3, the frequency deviation approaches to zero mark at exactly 1.5s. Consequently, Figure 4 shows tie line power deviation getting to zero mark with the designed extended state observer controller. By comparing the simulation results from the newly extended observer controller with results given shown in [16, 17], the newly extended state observer controller was able to assure fast response to the system and also capable of truncate smaller overshoots.

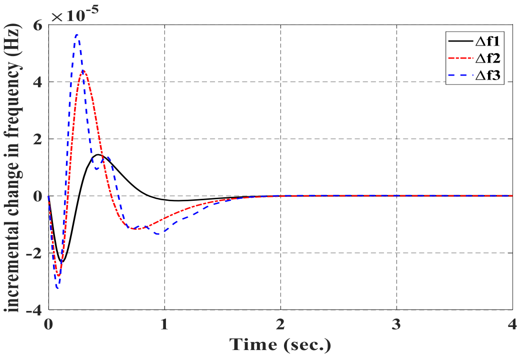

Figure 3. Frequency deviations (Hz) of the three-area without disturbances

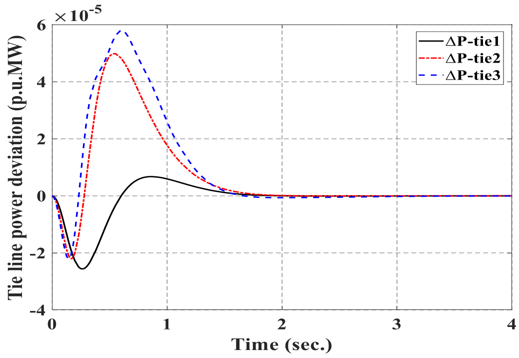

Figure 4. Tie line power deviation for power system without disturbances

Case 2: Designing a controller with the aim and capacity to perform excellent within an uncertainty environment of power networks are always the main goal of several electrical and control engineers. In this case, the proposed extended state observer controller was applied under uncertainties with matched parameters and load disturbance in other to examine the network performance under matched parameter uncertainties and load disturbances. The load disturbance; $\Delta P_{d_1}(t) = 0.02$ pu, $\Delta P_{d_2}(t) = 0.015$ pu, and $\Delta P_{d_3}(t) = 0.01$ pu were presume to take place at area 1, area 2, and area 3 accordingly. The responses in the closed-loop for everyone of the control area applying the extended state observer controller and the controller given in [16, 17] are shown in Figure 5 and Figure 6.

Figure 5, Figure 6 and Table 1 show clearly that the responses of the system are not only great to deal with overshoot-problems, but also ensures quick and fast settling period as matched-to the recent approach in [16, 17]. In the same condition, it is seen that frequency deviation converged to zero in about 1.6s with the newly proposed extended state observer that is, satisfied requiment of LFC problems.

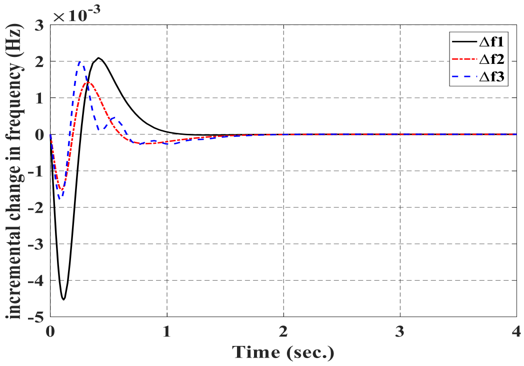

Figure 5. Frequency deviations (Hz) of the three-area under matched uncertainties and load disturbances

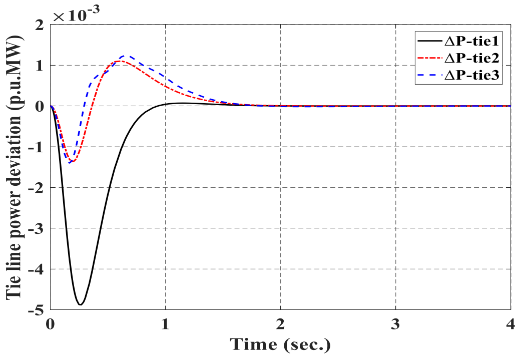

Figure 6. Tie line power deviation under matched uncertainties and load disturbances

Table 1. Setting time - T_s and Max.O.S (maximun- over-shoot-calculation) of ELFC and DLFC

Kinds of controller	Extended state observer-based load frequency controller (ELFC)		Decentralized load frequency controller (DLFC) [16]	
Parameters	T_s *(s)*	*Max.O. S (pu)*	T_s *(s)*	*Max.O. S (pu)*
Δf_1	1.5	2.1×10^{-3}	7.5	3.7×10^{-3}
Δf_2	2.0	1.45×10^{-3}	7.5	3.8×10^{-3}
Δf_3	1.8	2.0×10^{-3}	7.5	4.0×10^{-3}

Simulation 2: The practical power system with load disturbance is considered in this example. The conditions and parameters using in this simulation are the same with the recent research in [18]. Figure 7 and Figure 8 show that the proposed extended state observer control scheme has faster response and lesser signicant overshoot in comparing the previous control in [18].

Remark 3: By matching-up the results of the simulation for the two simulations above, the newly extended state observer-based load frequency controllers displayed robustness and fast response to distortions and disturbance occurring on the system correlated with variant of the matched uncertainties and load disturbances used for simulations.

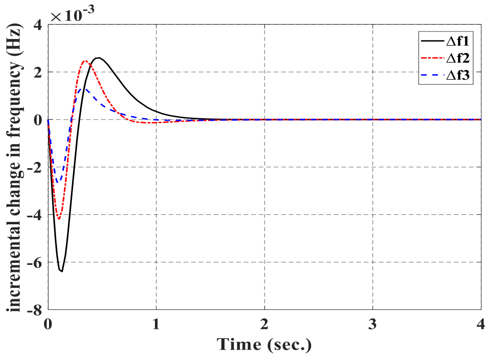

Figure 7. Frequency deviations of the three-area under matched uncertainties and load disturbances

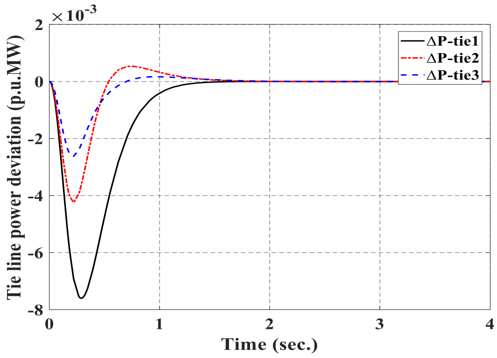

Figure 8. Tie line power deviation under matched uncertainties and load disturbances

5. CONCLUSION

In this paper, the newly extended state observer for LFC for an interconnected system is performed. In real environment, some various state variables are not measurable in load frequency control system for instance area control error or combination of area control errors. To resolve this unmeasurable state variables problem, the extended state observer is proposed for estimating the unmeasurable state variables. The extended state observer-based load frequency controllers utilize disturbance estimation techniques; thus, the controller gains are not set to be extremely high to attenuate disturbances of unknown boundaries, which is very useful in load frequency controller design. Therefore, it can be concluded that the application of the proposed extended state observer for load frequency controls of interconnected power system can operate effectively in practical sight. By using MATLAB/SIMULINK, the simulation results above present that the newly method improves the dynamics responses of the system and provide designs for new LFC's system that satisfies the LFC requirements. In the future work, we tend to design extended state observer for robust LFC's in multi-area power systems combined with renewable energy systems.

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REFERENCES

[1] Fu C., & Tan W., "Decentralised Load Frequency Control for Power Systems with Communication Delays via Active Disturbance Rejection," *IET Generation, Transmission & Distribution*, vol. 12, no. 6, pp. 1751-8687, 2018.
[2] Zhang Y., & Yang T., "Decentralized Switching Control Strategy for Load Frequency Control in Multi-Area Power Systems with Time Delay and Packet Losse," *IEEE Access*, vol. 8, pp. 15838-15850, Jan 2020.
[3] Devendra K. Chaturvedi, "Techniques and its Applications in Electrical Engineering" *Springer*, 2008.
[4] Vijay Vittal, James D. McCalley, Paul M. Anderson, A. A. Fouad P., "Power System Control and Stability," *Wiley 3rd Edition.*, October 2019.
[5] Guha D., Roy P. K., & Banerjee S., "Load Frequency Control of Interconnected Power System Using Grey Wolf Optimization," *Swarm and Evolutionary Computation*, vol. 27, pp. 97-115, Apr 2016.
[6] Yousef H. A., AL-Kharusi K., Albadi M. H., & Hosseinzadeh N., "Load Frequency Control of a Multi-Area Power System: An Adaptive Fuzzy Logic Approach," *IEEE Transactions on Power Systems*," vol. 29, no. 4, pp.1822-1830, Jan 2014.
[7] Zeng G. Q., Xie X. Q., & Chen M. R., "An Adaptive Model Predictive Load Frequency Control Method for Multi-Area Interconnected Power Systems with Photovoltaic Generations," *Electrical Power and Energy System*, vol. 10, no. 11, pp. 1-23, Nov 2017.
[8] Beni Rehiara A., Yorino N., Sasaki Y., & Zoka Y., "An Adaptive Load Frequency Control Based on Least Square Method," *Advances in Modelling and Control of Wind and Hydrogenerators*, vol. 49, pp. 220, 2020.

[9] Dong L. L, Zhang Y., Gao Z. Q., "A Robust Decentralized Load Frequency Controller for Interconnected Power Systems," *ISA Transactions*, vol. 51, no. 3, pp. 410-419, May 2012.

[10] Gheisarnejad M., & Khooban, M. H., "Design an Optimal Fuzzy Fractional Proportional Integral Derivative Controller with Derivative Filter for Load Frequency Control in Power Systems," *Transactions of the Institute of Measurement and Control*, vol. 41, no. 9, pp. 1-19, Jan 2019.

[11] Anwar M. N., and Pan S., "A New PID Load Frequency Controller Design Method in Frequency Domain Through Direct Synthesis Approach," *Electric Power and Energy Systems*, vol. 67, pp. 560-569, May 2015.

[12] Sonkar P., & Rahi O. P., "Tuning of Modified PID Load Frequency Controller for Interconnected System with Wind Power Plant via IMC Tuning Method," 2017 *4th IEEE Uttar Pradesh Section International Conference on Electrical*, *Computer and Electronics*, Jan 2018.

[13] K. Liao and Y. Xu, "A Robust Load Frequency Control Scheme for Power Systems Based on Second-Order Sliding Mode and Extended Disturbance Observer," *IEEE Transactions on Industrial Informatics*, vol. 14, no. 7, pp. 3076-3086, July 2018.

[14] Zheng Y., Liu J., Liu X., Fang D., & Wu L., "Adaptive Second-Order Sliding Mode Control Design for a Class of Nonlinear Systems with Unknown Input," *Mathematical Problems in Engineering*, vol. 2015, no. 1, pp.1-7, 2015.

[15] Y. Sun, Y. Wang, Z. Wei and X. Wu, "Robust H∞ Load Frequency Control of Multi-Area Power System with Time Delay: A Sliding Mode Control Approach," *IEEE/CAA Journal of Automatica Sinica*, vol. 5, no. 2, pp. 610-617, 2018.

[16] Yang M., Yang F., Chengshan W., and Peng W., "Decentralized Sliding Mode Load Frequency Control for Multi-Area Power Systems," *IEEE Transactions on Power System*, vol. 28, no. 4, pp. 4301-4309, Aug 2013.

[17] Muthana T. Alrifai, Mohamed F. Hassan, Mohamed Zribi., "Decentralized Load Frequency Controller for A Multi-Area Interconnected Power System," *Electrical Power and Energy Systems*, vol. 33, no. 2, pp.198-209, 2011.

[18] Yang Mi *et al.*, "The Sliding Mode Load Frequency Control for Hybrid Power System Based on Disturbance Observer," *Electrical Power and Energy Systems*, vol. 74, pp. 446-452, Jan 2016.

[19] D. Qian, and G. Fan, "Neural-Network-Based Terminal Sliding Mode Control for Frequency Stabilization of Renewable Power Systems," *IEEE/CAA Journal of Automatica Sinica*, vol. 5, no. 3, pp. 706-717, Apr 2018.

[20] S. Trip *et al.*, "Passivity-Based Design of Sliding Modes for Optimal Load Frequency Control," *IEEE Transactions on Control Systems Technology*, vol. 27, no. 5, pp.1893-1906, 2019.

[21] Li H. Y., Shi P., Yao D. Y., Wu L. G., "Observer-Based Adaptive Sliding Mode Control of Nonlinear Markovian Jump Systems," *Automatica*, vol. 64, pp.133-142, Mar 2016.

[22] Khayati K., "Multivariable Adaptive Sliding-Mode Observer-Based Control for Mechanical Systems," *Canadian Journal of Electrical and Computer Engineering*, vol. 38, no. 3, pp.253-265, Nov 2015.

[23] Wang B., Shi P., Karimi H. R., & Lim C. C, "Observer-Based Sliding Mode Control for Stabilization of a Dynamic System with Delayed Output Feedback,"*Mathematical Problems in Engineering*, vol. 3, pp. 1-6, Sep 2013.

[24] Ouassaid M., Maaroufi M., & Cherkaoui M, "Observer-Based Nonlinear Control of Power System Using Sliding Mode Control Strategy," *Electric Power Systems Research*, vol. 84, no. 1, pp. 135-143, Jan 2012.

[25] Yang B., Yu T., Shu H., Yao W., & Jiang L., "Sliding-Mode Perturbation Observer-Based Sliding-Mode Control Design for Stability Enhancement of Multi-Machine Power Systems," *Transactions of the Institute of Measurement and Control*, vol. 41, no. 15, pp. 1418-1434, Jul 2018.

[26] Prasad S., Purwar S., & Kishor N., "Non-Linear Sliding Mode Load Frequency Control in Multi-Area Power System," *Control Engineering Practice*, vol. 61, pp. 81-92, Dec 2017.

[27] Dianwei Q., Shiwen T., Xiangjie L., "Load Frequency Control for Micro Hydro Power Plants by Sliding Mode and Model Order Reduction," *Automatika*, vol. 56, no. 3, pp. 318-330, Jan 2017.

[28] Dianwei Q., Shiwen T., Hong L., Xiangjie L., "Load Frequency Control by Neural-Network-Based Integral Sliding Mode for Nonlinear Power Systems with Wind Turbines," *Neurocomputing*, vol. 173, pp. 875-885, Jan 2016.