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A Modern method of LFC in Multi Area Power System with Cascade and Port-Hamiltonian System

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ABSTRACT

The LFC has been successfully implemented to many aspects of power system, such as, the electric vehicles, renewable and sustainable energy, and time and so on. This project focuses on how to improve the control method of LFC system. The existed control methods of the multi-area load frequency control (LFC) system fail to decouple the total tie-line power flow. This defect can be addressed as a problem on how to effectively utilize the total tie-line power flow. To improve that defect, the energy and structure of multi-area LFC system have been carefully studied, such that, the energy goes through the systemic cascade parts and the systemic structure matrix is partially skew symmetry. Namely, the energy and structural properties of the multi-area LFC system are similar to the properties of Port-Hamiltonian (PH) system and cascade system. Inspired by the above properties, a new method based on the PH system and cascade system that is proposed to design some PID control laws for the multi-area LFC system successfully works out the aforementioned problem. Compared with the existed PID methods for the multi-area LFC system, the proposed method has two advantages, which are the decoupling of total tie-line power flow and the robust disturbance rejection. The simulation results will be validating in the environment of Matlab/Simulink.

Keywords— Cascade system, decoupling, load frequency control, Port-Hamiltonian system, power system.

I. 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 paper 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.

Conventionally, frequency regulation in power system is achieved by balancing generation and demand through load following, i.e., spinning and non-spinning reserves [1]. The future power grid, on the other hand, is foreseen to have high penetration of renewable energy (RE) power generation, which can be highly variable. In such cases, energy storage and responsive loads show great promise for balancing generation and demand, as they will help to avoid the use of the traditional generation following schemes, which can be costly and/or environmentally unfriendly.

The first attempt in case of LFC has to control the power system frequency by the help of the governor. This technique of governor control was not sufficient for the stabilization of the system. So, a extra supplementary control technique was introduced to the governor by the help of a variable proportional directly to the deviation of frequency plus it's integral. This scheme contains classical approach of Load Frequency Control (LFC) of power system. Cohn has done earlier works in the important area of LFC. [1] and [2] have described the basic importance of frequency and tie line power and tie line bias control in case of interconnected power system.

The revolutionary concept of optimal control (optimal regulator) for LFC of an interconnected power system was first started by [3]. There was a recommendation from the North American Power Systems Interconnection Committee (NAPSIC) that, each and every control area should have to set its frequency bias coefficient is equal to the Area Frequency Response Characteristics (AFRC). But [3-4] argued seriously on the basis of frequency bias and by the help of optimal control methods they presented that for lower bias settings, there is wider stability margin and better response. They have also proved that a state variable model on the basis of optimal control method can highly improvise the stability margins and dynamic response of the load frequency control problem.

For more than last three decades researches are going on load frequency control of power system. Linearized models of multi area (including two areas) power systems are considered so far for best performance.

Firstly, some new multi-area LFC systems that derive from the conventional multi-area LFC systems satisfy the dynamic model of i^{th} control area of multi-area LFC scheme and are equal to the conventional multi-area LFC systems. Since the new and conventional systems are equivalent, the control problem of conventional system is transferred to the control problem of new one. Secondly, the new LFC system that is represented as a cascade system with some transformations yields two subsystems.

The proposed method has two advantages. The first one is that it decouples the total tie-line power flow into two parts. One useful part is used as an integral feedback to reduce the systemic steady static difference of area *i*, while the other disturbed part is simultaneously rejected by the IA method. The second advantage is that it designs a robust disturbance rejection controller via the property of IA method. In short, the proposed method works out the problem on how to effectively utilize the total tie-line power flow. Finally, the simulations show the validity and advantages of the proposed method.

II. PROBLEM FORMULATION

The power systems means, it is the interconnection of more than one control areas through tie lines. The generators in a control area always vary their speed together (speed up or slow down) 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 a control area of an interconnected power system then there will be frequency deviation as well as tie line power deviation.

If there is a small change in load power in a single area power system operating at set value of frequency then it creates mismatch in power both for generation and demand. This mismatch problem is initially solved by kinetic energy extraction from the system, as a result declining of system frequency occurs. As the frequency gradually decreases, power consumed by the old load also decreases. In case of large power systems the equilibrium can be obtained by them at a single point when the newly added load is distracted by reducing the power consumed by the old load and power related to kinetic energy removed from the system. Definitely at a cost of frequency reduction we are getting this equilibrium .The system creates some control action to maintain this equilibrium and no governor action is required for this. The reduction in frequency under such condition is very large.

However, governor is introduced into action and generator output is increased for larger mismatch. Now here the equilibrium point is obtained when the newly added load is distracted by reducing the power consumed by the old load and the increased generation by the governor action. Thus, there is a reduction in amount of kinetic energy which is extracted from the system to a large extent, but not totally. So the frequency decline still exists for this category of equilibrium. Whereas for this case it is much smaller than the previous one mentioned above. This type of equilibrium is generally obtained within 10 to 12 seconds just after the load addition. And this governor action is called primary control.

After the introduction of governors action the system frequency is still different its predefined value, by another different control strategies it is needed the frequency to bring back to its predefined value. Conventionally Integral Controllers are used for this purpose. This control is called a secondary control (which is operating after the primary control operation) which brings the system frequency to its predefined value or close to it. Whereas, integral controllers are generally slow in operation.

In a two area interconnected power system, where the two areas are connected through tie lines, the control area are supplied by each area and the power flow is allowed by the tie lines among the areas. Whereas, the output frequencies of all the areas are affected due to a small change in load in any of the areas so as the tie line power flow are affected. So the transient situation information's of all other areas are needed 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.

Thus the load frequency control of a multi area power system generally incorporates proper control system, by which the area frequencies could brought back to its predefined value or very nearer to its predefined value so as the tie line power, when the is sudden change in load occurs.

III. LOAD FREQUENCY CONTROL

Load frequency control is one of the most densely researched topics in power system engineering. In fact not only load frequency control but the whole concept of automatic generation control has drawn attention of power system researchers. The solution to the problem of load frequency control has advanced over time. Various researchers have proposed various techniques to deal with the problem of load frequency control in power system. In order to track the development in LFC till today, in this chapter different approaches towards LFC are briefed. Due to diverse nature of approaches LFC strategies can be categorized into different groups. In this Chapter LFC techniques are categorized as follows:

1. Load frequency control based on different techniques.
2. Load frequency control with AC – DC parallel tie line.
3. Consideration of communication delay in LFC
4. Load frequency control of conventional sources integrated with distributed energy sources.
5. LFC of hybrid power system integrated with renewable energy sources.
6. Application of different learning techniques in LFC.
7. Application of power electronics devices in LFC.

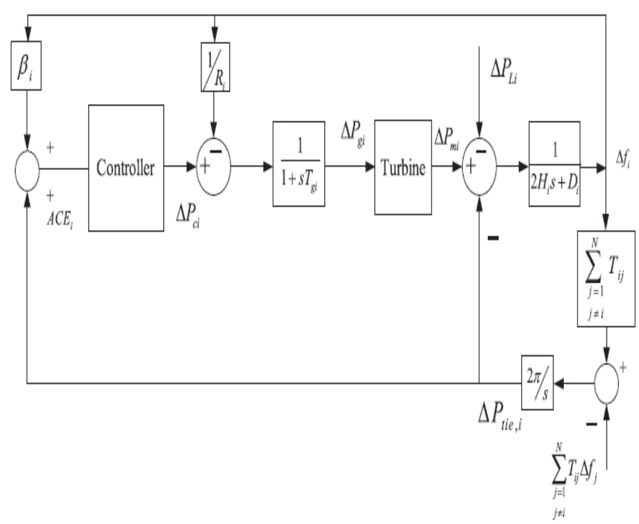

Fig.4.1 Block diagram of ith control area of multi-area LFC power system.

IV. SIMULATION RESULTS

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This Chapter, two area and four area power system model of simulation results are presented for non reheated and reheated turbines. In order to validate the proposed topology, simulation is carried out using the Matlab/Simulink.

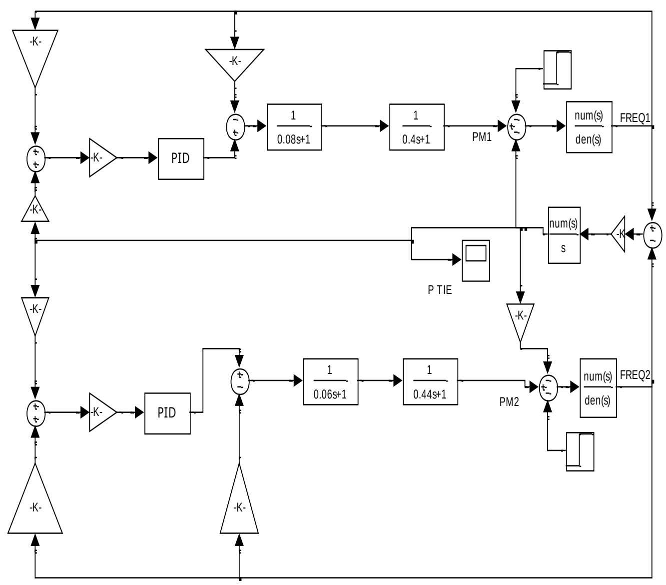


Fig.4.2: Matlab Simulink model of two area power system

Fig.4.2 is simulated for two-area with non reheated turbine model and the parameters used for this area is presented in Table 4.1. The simulations results are shown in Fig.4.3, Fig.4.4 and Fig.4.5.

Table 4.1 Parameters of a two area LFC power system with non-reheated turbines

Area	R (Hz/p.u MW)	T_g (s)	T_t (s)	T_p (s)	K_p
Area1	3	0.08	0.4	11.1133	66.7
Area 2	2.73	0.06	0.44	12.6062	62.5

When $t \geq 3s$, there are load demands $\Delta P_{L1} = \Delta P_{L2} = 0.01$ p.u.MW for the two Areas 1 and 2, respectively. It is necessary to point out that the overshoot and responding speed of $\Delta P_{\text{tie},i}$ are small and fast, respectively. Thus, the proposed method is effective.

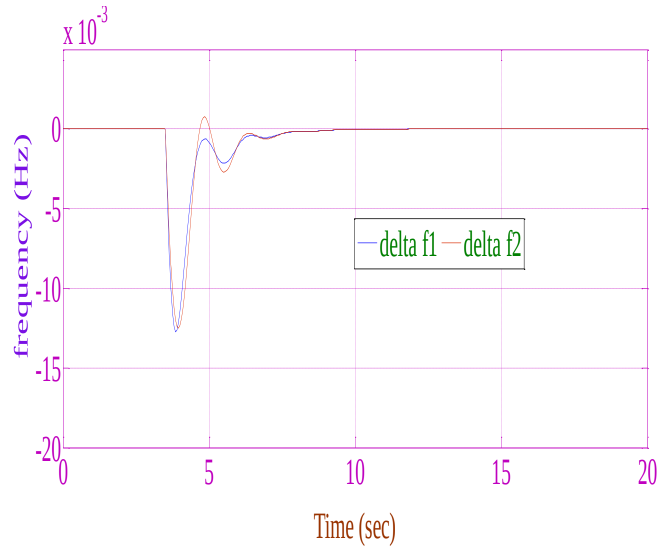


Fig.5.3: Frequency response for LFC two-area with non reheated turbine

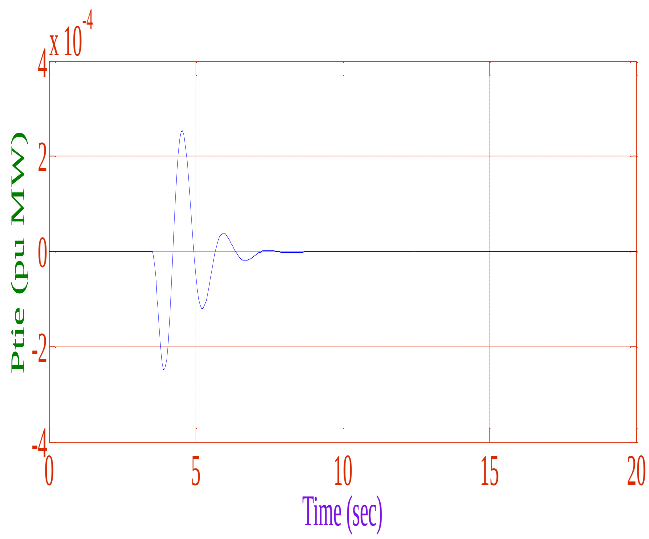


Fig.5.4: P_{tie} line response for LFC two-area with non reheated turbine

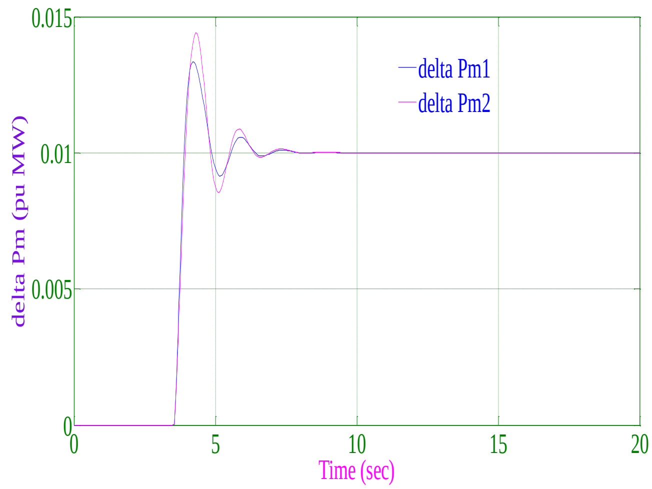


Fig.5.5: Pm responding curves for LFC two-area with non reheated turbine

To prove the advantages of the proposed method, a four area LFC system with non-reheated turbines containing four areas is considered, as shown in Fig. 4.6. Areas 1, 2 and 3 are interconnected with each other, while Area 4 is only connected with Area 1.

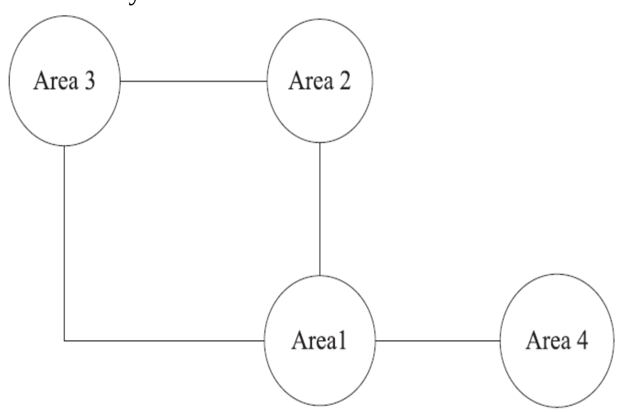


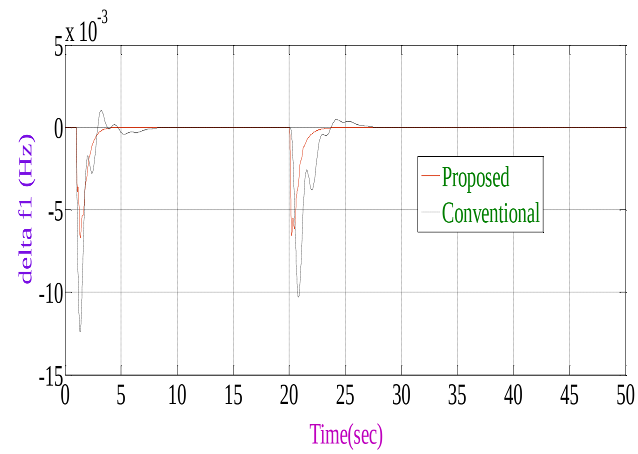
Fig.4.6: Simplified diagram of a four-area power system

Table 5.2 Parameters of a Four-Area LFC System with Non-Reheated Turbines

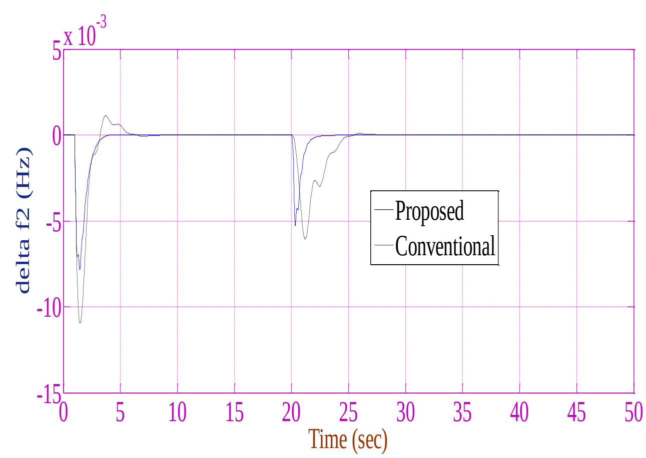
Area	R (Hz/p.u MW)	T_g (s)	T_t (s)	T_p (s)	K_p
Area1	2.4	0.08	0.3	20	120
Area 2	2.7	0.072	0.33	25	112.5
Area 3	2.5	0.07	0.35	20	125
Area 4	2.0	0.085	0.375	15	115

Fig.4.6 is simulated with parameters as shown in Table 4.2 and the response curves related to frequency and tie line power is presented in Fig.4.7 & Fig.4.8.

In the Figs. 4.7 and 4.8, the four-area LFC system faces the demand loads $\Delta P_{L1} = \Delta P_{L2} = 0.01$ p.u. MW at time t ≥ 1 s and $\Delta P_{L3} = \Delta P_{L4} = 0.01$ p.u. MW at time t≥ 20 s, respectively. The solid lines of the proposed method quickly and smoothly approach to the system equilibrium. Besides that, the responding speeds and overshoots of the proposed method are better than those of the conventional results.



(a) Frequency response of Area1



(b) Frequency response of Area2

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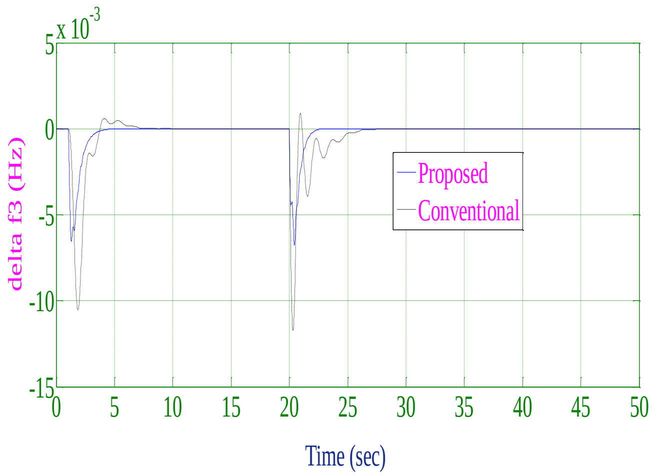
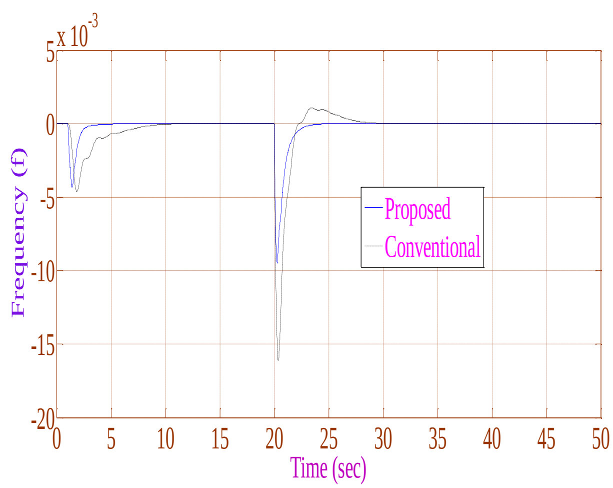
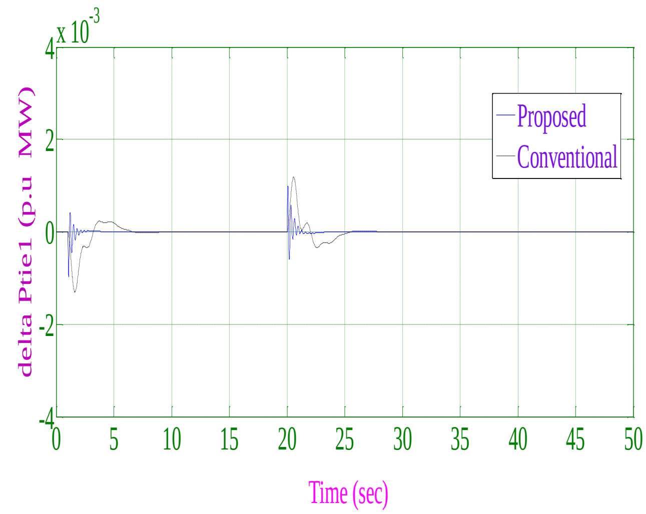


(c) Frequency response of Area3

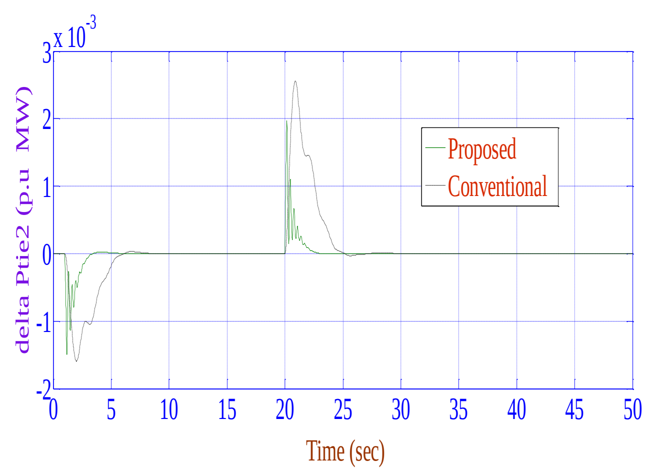


(d) Frequency response of Area4

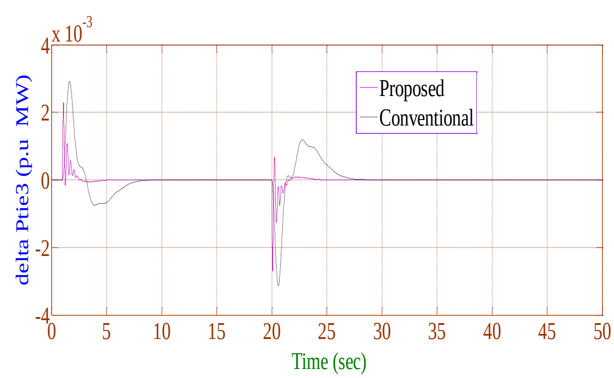
Fig.4.7: Frequency response curves of four area power system with non-reheated turbines



(a) Tie line power response curves of Area1



(b) Tie line power response curves of Area2



(c) Tie line power response curves of Area3

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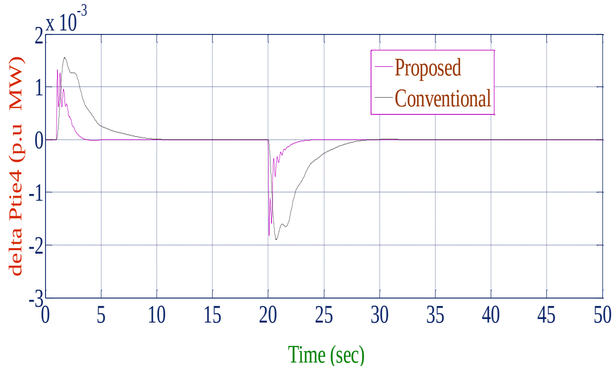
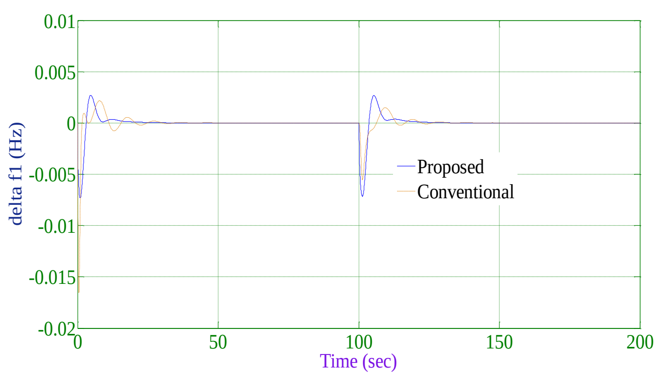


(d) Tie line power response curves of Area4

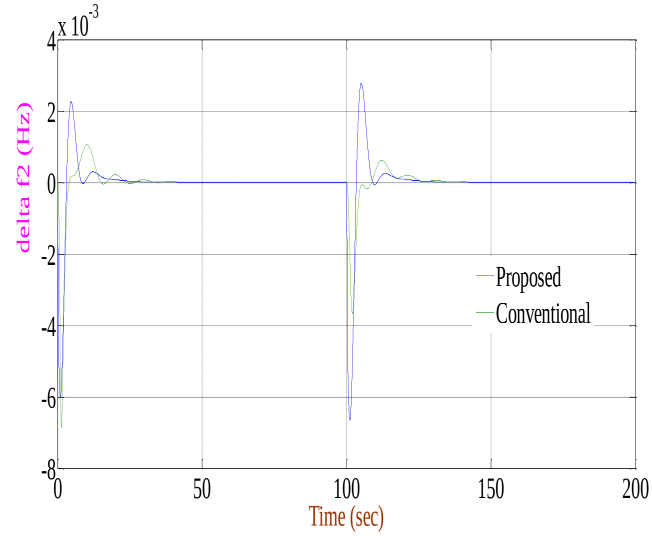
Fig.4.8: Tie line power response curves of four area power system with non-reheated turbines

Table 5.3 Parameters of a Four-Area LFC System with Reheated Turbines

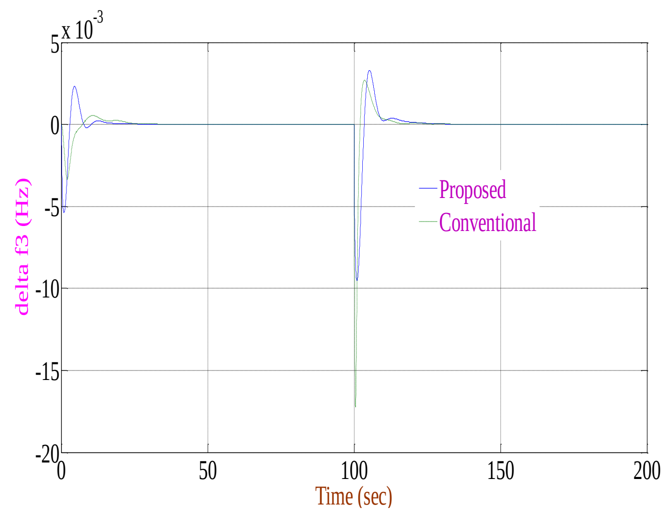
Area	R (Hz/p.u MW)	T_g (s)	T_t (s)	T_p (s)	K_p
Area1	2.4	0.08	0.3	20	120
Area 2	2.7	0.072	0.33	25	112.5
Area 3	2.5	0.07	0.35	20	125
Area 4	2.0	0.085	0.375	15	115



(a) Frequency response of Area1



(b) Frequency response of Area2



(c) Frequency response of Area3

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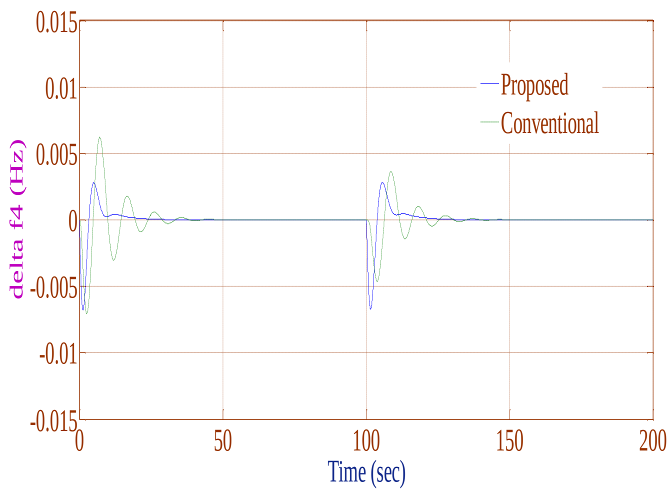
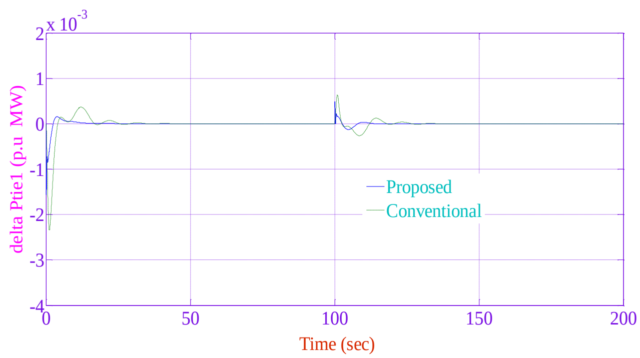
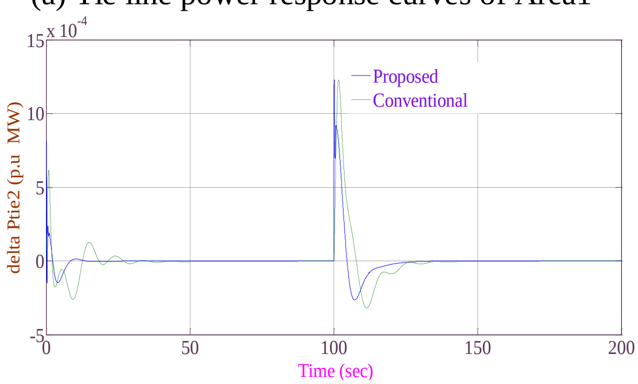


(d) Frequency response of Area4

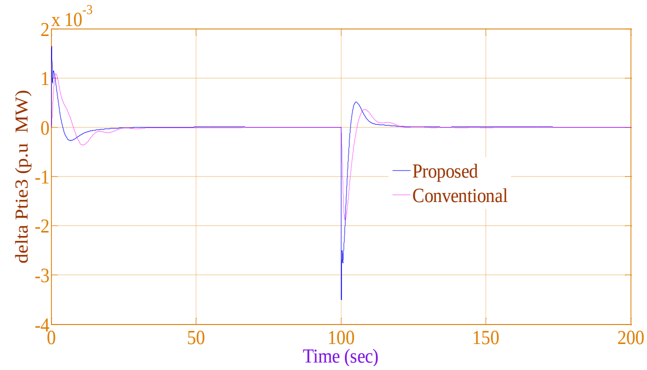
Fig.4.9: Frequency response curves of four area power system with reheated and hydro turbines



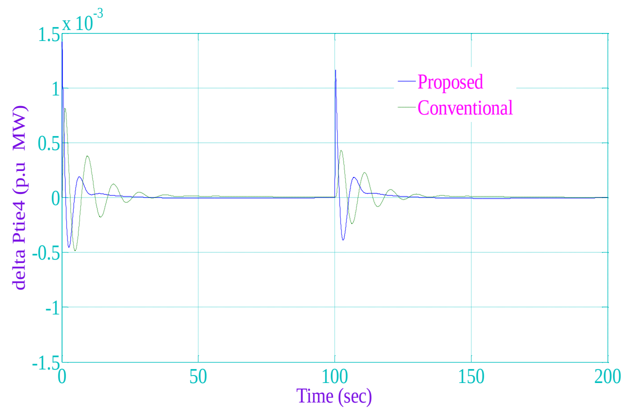
(a) Tie line power response curves of Area1



(b) Tie line power response curves of Area2



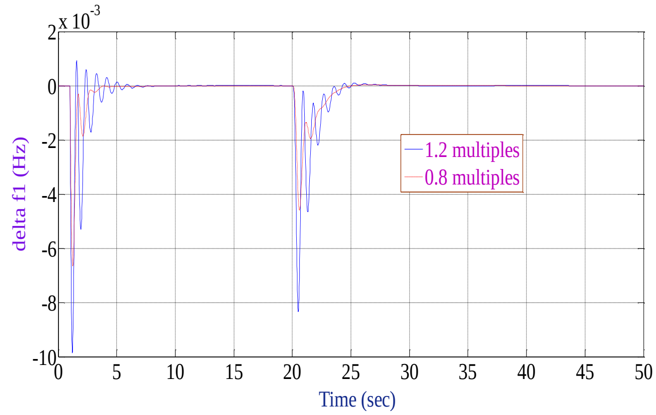
(c) Tie line power response curves of Area3



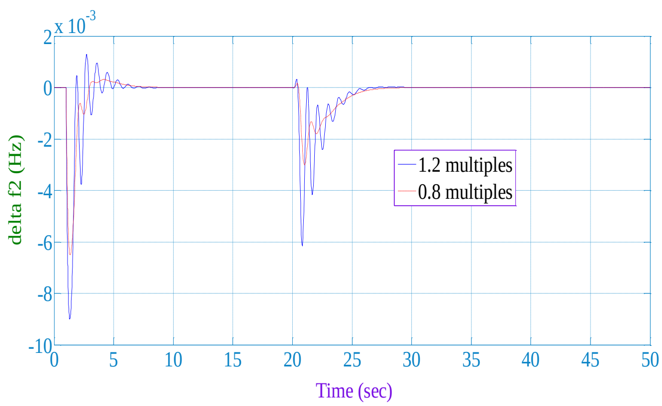
(d) Tie line power response curves of Area4

Fig.4.10: Tie line power response curves of a four-area power system with reheated turbines

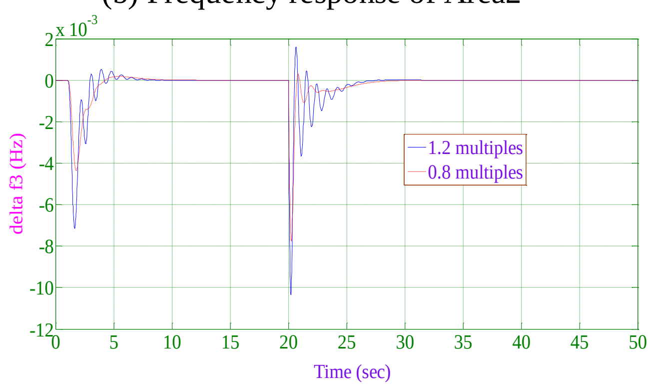
Fig.4.6 is simulated with parameters as shown in Table 4.3 and the response curves related to frequency and tie line power is presented in Fig.4.9 & Fig.4.10. Noting the Fig. 4.6 again, when the non-reheated turbines of the Areas 1, 2 and 3 in the above four-area LFC system are replaced by reheated turbines, while the non-reheated turbine of the Area 4 is replaced by a hydro turbine. Thus, a four-area LFC system with reheated and hydro turbines is considered. When t = 0 s and t = 100 s, there are step loads ΔP_{L1} = 0.01 p.u.MW and ΔP_{L3} = 0.01 p.u.MW for the Areas 1 and 3, respectively. It is clear that the responding speeds of the proposed method are faster than those of the conventional results.



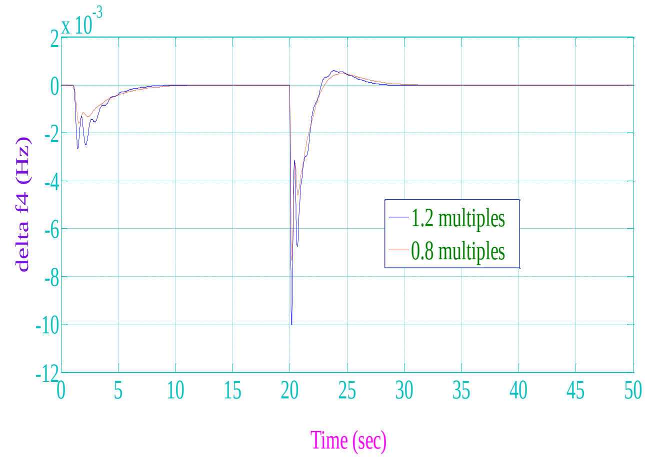
(a) Frequency response of Area1



(b) Frequency response of Area2

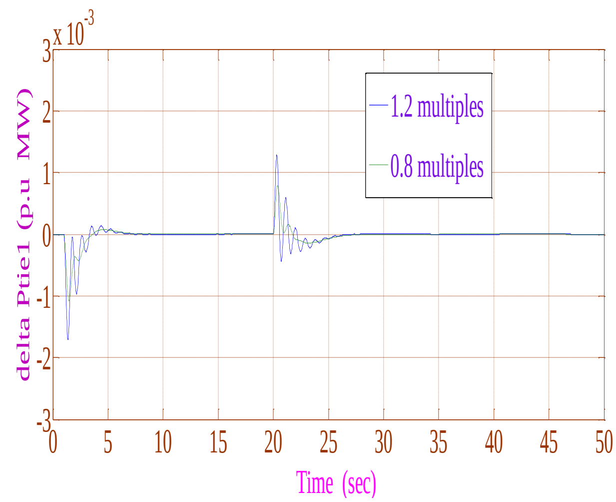


(c) Frequency response of Area3



(d) Frequency response of Area4

Fig.4.11: Frequency response curves of four-area power system with non-reheated Turbines



(a) Tie line power response curves of Area1

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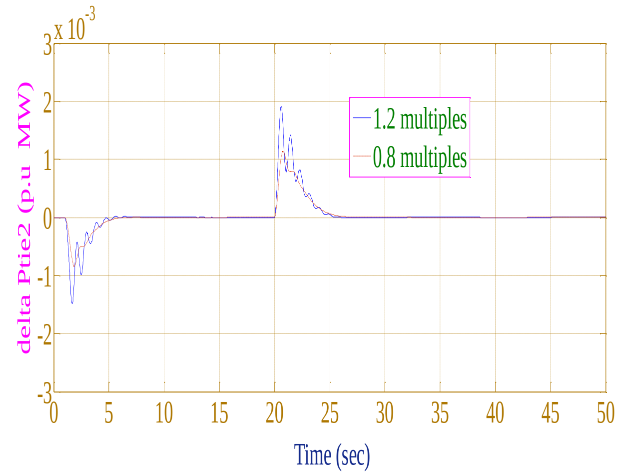
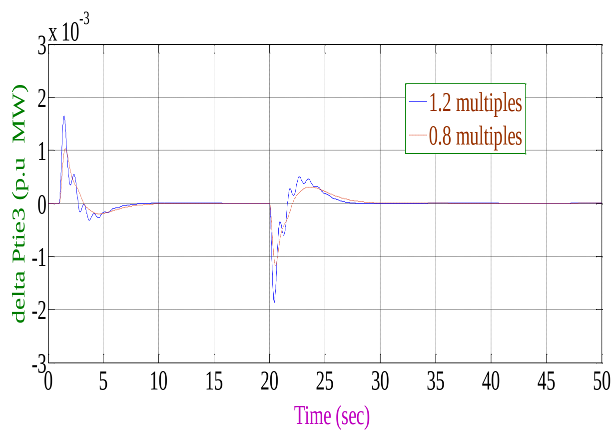
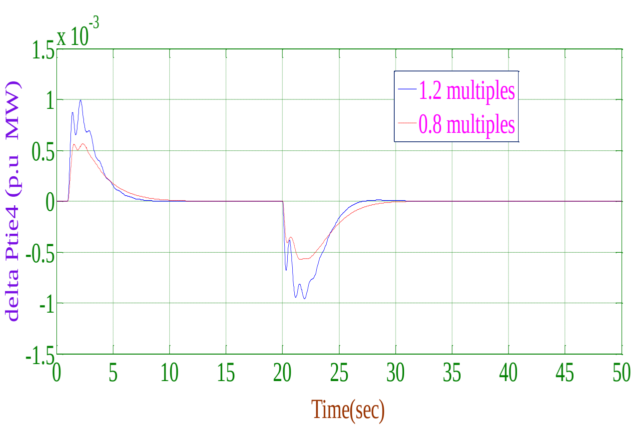


(b) Tie line power response curves of Area2



(c) Tie line power response curves of Area3



(d) Tie line power response curves of Area4

Fig.4.12: Tie line power response curves of a four-area power system with non reheated turbines

A four-area LFC system with non-reheated turbines that is considered is interconnected as the configuration shown in the Fig.4.6. Namely, the parameters of the four-area LFC system are in the Table 4.2, and the rates of areas are mentioned as before. To test the robustness, the above system is simulated for different parameter variations within ± 20% as shown Figs.4.11 and 4.12. It is clear that the control laws still asymptotically stabilize the four-area LFC system with some varying parameters. Thus, the proposed method is robust.

V. CONCLUSION

In this thesis, a control method based on the PH system and cascade system for the multi-area LFC system is proposed with two contributions. One is that the proposed method decouples the total tie-line power flow $\Delta P_{tie,i}$, while the other is that the proposed method designs a robust disturbance rejection controller in the same time. In other words, due to the decoupling of $\Delta P_{tie,i}$, the useful part $\int \Delta f_i dt$ of $\Delta P_{tie,i}$ is used as the integral feedback to improve the systemic steady static difference, while the disturbed part $\int \Delta f_j dt$ of $\Delta P_{tie,i}$ is simultaneously robust rejected by the IA method. In short, compared with the traditional methods, the proposed method applies the structure and energy properties of multi-area LFC system to design a control law, which successfully works out the problem on how to effectively utilize the total tie-line power flow $\Delta P_{tie,i}$.

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