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Load Frequency Control of Three Area Power System using Fuzzy Logic Controller

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ABSTRACT
This paper proposes a method to determine the magnitude and location of load disturbances in multi-area power systems via monitoring tie-line power flows, implementing demand response regionally. In this work, proposes an intelligent coordination between secondary control and demand response through a supervisory fuzzy-PI-based coordinator. The simulations were performed in the environment of MATLAB/SIMULINK.

KEYWORDS: *Multi-Area Power System, Load Frequency Control, fuzzy-PI-based coordinator*

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I. INRODUCTION

Understanding of the frequency dynamics of power systems is essential for several issues including frequency control design and estimation of the system inertia through measurements. Consider a power system with several conventional synchronous generators. If this power system is subjected to a disturbance such as a sudden outage of a generator, then dynamical changes in the system start instantaneously. These dynamics are mainly caused by the instantaneous power imbalance between the instantaneous generation and consumption of electric power. Consequently, the remaining synchronous generators are subjected to acceleration and deceleration effects. Due to the strong connection between the mechanical and electrical frequency, the changes in the rotor speed results in changes in the electrical frequency. Eventually, the power balance and the frequency are restored in the system has sufficient capacity to compensate the lost generation. This control action is called primary Automatic Load Frequency Control (ALFC). In this direction, the load-frequency control (LFC) is one of important control problems in concerning the integration of wind power turbine in a multi-area power system [2, 8, 18, 20, 21].The increasing need for electrical energy in the twenty-first century, as well as limited fossil fuel reserves, very high transportation and fuel cost and the increasing concerns with environmental issues for the reduction of carbon dioxide (CO2) and other greenhouse gasses, causes fast development in the area of renewable energy sources (RESs). One of the adaptive and nonlinear intelligent control techniques that can be effectively applicable in the frequency control design is reinforcement learning (RL). Some efforts are addressed in [3, 4, 5, 7, 16, 17]. RL based controllers learn and are adjusted to keep the area control error small enough in each sampling time of a LFC cycle. Since, these controllers are based on learning methods; they are independent of environment conditions and can learn a wide range of operating conditions. The RL based frequency control design is a model-free design and can easily scalable for large scale systems and suitable for frequency variation caused by wind turbine fluctuation. Using conventional linear control methodologies for the LFC design in a modern power system is not more efficient, because they are only suitable for a specific operating point in a traditional structure. If the dynamic/structure of system varies; they may not perform as expected. Most of conventional control strategies provide model based controllers that are highly dependent to the specific models, and are not useable for large-scale power systems concerning the integration of RES units with nonlinearities, undefined parameters and uncertain models. If the dimensions of the power system increase, then these control design may become more different as the number of the state variables also increases, significantly. Therefore, design of intelligent controllers that are more adaptive and flexible than conventional controllers is become an appealing approach. When WTGs are introduced to the power system, as they generate a part of power system loads, much portion of conventional nominal power can be available for using in supplementary control. However, as the variable wind farms power output may or may not be available during peak demand and abnormal periods, due to unpredictable nature of wind; it might be that these resources cannot contribute to the overall system frequency regulation and reliability. On the other hand, the additional power variation from WTGs results in frequency deviation. It seems that for a large wind power penetration, this deviation will be so larger and as a result, the conventional LFC reserve may be insufficient to maintain frequency within the bounds for service quality. It was found that wind power, does not impose major extra variations on the system until a substantial penetration is reached [11]. Large geographical spreading of wind power will reduce variability, increase predictability, and decrease the occasions with near zero or peak output [22]. It is investigated in [11] that the power fluctuation from geographically dispersed wind farms will be uncorrelated with each other, hence smoothing the sum power and not imposing any significant requirement for additional frequency regulation reserve, and required extra balancing is small.

The fluctuation of the aggregated wind power output in a short term (e.g., tens of seconds) for a larger number of wind turbines are much smoothed. It is investigated that the wind turbines aggregation has positive effects on the regulation requirement. Relative regulation requirement decreases whenever larger aggregations are considered [22].

II. POWER GENERATING SYSTEM

The relationship between ΔP_m and Δf is shown in Fig.1, where M is the inertia constant of the generator.

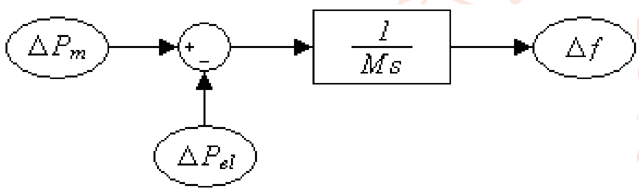


Fig.1: Block diagram of the generator

If the mechanical power remains unchanged, the motor loads will compensate the load change at a rotor speed that is different from a scheduled value, which is shown in Fig.2. Where, D is the load damping constant.

The reduced form of Fig.2 is shown in Fig.3, which is the generator model that we plan to use for the LFC design. The Laplace-transform representation of the block diagram is shown in Fig.3.

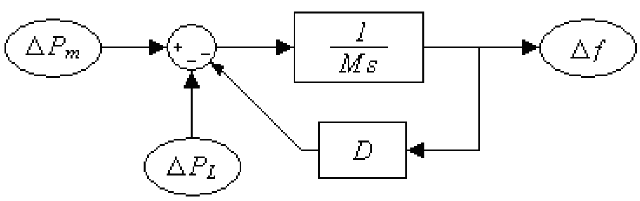


Fig.2: Block diagram of the generator with load damping effect

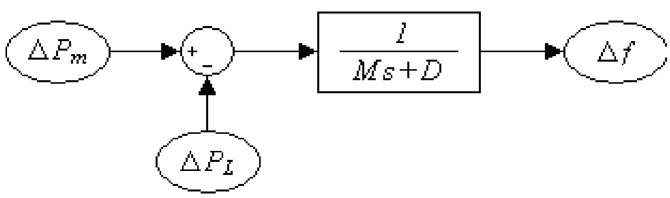


Fig.3: Reduced block diagram of the generator with the load damping effect

Governors are the units that are used in power systems to sense the frequency bias caused by the load change and cancel it by varying the inputs of the turbines. The schematic diagram of a speed governing unit is shown in Fig.4, where R is the speed regulation characteristic and Tg is the time constant of the governor [1].

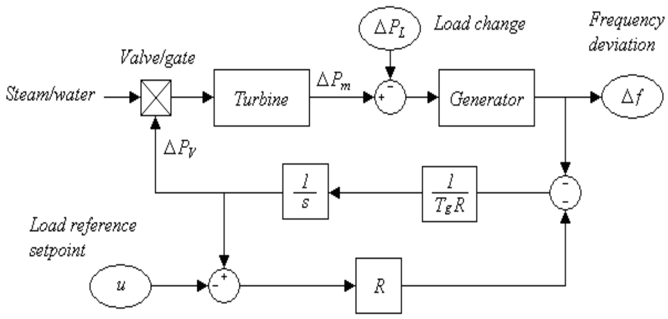


Fig.4: Schematic diagram of a speed governing unit

The reduced form of Fig.4 is shown in Fig.5. The Laplace transform representation of the block diagram in Fig.5 is given by

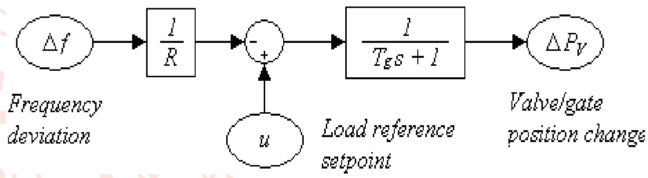


Fig.5: Reduced block diagram of the speed governing unit

In an interconnected power system, different areas are connected with each other via tie-lines. When the frequencies in two areas are different, a power exchange occurs through the tie-line that connected the two areas. The tie-line connections can be modeled as shown in Fig.6.

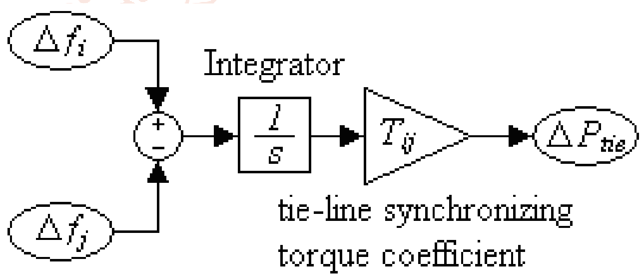


Fig.6: Block diagram of the tie-lines

With the power generating units and the tie-line connections of interconnected areas introduced and a complete form of one-area power generating unit can be constructed as Fig.7.

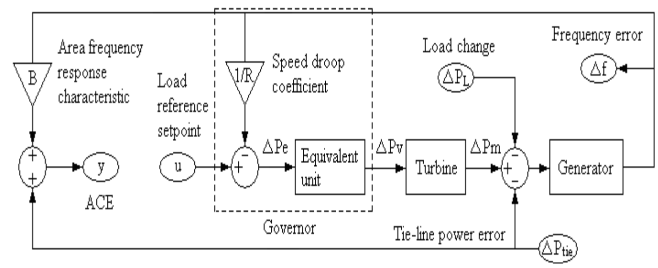


Fig.7: Schematic of one-area power generating unit

The communication delays can be mainly considered on the control input and the control output of the LFC system: The delays on the measured frequency and power tie-line flow from RTUs to the control center, which can be reflected into the ACE and the produced control command signal from control center to individual generation units. A simplified time-delayed LFC system is shown in Fig. 8.

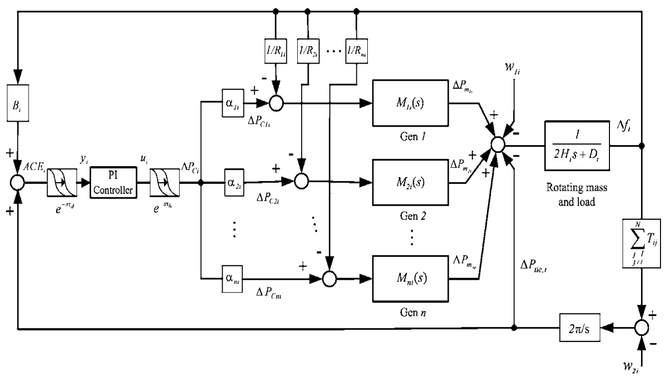


Fig.8: A general control area with time delays

III. MULTI-AREA POWER SYSTEM

Fig. 9 is a control block diagram for the ith area of a multi area power system. Although a power system is nonlinear and dynamic, the linearized model is permissible in the load frequency control problem because only small changes in load are expected during its normal operation [21].

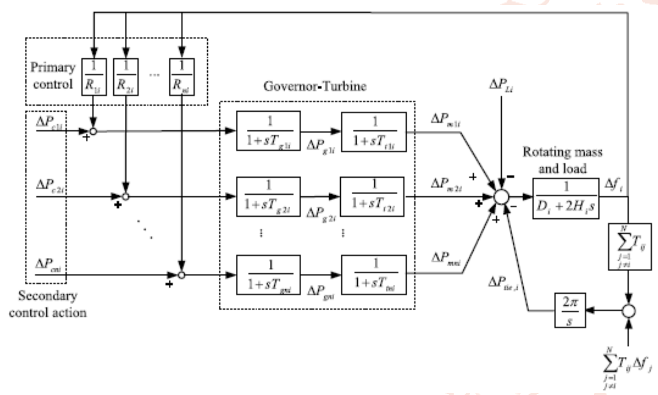


Fig.9: Block diagram of the ith area of a multi-area power system

IV. FUZZY-PI-CONTROLLER

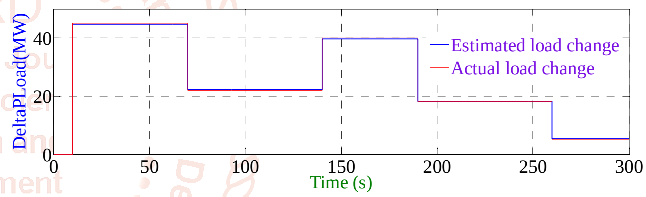
Most robust and optimal load–frequency control methods published in the last two decades suggest complex state-feedback or high-order dynamic controllers [1–8], which are impractical for industry practices.

In practice, LFC systems use simple proportional–integral (PI) controllers. However, since the PI controller parameters are usually tuned based on experiences, classical or trial-and-error approaches, they are incapable of obtaining good dynamical performance for a wide range of operating conditions and various load changes scenarios in a multi-area power system. Recently, some control methods have been applied to the design of decentralized robust PI or low-order controllers to solve the LFC problem [9–12].

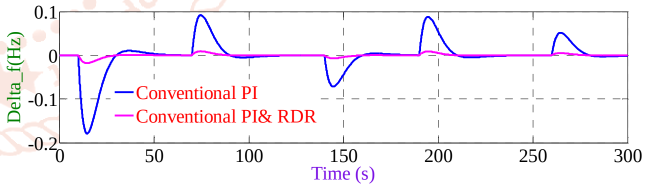
Fuzzy logic is used to cope with this phenomenon, i.e., protecting the system against excessive overshoots/undershoots and consequently reducing CO2 emission and to adjust the responsive generators according to the amount of regulation provided by the RDR. Therefore, fuzzy logic is used not only for handling control actions, but also for making coordination between generation side and demand side. Minimizing the frequency deviations due to fast changes in output power of wind turbines, and limiting the tie-line power interchanges in an acceptable range are the other goals of this effort. Furthermore, the fuzzy logic is able to compensate the inability of the classic control theory for covering complex power systems with uncertainties and inaccuracies. Recent work of the authors in [2] demonstrates that fuzzy logic can be used as a suitable intelligent method for online tuning of PI controller parameters. In this case, fuzzy logic is used as a supervisor for fine tuning of conventional PI controllers. In the present work, the PI controller is remained, and the fuzzy logic is used for on-line tuning of its parameters. Therefore, this control configuration provides a smooth performance in startup and transient circumstances and it could be more acceptable for real-time LFC application.

V. SIMULATION RESULTS

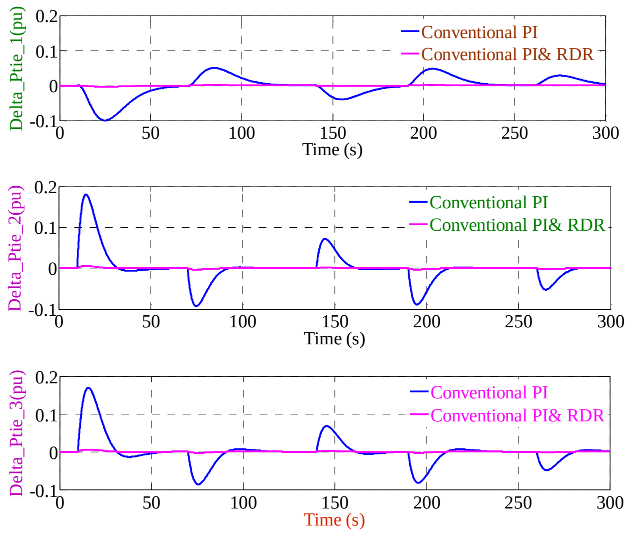
The three-area interconnected power system is analyzed to illustrate the effectiveness of the proposed control scheme. In order to validate the proposed topology, simulation is carried out using the Matlab/Simulink. Fig.8 and Fig.9 is simulated to evaluate the performance of Fuzzy-PI for three area power system. As can be seen, there is a significant resemblance between the estimated and actual load changes. Fig. 10 (b) and Fig. 10 (c) show that the proposed RDR can effectively reduce the amount of the frequency excursion and variations, and also demonstrate that the tie-line power changes are maintained within a narrow band.



(a)



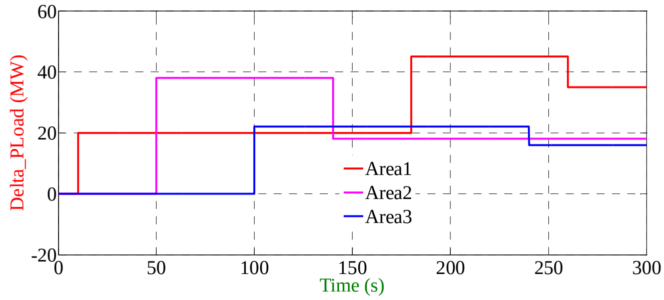
(b)



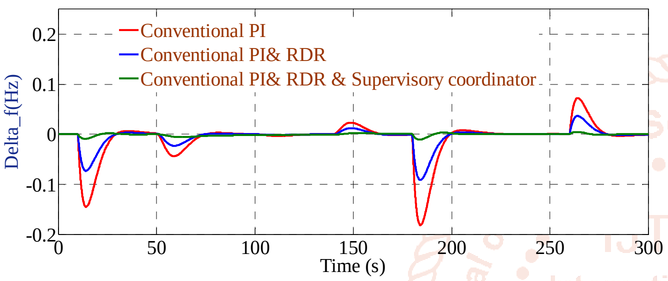
(c)

Fig.11 comparison of conventional PI controller versus the RDR contribution

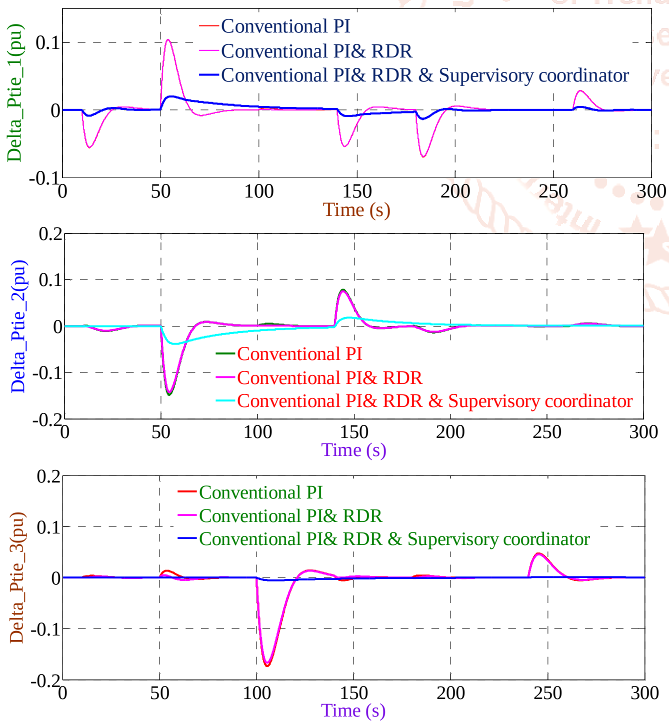
A random step loads are applied to all three areas according to Fig. 12(a). System frequency response and tie-line power changes, in the case of comparing the performance of conventional controllers versus participation of the RDR and supervisory fuzzy-PI-based coordinator are given in Fig. 12(b) and Fig. 12(c), respectively. The obtained results show that the designed method can ensure a good performance in a multi-area power system in the existence of random step load changes and wind power fluctuations.



(a)



(b)



(c)

Fig.12: System response following a sequence of step load changes in all areas

VI. CONCLUSIONS

A fuzzy-PI-based supervisory controller is introduced as a coordinator between the demand response and secondary frequency control to adjust the responsive generators according to the amount of regulation provided by the RDR. This coordinator will cover not only the system uncertainties but also time delay side effects of the RDR scheme.

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