Implementation of Hydro-Thermal LFC-DR Model using Fuzzy logic approach

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Abstract : ***Dynamic demand response (DR) became an essential part of ancillary services markets. This incorporation of dynamic DR control loop into the conventional load frequency control (LFC) model is presented by many of the authors in their previous work. Extensive analytical analyses were carried out on single-area power system in previous study. In this paper, the idea is expanded to a general two area Hydro-Thermal interconnected power system. Then, impacts of the proposed LFC-DR on the dynamic performance i.e DR communication delay latency in the controller design is considered and is linearized using Padé approximation for the multi-area power systems in different conditions are simulated. Simulation results shows that Fuzzy Logic Controller LFC-DR multi-area power system have better performance and superiority over a classical controller at different operating scenarios.***

IndexTerms - Demand Response, Fuzzy Logic Control, Load Frequency Control, Padé approximation

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Nomenclature:

Δf_i	*Change in frequency of area i (Hz)*
R_i	*speed regulation constant (Hz/p.u.)*
T_g	*speed governor time constant (s)*
M_i	*inertia constant of the generator (p.u. s)*
Di	*load damping constant (p.u./Hz)*
T_i	*synchronizing torque coefficient of the tie-line which is connected to area i (p.u./rad.)*
T_t	*non-reheat turbine time constant (s)*
T_{rh}	*low pressure reheat time constant (s)*
F_{hp}	*high pressure stage*
T_w	*water starting time (s)*
T_R	*reset time of hydraulic unit (s)*
β_i	*frequency response characteristic for area i (p.u./Hz)*
ACE_i	*area control error*
ΔP_{Li}	*load demand change in area i*
ΔP_{Ci}	*the change in speed changer position in area i*
ΔP_{Gi}	*change in governor valve position of ith area generator*
ΔP_{tie}	*change in tie-line power*
ΔP_{DRi}	*Change due to demand Response*
ΔP_{Ti}	*Change in turbine output*
T_d	*Communication delay latency*
i	*Number of areas..1,2*

I. INTRODUCTION:

From the past decade an extensive literature review has been done on the load–frequency control (LFC) problem in power system. The various configurations of power system models and control techniques/ strategies that concerns to LFC issues have been addressed in conventional as well as distribution generation-based power systems. Thus, Load–frequency control (LFC) gained importance in electric power system design and operation. The objective of the LFC in an interconnected power system is to maintain the frequency of each area within limits and to keep tie-line power flows within some pre-specified tolerances by adjusting the MW outputs of the generators so as to accommodate fluctuating load demands [1]. A well designed and operated power system must cope with changes in the load and with system disturbances, and it should provide acceptable high level of power quality while maintaining both voltage and frequency within tolerance limits. Subjected to any disturbance, the nominal operating point of a power system changes from its pre-specified value. As a result, the deviation occurs about the operating point such as nominal system frequency, scheduled power exchange to the other areas which is undesirable [2].

The LFC issues have been tackled with by the various researchers in different time through AGC regulator, excitation controller design and control performance with respect to parameter variation/uncertainties and different load characteristics. As the configuration of the modern power system is complex, the oscillation incurred subjected to any disturbance may spread to wide areas leading to system black out. In this context, advance control methodology such as optimal control, variable structure control, adaptive control, self-tuning control, robust and intelligent control were applied in LFC problem.

The further research in this area has been carried out by use of various soft computing techniques such as artificial neural net-work (ANN), fuzzy logic and fusion of these such as neuro-fuzzy, neuro-genetic etc. to tackle the difficulties in the design due to non-linearity in various segregated components of the controller. The controller parameters plays a vital role for its performance, thus it should be tuned properly with suitable optimization techniques. In this context, the application of genetic algorithm (GA), particle swarm optimization

(PSO), simulated annealing (SA) etc. is exploited to address the optimization objective. Due to non-linearity in the power system components and also the uncertainty in the system parameters, the performance differs from actual models, so robust control design is indispensible to achieve acceptable deviation in frequency about the nominal operating point. Various robust control techniques such as Riccati equation, H_∞, m-synthesis, robust pole assignment, loop shaping, linear matrix inequality (LMI) has been adopted to tackle the LFC problems [3].

Now, there is rapid momentum in the progress of the research to tackle the LFC in the deregulated environment, LFC with communication delay, and LFC with new energy systems, FACTS devices, and HVDC links as well with the increase in Demand. The upcoming power grid, 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. Given the limited availability, low efficiency, and high cost of large storage devices, real -time smart responsive load participation, known as demand response (DR), has been actively considered for power balancing as it is well known that DR increases system reliability and flexibility to manage the variability and uncertainty of some RE resources, decreases the cost of operation, and enhances system efficiency. Furthermore, DR can be used to provide ancillary services (AS) for regulation reserve and to respond momentarily to the area control error (ACE). Although AS are called more frequently than traditional load shedding events, the annual total hours of curtailment is much less, and individual events are much shorter. Thus, AS programs may appeal to retail customers, as they will find more frequent and short on/off switching of some of their end-use loads more acceptable than infrequent and long curtailments [4]. Examples of customer end-use loads that have instantaneous response and are potential candidates for DR are electric water heaters (EWHs) and HVACs. With the above reasons considerable attention has been recently given to DR for different purposes, for e.g., economic benefits of DR [5]–[9], offline planning and day-ahead scheduling [10]–[16], availability assessment of the DR resources for reserve capacity [17]–[19], and analysis of the effectiveness of DR in providing AS at the islanded distribution-level micro grids [20]–[22]. A number of studies have also addressed the effectiveness of de-centralized dynamic demand control on stabilization of grid frequency, mainly at the transmission level [23]–[32]. However there are also some inadequacies in all the above studies. i.e. the general frame work on the analysis of the impact of DR on the power system model and load was not presented [23]–[29], [31], [32].The AGC model has not been considered also.Communication delay in central DR, and measurement delay in decentralized DR have not been considered [23]–[27], [31], [32]. Frequency regulation as AS have not been studied. Only under-frequency load shedding (UFLS) characterization has been analyzed [30], [32]. Load-damping coefficient, which can improve frequency stabilization, has been ignored [28]. Only sensitivity analysis of frequency-related load-damping coefficient characteristic without generalization and DR control is presented [32].

This paper is to make the model as general as possible and to include communication latency associated with DR between the load aggregator companies (Lagcos) and the end-use customers' devices. This is an important parameter in the system dynamic performance of LFC-DR. It has assumed the communication delay between the balancing authority (BA) and the Lagcos to be the same as that between the BA and generation companies (Gencos). The proposed LFC- DR also gives an opportunity to the system operator to choose the DR option or spinning/non-spinning reserve, or a combination of the two, based on the real-time market price. Furthermore, the LFC-DR model can be used to estimate the actual value of the required responsive load manipulation when the magnitude of the disturbance is unknown to the system operator.

The LFC -DR model will help the operators to investigate the impact of DR on the dynamic performance of the system prior to its usage and during the automatic generation control (AGC) design process. The idea of DR for AS used in this paper, has been fully explored in previous works [33] [34].

It is indicated that frequency control could be performed by a pre-scheduled scenario instead of generation resources; hence the ease and priority of the customers are guaranteed. These models are useful in small disturbance studies such as small variations in load and generation, and in controller design [35]. In the past decades, Fuzzy Logic Controllers (FLCs) have been successfully developed for analysis and control of non-linear systems [36], [37]. The fuzzy reasoning approach is motivated by its ability to handle imperfect information, especially uncertainties in available knowledge. The load frequency control with Demand response for single area power system with intelligent controllers were well documented [33]. The idea has been extended the multi area power system for restructured environment using Adaptive Neuro Fuzzy logic controllers.

The objective of this research is to investigate the Load Frequency Control with Demand Response (LFC-DR) control loop in multi-area at different operating conditions using the Adaptive intelligent control techniques [33]. Power system is a highly non-linear and uncertain system. In order to linearize the system from nonlinearities (communication latency associated with DR between the load aggregator companies (Lagcos) and the end-use customers' devices) Padé approximation is used which is an important parameter in the system dynamic performance of LFC-DR. To take care about the uncertainties many authors have proposed Adaptive Neuro fuzzy logic based controllers to power systems [38] [39].The proposed controller is simulated for a Demand response multi -area power system. Results of simulation show that the adaptive network-based fuzzy inference systems (ANFIS) control technique guarantee the robust performance.

II. FORMULATION EXPANSION TO MULTI-AREA POWER SYSTEM

Large power systems are normally divided into multiple areas connected by high voltage transmission lines or tie-lines, where each area may include generation units of different types. Therefore, it is necessary to consider the differences between Gencos in the LFC studies and controller design in each area. A lot of attention has been focused on decentralized LFC model for controller design and analysis of interconnected power systems with multiple Gencos in each area. It is shown that the LFC problem for a large power system can be effectively reduced to an equivalent LFC problem for each area. Then, each control area regulates the power interchange with the neighboring control areas, as well as its local frequency [2]. The LFC model with multiple Gencos has already been developed, e.g. [2]. However to the best of our knowledge, the dynamic DR control concept has not been included in the LFC model for multi-area power system as shown in Fig 1.

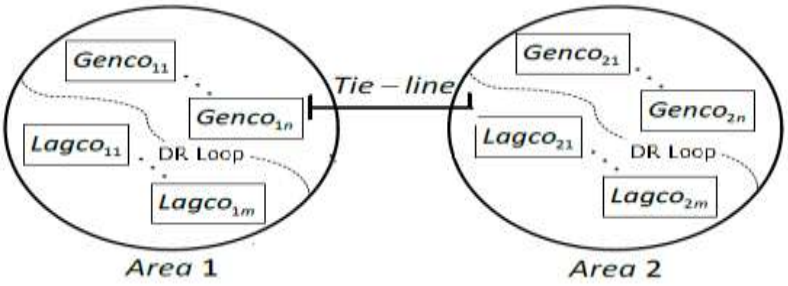

Fig.1 Two-area interconnected power system including Demand response (DR) control loop

In general the power balance equation in the frequency-domain for low-order linearized power system LFC model for the purpose of frequency control synthesis and analysis is given by [1], [2]:

$$\Delta P_T(s) - \Delta P_L(s) = 2H.s.\Delta f(s) + D.\Delta f(s) \tag{1}$$

The modified block diagram of single area thermal power system with the consideration of demand response (DR) control loop for load frequency control, with communication delay latency is shown [33]. Since DR performs like spinning reserve in magnitude and power flow direction, i.e., once frequency deviation becomes negative (positive), it is required to turn OFF (ON) a portion of the responsive loads for ancillary services (i.e., DR), Equation (1) can be modified as Equation (2):

$$\Delta P_T(s) - \Delta P_L(s) + \Delta P_{DR} = 2H.s.\Delta f(s) + D.\Delta f(s) \tag{2}$$

The power consumption status of controllable loads can be changed instantaneously by the command signal they receive. Unlike the usual spinning reserve-provider power plants, there is no ramp up and down limitations on the DR resources. The Multi area power system with dynamic demand response control loop with load disturbance is shown in Fig 1.The power balance equation for the two area power system i.e. for thermal and hydro unit includes Area Control Error (ACE) can be written as Equations (3)&(4):

Area1: $ACE(s) = \Delta P_{tie1}(s) + \beta_1 \Delta f_1(s)$ (3)

Area2: $ACE_2(s) = \Delta P_{tie2}(s) + \beta \Delta f_2(s)$ (4)

Therefore; the only obstacle for DR is communication delay, known as latency, which could affect the system dynamic performance. There are various methods available for Input-Output Linearization Problem (IOLP) for a class of single-input-single-output nonlinear systems with delays .In order to linearise the communication delay latency Padé approximation is used which is explained in the next sections.

State- Space Dynamical Model for LFC-DR for Two-Area Hydro-Thermal Power system

State-space representation of the LFC model is a useful tool for the application of modern/robust control theory. For creating a general framework of LFC in dynamic frequency analysis this type of representation can be conveniently modified and applied to power system of any size. Therefore deriving the dynamic model of the power system, including DR in the state-space representation, in order to study the effect of DR on LFC performance and controller design. The proposed LFC-DR model is based on a simplified power system model with a non-reheat steam turbine and hydraulic unit. The state-space realization of a two-area power system with DR is given by equations(5).the detailed matrix is given in Appendix

$$\begin{aligned}\dot{X}(t) &= \mathrm{A}\cdot x(t) + \mathrm{B}\cdot u(t) + \Gamma\cdot w(t)\\ y(t) &= C\cdot x(t)\end{aligned} \tag{5}$$

where

A - System matrix, ***B*** -control input matrix,
r- Disturbance matrix, ***X*** - State vector,
u (t) - input vector, ***Y***- System output which are $\Delta f_1(s)$ and $\Delta f_2(s)$

III. PADÉ APPROXIMATION

In order to linearize systems with time delays in control engineering with very strong and successive convergent results Padé approximation is widely used [22]. Among the many methods Padé approximations are the most frequently used methods to approximate a dead-time by a rational function.It basically approximates time delays by a quotient of polynomials. Classical control system theory provides the basic relation, but usually only for an approximation with equal numerator and denominator degree are most widely recommended.

The Padé function for the time delay functions

$$e^{-sT_d} \approx R_{mn}(-s.T_d) \tag{6}$$

It is as follows:

$$R_{mn}(-s.T_d) = P_m(e^{-sT_d}) / Q_n(e^{-sT_d}) \tag{7}$$

where

$$P_m(e^{-sT_d}) = \sum_{k=0}^{m} \frac{(m+n-k)!m!}{(m+n)!k!(m-k)!}(-s.T_d)^k \tag{8}$$

$$Q_n(e^{-sT_d}) = \sum_{k=0}^{n} \frac{(m+n-k)!n!}{(m+n)!k!(n-k)!}(-s.T_d)^k \tag{9}$$

From the Equations (6)-(9), ‘P’ and ‘Q’ are the polynomials of order ‘m’ and ‘n’, respectively. It is usually common for the numerator and denominator of the approximation fractional functions to have the same order, and the order usually varies between 1 and 10.The 5th-order Padé approximation is acceptable and is used in this study, Since the cut-off frequency of the low pass filters, i.e., speed-governor and turbine, in the model of the power system are usually less than 15 rad/sec. The magnitudes of all orders of Padé approximation in the frequency domain have also been compared to that of pure time delay. Simulation studies are carried over different values of communication delay latencies (T_d) and the proposed method shows the effective and robust dynamic performance.

IV. CONTROLLING TECHNIQUES FOR THE MULTI AREA DEMAND RESPONSE POWER SYSTEM

Among all the various controller present usually P,PI,PID are called classical controllers which are very widely used in the power system environment. Besides of the usage there is lot of disadvantages in using these classical controllers which made to move towards intelligent controllers. In the quest for developing a model for a system based on its available input output data, it has been observed that in the conventional modeling approach the results depend on the mathematical model of the system and its accuracy. In cases where the mathematical model is not available the system analysis becomes very difficult. It is in this context that the soft computing approach can provide a viable alternative. Performance (such as more number of oscillation and more settling time), especially in the presence of parameters variation and non-linearity. To solve this problem, Fuzzy Logic techniques have been proposed in [33].System operating conditions are observed and used as inputs to a fuzzy system whose output signal controls the inputs to governor for increasing or decreasing the generation for maintaining the system frequency. The prime inherent advantage associated with the soft computing techniques of not requiring a mathematical model has been a motivating factor for consideration in our present work. Motivated by this advantageous feature of soft computing based system identification, the present work focuses on building a model for an ill defined real world system based on its available record of input-output data using ANFIS.

Fuzzy logic controllers:

Fuzzy logic controllers(FLC) are rule-based systems which are useful in the context of complex ill-defined processes, especially those which can be controlled by a skilled human operator without the knowledge of their underlying dynamics. The essential part of the FLC system is a set of Fuzzy Control Rules (FCRs) related by means of a fuzzy implication and the compositional rule of inference. Since power system dynamic characteristics are complex and variable, conventional control methods cannot provide desired results. Intelligent controllers can be replaced with conventional controllers to get fast and good dynamic response in load frequency control problems. If the system robustness and reliability are more important, fuzzy logic controllers can be more useful in solving a wide range of control problems since conventional controllers are slower and also less efficient in nonlinear system applications. Fuzzy logic controller is designed to minimize fluctuation on system outputs.

FLC is designed to eliminate the need for continuous operator attention and used automatically to adjust some variables the process variable is kept at the reference value. The basic configuration of a fuzzy-logic control is composed of four principle components: a fuzzification, a knowledge base, a inference engine, and defuzzification. The fuzzifier maps the input crisp values into fuzzy variables using normalized membership functions and input gains. The fuzzy logic inference engine then infers the proper control action based on the available rule-base. The fuzzy control action is translated to the proper crisp value through the defuzzifier using normalized membership functions and output gains. The block diagram of a fuzzy logic system is shown Fig.2. The two normalized input variables, ACE and change in ACE (ΔACE) are inputs of FLC, are first fuzzified by T1 fuzzy sets. Two inputs signals are converted to fuzzy numbers first in fuzzifier using three Triangular membership functions, named as Negativebig (N), Positive Small(P), and Zero (Z)).

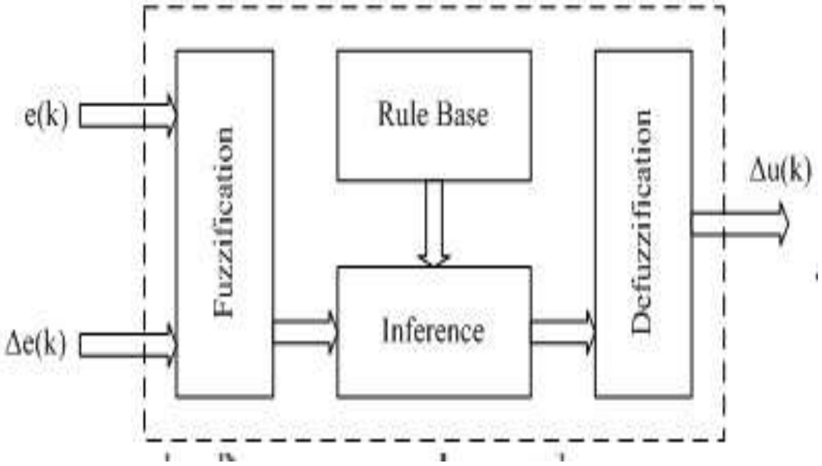

Fig. 2. Block Diagram representation of a fuzzy logic system

Finally resultant fuzzy subsets representing the controller output are converted to the crisp values using the Central Of Area (COA) defuzzifier scheme. The rules for the controller design are shown in the Table I are applied and the robust performance for the proposed model can be achieved

Table I:Control Rules For Fuzzy Logic Controller

	ΔACE			
ACE		N	Z	P
	N	P	N	N
	Z	N	Z	N
	P	N	N	P

V. ANALYTICAL EVALUATION OF THE MODEL

The conventional load frequency control steady state equations are well documented, e.g. [2], [2]. However, the DR control loop is added to the LFC problem in this study. Investigations are done earlier on the impact of the DR control loop on the stability analysis and steady-state error of the given power system. Rewriting the above equation (1)-(4) as Equations (10)-(12), the system frequency deviation can be expressed as follows for Area 1 i.e Thermal Unit:

$$\Delta f_1(s) = (2H_1.s + D_1)^{-1}[\Delta P_{T1}(s) + \Delta P_{L1}(s) + G(s).\Delta P_{DR1}] \quad (10)$$

$$\&\& \; ACE(s) = \Delta P_{tie1}(s) + \beta_1 \Delta f_1(s)$$

Where $\Delta P_{T1}(s) = H_1(s)[\Delta P_{s1}(s) - \frac{1}{R_1}\Delta f_1(s)]$, $H_1(s) = \frac{1}{(1+sT_{t1})(1+sT_{g1})}$ (11)

$$G(s) = \frac{-s^5 + \frac{30}{T_d}.s^4 - \frac{420}{T_d^2}.s^3 + \frac{3360}{T_d^3}.s^2 - \frac{15120}{T_d^4}.s + \frac{30240}{T_d^5}}{s^5 + \frac{30}{T_d}.s^4 + \frac{420}{T_d^2}.s^3 + \frac{3360}{T_d^3}.s^2 + \frac{15120}{T_d^4}.s + \frac{30240}{T_d^5}} \quad (12)$$

Equations for the Hydro plant are given as:

$$\Delta f_2(s) = (2H_2.s + D_2)^{-1}[\Delta P_{T2}(s) + \Delta P_{L2}(s) + G(s).\Delta P_{DR2}] \quad (13)$$

$$\&\& \; ACE(s) = \Delta P_{tie2}(s) + \beta_2 \Delta f_2(s)$$

Where $\Delta P_{T2}(s) = H_2(s)[\Delta P_{s2}(s) - \frac{1}{R_2}\Delta f_2(s)]$,

$$H_1(s) = \frac{(1+sT_2)(1-sT_w)}{(1+sT_1)(1+sT_2)(1+0.5T_w)} \quad (14)$$

$$G(s) = \frac{-s^5 + \frac{30}{T_d}.s^4 - \frac{420}{T_d^2}.s^3 + \frac{3360}{T_d^3}.s^2 - \frac{15120}{T_d^4}.s + \frac{30240}{T_d^5}}{s^5 + \frac{30}{T_d}.s^4 + \frac{420}{T_d^2}.s^3 + \frac{3360}{T_d^3}.s^2 + \frac{15120}{T_d^4}.s + \frac{30240}{T_d^5}} \quad (15)$$

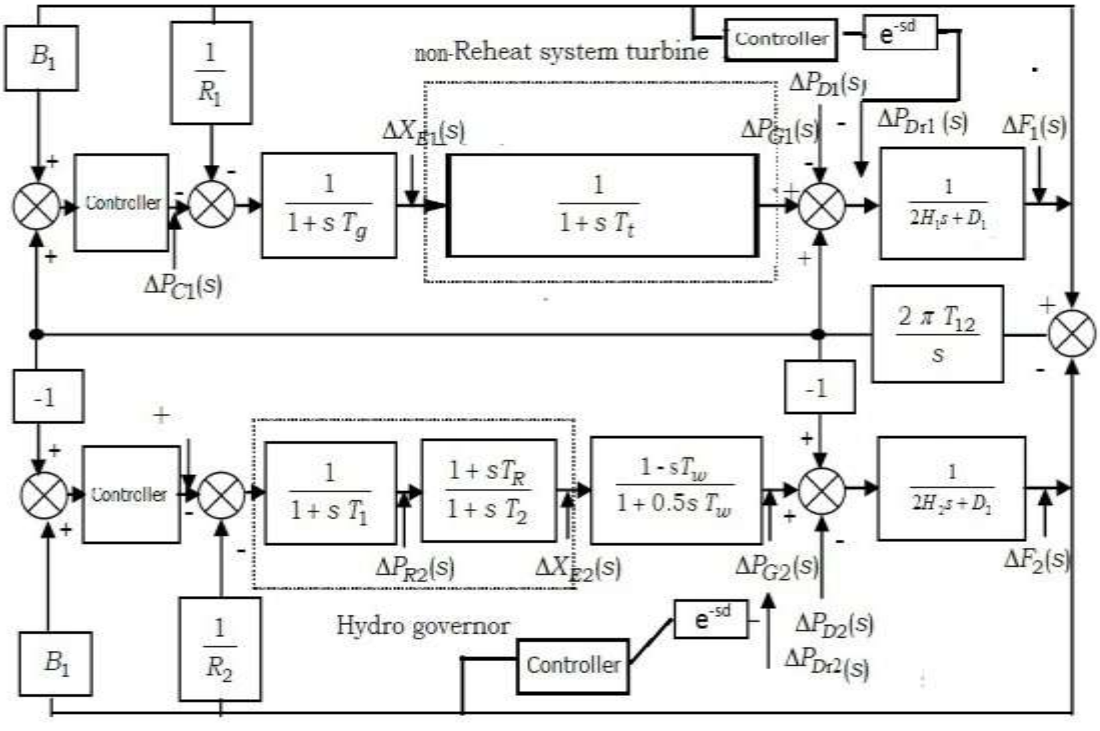

Fig. 2. Block Diagram of LFC-DR Hydro Thermal Model

The Block Diagram Hydro-Thermal LFC-DR Model is shown in Figure 2 in which the demand control loop with two-way communication delay latencies are included.Based on the final value theorem, the steady state value of the frequency deviation can be obtained. The following conclusions can be made for the analysis of the model:

→As the frequency deviation will not be zero unless the supplementary and/or DR controls exist.

→With DR available in the LFC, a higher reliability of frequency regulation can be achieved, since the DR control loop can complement the supplementary control loop. In cases when the supplementary control is not available, the performance of the frequency regulation can be guaranteed by the DR loop, if enough DR resources are available.

→ In order to have zero frequency deviation at steady-state, the required control effort can be split between the supplementary and DR control loops. In other words, an ISO/RTO will have the opportunity to perform the regulation services in a cost-effective way and analyze the frequency response of the system quickly. This goal can be achieved only in the proposed formulation [18] with an added control loop for DR.

Therefore, taking above conclusions into consideration: With DR availability in the LFC, the required control effort can be splitted in to two control loops based on their cost at real –time electricity market

$\Delta P_{s1}(s) = \alpha$ Control effort (16)

$\Delta P_{DR1}(s) = (1-\alpha)$ Control effort (17)

And finally based on the control effort the supplementary and DR control loop of the system are modified and governed by the below equation:

$$(1-\alpha)G(s)+\alpha H_1(s) \tag{18}$$

From the above Equations (13)-(15) ,where 0<α<1 is the share of traditional regulation services in the required control effort. It shows that if α=1, the total regulation is provided by traditional regulation services and if α=0 i.e. for this time the total control would be provided by DR. The decision of α should be made by ISO/RTO, based on the price of DR and Traditional regulatory services in the real time market explored by authors in [10].the range of alpha values will be 10% to that of thermal when compared with hydro system. Simulation studies are carried on the system frequency deviation considering two different values of α.

If α = 0.1, 10% of the regulation id provided by the supplementary control and 90% from DR

If α = 0.8, 80% of the regulation id provided by the supplementary control and 20% from DR

In the next section, simulation results for the LFC-DR model of a multi-area power system are presented to verify the effectiveness of the proposed model compared to that conventional LFC's and classic controllers

VI. SIMULATION RESULTS

The results of several different simulation studies are reported in this section for a multi -area power system to show some important features of the proposed LFC-DR model. .The parameters used in the simulation studies are given in Appendix. Using, the load disturbance, as the system input.. It can be noticed from this table that a higher share of control effort for the DR control loop, i.e., smaller α, will provide a higher gain and phase margin, indicating a more stable system. The proposed method for the system is Fuzzy logic controller.

Case.1:

In the first simulation study, a 0.1 pu load disturbance (with 10% Load perturbation) was applied to the two-area power system with conventional LFC and LFC -DR model with the parameters in Appendix, Using proposed method, the frequency deviations is quickly driven back to zero and the controller designed using Fuzzy controller has the best performance in control and damping of frequency when compared with conventional LFC and LFC-DR conventional PID Controller. Figures 4 & 5 shows the performance of Frequency deviation for LFC-DR models with PID controller and α =0.8 andα=0.1 for Area1and Area2

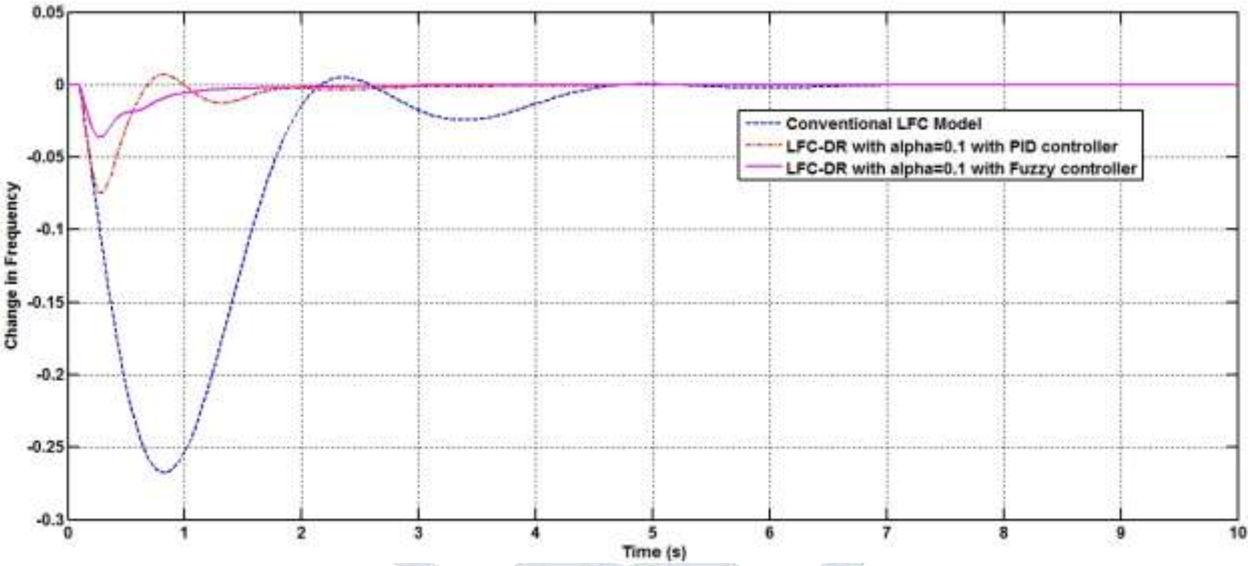

Fig. 4. Frequency deviation for LFC-DR models with different controllers and α=0.1 for Area1

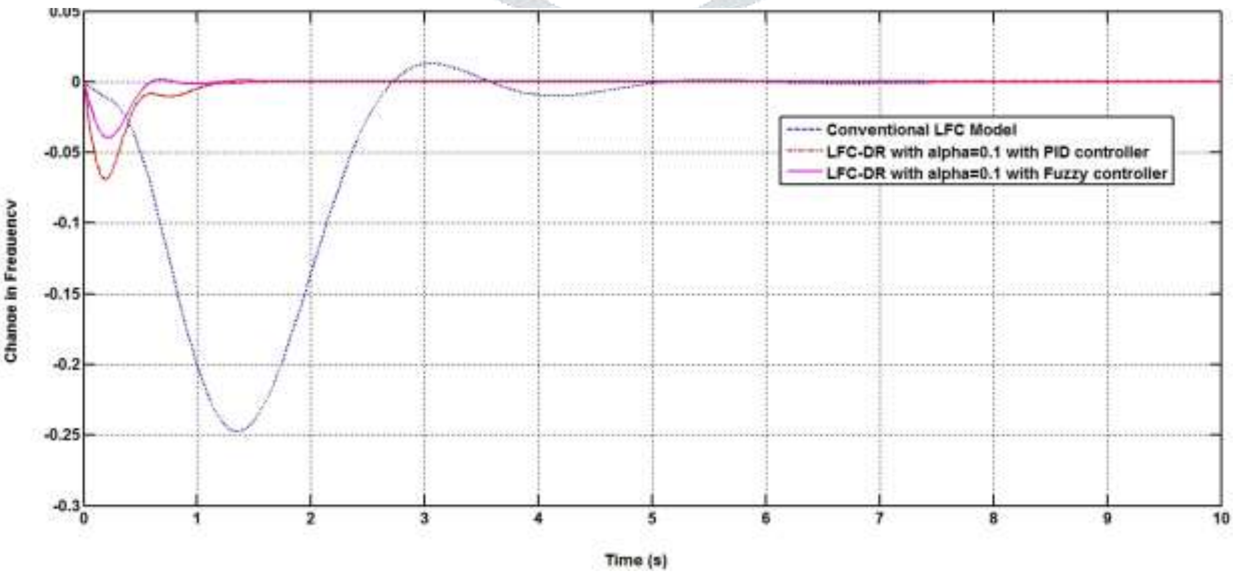

Fig. 5. Frequency deviation for LFC-DR models with different controllers and α=0.1 for Area2

Using proposed method, the frequency deviations are driven back to zero and the controller designed using fuzzy controller has the good performance in control and damping of frequency when compared with conventional LFC.

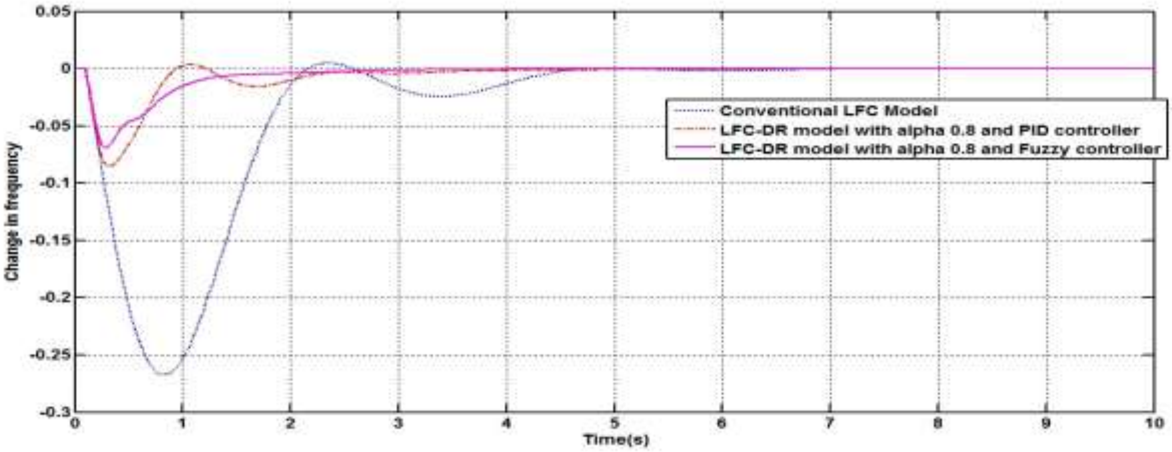

Fig. 6. Frequency deviation for LFC-DR models with different controllers and α=0.8 for Area1

The proposed LFC-DR model has a superior performance over the conventional LFC during the transient period. Frequency deviation for conventional LFC and classical LFC-DR models are compared with the Intelligent controllers such as Fuzzy logic controllers and Neuro-fuzzy logic controllers considering the control effort i.e alpha values(DR participation)=0.8. Frequency deviation for LFC-DR models (with Fuzzy logic controllers and PID controller) with α =0.8 value are shown in Fig.6 to Fig 7.

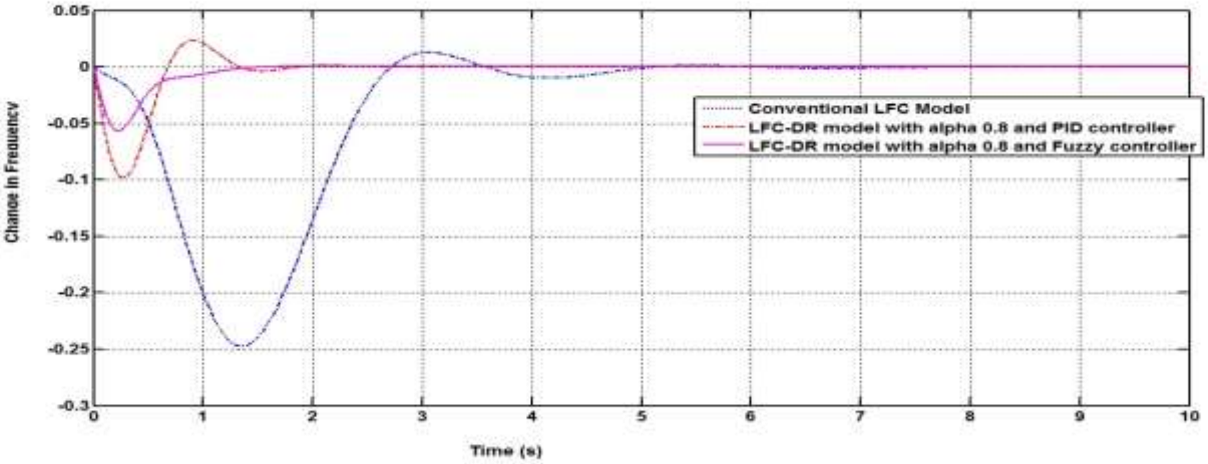

Fig. 7. Frequency deviation for LFC-DR models with different controllers and α=0.8 for Area2

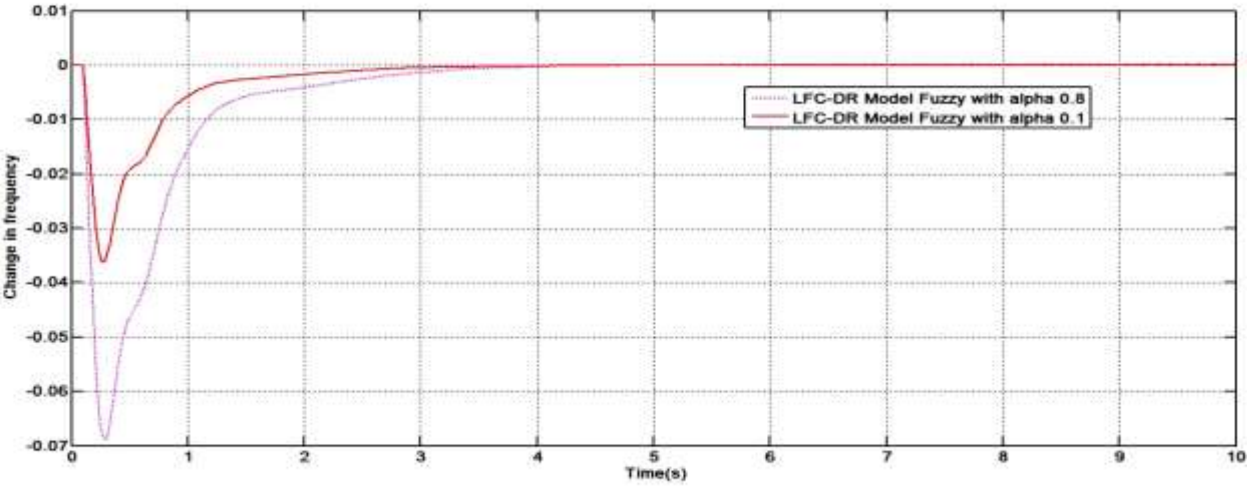

Fig. 8. Area-1 Frequency deviation for LFC-DR models with proposed controller for the different control efforts

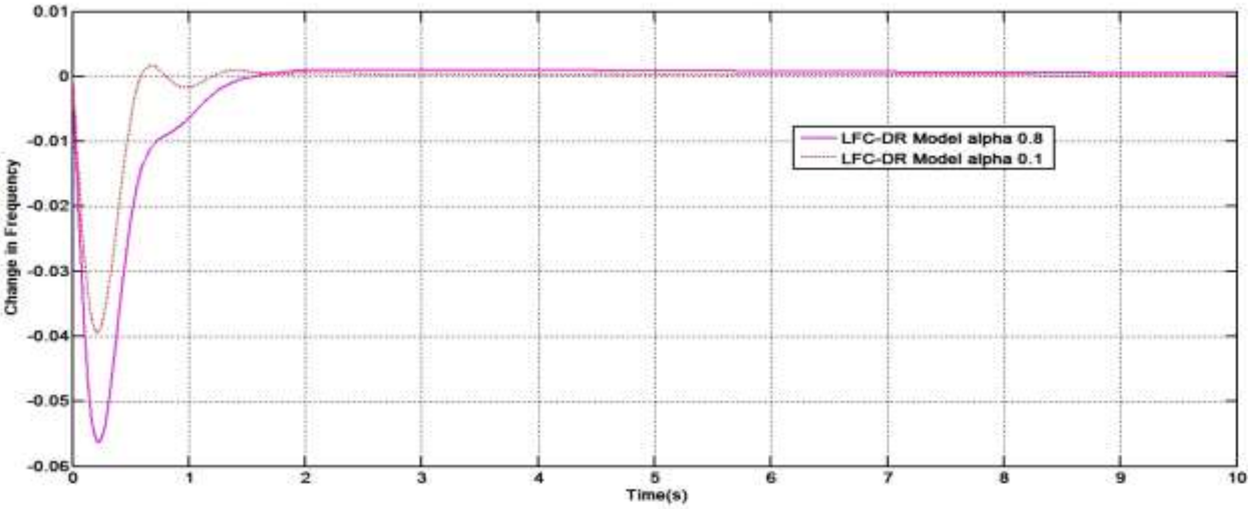

Fig. 9. Area-2 Frequency deviation for LFC-DR models with proposed controller for the different control efforts

The Fig 8 and 9 shows the effect of the DR participation with the proposed controller. For above cases the numerical analysis is carried based on the settling time and Undershoot for all the models i.e. conventional LFC and LFC-DR with PIDcontrollers and the proposed approach as shown in Table-II .From the analysis robust & best system dynamic performance is achieved by the proposed Fuzzy approach

Case.2:

Another significant feature of the LFC-DR model is to evaluate the impact of communication delay of the DR control loop on the system performance for frequency stabilization. In order to show the impact of latency, a simulation study was performed on LFC-DR for different values of communication delay latency T_d with control effort share of α =0.1. The change in frequency for various communication delay latencies are shown in Fig.10.

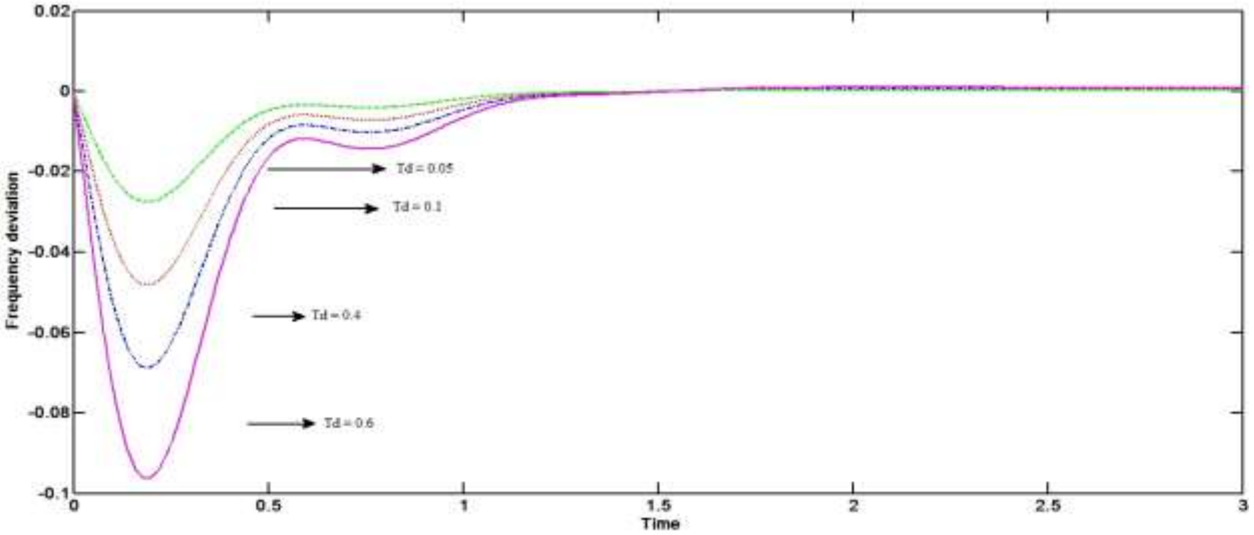

Fig 12. Impact of Communication Delay Latencices(T_d) on Frequency deviations for LFC-DR model considering one Area with α=0.1

Table-2

The numerical analysis

Area			**Settling Time (Sec)**	**Under shoot (p.u.)**
Area1	Change in frequency,Δf_1(Hz)	Conventional LFC	>10sec	0.28
		LFC-DR, α=0.8, PID	>4sec	0.075
		LFC-DR, α=0.1, PID	>2sec	0.06
		LFC-DR, α=0.8, fuzzy control	>4sec	0.06
		LFC-DR, α=0.1, fuzzy control	>2sec	0.035

Area 2	Change in frequency,Δf_2(Hz)	Conventional LFC	>8sec	0.25
		LFC-DR ,α=0.8, PID	>2sec	0.1
		LFC-DR, α=0.1, PID	>2sec	0.06
		LFC-DR, α=0.8, fuzzy control	>1.5sec	0.055
		LFC-DR ,α=0.1, fuzzy control	<2sec	0.04

VII. CONCLUSIONS:

The Fuzzy controller is designed for Demand Response Load frequency control of two area hydro-thermal system. The results obtained by using fuzzy controller in this paper is more improved than those of conventional PID controller. It mainly controls the frequency deviation and tie-line power deviation of two area system and to increase the dynamic performance. It has been shown that the proposed controller is effective and provides significant improvement in system performance. The Undershoot and settling time of proposed Fuzzy controller is lower than that of conventional PI controller**.** In our future work, the application can be extended to LFC-DR in restructured environment for operating scenarios.

REFERENCES

[1] P. Kundur, *Power system Stability and Control*. New York, NY, USA: McGraw-Hill, ch. 11(1994).

[2] H. Bevrani, *Robust Power System Frequency Control. New York*, NY, USA: Springer, ch. 1–3(2009).

[3] Shashi Kant Pandey, Soumya R. Mohanty, Nand Kishor, "*A literature survey on load–frequency control for conventional and distribution generation power systems"* elsevier Renewable and Sustainable Energy Reviews 25 (2013) 318–334

[4] C. Goldman, M. Reid, R. Levy, and A. Silverstein, *Coordination of Energy Efficiency and Demand Response a Resource of the National Action Plan for Energy Efficiency*, U.S. Environmental Protection Agency, U.S. Department of Energy , 2010, Tech. Rep

[5] R. Walawalkar, S. Blumsack, J. Apt, and S. Fernands, "An economic welfare analysis of demand response in the PJM electricity market," *Energy Policy*, vol. 36, no. 10, pp. 3692–3702, Oct. 2008.

[6] M. Klobasa, "Analysis of demand response and wind integration in Germany's electricity market," *IET Renew. Power Gener.*, vol. 4, no. 1, pp. 55–63, Jan. 2010.

[7] A. Brooks, E. Lu, D. Reicher, C. Spirakis, and B. Weihl, "Demand dispatch: Using real-time control of demand to help balance generation and load ," *IEEE Power Energy Mag.*, vol. 8, no. 3, pp. 20–29, May/ Jun. 2010.

[8] J. Medina, N. Muller, and I. Roytelman, "Demand response and dis-tribution grid operations: Opportunities and challenges," *IEEE Trans. Smart Grid*, vol. 1, no. 2, pp. 193–198, Sep. 2010.

[9] H. Saele and O. S. Grande, "Demand response from household cus-tomers: Experiences from a pilot study in Norway," *IEEE Trans. Smart Grid*, vol. 2, no. 1, pp. 102–109, Mar. 2011.

[10] N. Ruiz, I. Cobelo, and J. Oyarzaabal, "A direct load control model for virtual power plant management," *IEEE Trans. Power Syst.*, vol. 24, no. 2, pp. 959–966, May 2009.

[11] A. J. Conejo, J. M. Morales, and L. Baringo, "Real-time demand re-sponse model," *IEEE Trans. Smart Grid*, vol. 1, no. 3, pp. 236–242, Dec. 2010.

[12] D. T. Nguyen, M. Negnevitsky, and M. de Groot, "Pool-based demand response exchange-concept and modeling," *IEEE Trans. Power Syst.*, vol. 26, no. 3, pp. 1677–1685, Aug. 2011.

[13] P. Faria, Z. Vale, J. Soares, and J. Ferreira, "Demand response manage-ment in power systems using a particle swarm optimization approach ," *IEEE Intell. Syst.*, to be published.

[14] M. Parvania and M. Fotuhi-Firuzabad, "Integrating load reduction into wholesale energy market with application to wind power integration ," *IEEE Syst. J.*, vol. 6, no. 1, pp. 35–45, Mar. 2012.

[15] K. Dietrich, J. M. Latorre, L. Olmos, and A. Ramos, "Demand response in an isolated system with high wind integration," *IEEE Trans. Power Syst.*, vol. 27, no. 1, pp. 20–29, Feb. 2012.

[16] M. Rastegar, M. Fotuhi-Firuzabad, and F. Aminifar, "Load commit-ment in a smart home," *J. Appl. Energy*, vol. 96, pp. 45–54, Aug. 2012.

[17] N. Navid-Azarbaijani and M. H. Banakar, "Realizing load reduction functions by aperiodic switching of load groups," *IEEE Trans. Power Syst.*, vol. 11, no. 2, pp. 721–727, May 1996.

[18] K. Y. Huang, H. C. Chin, and Y. C. Huang, "A model reference adap-tive control strategy for interruptible load management," *IEEE Trans. Power Syst.*, vol. 19, no. 1, pp. 683–689, Feb. 2004.

[19] D. Westermann and A. John, "Demand matching wind power gener-ation with wide-area measurement and demand-side management ," *IEEE Trans. Energy Convers.*, vol. 22, no. 1, pp. 145–149, Mar. 2007.

[20] S. A. Pourmousavi and M. H. Nehrir, "Demand response for smart microgrid: Initial results," in *Proc. 2nd IEEE PES Innov. Smart Grid Technol. (ISGT)*, Anaheim, CA, USA, 2011, pp. 1–6.

[21] S. A. Pourmousavi, M. H. Nehrir, and C. Sastry, "Providing ancillary services through demand response with minimum load manipulation ," in *Proc. 43rd North Amer. Power Symp. (NAPS)*, Boston, MA, USA, 2011, pp. 1–6.

[22] S. A. Pourmousavi and M. H. Nehrir, "Real-time central demand re-sponse for primary frequency regulation in microgrids," *IEEE Trans. Smart Grid*, vol. 3, no. 4, pp. 1988–1996, Dec. 2012.

[23] D. Trudnowski, M. Donnelly, and E. Lightner, "Power-system fre-quency and stability control using decentralized intelligent loads," in *Proc., IEEE PES Conf. Exhib. Transm. Distrib.*, Dallas, TX, USA, 2005, pp. 1453–1459.

[24] J. A. Short, D. G. Infield, and L. L. Freris, "Stabilization of grid fre-quency through dynamic demand control," *IEEE Trans. Power Syst.*, vol. 22, no. 3, pp. 1284–1293, Aug. 2007.

[25] A. Molina-García, F. Bouffard, and D. S. Kirschen, "Decentralized demand-side contribution to primary frequency control," *IEEE Trans. Power Syst.*, vol. 26, no. 1, pp. 411–419, Feb. 2011.

[26] D. Jay and K. S. Swarup, "Dynamic demand response and control in smart grid environment," in *Proc. Annual IEEE India Conf. (IN-DICON)*, Hyderabad, 2011, pp. 1–4.

[27] D. Jay and K. S. Swarup, "Frequency restoration using dynamic de-mand control under smart grid environment," in *Proc. IEEE PES In-novative Smart Grid Technologies—India (ISGT India)*, Kerala, 2011, pp. 311–315.

[28] K. Samarakoon, J. Ekanayake, and N. Jenkins, "Investigation of do-mestic load control to provide primary frequency response using smart meters ," *IEEE Trans. Smart Grid*, vol. 3, no. 1, pp. 282–292, Mar. 2012.

[29] D. Angeli and P.-A. Kountouriotis, "A stochastic approach to dynamic demand refrigerator control," *IEEE Trans. Control Syst. Technol.*, vol. 20, no. 3, pp. 581–592, May 2012.

[30] Z. Changhong, U. Topcu, and S. H. Low, "Frequency-based load control in power systems," in *Proc. American Control Conf. (ACC)*, Canada, 2012, pp. 4423–4430

[31] L. R. Chang-Chien, L. N. An, T. W. Lin, and W. J. Lee, "Incorporating demand response with spinning reserve to realize an adaptive fre-quency restoration plan for system contingencies," *IEEE Trans. Smart Grid*, vol. 3, no. 3, pp. 1145–1153, Sep. 2012.

[32] H. Huang and F. Li, "Sensitivity analysis of load-damping character-istic in power system frequency regulation ," *IEEE Trans. Power Syst.*, vol. 28, no. 2, pp. 1324–1335, May 2013.

[33] P.Srividya Devi, Dr. R Vijaya Santhi, Dr. D.V.Pushpalatha, "*Introducing LQR-Fuzzy Technique with Dynamic Demand ResponseControl Loop to Load Frequency Control Model*" International Federation of Automatic control(IFAC-Eleseveir) volume 49,Issue 1 , pp 567-572(2016)

[34] S. Ali Pourmousavi,M. H. Nehrir, *"Introducing Dynamic Demand Response in the LFC Model*" IEEE Trans. Power Syst., vol. 29, no. 4, pp. 1562–1572, June(2014).

[35] Karnavas YL, Papadopoulos DP. "*AGC for autonomous power system using combined intelligent techniques*", Electr Power Syst Res;62:225–39(2002).

[36] Indulkar CS, Raj B. *"Application of fuzzy controller to automatic generation control"* Electr Mach Power Syst;23:209–20(1995).

[37] Chown GA, Hartman RC. "*Design and experiment with a fuzzy controller for automatic generation control (AGC)".* IEEE Trans Power Syst 1998;13:965–70J. Jang "*ANFIS: adaptive network-based fuzzy inference systems"*IEEE Trans Syst Man Cybern, 23 (1993), pp. 665–685

[38] C.Srinivasa Rao , "*Adaptive Neuro-Fuzzy Based Inference System for Load Frequency Control of Hydrothermal System under Deregulated Environment*"I nternational Journal of Engineering Science and Technology, Vol.2(12), 2010,6954-6962.

Appendix

T_{g1}= 0.08 Sec,T_{t1}=0.4 sec,R_1=R_2=3Hz/p.u,2H_1=2H_2=0.1667 p.u,D_1=D_2=0.015 p.u.T_d=0.1 sec,ΔP_{L1}=ΔP_{L2}=0.1 p.u,.$T_{1=}$0.08sec,T_w=5sec,T_2=0.3sec