

Electrical Load Frequency Control Using AI Techniques for EV Connected Power Systems

Rahul Parmar¹, Dr. Saurabh Gupta², Dr. Devendra Sharma³

Abstract: There are several challenges associated with electric vehicles. This work discusses the effect of electric vehicles on the load frequency deviation.. However, Load cannot be the same throughout, load deviates from time to time. To get rid of these disadvantages related to conventional controllers, a lot many schemes have been put forth in literature. This work presents a new design of various types of load frequency controllers based on different types of Artificial Intelligent (AI) optimization techniques such as Fuzzy logic, ANN tuner for a single area power system. The performance of the controller under study shows an enhancement in the frequency deviation signal as well as the peak overshoot and settling time for the frequency output signal. The performance of the proposed scheme is validated using MATLAB/SIMULINK tools.

KEYWORDS: Multi- Area Power System., Electric Vehicles, Load Frequency Control, Artificial Neural Networks (ANN), Adaptive Neuro Fuzzy Inference Systems (ANFIS).

I.Introduction

Stable operation of power system requires matching between total generation with total load demand and system losses. Due to rising and falling of load demand, the real and reactive power balance is disturbed This results in deviation of system frequency and tie line interchange power from their scheduled value.

High deviation of system frequency may lead to system collapse. For the satisfactory operation of a power system, frequency should remain nearly constant. Frequency deviations can directly affect a power system operation, system reliability, and efficiency. Large frequency deviations can damage equipment, degrade load performance, overload transmission lines, and interfere with system protection schemes. These large-frequency deviation events can ultimately lead to a system collapse. Variation in frequency adversely affects the operation and speed control of induction and synchronous motors. The reduced speed of motor-driven generating station auxiliaries, associated with the fuel, the feed-water, and the combustion air supply systems, such as fans, pumps, and mills, will bring down plant output. The considerable drop in frequency could result in high magnetizing currents in induction motors and transformers thereby increasing reactive power consumption. The extensive use of electric

clocks and the use of frequency for other timing purposes require accurate maintenance of synchronous time, which is proportional to the integral of frequency.

II Need for Load Frequency Control

For large scale, electric power systems with interconnected areas, Load Frequency Control (LFC) is important to keep the system frequency and the inter-area tie power as near to the scheduled values as possible. The input mechanical power to the generators is used to control the frequency of output electrical power and to maintain the power exchange between the areas as scheduled. A well designed and operated power system must cope with changes in the load and with system disturbances, and it should provide an acceptable high level of power quality while maintaining both voltage and frequency within tolerable limits. Load frequency control is a basic control mechanism in the power system operation. Whenever there is variation in load demand on a generating unit, there is a momentarily an occurrence of an unbalance between real-power input and output. This difference is being supplied by the stored energy of the rotating parts of the unit. Load Frequency Control (LFC) is being used for several years as part of the Automatic Generation Control (AGC) scheme in electric power systems. One of the objectives of AGC is to maintain the system frequency at a nominal value (50 Hz).

A power system consists of a governor, a turbine, and a generator with the feedback of regulation

constant. The system also includes step load change input to the generator. This work mainly, related to the controller unit of a two-area power system. The load frequency control strategies have been suggested based on the conventional linear Control theory. These controllers may be unsuitable in some operating conditions due to the complexity of the power systems such as nonlinear load characteristics and variable operating points. To some authors, variable structure control maintains the stability of system frequency. However, this method needs some information for system states, which are very difficult to know completely. Also, the growing needs of complex and huge modern power systems require the optimal and flexible operation of them. The dynamic and static properties of the system must be well known to design an efficient controller.

Under the normal operating condition, the controller is set for small changes in load demand without voltage and frequency exceeding the pre-specified limits. If the operating condition changes by any cause, the controller must be reset either manually or automatically. The objective of the load frequency controller is to exert the control of frequency and at the same time real power exchange via an outgoing transmission line. The frequency is sensed by a frequency sensor. The change in frequency and tie-line real power can be measured by a change in rotor angle δ . The load frequency controller amplifies and transforms the error signal, i.e., (Δf_i) into real power command signal ΔP_{ci} , which is sent to the prime mover via governor (that controls the valve mechanism).

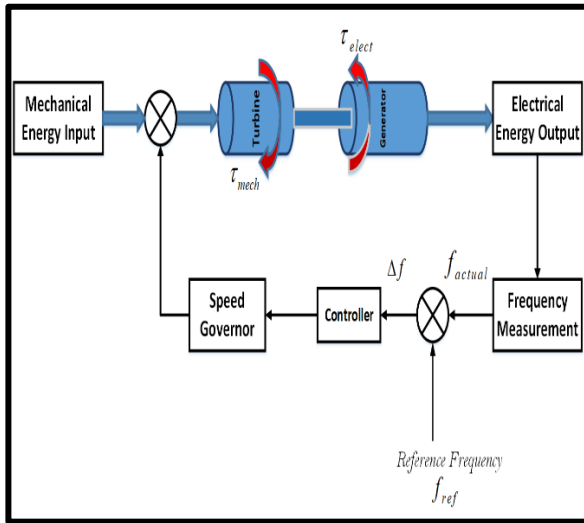


Fig.1 The AGC system

III. Methodology

A complete block diagram representation of an isolated power system comprising the turbine, generator, governor, and load is easily obtained by combining the block diagrams of individual components.

In this case, no controller action is applied because of actual system performance due to a step change of load. The dynamic behavior for the nominal system as the change in frequency consists of Hydraulic Amplifier, Turbine, and Generator model as shown in Fig2.

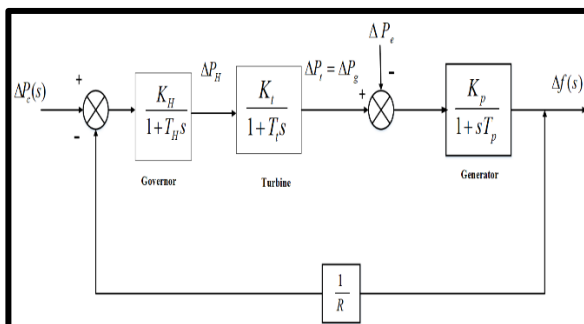


Fig.2 Block Diagram of Load Frequency Control

Fig. 2 can be modeled in the state space form with the help of the following matrix equation:

$$\dot{x} = Ax + Bu + F\rho \quad (1)$$

Here,

$$A = \begin{bmatrix} -\frac{1}{T_p} & \frac{K_p}{T_p} & 0 \\ 0 & -\frac{1}{T_t} & \frac{1}{T_t} \\ \frac{1}{RT_H} & 0 & -\frac{1}{T_H} \end{bmatrix} \quad (2)$$

$$B = \begin{bmatrix} 0 \\ 0 \\ \frac{1}{T_H} \end{bmatrix} \quad (3)$$

$$f = \begin{bmatrix} -\frac{K_p}{T_p} \\ 0 \\ 0 \end{bmatrix} \quad (4)$$

$$\rho = [\Delta P_E] \quad (5)$$

Here,

x^T = State vectors, $[\Delta f \quad \Delta P_T \quad \Delta P_H]$

u = Control vector, it is zero in uncontrolled case.

III. Introduction to Electric Vehicles

This India does not have adequate petroleum reserves. Therefore, it is heavily dependent on crude oil and natural gas imports. Presently, India is the third-biggest oil importer after the US and China. The total

crude basket of India includes 82.8% import of crude oil and 45.3% import for natural gas. As petroleum products consumption contributes to air pollution, there has been a huge demand to contain the consumption of petroleum products to address the pollution problem. Further, it also causes a huge economic burden on Indian citizens due to the large size of crude oil imports. Therefore, to reduce the dependence on petroleum products and save the environment, it is required to switch over to alternate clean fuel and clean technology.

A major portion of the petroleum products is being consumed by motorized vehicles. Hence, running these vehicles is causing major damage to our environment by adding air pollution. As the Indian transport sector is heavily dependent on petroleum products, the technologies like battery-powered Plug-in Electric Vehicle (PEV) and Plug-in Hybrid Electric Vehicle (PHEV) are gaining momentum to combat greenhouse gas emissions and air pollution. The vehicles in which charging takes place from an external source of power supply, such as the electric grid, are called plug-in electric vehicles (PEV). The Plug-in Hybrid Electric Vehicle (PHEV), on the other hand, comprises both plug-in electric vehicle systems to charge from an electrical power source and a petrol/diesel engine which acts as a backup power source to charge the battery and run the electric motor of the vehicle. To connect EVs to the electric grid, power electronics controllers based on Electric Vehicle Supply Equipment (EVSE) are required. The onboard AC to DC converter, with single or three-phase connectors, is an integral part of these controllers. Recently, a lot of new EV charging technologies are

being developed and deployed commercially across the globe [9]. This enables EVs to get charged at a very fast rate. In the future, there will be further innovations in the development of ultra-fast charging technologies for EVs, which will enable a large size of EVs to be charged in a few minutes. Although the fast-charging technology for the EV makes vehicle owners comfortable in getting their vehicle charged quickly, it may pose a lot of challenges in the smooth functioning of the electrical power distribution system (EPDS). Further, charging a large number of EVs simultaneously from the grid may also cause various power system operational challenges due to higher peak load demands and system harmonics. Therefore, it is required to analyze the impact of a large number of EV charging on the EPDS. In this work, key challenges to be faced by EPDS operators, due to massive EV charging load, are highlighted.

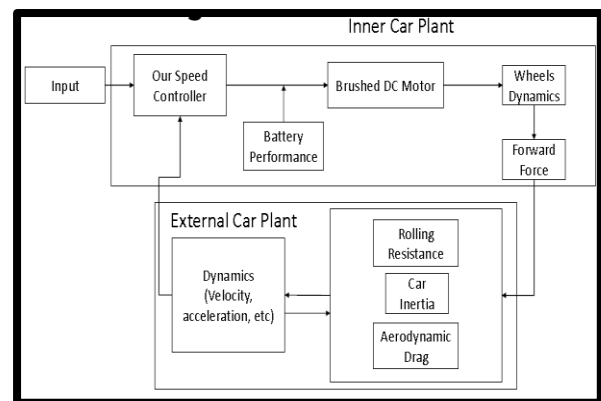


Fig.3 Model Diagram for EV

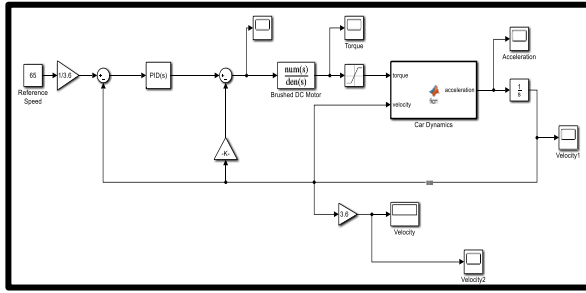


Fig.4 Simulink Model for EV

Mathematical Modelling of EVs:

With K_E the back EMF constant and (t) the rotational speed of the motor in rad/s. Hence, we can write:

$$V(t) = I(t) * R + L * \frac{dI}{dt} + K_E * \omega(t) \quad (6)$$

Transforming this equation to the Laplace domain, we get:

$$V(s) = R * I(s) + sL * I(s) + K_E * \omega(s) \quad (7)$$

We can also apply this to the torque equation to obtain:

$$T(s) = K_T * I(s) \quad (8)$$

Hence, we can write:

$$I(s) = \frac{V(s) - K_E * \omega(s)}{sL + R} \quad (9)$$

Replacing to get Torque as a function of Voltage Input and rotational velocity:

$$T(s) = K_T * \frac{V(s) - K_E * \omega(s)}{sL + R} \quad (10)$$

The control methodology proposed in this work is the ANFIS. ANFIS stands for Adaptive Neuro-Fuzzy Inference System. The ANFIS controller combines the advantages of a fuzzy controller as well as the quick response and adaptability nature of ANN. Fundamentally, ANFIS is about taking a fuzzy inference system (FIS) and tuning it with a backpropagation algorithm based on some collection of input-output data. This allows your fuzzy systems to learn. A network structure facilitates the computation of the gradient vector for parameters in a fuzzy inference system. Once the gradient vector is obtained, several optimization routines are applied to reduce an error measure. This process is called learning by example in the neural network literature.

The fuzzy inference system that has been considered is a model that maps:

- Input characteristics to input membership functions,
- Input membership function to rules,
- Rules to a set of output characteristics,
- Output characteristics to output membership functions, and
- The output membership function to a single-valued output, or
- A decision associated with the output.

Only membership functions have been considered that have been fixed and somewhat arbitrarily chosen. Also, the only fuzzy inference is applied for modeling systems whose rule structure is essentially predetermined by the user's interpretation of the characteristics of the variables in the model. In

general, the shape of the membership functions depends on parameters that can be adjusted to change the shape of the membership function. The parameters can be automatically adjusted depending on the data that has been tried to model.

Mathematical Modelling of ANFIS

While there are several algorithms to train the ANN/ANFIS model, yet one of the fastest and most efficient algorithms is the Levenberg Marquardt (LM) algorithm which is a modified version of the steepest gradient descent. Taking a look at the nature of the steepest descent algorithm it is concluded that it is 1st order derivative of the minimization function which makes it an asymptotic convergence. Considering the gradient of the error with respect to weights for a loss minimization, we obtain the derivative gradient as:

$$g = \frac{\partial E(x, w)}{\partial x} = \left[\frac{\partial E}{\partial w_1} \quad \frac{\partial E}{\partial w_2} \quad \dots \quad \frac{\partial E}{\partial w_N} \right]^T \quad (11)$$

Considering the loss/cost function as the mean squared error, the weight update rule for LM algorithm is:

$$w_{k+1} = w_k - [J_k J_k^T + \mu I]^{-1} J_k^T e_k \quad (12)$$

Here,

k is the iteration number

w_{k+1} is weight of next iteration,

w_k is weight of present iteration

J_k is the Jacobian Matrix and is given by the terms

$J_k = \frac{\partial^2 e}{\partial w^2}$ i.e. the second order rate of change of errors with respect to weights

J_k^T is Transpose of Jacobian Matrix

e_k is error of Present Iteration

μ is step size i.e. amount by which weight changes in each iteration

I is an identity matrix, with all diagonal elements equal to 1 and other elements 0.

The training is truncated as the cost or loss function is stable or the maximum iterations are over. The cost or loss function is defined as:

$$MSE = \frac{1}{N} \sum_{t=1}^N e_t^2 \quad (13)$$

The mean absolute percentage error can also be computed as:

$$MAPE = \frac{100}{N} \sum_{t=1}^N \frac{|V_t - \hat{V}_t|}{V_t} \quad (14)$$

Here,

N is the number of predicted samples

V is the predicted value

\hat{V}_t is the actual value

e is the error value

The complete implementation and validation of the results can be performed by sequentially implementing the steps in the flowchart of the proposed system:

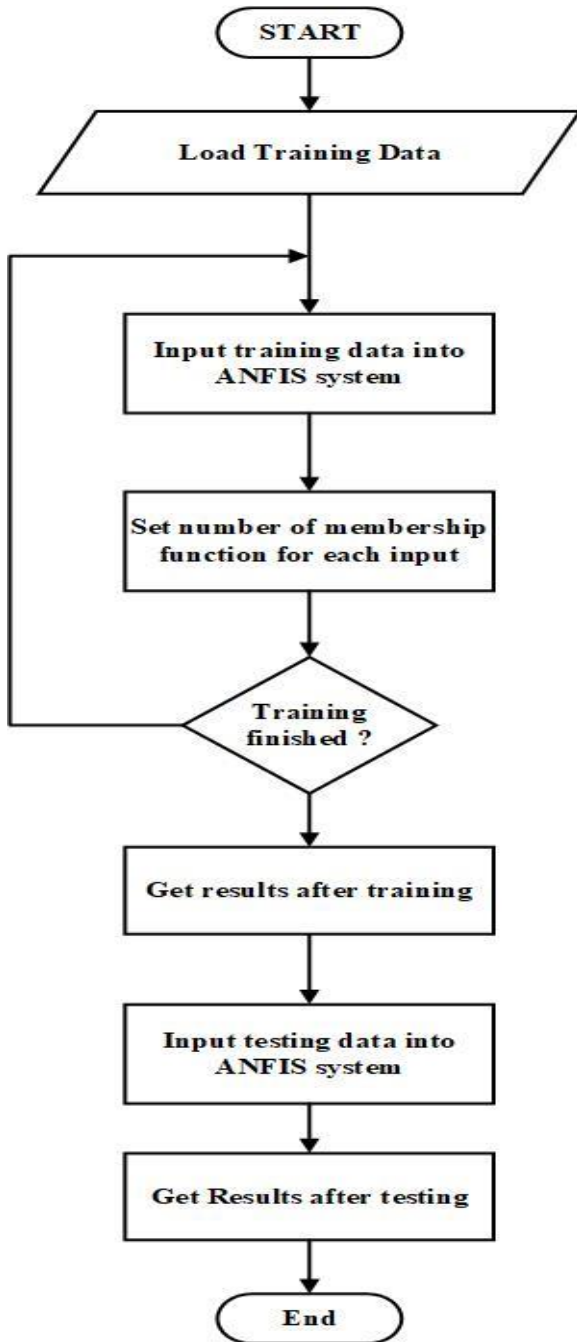


Fig.5 ANFIS Flowchart

IV. Results and Discussions

The system has been designed on MATLAB/SIMULINK

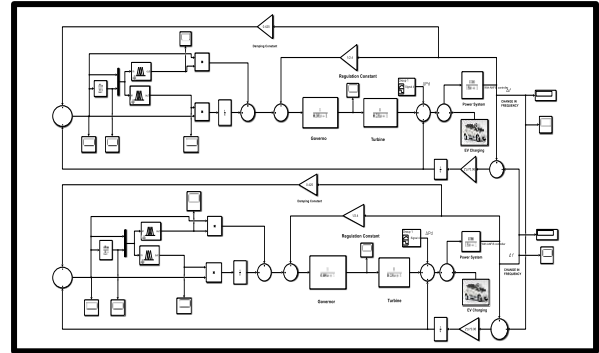


Fig.6 ANFIS Controlled LFC Model

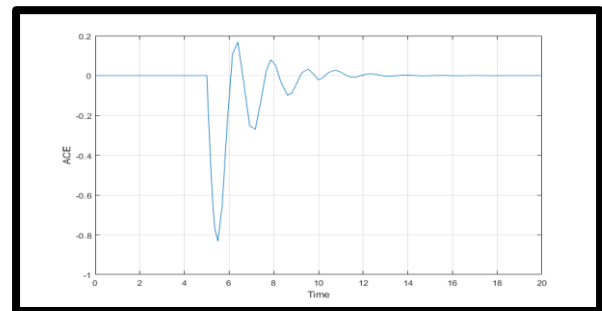


Fig.7 ACE for ANFIS Controller

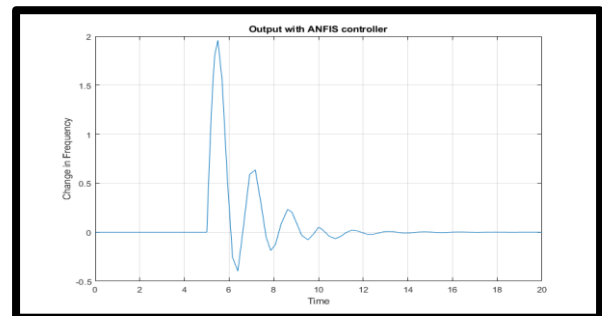


Fig.8 Change in Frequency for for ANFIS Controller

Table.1 Summary of Results

Parameter	Value
Rise Time:	1.3832e-05 sec
Settling Time:	11.0145 sec
Settling Min:	-0.3966 Hz
Settling Max:	0.6361 Hz
Overshoot:	6.6417e+05
Undershoot:	3.2790e+06
Peak:	1.9579 Hz
Peak Time:	5.4959 sec

V. Conclusion:

For Electric Vehicles, Load Frequency Control (LFC) is used to regulate and control the output frequency signal of the electrically generated power within an area in response to changes in system loads. This work discusses the effect of electric vehicles on the load frequency deviation. This project shows a case study of designing a controller that can withstand optimal results in a two-area power system when the input parameters of the system are changed. Two methods of Load Frequency Control were studied considering an isolated power system.

The performance of the controller's understudy is tested and validated using MATLAB/SIMULINK tools. On

comparison, it was found that ANFIS has minimum settling time, and minimum percentage overshoot out of the two.

In the future scope , a signal processing tool can be utilized to check their effect on results.

Some of the Hybrid techniques like Wavelet Neural Network etc. can be checked to see improvement in results.

By adding generation control and governor dead band into the system the system will look more realistic and nonlinear

References

[1] P. Sharma, A. Mishra, A. Saxena and R. Shankar, "A Novel Hybridized Fuzzy PI-LADRC Based Improved Frequency Regulation for Restructured Power System Integrating Renewable Energy and Electric Vehicles," in IEEE Access, 2021, vol. 9, pp. 7597-7617.
DOI: 10.1109/ACCESS.2020.3049049.

[2] Anestis G. Anastasiadis, Georgios P. Kondylis, Apostolos Polyzakis, Georgios Vokas, "Effects of Increased Electric Vehicles into a Distribution Network", Technologies and Materials for Renewable Energy, Environment and Sustainability, TMREES18, Athens, Greece, pp. 586–593, Energy Procedia 157, ScienceDirect, 2019.

DOI: 10.1016/j.egypro.2018.11.223

- [3] Anil Annamraju and Srikanth Nandiraju, “Coordinated control of conventional power sources and PHEVs using jaya algorithm optimized PID controller for frequency control of a renewable penetrated power system”, Protection and Control of Modern Power Systems, Springer open, 2019.
DOI: <https://doi.org/10.1186/s41601-019-0144-2>
- [4] Neofytos Neofytou, Konstantinos Blazakis, Yiannis Katsigiannis, and Georgios Stavrakakis, “Modeling Vehicles to Grid as a Source of Distributed Frequency Regulation in Isolated Grids with Significant RES Penetration”, Energies 2019, volume 12, mdpi journals, 2019.
DOI: 10.3390/en12040720
- [5] Tawfiq Hussein and Awad Shamekh, “Design of PI Fuzzy Logic Gain Scheduling Load Frequency Control in Two-Area Power Systems”, Designs 2019, Volume 3, Edition 26, mdpi journals, 2019.
DOI: 10.3390/designs3020026
- [6] T. Mohammed, J. Momoh and A. Shukla, "Single area load frequency control using fuzzy-tuned PI controller," 2017 North American Power Symposium (NAPS), Morgantown, WV, pp. 1-6, IEEE, 2017.
DOI: 10.1109/NAPS.2017.8107352.
- [7] S. Jennathu Beevil, R. Jayashree, S. Shameer Kasim, “ANN Controller For Load Frequency Control”, International Journal for Research in Applied Science & Engineering Technology (IJRASET), Volume 4 Issue I, 2016.
- [8] V. S. Sundaram and T. Jayabarathi, "Load Frequency Control using PID tuned ANN controller in power system," 2011 1st International Conference on Electrical Energy Systems, Newport Beach, CA, pp. 269-274, 2011.
DOI: 10.1109/ICEES.2011.5725341.
- [9] S. Baghya Shree, N. Kamaraj, “Hybrid Neuro Fuzzy approach for automatic generation control in restructured power system”, Electrical Power and Energy Systems 74, pp. 274–285, Elsevier, 2016.
DOI: <http://dx.doi.org/10.1016/j.ijepes.2015.05.029>
- [10] D. K. Sambariya and Vivek Nath, “Load Frequency Control Using Fuzzy Logic Based Controller for Multi-area Power System”, British Journal of Mathematics & Computer Science”, 13(5), PP. 1-19, SCIENCEDOMAIN international, 2016.
DOI: 10.9734/BJMCS/2016/22899
- [11] S. K. Jain, A. Bhargava and R. K. Pal, "Three area power system load frequency control using fuzzy logic controller," 2015 International Conference on Computer, Communication and Control (IC4), Indore, pp. 1-6, IEEE, 2015.
DOI: 10.1109/IC4.2015.7375614.
- [12] H. Shayeghi, H. A. Shayanfar, “Application of ANN Technique for Interconnected Power System Load Frequency Control”, 2015 International Conference on Computer, Communication and Control (IC4), 2015.
- [13] S. K. Jain, A. Bhargava and R. K. Pal, "Three area power system load frequency control using fuzzy logic controller," 2015 International Conference on Computer, Communication and Control (IC4), Indore, 2015, pp. 1-6, IEEE, 2015.
DOI: 10.1109/IC4.2015.7375614.
- [14] Poonam Rani, Mr. Ramavtar Jaswal, “Automatic load frequency control of multi-area power system using ANN controller and Genetic algorithm”,

International Journal of Engineering Trends and Technology (IJETT) – Volume 4 Issue 9, 2013.

[15] David B. Richardson, “*Electric vehicles and the electric grid: A review of modeling approaches, Impacts, and renewable energy integration*”, Renewable and Sustainable Energy Reviews 19, pp 247–254, Elsevier, 2013.

DOI: <http://dx.doi.org/10.1016/j.rser.2012.11.042>

[16] K. A. Ellithy, K.A. El-Metwally, “*Design of Decentralized Fuzzy Logic Load Frequency Controller*”, I.J. Intelligent Systems and Applications, MECS volume 2, pp 66-75, 2012.

DOI: 10.5815/ijisa.2012.02.08

[17] S. Prakash and S. K. Sinha, “*Four area Load Frequency Control of interconnected hydro-thermal power system by Intelligent PID control technique*,” 2012 Students Conference on Engineering and Systems, Allahabad, Uttar Pradesh, pp. 1-6, IEEE, 2012.

DOI: 10.1109/SCES.2012.6199090.

[18] V. S. Sundaram and T. Jayabarathi, “*Load Frequency Control using PID tuned ANN controller in power system*,” 2011 1st International Conference on Electrical Energy Systems, Newport Beach, CA, pp. 269-274, IEEE 2011.

DOI: 10.1109/ICEES.2011.5725341.