Intelligent Controllers for Load Frequency Control of Two-Area Power System

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Abstract: Load Frequency Control (LFC) is necessary for economic power generation. Proportional-integral (PI) controllers are widely used in power generation units of power plants to provide an automatic generation control (AGC) that not only provides frequency regulation but also restores the power flow across the tie-lines to its predefined value. This paper considers the problem of load frequency control using intelligent controllers. Three types of turbines, namely the non-reheat steam turbine, reheat steam turbine and hydraulic turbine, are considered. Two-area power systems undergoing sudden load changes in each area are implemented and analysed. The objective is to eliminate errors due to the disturbances in both frequency and tie-line power so as to ensure an economic power generation. PID, Fuzzy Logic and ANN-NARMA-L2 compensating schemes are designed and successfully simulated. In all the three cases, steady-state errors present in the systems are removed. Although the two intelligent controllers provided better performance than PID, the latter shows better robustness in a load-variable environment.

Keywords: Load Frequency Control, PID, Fuzzy Logic, ANN-NARMA-L2, Two-area Power Systems

1 INTRODUCTION

The objective behind an electric power system is to generate and supply electrical energy to consumers at nominal system frequency and voltage magnitude defined by a certain power quality standard (Ragini et al. 2015). Starting from the generation of real and reactive power at the generators until its utilization by the customers, the generated power must be balanced with the load demand. The real power and reactive power which correspond to frequency and voltage equilibrium are crucial for a good power quality (Zhang 2009). The nominal frequency of a system is dependent on the balance between the load demand and the generated real power. When the generated power is less than the load demand, the speed and thus the frequency of the generating units start to decrease. The contrary occurs when the generated power is greater than the load demand thereby causing wastage of resources (Ragini et al. 2005). Normally, the load demand varies randomly depending on the customers' need and this indeed affects the frequency and the voltage of the system. The latter therefore requires certain control actions which are carried out by the automatic voltage regulator (AVR) and LFC; these two compensators are implemented on each alternator in a power system for both voltage and frequency control (Saadat 1999).

A power system has many interconnected utilities forming a grid and the transfer of power is done via the tie-lines. As the frequency of the system decreases, the speed governor for each generator will provide the primary speed control so as to match the system power generation with the load demand. However, this primary control action is not enough to restore back the frequency. A secondary control action is required to remove any deviation in frequency and maintains the tie-line power flow by adjusting the generators' output. This secondary control action is known as LFC. Both the primary and secondary controls form part of the automatic generation control (AGC). The transient responses of the primary and secondary controls are in the range of seconds and minutes respectively (Tan 2011). Though in an interconnected network the area that is subjected to a load change will obtain energy from the other areas via the tie-lines, the concerned area should be able to restore the equilibrium prior to the load change without any external help. Otherwise, the power swings occurring due to transient disturbances in one area can induce power swings in adjacent areas via the tie-lines. Therefore, each area requires a controller that will not only restore the frequency to its standard value but also remove any error in the tie-line power flow (Zhang 2009).

In the last decades, engineers have turned towards artificial intelligence techniques in order to ensure continuous power flow. Many artificial intelligence techniques have been adapted to LFC with Fuzzy Logic and Artificial Neural Network (ANN) being the most common ones. Even a combination of these two intelligent techniques to form a hybrid Neuro-Fuzzy controller has been adapted to power systems (Shree and Kamaraj 2015).

There are several ANN controllers; one of them is NARMA-L2 which is the easiest one to compute. Though automatic control scheme has gained much popularity over the years due to the advances in technology, the PID controller is still being implemented in more than 90% of industrial control systems. This is because it provides a simple yet efficient solution that no other controllers can attain (Ang et al. 2005). Moreover, several optimization techniques like Particle Swarm Optimization (PSO), Genetic Algorithm (GA), Ant Colony Optimization (ACO), Backtracking Search Algorithm (BSA) and Multiple Tabu Search (MTS) that are available to tune the parameters of the PID proved to yield better

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responses than the conventional tuning methods (Ragini et al. 2005; Pothiya et al. 2006; Omar et al. 2013; Ismail and Mustafa Hassan 2012).

2 POWER SYSTEM MODEL

The power system model includes the power generating system with three different types of turbine, and the interconnection of a network by means of the tie-line. The transfer function of each unit of a power generating system is derived for the development of the single-area power system model which is then extended to the two-area model with the introduction of interconnection units.

The two-area power system model is shown in Fig.1. LFC is provided by the controller such that zero error is obtained in both frequency and tie-line power flow. Since the ACE output consists of both the frequency deviation and tie-line power error as given by (1), once it has output zero automatically the errors in the frequency and the tie-line power will be eliminated. Hence, it is fed as input to the controller.

$$ACE_i = \sum_{j=1,\ldots,n,j\neq i} \Delta P_{tie\ ij} + B_i \Delta f_i \tag{1}$$

Where
ACE_i : Area control error of area *i*
$\Delta P_{tie\ ij}$:Tie-line net power flow between area *i* and *j*
Δf_i : Frequency deviation in area *i*
B_i : Frequency response characteristic of area *i* (Zhang 2009)

The transfer function of each turbine is as given by (2):

2.1 Non-Reheat Steam turbine

$$G_{NR}(s) = \frac{1}{1 + sT_{CH}} \tag{2}$$

T_{CH}: Constant time delay between the change in the valve opening position and the mechanical torque of the turbine

2.2 Reheat Steam turbine

$$G_R(s) = \frac{1 + sF_{HP}T_{RH}}{(1 + sT_{CH})(1 + sT_{RH})} \tag{3}$$

T_{RH}: Time constant of the reheater
F_{HP}: Rating of the high pressure stage with respect to total generated mechanical power of turbine

2.3 Hydraulic turbine

$$G_H(s) = \frac{1 - T_w s}{1 + s(T_w/2)} \tag{4}$$

$\mathbf{T_w}$: Water starting time which varies with the load

In order to provide a stable control performance during the transient state, a transient droop compensator is to be added to the governor for this type of turbine so that a fast transient response is obtained. Once the system has reached the steady-state, the normal droop is exhibited. The transfer function of the compensator is described as given by (5):

$$G_C(s) = \frac{1 + sT_R}{1 + s(R_T/R_P)T_R} \tag{5}$$

R_P: Permanent droop
T_R: Reset time
R_T: Temporary droop

The turbines' transfer function is obtained based on the change in mechanical power output of the turbine ΔP_{mech} against the valve/gate opening position ΔP_V (Kundur 1994). A load disturbance of 0.07p.u was added to Area-1 of each system whilst that of Area-2 was set to 0.05p.u. The verification of the systems' stability followed up by means of the root locus method. After the simulation of the stable systems over a time interval of 100s, the design of the compensators was carried out. The parameters used for each generating unit can be found in Appendix I.

3 COMPENSATOR DESIGN

3.1 PID

In this paper, the PID function block in Simulink was chosen for the design and simulation processes. *U(s)* is the output of the controller and *E(s)* is the error input. The parameters K_p , K_i and K_d represents the gains of the proportional, integral and differential terms of the PID (Ang et al. 2005).The gains of the PID were found by trial and errors by tuning the three PID terms.

3.2 Fuzzy Logic

Fuzzy control is based on representing and manipulating humans' experiences on control systems prior to implementation. The Fuzzy Logic controller performs similar tasks as a human operator by adjusting the input variables just by looking at the output of the plant (Altas and Neyens 2006). The four processes of the Fuzzy Logic system are: fuzzification, rule base set up, decision-making by means of an inference mechanism and defuzzification. The schematics of the implemented Fuzzy Logic can be found in the technical report titled *"Tuning of Fuzzy PID Controllers"* by Jantzen(1998).

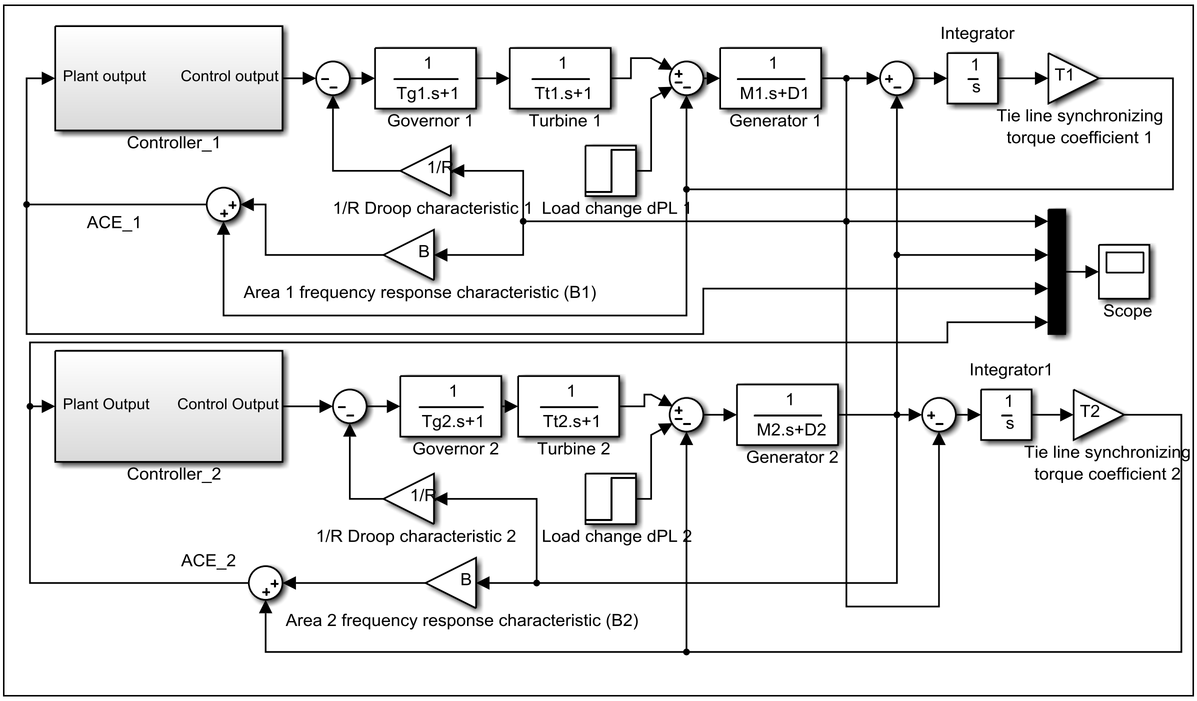

Fig. 1. Block diagram of compensated two-area power system

The two inputs drawn to the Fuzzy controller were the ACE output and its derivative. Gains were added as scale factors of the Fuzzy Logic at each input and output of the controller for fine-tuning. A Fuzzy Inference System (FIS) is required to define the four processes of the Fuzzy Logic for it to perform control actions.

The fuzzification process consists of converting the inputs ACE and its derivative into fuzzy membership range of values to be used by the rule base for execution of the rules at the decision-making unit. XY plot of the ACE and its derivate were used to plot the membership functions. Though the output membership range was chosen at random, the final constant output of the Fuzzy Logic should be equal to the final constant value of the PID output so that the error in the ACE output is completely eliminated thereby eliminating all the errors in the system. Hence, the PID outputs were used to plot the output membership function of the Fuzzy Logic.

The fuzzified inputs ACE and its derivative were mapped onto the defined output space by means of the defined control rules. The rule based table can be found in the conference paper *"A Fuzzy Logic Load-Frequency Controller for Power Systems"* by Altas and Neyens (2006). The decision making process consists of executing the defined rules in order to yield a Fuzzy control output in the inference system and the deffuzification process consists of yielding a non-Fuzzy control action from the inference system process that will eventually rectify the output of the system. The method used was centroid.

3.3 ANN-NARMA-L2

An artificial neural network (ANN) may be considered as a function approximator. The ANN architecture of Fig.2 described the way a neural network works to perform the required control action by approximating the unknown function. The parameters of the network must be adjusted so that the same output is obtained at both the unknown function output and the network output, provided that both systems experienced the same input. In this direction, any error in the system will be eliminated (Hagan et al. 2002).

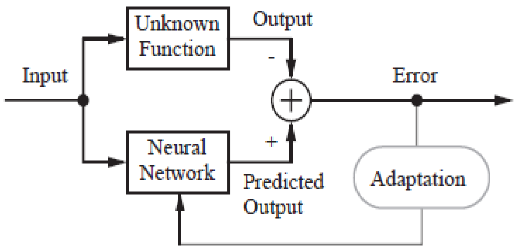

Fig 2. ANN architecture (Hagan et al. 2002)

The pattern used by the ANN is the multilayer perceptron whereby multiple-inputs neurons operating in parallel are stacked together to form layers which are then cascaded to form the entire network (Hagan et al. 2002). The NARMA-L2 controller is simply a neurocontroller that can approximate a plant model to the same form of the

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controller. The design of the NARMA-L2 consists of two stages: plant identification and control design. The NARMA-L2 block is available in Simulink Neural Network Toolbox. The output of the controller which is the control signal also represents the plant input. The ACE output is the plant output to be controlled. The first step in designing the NARMA-L2 controller is to train a neural network such that it will represent the actual dynamics of the plant under control. The *Maximum Plant Input* and *Minimum Plant Input* for all NARMA-L2 were chosen according to the steady-state value of the PID output. The values are presented in Table 1.

The training function chosen was the Levenberg-Marquardt (TRAINLM) backpropagation algorithm (Nag and Philip 2014). The training data should compulsorily cover both the transient and steady state performance of the plant under control. If the data set does not contain enough information regarding the transient performance or the steady-state performance or both, the neural network after training will not be representative of the actual behaviour of the plant. The controller will then fail to perform the required control action.

The data required for training the ANN controller was obtained by importing the data of the input and output of the PID controller implemented previously in each system.

Table 1: Parameters for training data of two-area power systems

Area-1			
System	1	2	3
Turbine	Non-Reheat	Reheat	Non-Reheat
Maximum Plant Input	-0.0699	-0.014	-0.0699
Minimum Plant Input	-0.07	-0.0141	-0.07
Area-2			
System	1	2	3
Turbine	Hydro	Hydro	Reheat
Maximum Plant Input	-0.0499	-0.0499	-0.0499
Minimum Plant Input	-0.05	-0.05	-0.05

4 RESULTS

The simulation time was set to 100s and the load change was applied at time t=0s in each area. The load change in Area-1 was set to 0.07p.u and that of Area-2 was set to 0.05p.u. Fig.4 to Fig.9 show the frequency deviation and ACE output due to each controller in the respective areas.

4.1 Hydro-Non-Reheat Thermal Power System

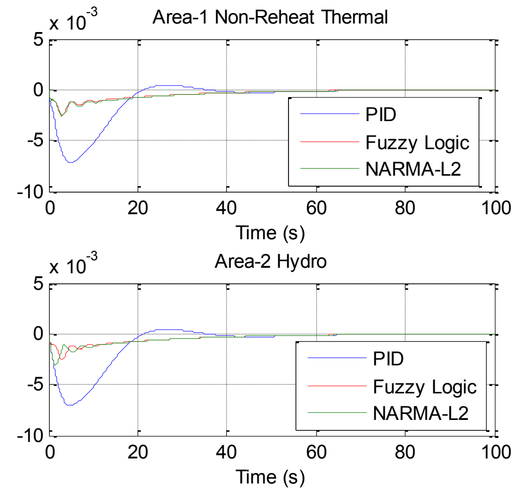

Fig. 4. Frequency deviation of hydro-non-reheat power system

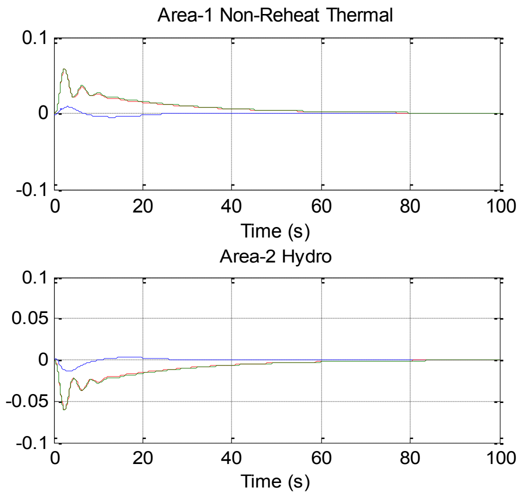

Fig. 5. ACE output of hydro-non-reheat power system

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4.2 Hydro-Reheat Thermal Power System

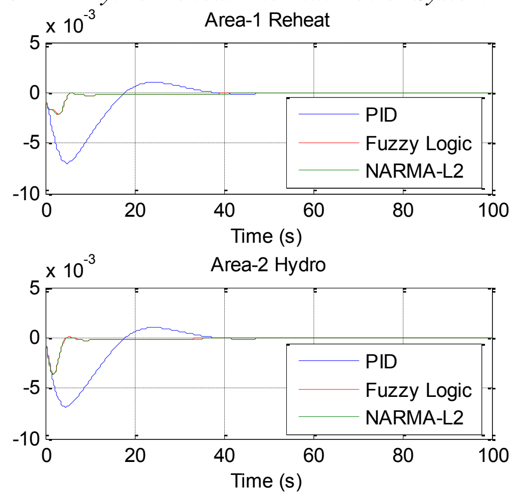

Fig. 6. Frequency deviation of hydro-reheat power system

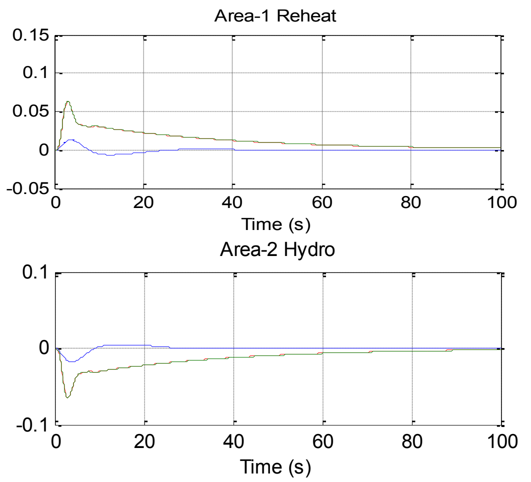

Fig. 7. ACE output of hydro-reheat power system

The initial percentage overshoots and undershoots noted before designing the compensators were well beyond 10% for each system. These high percentages can severely affect the power generation if adequate measures to reduce them are not taken. Considering all the three different interconnected power systems simulated, it can be clearly stated that the conventional PID has been overtaken by the two intelligent controllers when it comes to frequency regulation. Though the intelligent controllers have not been able to diminish the overshoot and undershoot beyond that attained by the PID for the ACE output still, the

4.3 Non-Reheat–Reheat Thermal Power System

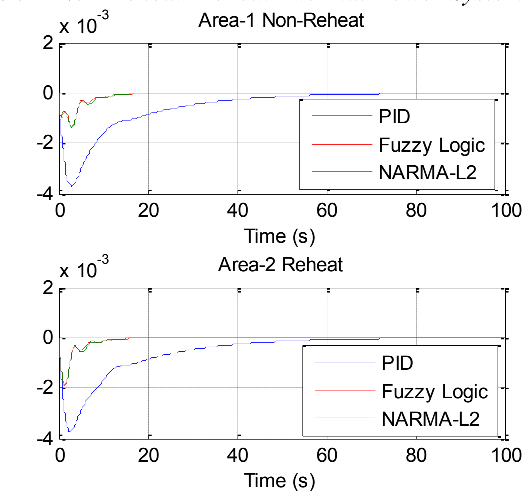

Fig. 8. Frequency deviation of non-reheat-reheat thermal power system

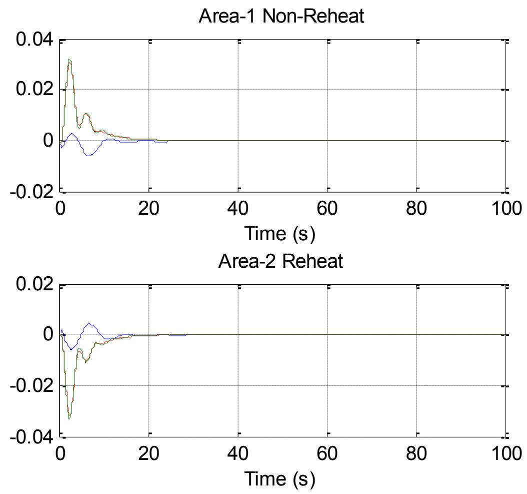

Fig. 9. ACE output of non-reheat-reheat thermal power system

values recorded with the intelligent controllers are undoubtedly negligible compared to the uncompensated cases. The settling time of the ACE outputs with the incorporated controllers could be decreased to only a few seconds because the controllers provide the secondary control action to the power system which is in the time-scale of minutes. Hence, both intelligent controllers can be used for effective power generation and transmission.

5 CONCLUSION

With the increasing complexity of power systems, the conventional PI controller provides a large transient response which is not satisfactory for a power generation system. In-depth studies on techniques that make use of artificial intelligence have proved that the latter can effectively perform the required control actions. In this paper, two intelligent controllers namely Fuzzy Logic and ANN-NARMA-L2 are proposed to challenge the response of a conventional PID controller in terms of overshoots, undershoots and settling times. Three different turbine models were considered and a combination of two different turbines was implemented in a two-area power system. Based on the responses due to the disturbances, appropriate actions were taken for the design of the compensators. After a comparative analysis on all the compensated systems simulated, both intelligent controllers gave better responses than the PID. However, the PID was more robust than the intelligent controllers against a variable load change in each area. In summary, the study yielded promising results for the load frequency control of power systems.

6 REFERENCE

Adaryani, M. R. and Afrakhte, H. (2011). NARMA-L2 Controller for Three-area Load Frequency Control. *19th Iranian Conference on Electrical Engineering (ICEE)*, 1-6.

Altas, I. H. and Neyens, J. (2006). A Fuzzy Logic Load-Frequency Controller for Power Systems. *International Symposium on Mathematical Methods in Engineering*, 1-10.

Ang, K. H., Chong, G. and Li, Y. (2005). PID Control System Analysis, Design, and Technology. *IEEE Transactions on Control Systems Technology,* 13(4), 559-576.

Bansal, R.C.(2005). Optimization Methods for Electric Power Systems: An Overview. *International Journal of Emerging Electric Power Systems* 2(1), 1-25.

Hagan, M. T., Demuth, H.B. and De Jesus, O. (2002). An Introduction to the use of Neural Networks in Control Systems. *International Journal of Robust and Nonlinear Control,* 12 (11), 959-985.

Ismael, M. M. and Mustafa Hassan, M. A. (2012). Load Frequency Control Adaptation Using Artificial Intelligent Techniques for One and Two Different Areas Power System. *International Journal of Control, Automation and Systems,* 1(1), 12-23.

Jantzen, J. (1998). *Tuning of Fuzzy PID Controllers*. Technical Report. University of Denmark.

Kundur, P. (1994). *Power System Stability and Control.* India: McGraw-Hill Education Pvt Limited.

Nag, S. and Philip, N. (2014). Application of Neural Networks to Automatic Load Frequency Control.*Interenational Conference on Control, Instrumentation, Energy & Communication,* 345-350.

Omar, M., Soliman, M., Abdel Ghany, A. M. and Bendary, F. (2013). Optical Tuning of PID Controllers for Hydrothermal Load Frequency Control Using Ant Colony Optimization. *International Journal on Electrical Engineering and Informatics,* 5 (3), 348-360.

Pothiya, S., Ngamroo, I., Runggeratigul, S. and Tantaswadi, P. (2006). Design of Optimal Fuzzy Logic based PI Controller using Multiple Tabu Search Algorithm for Load Frequency Control. *International Journal of Control, Automation, and Systems,* 4(2), 155-164.

Ragini, Kumar, S., Akash, Nath, A., Singh, S. K., Awanish, et al. (2015). Automatic Generation Control for a Two Area Power System Using Backtracking Search Algorithm. *International Conference on Energy, Power and Environment: Towards Sustainable Growth,* 1-6.

Saadat, H. (1999). *Power System Analysis*. New York: McGraw-Hill.

Shree, B. S. and Kamaraj, N. (2015). Hybrid Neuro Fuzzy approach for automatic generation control in restructured power system. *International Journal of Electrical Power and Energy Systems,* 74 (2016), 274-285.

Tan, W. (2011). Load Frequency Control: Problems and Solutions. *Proceedings of the 30th Chinese Control Conference,* 6281-6286.

Valluru, S. K., Singh, M., Bushan, B. and B.S. (2015). Comparative Analysis of PID, NARMA-L2 and PSO Tuned PID Controllers for Nonlinear Dynmaical System. *Journal of Automation & Systems Engineering,* 9(2), 94-108.

Zhang, Y. (2009). *Load Frequency Control of Multiple-Area Power Systems.* Thesis (MSc). Cleveland State University.

Preprint submitted to Control Conference Africa, 2017. Received May 22, 2017.