LOAD FREQUENCY CONTROL OF INTERCONNECTED AREA NETWORK USING ARTIFICIAL INTELLIGENCE: A STUDY OF OWERRI METROPOLIS

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ABSTRACT

This paper focuses on the analysis of Owerri network using load frequency control. The LFC is further analyzed using fuzzy logic controller and neural network controller for optimization. The result is compared and relevant conclusions are drawn. Applying a conventional load frequency control (LFC), the deviation error in the frequency is high after about 15 seconds and it continues on that steady deviation error. When fuzzy logic control is applied, it continue in a stable manner without error until 10 seconds. The frequency continues to fluctuate until it comes to stability for the specified three areas. Area 1 became perfectly stable after 27 seconds, while area 2 became perfectly stable after 19 seconds and area 3 after 26 seconds. It can be concluded that applying Fuzzy Load Frequency Controls (FLFC) to Owerri network helped to stabilize the frequency of the network. It also achieved zero steady state error and inadvertent interchange, safe operation of the system, balancing of the voltage and achieved load reducing system collapse and low power outages.

Keywords: Load Frequency Control, Fuzzy logic, Generator, Network.

1.0 INTRODUCTION

Nigerian power system has been undergoing a serious issue due to over-usage of the generators, old facilities, political issues and vandalization etc. This is as a result of the old generators still in use and the demand of the individuals increasing on daily basis. As the day goes by, new transformers are been installed and the only way to meet to everybody's need is to load shed some areas in order not to overload the network. To do this, so many factors have to be considered, like the amount of power generated, the total load demand, peak and off-peak period, the number of transformers in a particular area, the fuel entering the generator, etc. The fuel consumption in the combustion chamber is of a great importance in this study because it determines the frequency of the network. When the demand is high more fuel will be introduced into the combustion chambers to balance the frequency, while when the demand is low, the fuel input will be reduced to balance the frequency which is not to exceed 50Hz. This is known as Load Frequency Control. The modes of control of this fuel consumption and the frequency output base on the load demand have caused a lot of problems in the power system.

Load Frequency Control is defined as the regulation of power output of controllable generators within a prescribed area in response to change in system frequency, tie-line loading, or a relation of these to each other, so as to maintain the schedules system frequency and / or the established interchange with other areas within predetermined limits. Among the various types of load frequency controllers, the most widely employed is the convectional proportional integral (PI) controller. The Proportional Integral controllers, is very simple for implementation and gives better dynamic response, but their performances deteriorate when the complexity in the system increases due to disturbances like load variation boiler dynamics. This is why it will be necessary to introduce more sophisticated mechanism to control the load and the frequency of the network. For the benefit of this study we will consider fuzzy logic as a control mechanism. The inherent gain of these techniques is that they do not require the system model and identification but depend on human expertise knowledge of the behavior.

Since the Nigerian power system is so vast, a small area of the power system is taken into account which can be used to conclude for other areas of Nigerian power system. The area considered is the Owerri, Imo state network. This network is considered due to an ongoing upgrade in the network. It formally comprises of two generators with an upgrade now to introduce a new generator to boost the energy supply of the state. These three generators were considered as the three areas for the purpose of this study. This will aid to satisfy the demands of the area and reduce load shedding.

2.0 RELATED WORKS

So many works have been done on LFC especially on two and three area network. Mohammed et al [1] considered LFC of two area network of hydro-thermal generators using PI and Fuzzy controller. This study shows a superior behavior in the application of fuzzy logic for a step change in loading conditions.

Atlas and Neyens [2] shows proposed a way of designing a fuzzy logic controller. The proposed simulation model is compared with the classical regulating systems in order to verify and show the advantages of the model and controller developed. The design process of the proposed fuzzy logic controller is given in detail step by step to show a direct and simple approach for designing fuzzy logic controllers in power systems.

Surya and Sinha [3] presents a paper on dynamic performance of Load Frequency Control (LFC) of three area interconnected hydrothermal reheat power system by the use of Artificial Intelligent and PI Controller. In the proposed scheme, control methodology developed using conventional PI controller, Artificial Neural Network (ANN) and Fuzzy Logic controller (FLC) for three area interconnected hydro-thermal reheat power system. In this paper area-1 and area-2 consists of thermal reheat power plant whereas area-3 consists of hydro power plant. In this proposed scheme, the combination of most complicated system like hydro plant and thermal plant with reheat turbine are interconnected which increases the nonlinearity of the system. The performances of the controllers are simulated using MATLAB/SIMULINK package. A comparison of PI controller, Fuzzy controller and ANN controller based approaches shows the superiority of proposed ANN based approach over Fuzzy and PI for same conditions.

For the purpose of this study, a three area network will be considered on Owerri, Imo state, Nigerian network to ascertain the effect of load on frequency on the upgraded network.

3.0 NETWORK AND COMPONENTS

3.1 IMO STATE NETWORK

The Owerri distribution network is shown in Figure 1 below and how it connects to all the Imo State power lines. The Line Diagrams was gotten from Owerri 132/33KV T/S Egbu Road transmission station at Owerri Imo.Imo State consists of two power supply sources one coming from Alaoji 132KVLine 1 and Line 2of Afam/Alaoji 330/132KV Aba Abia State and the other one from Orlu 132KV Line 1 of Egbeama 330/132V Imo State. For now, that of Orlu (Egbeama) is not active, but it was included in the simulation because it is under reconstruction. In the Owerri T/S there are 2NO, 60MVA, 132/33KV and 1NO MOBITRA 40MVA, 132/33KV power transformers where six 33KV feeders radiated from the 3 number power transformers namely, Mbaise 33KV Line 1, Owerri 33KV Line 2, Owerri (Airport) 33KV Line 3, Oguta 33KV Line 4, Orlu 33KV Line 5, and Okigwe 33KV Line 6. Also outgoing Ahoda 132KV Line 1 and Line 2 feeding Bayelsa State from Owerri. Interviews were conducted on the System Operators of Owerri T/S on duty and Work Center Manager to ascertain the method of controlling the Frequency, Voltage and the Load when there is Electricity .According to the Operators, the error in the frequency should not be more than 1 or less than -1 (49-51Hz) while the normal frequency should operate at 50Hz.Circit Breakers, Relay, D.C Voltmeter and Frequency meter are connected in each feeder to trip the feeder either on Fault or Over Load. According to the two operators interviewed, on duty when the frequency is too high, Alaoji TCN notified Owerri T/S Load Center through Radio Phone or Telephone calls to add Loads to the network that is picking or closing feeders in order to balance the frequency. When the frequency is low, the Load Center will be informed to drop loads or Shed Loads. All these are aimed at avoiding a system collapse.

According to them, these are done majorly by manual operation and the error rate despite the control is a bit high though on the range of operation. (As at time observe, the frequency was at 50.9Hz).The Owerri distribution network still feeds many 11KV Feeders that radiated from 33KV Injection Substations that are into the six mentioned 33KV Feeders. There are problems militating against electricity supply to it. This poor quality power supply is caused by overloaded feeders, line faults (Earth faults, Load imbalance and Over currents faults), and Vandalization. The Imo State distribution networks together with other State offices (districts) are under Enugu Electricity Distribution Company (EEDC). The expected power demand is about 180MW to 200MW, but what is available for now is about 80MW to 100MW. It is observable that there are fluctuations from the expected power demand to that supplied .This may be due to short fall in the generation's capacity being witnessed by the country for some time now. There are fluctuations in the power supplied to Owerri T/S from time to time and even days without power supply. The recent improvement was done by introduction of a generator to the network. This is why this dissertation focuses on how to manage the generators, frequency and load demand to improve the network using artificial intelligence.

3.2 COMPONENTS OF POWER GENERATING UNITS

The different components of power generating units are outlined below;

Turbine: A turbine unit in power system is used to transform the natural energy, such as energy from steam and water, into mechanical power (ΔPm) that is supplied to the generator. In Load Frequency Control model, there are three kinds of commonly used turbines: non-reheat, reheat and hydraulic turbines, all of which can be modeled by transfer functions.

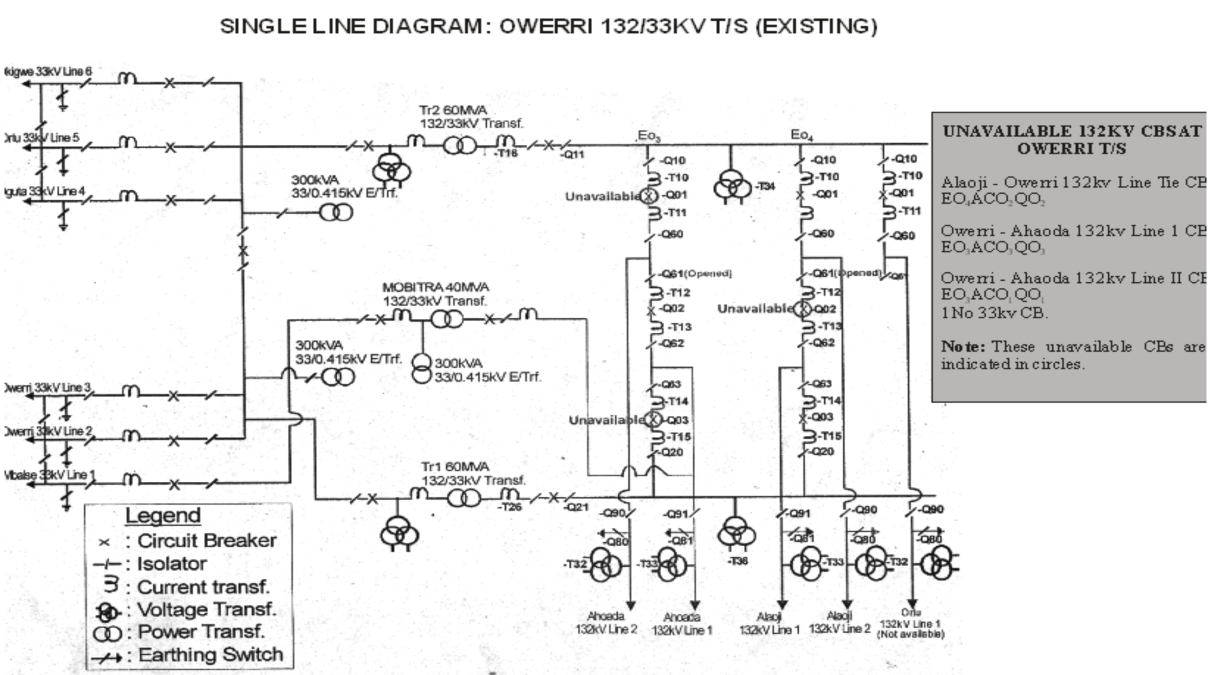

Figure 1: Owerri single line diagram (Owerri 132/33KV T/S)

Non-reheat turbines are first-order units. The transfer function can be of the non-reheat turbine is represented as:

$$G_{NR}(s) = \frac{\Delta P_m(s)}{\Delta P_v(s)} = \frac{1}{T_{ch}s+1} \quad (1)$$

Where ΔP_V is the valve/gate position change.
Reheat turbines are modeled as second-order units, since they have different stages due to high and low steam pressure. The transfer function can be represented as

$$G_R(s) = \frac{\Delta P_m(s)}{\Delta P_v(s)} = \frac{F_{hp}T_{rh}s+1}{(T_{ch}s+1)(T_{rh}s+1)} \quad (2)$$

Where T_{rh} stands for the low pressure reheat time and F_{hp} represent the high pressure stage rating.
Hydraulic turbines are non-minimum phase units due to the water inertia. In the hydraulic turbine, the water pressure response is opposite to the gate position change at first and recovers after the transient response. Thus the transfer function of the hydraulic turbine is in the form of

$$G_H(s) = \frac{\Delta P_m(s)}{\Delta P_v(s)} = \frac{-T_W s+1}{(T_W/2)s+1} \quad (3)$$

Where T_w is the water starting time
For stability concern, a transient droop compensation part in the governor is needed for the hydraulic turbine. The transfer function of the transient droop compensation part is given by

$$G_{TDC}(s) = \frac{T_R s+1}{T_R(R_T/R)s+1} \quad (4)$$

Where T_R, R_T and R represent the reset time, temporary droop and permanent droop respectively.

Generators: A generator unit in power systems converts the mechanical power received from the turbine into electrical power. Once a load change occurs, the mechanical power sent from the turbine will no longer match the electrical power generated by the generator. This error between the mechanical (ΔP_m) and electrical powers (ΔP_{el}) is integrated into the rotor speed deviation (Δωr), which can be turned into the frequency bias (Δf) by multiplying by 2π. The relationship between ΔPm and Δf is shown in Figure 2.2, where M is the inertia constant of the generator [5].

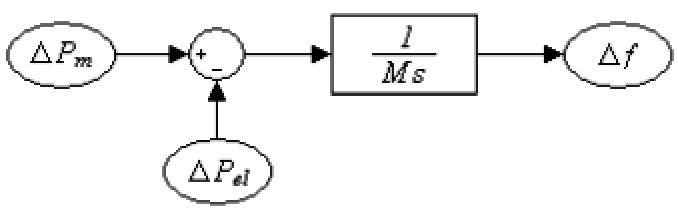

Figure 2: Block Diagram of the Generator

The power loads can be decomposed into resistive loads (ΔP_L), which remain constant when the rotor speed is changing, and motor loads that change with load speed [5].

Governors: 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 Figure 2.3, where R is the speed regulation characteristic and Tg is the time constant of the governor [4]. If without load reference, when the load change occurs, part of the change will be compensated by the valve/gate adjustment while the rest of the change is represented in the form of frequency deviation.

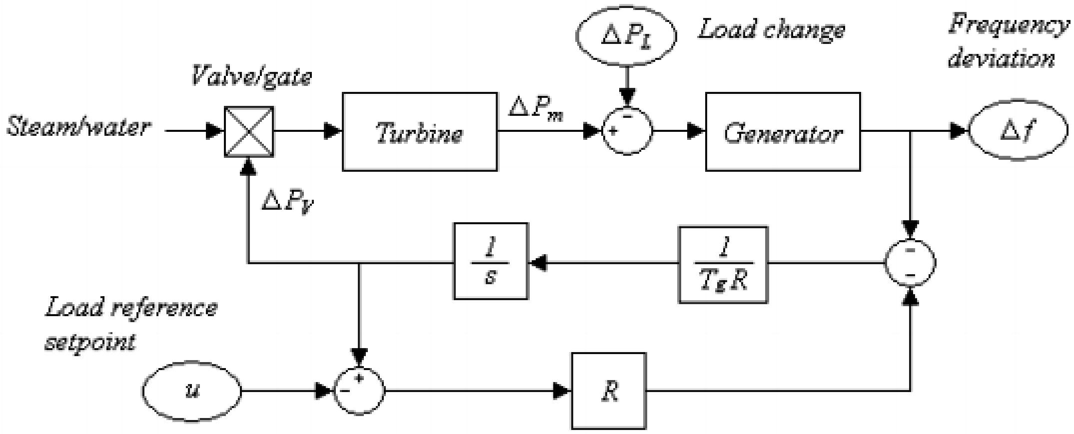

Figure 3: Schematic diagram of a speed governing unit

The Laplace transform representation of the block diagram in Figure 3 is given by

$$U(s) - \frac{\Delta F(s)}{R} = (T_g s + 1)\Delta P_v(s) \tag{5}$$

3.3 THE INTERCONNECTED POWER SYSTEM

Tie-lines: 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 Figure 2.4. The Laplace transform representation of the block diagram in Figure 2.4 is given by

$$\Delta P_{tieij}(s) = \frac{1}{s} T_{ij}(\Delta F_i(s) - \Delta F_j(s)) \tag{6}$$

Where ΔP_{tieij} is tie-line exchange power between areas i and j, and T_{ij} is the tie-line synchronizing torque coefficient between area i and j [5].

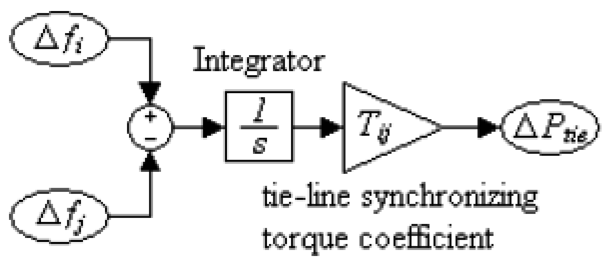

Figure 4: Block Diagram of the Tie-lines

Area control error: The goals of Load Frequency Control are not only to cancel frequency error in each area, but also to drive the tie-line power exchange according to schedule [4].Since the tie-line power error is the integral of the frequency difference between each pair of areas, if we control frequency error back to zero, any steady state errors in the frequency of the system would result in tie-line power errors. Therefore we need to include the information of the tie-line power deviation into our control input. As a result, an Area Control Error (ACE) is defined as:

$$ACE_i = \sum_{j=1,\dots,j\neq i} \Delta P_{tieij} + B_i \Delta f_i \tag{7}$$

Where B_i is the frequency response for area I and

$$B_i = D_i + \frac{1}{R_i} \quad (8)$$

This Area Control Error signal is used as the plant output of each power generating area. Driving Area Control Errors in all areas to zeros will result in zeros for all frequency and tie-line power errors in the system [5].

Parallel operation: If there are several power generating units operating in parallel in the same area, an equivalent generator will be developed for simplicity. The equivalent generator inertia constant (M_{eq}), load damping constant (D_{eq}) and frequency response characteristic (B_{eq}) can be represented as follows.

$$M_{eq} = \sum_{i=1,\dots,n} M_i \quad (9)$$

$$D_{eq} = \sum_{i=1,\dots,n} D_i \quad (10)$$

$$B_{eq} = \sum_{i=1,\dots,n} \frac{1}{R_i} + \sum_{i=1,\dots,n} D_i \quad (11)$$

3.4 MULTI-AREA NETWORK

In many cases a group of generators are closely coupled internally and swing in unison. Furthermore, the generator turbines tend to have the same response characteristics. Such a group of generators are said to be coherent. This is possible to let the Load Frequency Control loop represent the whole system and the group is called the control group. For a two area system, during normal operation the real power transferred over the tie line is given by

$$P_{12} = \frac{|E_1||E_2|}{X_{12}} \sin \delta_{12} \quad (12)$$

Where $X_{12} = X_1 + X_{tie} + X_2$ and $\delta_{12} = \delta_1 + \delta_2$.

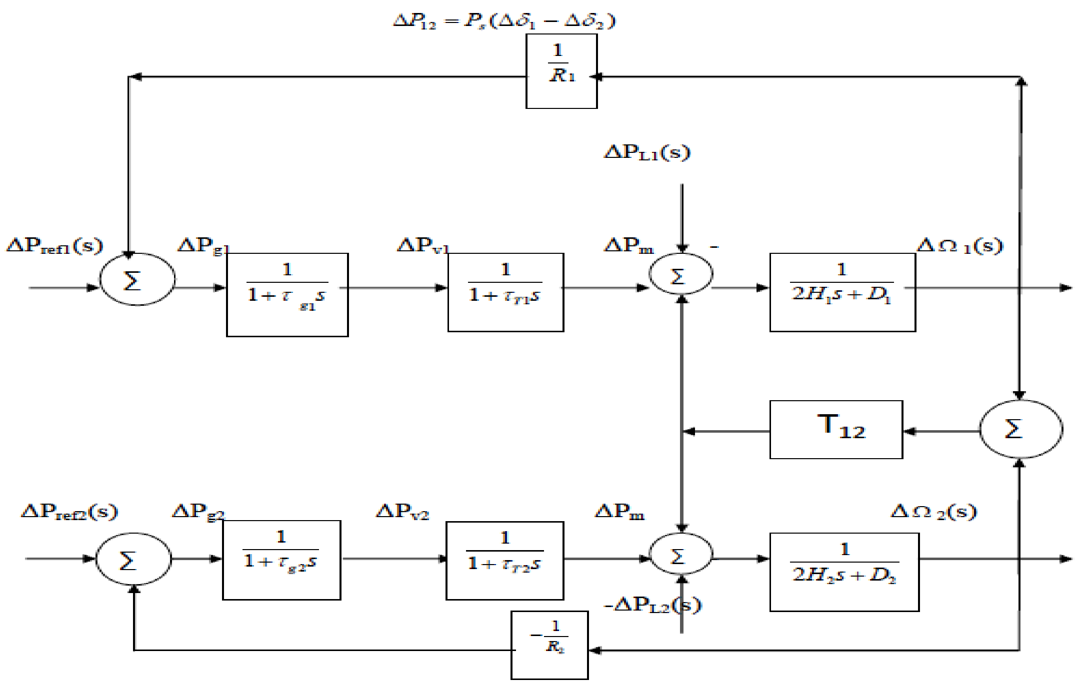

Figure 5: Block Diagram for Multi-area Network

Modern Control design is especially based on the multivariable state vector system. In this design algorithm we make use of the state variable parameters that can be obtained from the system. For the systems where all the state variables are not available a state estimator is designed.

3.5 FUZZY LOGIC CONTROL

Fuzzy logic is a form of many-valued logic; it deals with reasoning that is approximate rather than fixed and exact. Compared to traditional binary sets (where variables may take on true or false values), fuzzy logic variables may have a truth value that ranges in degree between 0 and 1. Fuzzy logic has been extended to handle the concept of partial truth, where the truth value may range between completely true and completely false. Furthermore, when linguistic variables are used, these degrees may be managed by specific functions.
The results can be useful to construct the rule table. The values we read on this graphics will be used to define the first fuzzy set intervals. By applying trial-and-error in order to achieve improved results with the Frequency Load Control, these intervals may change.A summary of all possible situations, or so called operation regions, is given in Table 1.

Table 1: Output Decision Making Table.

	Operating Regions								
Δω	+	0	-	-	0	+	-	+	0
Δ(Δω)	-	-	-	+	+	+	0	0	0
Δ(ΔP)	+	-	-	-	+	+	-	+	0

The sign of Δ (ΔP) should be positive if ΔP has to be increased and it should be negative otherwise. This simple rule is applied as in Table 1 to determine the sign of Δ (ΔP). A verbal example of these rules is: "The error is positive and decreasing towards zero. Therefore, Δ (ΔP) is set to positive to reduce the error." This example expresses the first column of Table 1. Similar reasoning can be applied for the other columns.
From this table on, some logical reasoning should be considered. A closer look at Table 2 shows that in some cases, there is a transition from negative to positive, without passing zero. Therefore, an adjustment in the initial rule table leads to another table without this inconvenience. The influence of Δ (Δω) must stay, and a symmetric solution has to be advised, so the modified rule table is the one that can be found as in Table 2.

Table 2: Initial Rule Table

	NB	**NS**	**ZZ**	**PS**	**PB**	**Δω**
NB	NS	NS	NS	NS	ZZ	
NS	NS	NS	NS	ZZ	ZZ	
ZZ	NS	NS	ZZ	PS	PS	
PS	NS	ZZ	PS	PS	PS	
PB	ZZ	PS	PS	PS	PS	
Δ(Δω)						**Δ(ΔP)**

Table 3: Modified Rule Table

	NB	**NS**	**ZZ**	**PS**	**PB**	**Δω**
NB	NB	NB	NS	NS	ZZ	
NS	NB	NS	NS	ZZ	ZZ	
ZZ	NS	NS	ZZ	PS	PS	
PS	NS	ZZ	PS	PS	PB	
PB	ZZ	PS	PS	PB	PB	
Δ(Δω)						**Δ(ΔP)**

In Table 3, a slightly different meaning of the applied letters is used: 'NB' means large negative, 'N' small negative, 'ZZ' stays zero, 'PS' becomes small positive and 'PB' large positive. Now the output values of $\Delta(\Delta P)$ are extended to five regions as it is done for input spaces. This rule table is the final one; the one that's going to be used in the Frequency Load Control. The MATLAB simulation is given below:

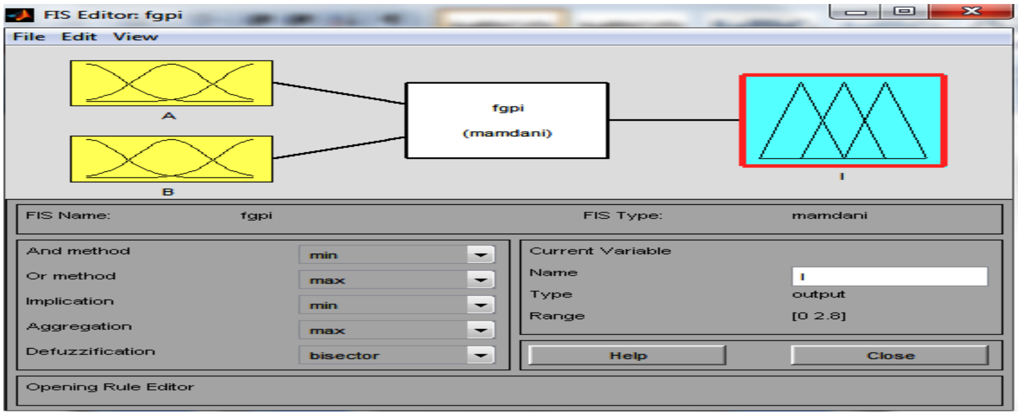

Figure 6: The MATLAB Fuzzy Logic Environment

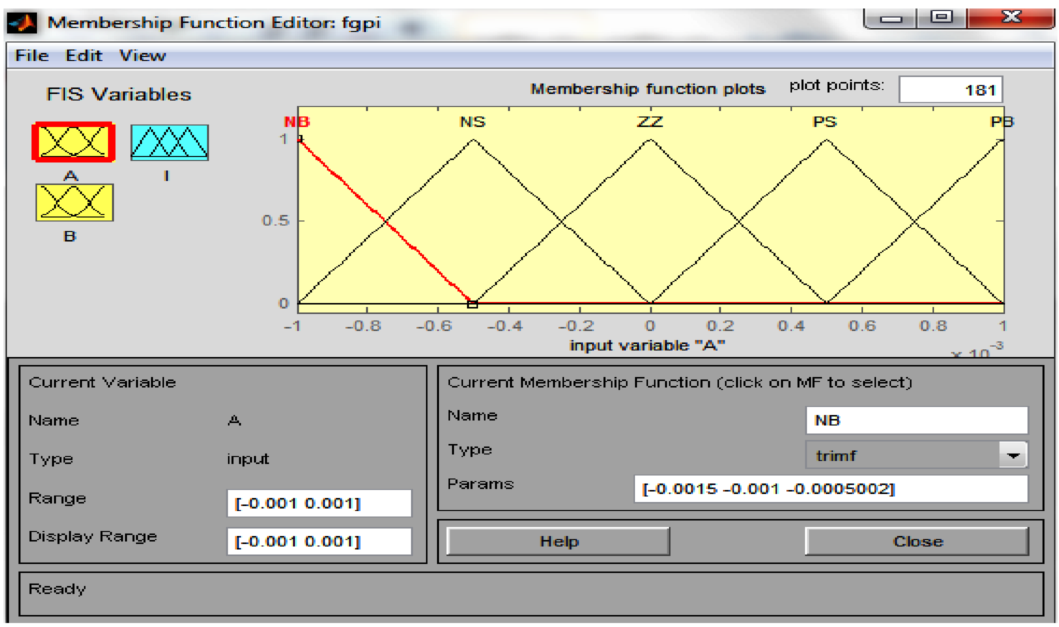

Figure 7: Definition of the Membership Function for Input Variable

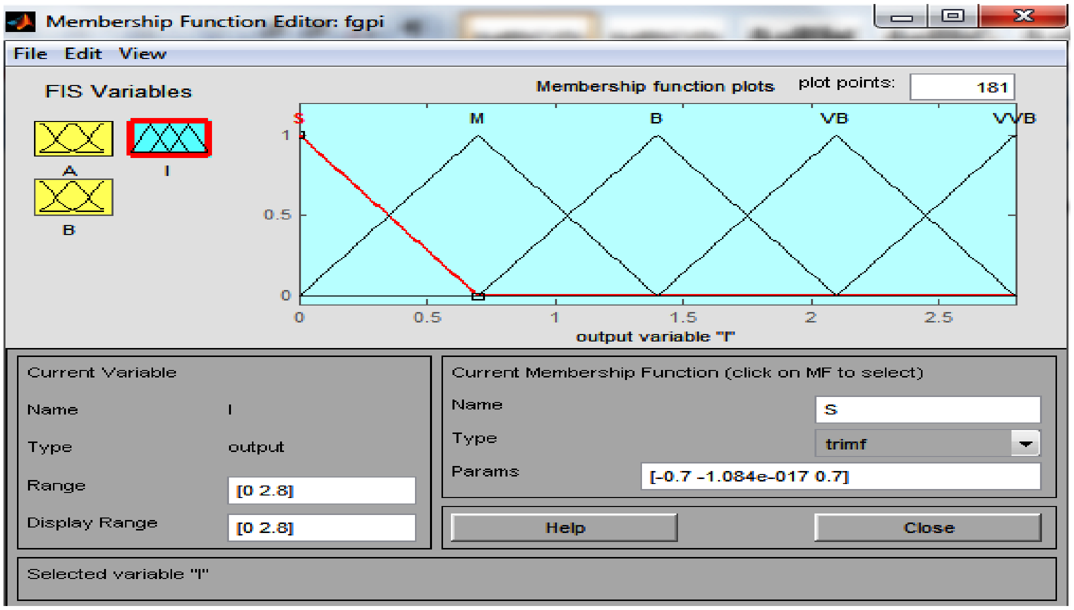

Figure 8: Definition of the Membership Function for Output Variable

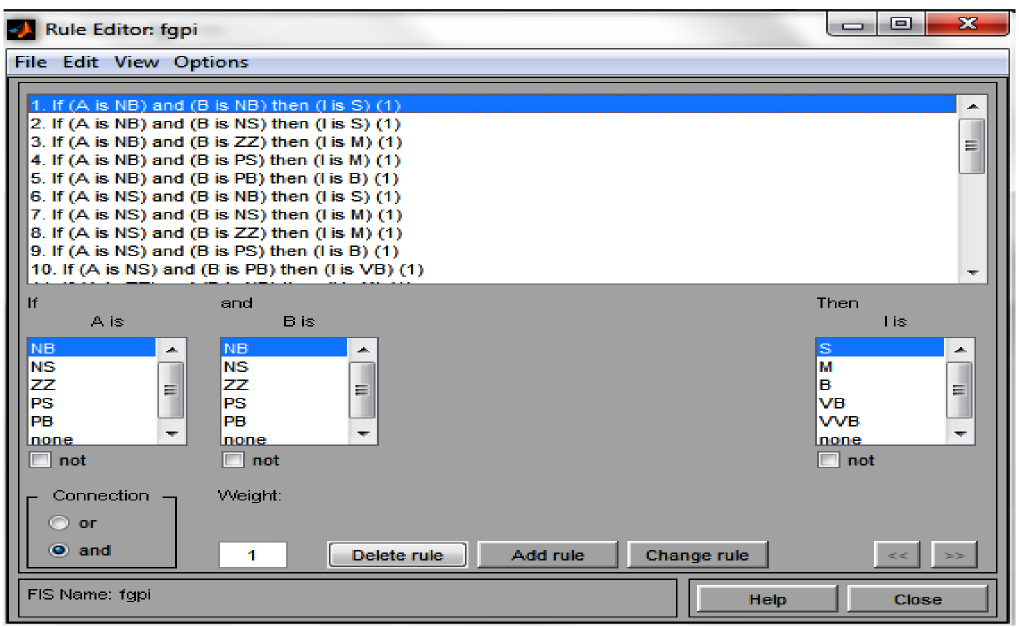

Figure 9: The Fuzzy Logic Rule

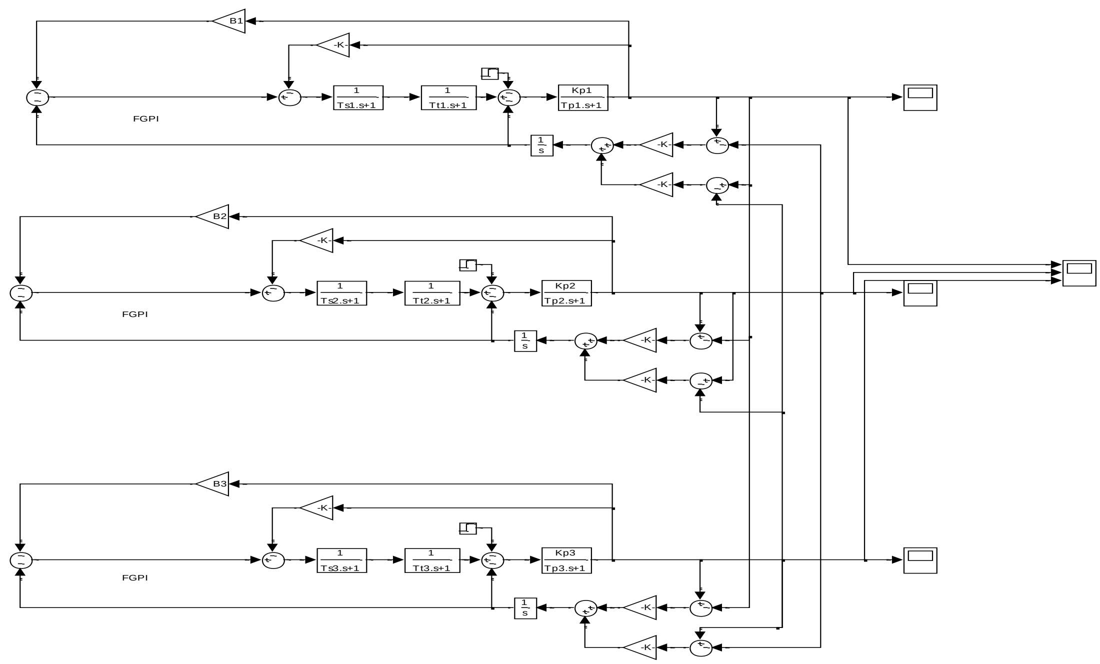

Figure10: Load Frequency Control Simulink without ALFC

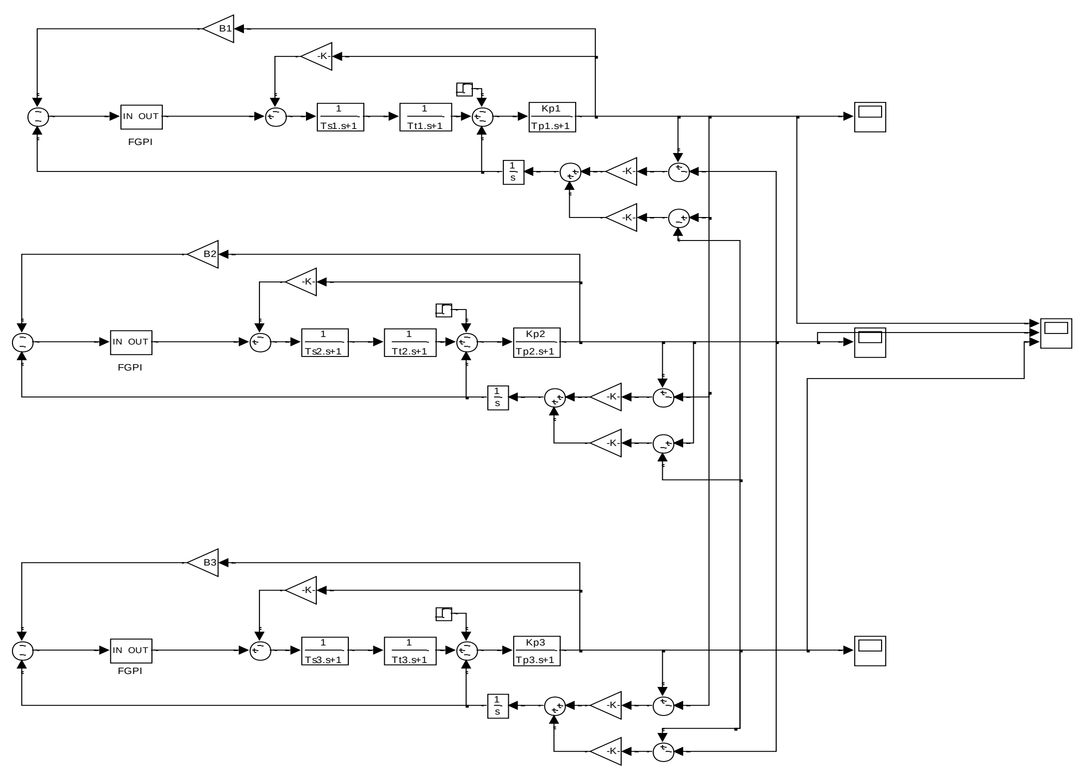

Figure 11: Load Frequency Control Simulink with Fuzzy Logic Controller

4.0 RESULTS AND ANALYSIS

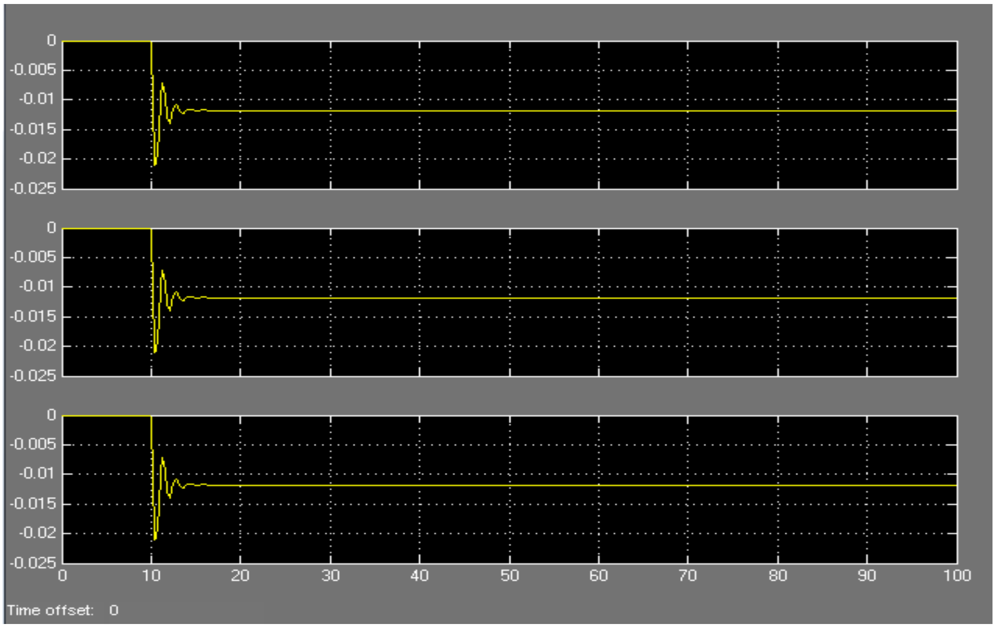

Figure 12: Frequency Deviation of Three Area Network Load Frequency Control without AGC

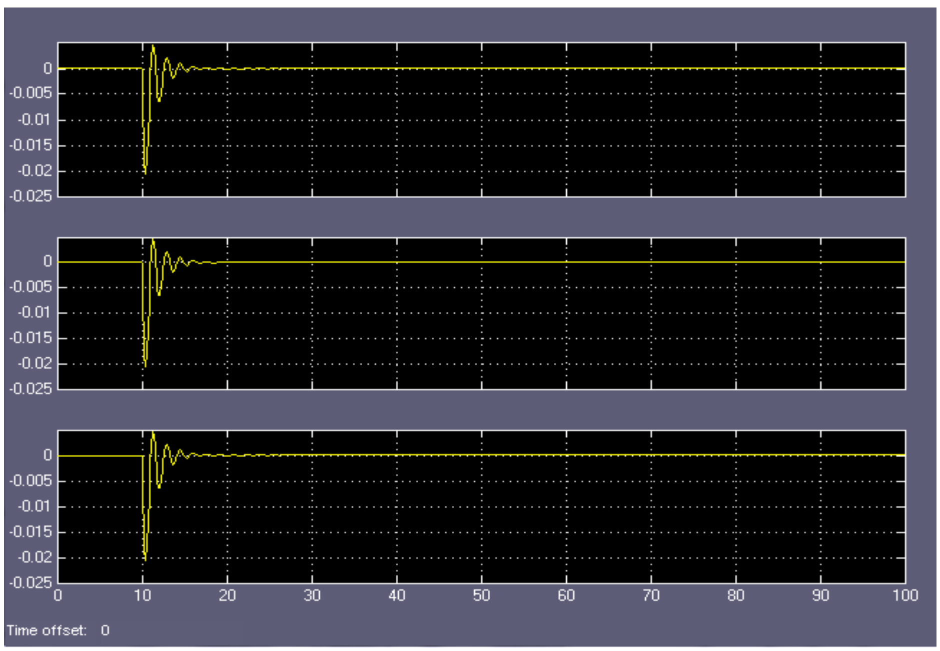

Figure 13: Frequency Deviation of Three Area Network Load Frequency Control using Fuzzy Logic Controller

Load Frequency Control for three area network was considered. This was done for the convention method and for the artificial intelligence. The artificial intelligence was studied for fuzzy logic controller. MATLAB Simulink was helpful in simulating the network to observe its influence on the frequency deviation of the network.

According to the frequency result base on the deviation error in figure 12 and 13 it can be seen that the loads was introduced after ten (10) seconds which staggered the network before the network now continued at a

constant rate. This shows that the frequency does now balance immediately the load is added; it fluctuates before maintaining a constant frequency.
Without using any automatic control as seen in figure 12, the error in the frequency is much after about 16 seconds and it continues on a constant frequency deviation of about 0.015Hz. This shows an unstable state in the frequency without using any artificial intelligence.
Applying fuzzy logic continue in a stable manner without error until 10 seconds when the load is applied, the frequency continues fluctuating until it came to stability back for the three areas. Area 1 became perfectly stable after 27 seconds, while area 2 became perfectly stable after 19 seconds and area 3 after 26 seconds. This is shown in figure 13.

CONCLUSION

MATLAB environment is a very good environment for the analysis of power system stability. It contains toolboxes that enable an easy analysis of any form of power system. From the result stated above, it is clearly seen that application of load frequency using both fuzzy logic controller offers a better result as compared to the conventional method. This shows that it will be of a very good idea to replace the controller with the artificial intelligence to be able to control the frequency efficiently for proper maintenance, effectiveness and economic advantages. The upgraded Owerri network will be greatly improved and maintained if we can switch from the conventional method of controlling to the artificial method of controlling the load and frequency of the network.

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