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Automatic Load Frequency Control Of Two Area Interconnected Power System With Diverse Source In Nigeria

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***Abstract*—This paper presents the use of Artificial Neural Network and conventional PID to control load frequency of Two area interconnected power system in Nigeria. The main aim of load frequency control is to minimize the transient variations in frequency and tie line power deviations and also to ensure that their steady state errors are zero. Many modern control techniques have been used to implement a reliable controller. The objective of these control techniques is to produce and deliver power reliably by maintaining both voltage and frequency within permissible range. This research presents the dynamic modeling and simulation for ALFC of two area interconnected hydro-thermal power system in Nigeria using ANN based non-linear auto regressive moving average (NARMA-L2) controller in matlab. The Results obtained show that the convergence characteristics improved using Narma-L2 controller as compared with PID controller following a load disturbance in either area. The overshoot, settling time and steady state error for PID is 0 and -0.11 respectively. While Narma-L2 has 0.01, 20s and 0 respectively following a step change in load. As seen the NARMA-l2 based controller gives better dynamic response, reduced error magnitude and minimized frequency transients than the PID controller.**

I. INTRODUCTION

An interconnected power system normally consists of a number of subsystems/areas interconnected via tie lines. For each subsystem the requirements include matching system generation to system load and regulating system frequency. This is basically known as load-frequency control or automatic generation control (AGC) problem[1]. The role of AGC is to divide the loads among the system, station and generator to achieve maximum economy and accurate control of the scheduled interchanges of tie-line power while maintaining a reasonable uniform frequency. The primary purpose of the AGC is to balance the total system generation against system load and losses so that the desired frequency and power interchange with neighboring systems are maintained. Any mismatch between generation and demand causes the system frequency to deviate from scheduled value. This high frequency deviation may lead to system collapse[2].

Power system operation at a lower frequency affects the quality of power supply. When operating at frequencies below 49.5 Hz, some types of steam turbines undergo excessive vibration in certain turbine rotor stages with resultant metal fatigue and blade failure. When frequency falls below 49Hz, turbine regulating devices fully open and the generating units becomes completely loaded, a further decrease in frequency reduces the efficiency of the auxiliary mechanisms at the thermal power stations especially feed pumps. Prolonged operation at a lowered frequency will result to a drop in the generated output and further loss of power. The decrease in power system frequency may assume an avalanche nature which can stop the power stations for a prolonged outage[3].

As the frequency decreases, the generators exciter loss their speed and generator emf falls, the voltage in power system unit drops. This brings the danger of a “voltage avalanche” and disconnection of consumers. A frequency avalanche drop aggregated by a voltage avalanche drop causes grave breakdown in the power system and complete stoppage of the paralleled station or division of power system in to separately operating sections with interruption of power supply of

many consumers. The function of automatic load frequency control is to provide control signals to regulate the real power output of various electric generators within a prescribed area in response to changes in system frequency and tie-line loading so as to maintain the scheduled system frequency and established interchange with other areas. In this case the power system supplies to majority of consumers suffer no interruption and system to disconnect load can be restored within a fairly short period of time. Whenever such an interconnected power system experiences a change in the demand imposed on it, the frequency of the bus bar voltages and currents and the inter-area tie line power flow among interconnected areas deviated from their specified values, the shares of the total power demand on the whole system carried by individual generator also deviate from their optimal values. The deviation in frequency and the inter-area tie line power flow are traditionally restored to their schedule values by a load frequency control (LFC) system[4].

II. DISCUSSION

A. Power System Frequency Control

Frequency deviation is a direct result of the imbalance between the electrical load and the active power supplied by the connected generators. A permanent off-normal frequency deviation directly affects power system operation, security, reliability, and efficiency by damaging equipment, degrading load performance, overloading transmission lines, and triggering the protection devices.

Since the frequency generated in the electric network is proportional to the rotation speed of the generator, the problem of frequency control may be directly translated into a speed control problem of the turbine generator unit. This is initially overcome by adding a governing mechanism that senses the machine speed, and adjusts the input valve to change the mechanical power output to track the load change and to restore frequency to a nominal value [5].

Depending on the frequency deviation range, as shown in Figure 1, in addition to the natural governor response known as the primary control, the supplementary control (AGC), or secondary control, and emergency control may all be required to maintain power system frequency. There are three types of control for frequency deviation in

the power systems which are as follows:

- Primary control,
- Supplementary control and
- Emergency control.

The supplementary loop gives feedback via the frequency deviation and adds it to the primary

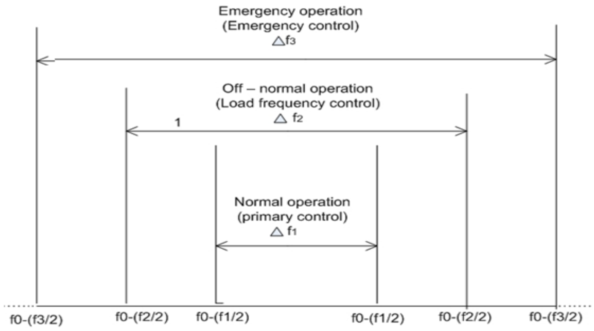

Figure 1; *Frequency Deviations and Associated Operating Controls*

control loop through a dynamic controller. The resulting signal is used to regulate the system frequency. In real-world power systems, the dynamic controller is usually a simple integral or proportional integral (PI) controller. Following a change in load, the feedback mechanism provides an appropriate signal for the turbine to make generation (Δ Pm) track the load and restore system frequency. The objective of an effective load shedding (emergency control) scheme is to curtail a minimum amount of load, and provide a quick, smooth, and safe transition of the system from an emergency situation to a normal equilibrium state.

B. Performance of AGC under Nnormal and Abnormal Conditions

Four basic objectives of power system operation during normal operating conditions are associated with automatic load frequency control (ALFC):

- Matching total system generation to total system load;
- Regulating system electrical frequency error to zero;
- Distributing system generation among control areas so that net area tie flows match net area tie flow schedules;
- Distributing area generation among area generation sources so that area operating costs are minimized.

In the power system, numbers of utilities are interconnected through a tie-line by which power is exchanged between them. Any sudden load perturbation in power system can cause variation in tie-line power interchange and frequency. ALFC is used in the power system to keep frequency of control areas at its nominal value and tie-line power exchange for different control areas at their scheduled values[3].

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 active and reactive power demands are never steady and they continuously change with the rising or falling trend of load demand. There is a change in frequency with the change in load which causes problems such as:

Most AC motors run at speeds that are directly related to frequency. The speed and induced electro motive force (e.m.f) may vary because of the change of frequency of the power circuit.

When operating at frequencies below 49.5 Hz; some types of steam turbines, certain rotor states undergo excessive vibration.

The change in frequency can cause mal operation of power converters by producing harmonics.

For power stations running in parallel it is necessary that frequency of the network must remain constant for synchronization of generators. 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 tolerable limits

E. Model of the Nigerian Two-Area Power System

For the purpose of management and control, the Nigerian power systems is divided into 2 control units called areas which are interconnected by the tie lines as shown in figure 2. The hydro area consists of all the hydro generating stations located in Northern Nigeria. The thermal area consists of gas fired stations mostly located in the southern part of the country. The two areas are interconnected by a tie line at Oshogbo. The deviations in mechanical and electrical power will be related to the deviations in rotating speed and mechanical torques. The relationship between net accelerating power and the electrical and mechanical powers is

$P_{net} = P_{mech} - P_{elec}$ (1)

Which is written as the sum of the steady – state value and the deviation term?

$P_{net} = P_{neto} + \Delta P_{net}$, (2)

Where $P_{neto} = P_{mecho} - P_{eleco}$ (3)

$\Delta P_{net} = \Delta P_{mech} - \Delta P_{elec}$, then

$\Delta P_{net} = (P_{mecho} - P_{eleco}) + (\Delta P_{mech} - \Delta P_{elec})$ (4)

Similarly, for torques,

$T_{net} = (T_{mecho} - T_{eleco}) + (\Delta T_{mech} - \Delta T_{elec})$ (5)

Using

$I\alpha = T_{net},\ M = \omega I$

$P_{net} = \omega\ T_{net} = \omega\ (I\alpha) = M\alpha$

$P_{net} = P_{neto} + \Delta P_{net} = (w_0 + \Delta w)(T_{neto} + {}_t\Delta T_{net})$ (6)

Substituting equation 4 into equation 6 and obtain

$(P_{mecho} - P_{eleco}) + (\Delta P_{mech} - \Delta P_{elec}) = (w_0 + \Delta w)[(T_{mecho} - T_{eleco}) + (\Delta T_{mech} - \Delta T_{elec})]$ (7)

Assume that the steady-state quantities can be factored out since

$P_{mecho} = P_{eleco}$, and

$T_{mecho} = T_{eleco}$

And further assume that the second-order terms involving products of Δw with ΔT_{mech} and ΔT_{elec} can be neglected. Then

$\Delta P_{mech} - \Delta P_{elec} = w_0\ (\Delta P_{mech} - \Delta P_{elec})$ (8)

The net torque is related to the speed change as follows:

$(T_{mecho} - T_{eleco}) + (\Delta T_{mech} - \Delta T_{elec}) = I\ d/dt\ (\Delta w)$ (9)

Then since $T_{mecho} = T_{eleco}$, we can combine equations (8) and (9) to get

$\Delta P_{mech} - \Delta P_{elec} = \omega_0 I\ d/dt(\Delta\omega)$

$= M\ d/dt\ (\Delta\omega)$ (10)

In an interconnected power system purpose of controller is to maintain frequency at scheduled value and also the net power exchange at scheduled value.

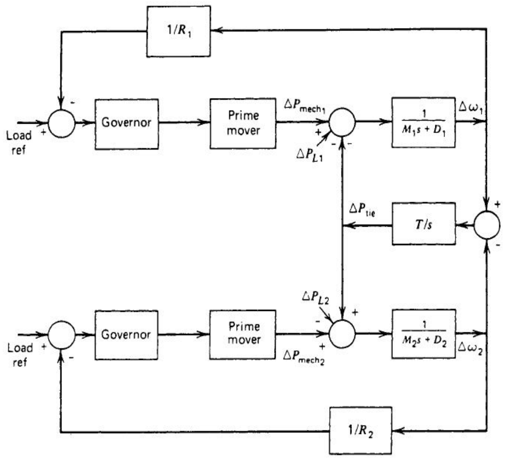

Figure 2: Block Diagram of Two Area Interconnected Power System[5]:

F. NARMA-L2 Control

NARMA-L2 is one of the popular neural network architectures for prediction and control. The principle idea of this control scheme is to apply the input output linearization method where the output becomes a linear function of a new control input as shown in figure 3. There are two steps involved when using NARMA L2 control: system identification and control design. In the system identification stage design, a neural network of the plant that needs to be controlled is developed using two subnetworks for the model approximation. The network is then trained offline in batch form using data collected from the operation of the plant. Next, the controller is simply the rearrangement of two subnetworks of the plant model. Computation of the next control input to force the plant output follows a reference signal.

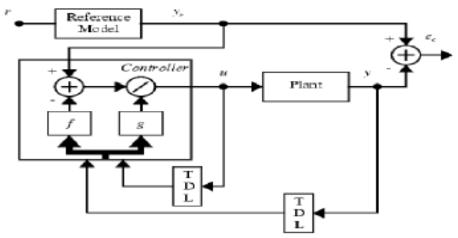

Figure 3: Block Diagram of the NARMA-L2 Control[6].

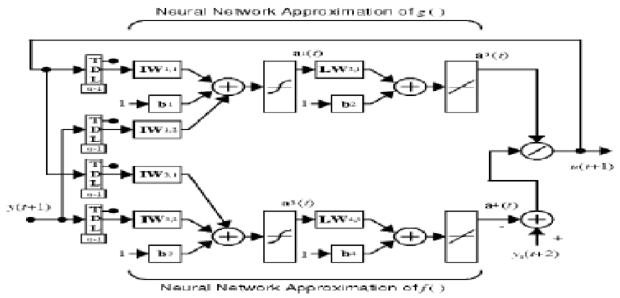

Figure 4: Structure of NARMA-L2 neurocontroller[6].

The Nonlinear Auto Regressive Model Reference Adoptive Controller is adopted in this study. This controller consists of reference, plant output and control signal. The controller is adaptively trained to force the plant output to track a reference model output. The model network is used to predict the effect of controller changes on plant output, which allows the updating of controller parameters. The neural model reference control architecture uses two subnetworks: a controller network and a plant model network, as shown in figure 4. The plant model is identified first, and then the controller is trained so that the plant output follows the reference model output.

The outputs of the neural network are the control signals, which are applied to the governors in the area. The data required for the ANN controller training is obtained after a series of trial and error and modifications, the ANN architecture provides the best performance. It is a three-layer perceptron with two inputs, 9 neurons in the hidden layer, and one output in the ANN controller. The learning algorithm used is the trainlm function and training samples was taken to train over 300 epochs. The proposed network has been trained by using the learning performance. Learning algorithms causes the adjustment of the weights so that the controlled system gives the desired response.

G. NARMA-L2 Plant Model Identification

In NARMAL2 plant identification, the model structure used is the standard NARMA model and a companion form system is used as the identification model, i.e.:

$$\begin{aligned} &y(k+1) = \\ &f[y(k),\ldots,y(k-n+1), \\ &u(k-1),\ldots,u(k-m+1)] + \\ &g[(y(k),\ldots,y(k-n+1), \\ &u(k-1),\ldots,u(k-m+1)].u(k) \end{aligned} \quad \ldots (11)$$

In essence, the NARMA-L2 approximate model will be parameterized by two neural networks ˆf and ˆg that will be used to identify the system of Eq. (11), i.e.:

$$\begin{aligned} &\hat{y}(k+1|\theta) = \\ &\hat{f}[y(k),\ldots,y(k-n+1), \\ &u(k-1),\ldots,u(k-m+1),w] + \\ &\hat{g}[(y(k),\ldots,y(k-n+1), \\ &u(k-1),\ldots,u(k-m+1),v].u(k) \end{aligned} \quad \ldots (12)$$

The two subnetworks are used for the model approximation; MPL1 and MPL2 which are used to approximate nonlinear functions f and g respectively. The NARMA-L2 plant model identification is shown in fig. 5.

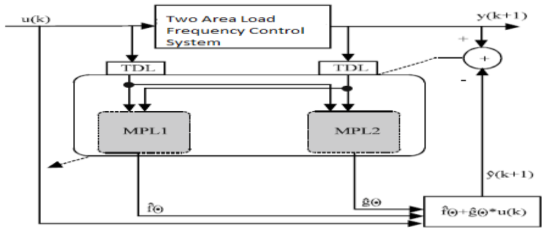

Figure 5: NARMA-L2 Plant Model Identification[7].

The plant model identification in NARMA-L2 Control starts off with a dataset of input output data the collected dataset is divided into two parts; one for the training of the neural nets and the other for cross validating the resulting neural model. Subsequently, the selected neural network structure is trained using the input pattern and the desired output from the dataset. Here, the parameters (weights and biases) of the two MLP subnetworks that properly approximate the modeling representing two area frequency control system are estimated. The optimization technique that will be used to update the parameters is also importantly determined. Finally, to measure the success at approximating the dynamical system plant model using the neural network model, the error should be uncorrelated with all linear and nonlinear combination of past inputs and outputs. Thus, the validation and cross validation tests are carried out to ascertain the validity of the obtained neural network model

III. Simulation and Results

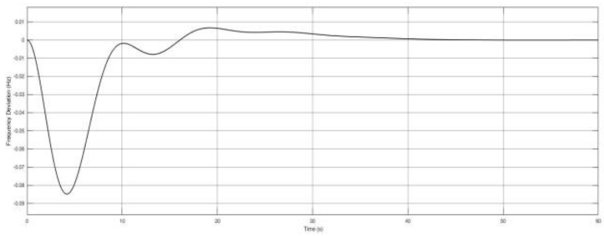

Figure 6: Change in Load in Area1 Showing Tie Line Power Deviation for Narma-L2 Controlled System.

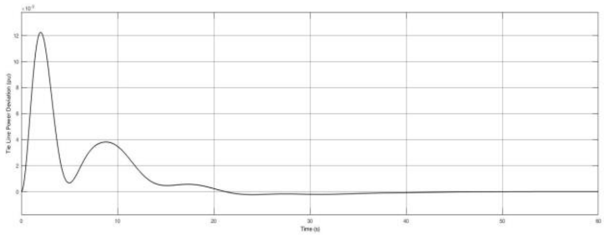

Figure 7: Change in Load in Area 2 Showing Tie Line Power Deviation for Narma-L2 Controlled System.

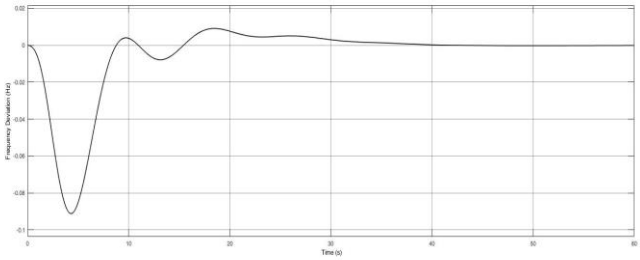

Figure 8: Change in Load in Area 1 & Area 2 Showing Tie Line Power Deviation for Narma-L2 Controlled System.

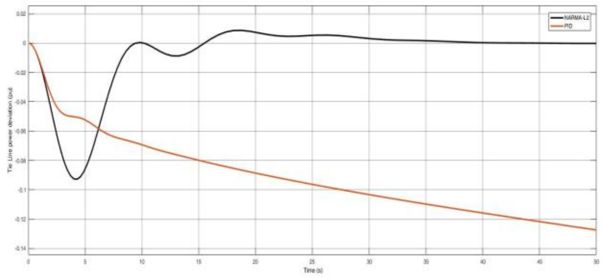

Figure 9: Tie-Line Power Deviation due to disturbance in Area 1.

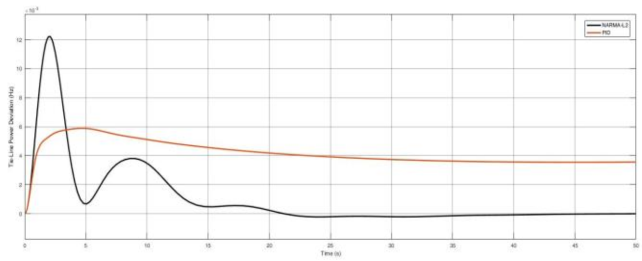

Figure 10: Tie-Line Power Deviation due to disturbance in Area 2.

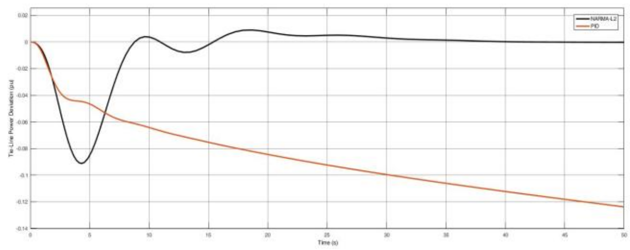

Figure 11. Tie-Line Power Deviation due to disturbance in Area 1 & 2.

IV. Conclusions

The ultimate aim of this research is to design an improved Automatic Load Frequency Control for the Nigerian power system whenever there is change in load demand the frequency change while the ALFC will maintained the frequency to normal acceptable value which has been realized and the parameters for the generating power system were identified.

Artificial neural network controller was developed that is NARMA-L2 controller for the hydro-thermal areas of the Nigeria power system which a gives a better response in terms of the steady state error, over shoot and settling time.

The NARMA-L2 controller and PID controller developed was compared and the performance of each of the developed control schemes for the Nigerian two area system were exhaustively evaluated via the MATLAB platform. The superior performance of the NARMA-L2 controller over the PID controller was conclusively established. Also, a comparative study between these controllers were carried out which revealed that the NARMA-L2 controller returned the best performances indices compared to the PID controller because it minimizes the peak error, reduces the settling time and steady state error of frequency deviation, tie line power deviation compared to conventional PID controller.

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