Journal of Newviews in Engineering and Technology (JNET)
Vol 2, Issue 3, September 2020
Available online at http://www.rsujnet.org/index.php/publications/2020-edition

Grid Frequency Regulation and Stability Using Load Frequency Control in Power Plants

Chujor C. Cornelius, Dikio C. Idoniboyeobu, and Braide L. Sepiribo
Department of Electrical Engineering, Rivers State University
Nkpolu-Oroworukwo, Port-Harcourt
cornelius.chujor@fipl-ng.com.

ABSTRACT:

Unstable grid frequency impedes grid power system security, reliability and stability. Frequency outside the predefined range results to overheating, increases vibration, and destroys turbine shaft & blades. Under-frequency destroys equipment of consumers. Load-frequency controller is used to create the balance between load and generation of each control area by means of speed control. In this work, frequency deviation problem associated with load frequency control is analyzed by Genetic Algorithm (GA) tuned proportional integral controller (PID) for Afam two area power system. MATLAB codes were developed for GA based PID controller tuning, the results of which were used to study the system step response. Three cases were considered during the load perturbation and the system frequency performances based on the settling time, rise time and % peak overshoot were analyzed. Initially the system was run without the use of the controller (i.e., with all the PID gains = 0) and with a load change of 10% in area 1, and it is found out that the system is unstable. But the introduction of GA tuned PID controller improved the power system dynamic responses as zero ACE was achieved. It is observed from the result that frequency reached steady state value within reasonable time (around 12 sec), peak overshoot was well below 25%, and rise time around 0.5seconds. This illustrates that the improved technique (GA tuned PID controller) provides a lasting solution to the frequent grid frequency instability, caused by mismatch between load demand and generation, which threatens system security, reliability and stability.

KEYWORDS: Load Frequency Controller (LFC), Genetic Algorithm (GA), Proportional Integral Derivative (PID), Frequency, Area Control Error.

Cite This Paper: Cornelius, C. C., Idoniboyeobu, D. C., & Sepiribo, B. L. (2020). Grid Frequency Regulation and Stability Using Load Frequency Control in Power Plants. *Journal of Newviews in Engineering and Technology*. 2(3), 41 – 53.

1. INTRODUCTION

Power systems are used to transform natural energy into electric power. Electric power companies transport electricity to industries and homes to satisfy all kinds of power demands. To improve the performance of electrical equipment, it is significant to make secure the quality of the electric power. It is established that three-phase alternating current (AC) is generally utilized to transport the electricity. Amid the transportation, active power balance and reactive power balance must be controlled between generating and utilizing the AC (alternating current) power. The two balances conform to two stability points: frequency and voltage. When either of the two balances is broken and reset at a new level, the stability points will drift.

A satisfactory quality of the electric power system demands that both the frequency and voltage is maintained at predefined values during operation.

Even though the active power and reactive power have linked effects on the frequency and voltage, the problem of controlling the frequency and voltage can be disconnected. The frequency is deeply reliant on the active power while the voltage is deeply reliant on the reactive power. Therefore, the issue of control in power systems can be broken into two separate problems. The first is about the active power and frequency control and the second is about the reactive power and voltage control. Controlling the active power and frequency is referred to as load frequency control (LFC) (Arora *et al.* 2020). The highest task of LFC is to maintain the frequency constant against the randomly changing loads, which are also known as external perturbations.

Another task of the LFC is to control the transmission line power exchange error. A conventional large-scale power system is made up of various sets of generating units. In order to improve the fault tolerance of the complete power system, these sets of generating units are inter-connected through transmission lines. The use of transmission lines imports a new error into the control problem, i.e., transmission lines (Tie-line) power exchange error. When a sudden load change takes place in an area, that area will obtain energy through the transmission lines from other areas. But ultimately, the area that is subject to the load deviation should stabilize it without external support. Otherwise, it can result to economic conflicts between the areas.

Consequently, each area needs a separate load frequency controller to control the tie-line power exchange error so that all the areas in an interconnected power system can pre-select their set points differently. Therefore, the necessity of the LFC is that, it should be robust against the uncertainties of the system design and the deviations of system parameters in reality.

Summarily, the LFC has two major responsibilities, which are to maintain the predefined value of frequency and to keep the transmission line power exchange under schedule contingent upon any load changes (Saxena, 2019). Additionally, the LFC has to be robust against unknown external perturbation and system design and parameter ambiguities. The high-order interconnected power system could also increase the complexity of the controller design of the LFC.

Genetic Algorithm based technique was applied in carrying out the analysis of this work, because of its simplicity attribute and fast convergence as compared to other solution methods. The technique utilized here is a Genetic Algorithm based PID tuning technique where the two areas interconnected network under analysis is modelled in MATLAB/SIMULINK environment. Simulink is a powerful graphical user interfaces power system simulation software capable of modelling and simulating power system networks.

1.1 Review of Related Work

For satisfactory functioning of a power system, frequency should remain nearly constant. Frequency oscillations can have a negative effect on a power system operation, system efficiency and reliability. Broad frequency deviations can destroy equipment, reduce load performance, overburden transmission lines and meddle with system protection schemes. These high-frequency change events can seriously result to a grid system collapse (Saxena, 2019).

Variation in frequency unfavorably hinders the operation and speed control of synchronous and induction motors. The drop in 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 reduce plant output. Considerable reduction in frequency could lead to huge magnetizing currents in transformers and induction motors, therefore escalating reactive power use. In home appliances, where refrigerators' efficiency goes down, air conditioners and television reactive power use escalates reasonably with decline in power supply frequency. Therefore, it is very imperative to sustain the frequency within permissible limit. As a result of the statistical nature of the load deviations, we cannot avert continual load fluctuations but we can hope to maintain the power system frequency not outside sufficiently small tolerance levels by regulating the load continuously. This is accomplished using automatic generation control (AGC), which requires LFC mechanism for its operation.

Guha *et al.* (2018) had made mention of the main objectives of LFC as:

i. Making certain of zero steady-state error for frequency variations.

ii. Reducing unscheduled transmission line power flows between adjoining control areas.
iii. Getting good monitoring for load demands and perturbation.
iv. Controlling tolerable overshoot and settling down time on the frequency and transmission line power deviations.

Load Frequency Control (LFC) is an additional service that is connected to the temporary balance of load and power systems frequency and obtains a chief role to enhance exchanges of power and to produce a more excellent condition for electricity trading.

The major aim of the LFC is to support zero steady state errors for frequency oscillations and better follow-up of load demands in a multi-area power system. At the power generation unit level, speed governor controls the speed of the turbine as the load on the synchronous generator change. This is known as primary speed control function.

Many control techniques are proposed by the researchers in their earliest work to design LFC controllers (Sabhi *et al*. 2008; Kumar & Kothari, 2005). The controllers are based on:

i. Classical control techniques
   a) Linear Quadratic Regulator (LQR) Based Technique
   b) Proportional, Integral, Derivative (PID) Controlling Techniques
ii. Artificial Intelligence (AI)/Soft computing techniques
   a) Fuzzy Logic Based Techniques
   b) Artificial Neural network (ANN) based techniques
   c) Genetic Algorithm Based Techniques
   d) Particle Swarm Based Techniques
   e) Hybrid and other Techniques

Descriptions of load frequency control (LFC) techniques are chronicled by various researchers.

The analysis carried out using classical control techniques reveal that it will result in relatively high overshoots and transient frequency oscillations (Fathy and Kassem, 2019). Moreover, the settling time of the system frequency deviation is comparatively long and is of the order of 10–20s (Gheisarnejad, 2018).

Gheisarnejad and Khooban (2019) presented their pioneering work on optimal AGC regulator design using this concept. A two-area interconnected power system made up of two indistinguishable power generating plants of non-reheat thermal turbines were thought-out for investigations (Saxena, 2019). Adaptive control is a control technique of controller to conform to parameter variation (Karnavas & Papadopoulos, 2002.

Abazari *et al*. (2019) presented an adaptive controller which uses the a priori known information and satisfies the multi-objective character of the control of the Hungarian power system. They used a PI adaptation to gratify the hyper stability condition for taking care of the parameter variations of the system. Only the obtainable information on the states and output are needed for the control.

Tungadio and Sun (2019) proposed a multi-area adaptive load frequency control (LFC), established on the self-tuning regulator (STR), for an all-inclusive automatic generator control simulator (AGCS). The proposed controller employs a signal synthesis adaptation technique such that the conduct of the system under control is unresponsive to the dynamic load and system parameter deviations. It is modelled in a way that only the plant's-controlled output is fed back to the controller. A reduced reference model is used to streamline the design, making the controller simple to carry-out. Self-tuning controllers are also a part of adaptive control design.

2.0 MATERIALS AND METHODS

The main reason for writing this paper is to investigate the stability and regulation of the power grid network using high dynamic Load Frequency Controller (LFC) in synchronous generator to regulate the grid frequency. The major data sources for this research work are the Rivers State Independent Power Plant (Rivers IPP) and Afam (VI) Power Plant, about 5KM apart, all located at Afam Community, in Oyigbo local government Area of Rivers State. The materials required for the analysis are: The turbine and Governor, the Synchronous Machine, three phase transformer, and the tie-lines of the aforementioned power plants.

The software that has been used to carry out the simulations is the MATLAB/SIMULINKS. MATLAB/SIMULINK is a professional graphical user interface (GUI) that allows the creation of sophisticated electrical networks. MATLAB has a powerful GUI called Simulink which is also its simulation environment. It is designed to efficiently create and maintain small circuits as well as very large-scale networks. It has automatic sub-circuit creation methods, similar to other Engineering software, with unlimited levels of hierarchy which resulted particularly useful for the drawing of the simulated interconnected network and transfer function block diagrams.

The power generating plants under consideration are the Open cycle Gas Turbine plants of Rivers IPP and Afam (VI) power plant respectively.
In their research work, Mahmoud *et al*. (2015) posited that the active power control device of a generator is shown in Figure 1. The most important parts are:

i. Speed Changer (or Speed Set-point)
ii. Speed Governor
iii. Hydraulic Amplifier (Also called electrohydraulic unit)
iv. Fuel Gas Control valve.

The above essential parts are connected by linkage mechanism. Their incremental movements are in upward direction. In realism these movements are calculated in millimeters; but for the purpose of this analysis, it shall rather be expressed as power increments, given in MW or per unit MW (P.U MW). The movements are supposed positive in the directions of the arrows, equivalent to “raise” command, linkage motion will be: “A” will move in the downward direction; “C” will move in the upwards direction; “D” will move in the upwards direction; “E” will move in downwards direction. This admits more fuel gas into the combustion chamber, culminating in an incremental rise in generator power output. When the speed reduces, linkage point “B” moves in the upwards direction and again generator power output will increase.

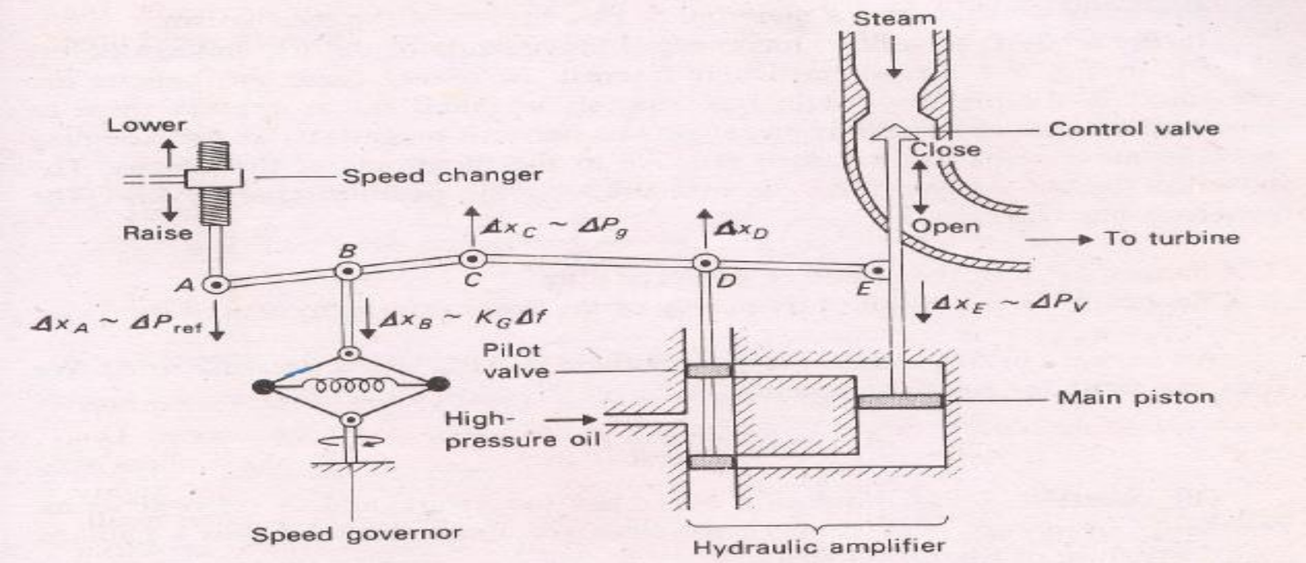

Figure 1: Functional Diagram of Active Power Control Mechanism of a Generator (Mahmoud *et al*., 2015).

As seen in Figure (1), the output command of the speed governor is denoted by ΔP_g, which matches to movement $\Delta_X C$. Speed governors have two inputs:

(i) ΔP_{ref} = Change in the default power setting,
(ii) Δf = Change in the generator speed, as measured by $\Delta_X B$.

Note that a positive ΔP_{ref} will culminate in positive ΔP_g, while a positive Δf will culminate in a linkage points B and C to move downwards, resulting in a negative ΔP_g.

Therefore:

$$\Delta P_g = \Delta P_{ref} - \frac{1}{R}\Delta f \qquad (1)$$

Where: ΔP_g is the change in active power generated, ΔP_{ref} is the change in reference power setting and Δf is the change in frequency of the generator.

The constant R is measured in hertz per MW (Hz/MW) and is known as governor speed regulation. Taking the Laplace transform of Equation (1), we have;

$$\Delta P_g(s) = \Delta P_{ref}(s) = P_{ref}(s) - \frac{1}{R}\Delta f(s)$$

In usual steady state, the turbine power P_T is kept in equilibrium with the electro-mechanical air-gap power P_G arising in zero acceleration, a constant speed and frequency. Amid transient state, let the change in turbine power be ΔP_T and the resulting change in generator power be ΔP_G. The accelerating power in turbine generator unit = $\Delta P_T - \Delta P_G$

Thus,

$$\text{accelerating power} = \Delta P_T(s) - \Delta P_G(s) \qquad (2)$$

Where: ΔP_T is the change in turbine power and ΔP_G is the change in active power generated

If $\Delta P_T - \Delta P_G$ is negative, it will decelerate.

ΔP_T, which is the turbine power increment relies totally on the valve power increment ΔP_v and the characteristic of the turbine. The characteristics of different turbines differ. The transfer function with single time constant for the turbine, can be written as in Equation 5:

$$\Delta P_T(s) = G_T\,\Delta P_v(s) = \frac{1}{1+s\,T_t}\Delta P_v(s) \qquad (3)$$

Where : ΔP_T is the change in turbine power, G_T is the turbine control, T_t the turbine time constant and ΔP_v is the change in turbine pressure. ΔP_G, which is also the generator power increment, relies totally on the change ΔP_D in the load P_D being fed from the generator. The generator always regulates its output so as to meet up with the demand changes ΔP_D. These regulations are significantly instantaneous, surely in comparison with the slow changes in P_T. We can therefore set:

$$\Delta P_G = \Delta P_D;$$

$$\Delta P_G(s) = \Delta P_D(s) \qquad (4)$$

Where: ΔP_G is the change in active power generated, and ΔP_D is the change in load demand.

With regards to Equations (2), (3) and (4), the block diagram developed is updated as shown in Figure 2. This correlates with the linear design of primary ALFC loop disregarding the power system response.

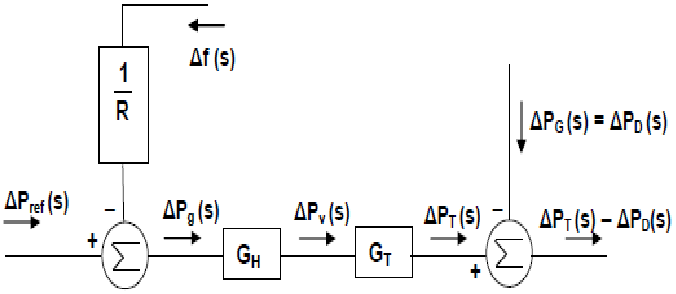

Figure 2: The Block Diagram Corresponding to Primary Loop of Automatic Load Frequency Control (ALFC) Excluding Power System Response. Source (Mahmoud *et al*., 2015).

The current control loop as shown in Figure 2 is open. We can however get some impressive facts about the static performance of the speed governor. The relationship between the static signals (subscript "0") is gotten by letting:

$S \rightarrow 0$. As $\mathbf{G_H(0) = G_T = 1}$

We get directly from Figure 2

$$\Delta P_{T0} = \Delta P_{ref0} - \frac{1}{R}\Delta f_0 \qquad (5)$$

Where: ΔP_{T0} is the change in static turbine power, Δf_0 is the change in frequency at no load and **R** is the speed regulation parameter.

Recall that at steady state, ΔP_T is equal to ΔP_G. i.e., $\Delta P_{T0} = \Delta P_{G0}$
Consider the following three cases:

Case A: The generator is synchronized to a power grid network of very big size, so big that its frequency will be significantly independent of any changes in the output power of this individual generator ("infinite" network). Since $f_0 = 0$, the above Equation (5) becomes:

$$\Delta P_{T0} = \Delta P_{ref0} \qquad (6)$$

Where: ΔP_{T0} is the change in static turbine power, ΔP_{ref0} is the change in static reference power setting.
Therefore, for a generator running at constant speed (or frequency), there exists a direct relationship between the turbine power and reference active power setting.
$\Delta P_{T0} = \Delta P_{ref0}$ i.e., when the generator is operating at constant frequency, if you raise or decrease the speed changer set point, the turbine power output will rise or (decrease) to that extent.

Case B: For instance, considering the network as "finite", i.e., its frequency is fluctuating. What is done however, keep at zero the speed changer set point, i.e., $\Delta P_{ref} = \mathbf{0}$. From Equation (5), we have that:

$\Delta P_{T0} = \Delta P_{ref0} - \frac{1}{R}\Delta f_0$, we now obtain:

$$\Delta P_{T0} = -\frac{1}{R}\Delta f_0 \qquad (7)$$

Where: ΔP_{T0} is the change in static turbine power, ΔP_{ref0} is the change in static reference power setting.

Equation (7) shows that, for a zero-speed changer set point, the static increase in turbine output power is directly proportional to the static frequency drop. Equation (7) can be revised as $\Delta P_{T0} = -R\frac{1}{R}\Delta f_0$. What this means is that, the plot of f_0 with respect to P_{T0} **(orP_{G0})** will be at straight line with – R as its slope.
The unit for **R** is hertz per mw (Hz/Mw). In practice, the power and the frequency can both be represented in per unit (p.u).

Case C: In overall case, changes may both occur in the speed changer set point and frequency in which case the relationship $\Delta P_{T0} = \Delta P_{ref0} - \frac{1}{R}\Delta f_0$ applies.

For a given speed changer set point, $\Delta P_{ref0} = 0$ and hence $\Delta f_0 = -R^*\Delta P_{T0}$. In a graph of frequency-generated power, this represents a straight line with - **R** as its slope.

For a given frequency, $\Delta f_0 = 0$ and hence $\Delta P_{T0} = \Delta P_{ref0}$. What this means is that, for a given frequency, generated power output can be decreased or increased by applicable raise or lower command.

2.1 PID Controller Design:

The design of the PID controller is the most significant part of the Load Frequency Controller (LFC). The preference of PID controller than PI controller guarantees enhanced system response in terms of overshoot and settling time. The Area Control Error signals are regulated by means of PID controller to give control vectors for the Automatic Generation Controllers. In this paper, the PID controller tuning was accomplished through Genetic Algorithm (GA). The proportional **(k_P)**, integral **(k_i)** and derivative **(k_d)** gains were gotten using GA. The transfer function of the PID controller used for the two areas is thought-out to be alike. To obtain the optimized values of the PID gains, appropriate objective function was developed. Moreover, the highest and lowest values of the gains were suitably selected. This objective function (OB) is represented as the sum of the squares of the area control errors (ACE_1 and ACE_2) in each area.

$$G_c = K_P + \frac{K_i}{S} + K_d S \qquad (8)$$

$$\mathbf{OB} = \int_0^{\infty} \sum_{i=1}^{2} (\mathbf{ACE})^2 \mathbf{dt} \qquad (9)$$

Where: $\mathbf{G_c}$ is the governor controller, $\mathbf{K_P}$ is the proportional gain, k_i, the integral gain, K_d, the derivative gain, and OB is the objective function. ACE is the Area Control error.

The optimization issue is established on the reduction of the Objective Function subject to the circumstances that the PID gains $\mathbf{k_p}$, $\mathbf{k_i}$ and $\mathbf{k_d}$ of the two controllers will be situated within the minimum and the maximum limits as established in Equation (10).

$$K_p^{Min} \le K_p \le K_p^{Max}$$

$$K_i^{Min} \le K_i \le K_i^{Max}, K_d^{Min} \le K_d \le K_d^{Max} \qquad (10)$$

Where: $\mathbf{K_P}$ is the proportional gain, k_i, the integral gain, and K_d the derivative gain

Therefore, the PID controller parameters are gotten employing equations (8) and (9) with the help of GA as established in the next section.

2.2 PID Controller Parameter Tuning using Genetic Algorithm:

A mixture of Darwinian Survival of the fittest rule and genetic operation is commonly regarded as Genetic Algorithm. This resulted into an effective approach of optimization. This all-round optimization technique includes stochastic search algorithm. Since the gains of PID controllers, $\mathbf{k_p}$, $\mathbf{k_i}$ and $\mathbf{k_d}$, were to be optimized using Genetic Algorithm, three binary strings were attached to each component of the population in this paper. To make room for the entire range of possible solutions, high value of population size (25) was selected. The application of GA was carried out with parameter encryption. This was accomplished with extreme concern so that the link between the objective function and the strings were controlled correctly. The decimal integers of binary strings were gotten using the following Equation (11).

$$\mathbf{Y_j} = \sum_{i=1}^{l} 2^{i-1} \mathbf{b_{ij}(j=1,2,3,\ldots..L)} \qquad (11)$$

Where:

$\mathbf{Y_j}$ is the decimal coded value of the binary string
$\mathbf{b_{ij}}$ is the ith binary digit of the jth string
l is the length of the string
L is the population size

Following a fixed mapping rule, the continuous variable $\mathbf{x_j}$, Equation (12) was found in the search space where $\mathbf{x_{min}}$ and $\mathbf{x_{max}}$ are the minimum and the maximum values of the variable $\mathbf{x_j}$.
Here, the lowest and highest values of the PID gains were selected as the minimum and maximum limits of the variables.

$$x_j = x_{min} + \frac{\mathbf{xmax-xmin}}{\mathbf{2^l-1}} \mathbf{Y_j(j=1,2,3\ldots\ldots L)} \qquad (12)$$

In the later step, the most demanding task was done; i.e., the estimation of the best values of PID controller gains was secured to minimize the objective function. This task guaranteed minimal overshoot, speedy rise time and fast settling time. Another significant step in Genetic Algorithm was to obtain the highly fit strings in population as the parents and a mating pool was formed. The probability for selecting the i_{th} string is given by:

$$\mathbf{P_i} = \frac{\mathbf{fi}}{\sum_{j=1}^{L}(\mathbf{fj})} \qquad (13)$$

Where:
$\mathbf{f_i}$ is the fitness here. $\mathbf{f_i}$ is the fitness of the $\mathbf{i_{th}}$ population.

Other significant steps were the crossover operation. In this process, new strings were created by swapping the information among the strings of the mating pool. The mutation operator was also brought in to bring variations. Here, mutation rate was selected to be 0.5. This recently tuned PID gains were used to form the PID controller transfer function. The controller transfer function was afterwards used to simulate the entire system response of the both area's Load Frequency Control for a step input. The major objective was to obtain the smallest overshoot, fastest rise time and the settling time for frequency deviation. The algorithm used for tuning PID controller is written below:

i. Set the population size, mutation rate, string size, generation counter, population counter, minimum and maximum values of variables etc.
ii. Code the problem variables $\mathbf{k_p}$, $\mathbf{k_i}$ and $\mathbf{k_d}$ into binary strings.
iii. Create the initial population of 25 members using random number generation
iv. Initialize the generation counter.
v. Increase the generation counter and initialize population counter.
vi. Increase the population counter.
vii. Decode the binary string using (ix) and (x). Use these values of variables in PIDGA blocks of Simulink model to find out the objective function i.e., area control errors (*ACEs*). Send these values to MATLAB code.
viii. Check the fitness.
ix. If the population counter is less than population size, GOTO step 4 and repeat.
x. Select highly fit strings as parents and produce off-springs according to their fitness.
xi. Generate new strings by mating current off-springs using crossover operation.
xii. Introduce variations by using mutation operator and replace the existing strings by new strings.
xiii. Check if the generation counter is less the maximum iteration number. It true, GOTO step 5 and repeat. Otherwise,
xiv. Stop.

3.0 RESULTS AND DISCUSSION

In this paper, simulations were carried out using MATLAB/SIMULINK in connection with Genetic Algorithm tool box. In this work, the study of load frequency control (LFC) is carried out for two-area Afam control and two-area model of non-reheat turbine power systems using load frequency controller (LFC). A load perturbation of 0.1(10%) p.u. is given to both of the areas in the two-area system. Data used for interconnected two-area system are given in Tables 1 and 2.

Here, in this Simulink model, Area 1 is the load frequency controller for Rivers IPP, while Area 2 is the load frequency controller for Afam (VI) power plant respectively. The code for PID controller tuning is written in MATLAB. The transfer functions of the PID controller used for the two areas are thought-out to be alike because it is the same GT model (ALSTOM GT13E2). The best values of PID controller parameters i.e., the gains $\mathbf{k_p}$, $\mathbf{k_d}$ and $\mathbf{k_i}$ obtained using Genetic Algorithm are used in PIDGA blocks of the two area LFC block diagram for Rivers IPP and Afam (VI) power plant (see Figure 3) drawn in MATLAB/SIMULINK environment. The power system parameters used here is given in Table 1. The DISCO (PHEDC) of this problem takes power from the two GENCOs (Rivers IPP & Afam (VI) Power Plant) according to the DISCO.

Participation Matrix (DPM). Here, each element of DPM has a value of 0.5. At the same time each of the GENCO participates in LFC (also Called automatic generation control) according to the area participation factors ($apf_{1)}$ = 0.5 and ($apf_{2)}$ = 0.5.

Table 1: Power System Parameters of Two Area Interconnected Power Systems

Power System Data	**Values**
Generator Time Constants $\mathbf{T_{g1}}$, $\mathbf{T_{g2}}$	**0.2s**
Turbine Time Constants $\mathbf{T_{t1}}$, $\mathbf{T_{t2}}$	**0.3s**
Power System Gains $\mathbf{K_{p1}}$, $\mathbf{K_{p2}}$	**120 Hz/pu MW**
Power System Time Constants	**20 s**
B_1, B_2	**0.425pu MW/Hz**
Speed Regulation of Governors R_1, R_2	**2.4 Hz/pu MW**

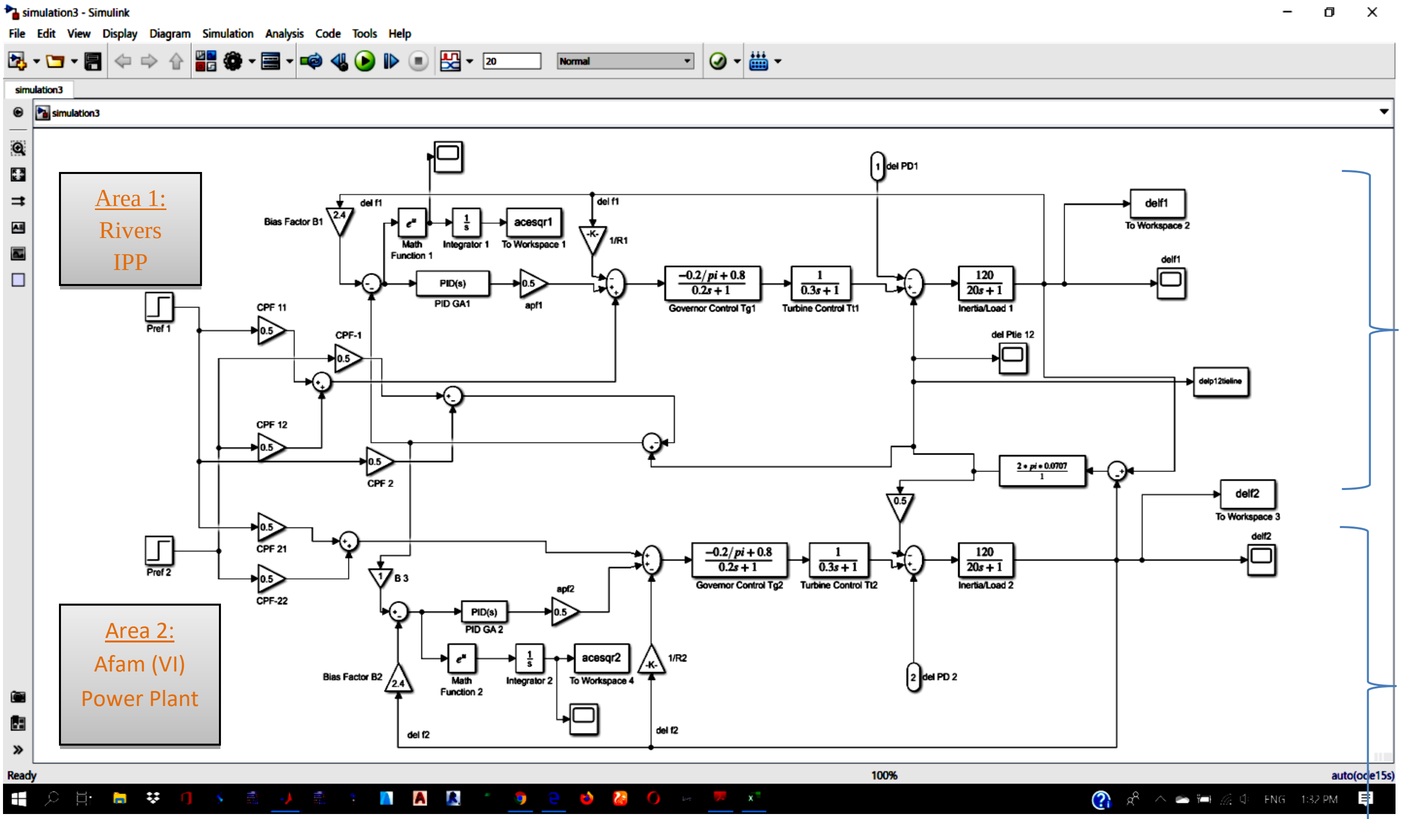

Figure 3: Screenshot of Simulink Model of Two Area Load Frequency Control of Rivers IPP and Afam (VI) PP.

3.1 Load Frequency Control without a Controller:

At first, the system is simulated without the use of the controller due to the load change in the first area (Area 1- Rivers IPP). But it is discovered that the system is unstable. The tie-line power change due to load change in area 1 (Rivers IPP) in the both area load frequency control without controller (i.e., the gains $\mathbf{k_p}$, $\mathbf{k_d}$ and $\mathbf{k_i} = \mathbf{0}$) is shown in Figure 4.

Table 2: Values of PID Gains

Area	K_p	K_i	K_d
1	1 0.224	0.414	0.231
2	0.224	0.414	0.231

3.2 Load Frequency Control with a Controller

Here, with the utilization of the PID controller, the simulation is repeated for the change of load in area 1 (Rivers IPP) by 0.1 (10%) p.u. The corresponding frequency deviations in area 1 (Rivers IPP) and area 2 (Afam (VI) power plant) are shown in Figure 5 and Figure 6 accordingly. The values of PID controller gains acquired through Genetic Algorithm are shown in Table 2. The both area power system without the use of PIDGA was run initially and it displayed unstable response. But with the utilization of Genetic Algorithm tuned PID controller, the system became stable. The performances of the system based on the settling time, rise time and % peak overshoot is shown in Table 3.

3.3 Load Frequency Control with a Controller:

Here, with the utilization of the PID controller, the simulation is repeated for the change of load in area 1 (Rivers IPP) by 0.1 (10%) p.u. The corresponding frequency deviations in area 1 (Rivers IPP) and area 2 (Afam (VI) power plant) are shown in Figures 5 and 6 accordingly. The values of PID controller gains acquired through Genetic Algorithm are shown in Table 2. The both area power system without the use of PIDGA was run initially and it displayed unstable response. But with the utilization of Genetic Algorithm tuned PID controller, the system became stable. The performances of the system based on the settling time, rise time and % peak overshoot is shown in Table 3.

Figure 4: Tie Line Power Deviation (in p.u) with Respect to Time (in seconds) due to Change in Load of Area 1 without any PID Controller.

The tie-line power characteristic shows that the 0.1 p.u change of load in area 1 (Rivers IPP) is shared by both the GENCOs (Rivers IPP and Afam (VI) Power Plant) as per the DPM matrix. It means that 0.05 p.u load will be supplied from GENCO 2 Afam (VI) power plant.

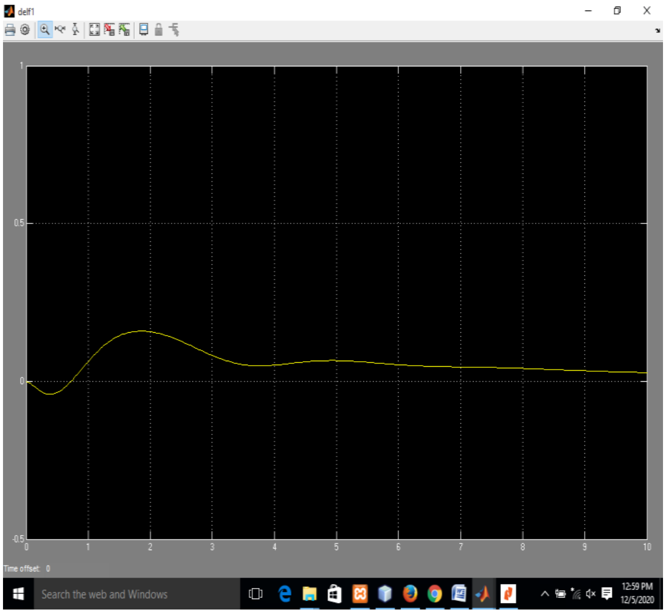

Figure 5: Frequency Deviation with Respect to Time (in seconds) in Area1 due to 0.1 p.u Load Change in Area 1

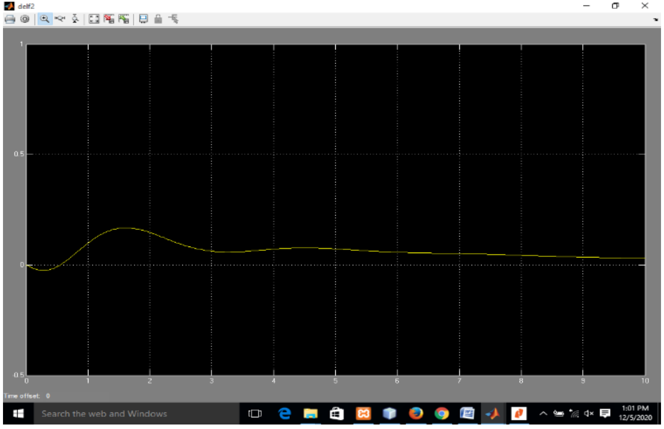

Figure 6: Frequency Deviation (in p.u) with Respect to Time (in seconds) in Area 2 due to 0.1 p.u Load Change in Area 1

Table 3: Performance Study

Parameters	ΔF_1	ΔF_2	$\Delta P_{tie12actual}$
Rise Time (s)	0.5086	0.466	4.3678
Settling Time (s)	12.562	12.44	10.155
% Peak Overshoot	13	17	9

It is shown from Table 3, that peak overshoot is well below 25%, rise time and settling time are also within predefined limits i.e., the steady state frequency is achieved within 12 sec (approximately) after the abrupt change of load in area 1. Performance of the Genetic Algorithm based PID controller used in this work was compared with the Conventional PI controller developed in the works of Huang (2019).

Table 4 shows the efficiency of the Genetic Algorithm based PID controller over the performance of the conventional PI controller.

Table 4: System Response with GA Based PID Compared with Conventional PI Controllers.

Controller	% Overshoot (Hz)	Settling Time (Sec.)
GA Based PID ΔF_1	13	12.5620
Conventional PI ΔF_1	22	35.0893
GA Based PID ΔF_2	17.0	12.44
Conventional PI ΔF_2	17.8	38.2914

4.0 CONCLUSION:

In this paper, the regulation of grid frequency using load frequency controllers (LFC) was been studied to understand the main challenges that grid regulation hold and what to do to stabilize and control the system frequency and tie-line power within predefined limit. The comprehension of how the grid system frequency is controlled using generator load frequency controller (LFC) has given place to the synchronous generator as the de facto controller of the grid frequency. It has been studied along with its regulator which proved significant in order to guarantee the mains stability. The aim of this dissertation is to design a load frequency controller (LFC) for the regulation and stability of grid system frequency as well as tie-line power in Afam two area interconnected power system.

The methodology adopted was first to perform a literature review on load frequency controllers. It was then followed by an analysis of many other load frequency control techniques (LQR, PID, Fuzzy Logic, ANN, GA, PSBT etc.).

Load frequency controllers (LFC) are an integral component of all GT sets as they play an important role of maintaining a balance between load generation and load demand as demonstrated in this research work. The objectives of this research were to design a load frequency controller for the regulation of the area control error within the shortest possible time as well as controlling the tie-line power swings in a two area Afam interconnected system. The tools used to accomplish these objectives were designed in MATLAB/SIMULINK, using tools from the SimPower Systems Toolbox PID and Genetic Algorithm.

Genetic algorithm optimization technique approach used in this work was useful for finding the optimal gains (**K_p**, **K_i** and **K_d**) of the proportional, integral and derivative controllers of the simulated system. Stability of the system was also verified after putting the optimized value of the integral gains of the controller. This proposed controller reduced the frequency deviation and net tie-line power flow deviation most effectively, which shows the effectiveness of the controller. As the effect of tunable parameters of GA technique present in both the areas of the two-area system is better. In thermal-thermal system, stability comes faster.

The peak deviation and amplitude of oscillation increases and settling time almost constant. The parameter of controller is managed by GA which gave more efficient output. It gave less distortion in output frequency and reduced the tie-line power swings in fewer time limits. Less time (around 12 sec) to settle the excursions of system frequency within acceptable limits which is better than the 38sec settling time for the conventional PI controllers. The system response rise time for both areas were well below 0.5 seconds, maximum deviation and settling time improved to around 12 seconds when we tuned the PID using GA optimization technique. In this work, %peak overshoot was around 13% as compared to 22% for the conventional PI controllers.

REFERENCES:

Abazari, A., Monsef, H., & Wu, B. (2019). Coordination Strategies of Distributed Energy Resources Including FESS, DEG, FC and WTG in Load Frequency Control (LFC) Scheme of Hybrid Isolated Micro-Grid. *International Journal of Electrical Power & Energy, , 109*, 535-547.

Abdullah, A.-D., & Yu, C. C. (2016). Generation and Load Balance using Linear Quadratic Gaussian Control. *North American Power Symposium (NAPS) 2016*, 1-5.

Ahmad, S., & Hawkins, J. (2015). Properties of Sparse Distributed Representations and their Application to Hierarchical Temporal Memory. *Numenta*.

Alhelou, H. H., Hamedani-Golshan, M. E., Zamani, R., Heydarian-Forushani, E., & & Siano, P. (2018). Challenges and Opportunities of Load Frequency Control in Conventional, Modern and Future Smart Power Systems:A comprehensive review. *Energies, 11(10)*, 2497.

Arora, K., Kumar, A., Kamboj, V. K., Prashar, D., Jha, S., Shresstha, B., & & Joshi, G. P. (2020). Optimization Methodoloies and Testing on Standard Benchmark Functions of Load Frequency Control for Interconnected Multi Area Power System in Smart Grids. *Mathematics, 8(6)*, 980.

Atul, D., Goshaidas, R., & Arun, K. (2016). Genetic Algorithm based Decentralized PI Type Controller: Load Frequency Control. *Journal of The Institution of Engineers (India)*, Series B.

Aziz, A., O. A. T., & & Stojcevski, A. (2018). Analysis of Frequency Sensitive Wind Plant Penetration Effect on Load Frequency Control of Hybrid Power System. . *International Journal of Electrical Power & Energy Systems, 99*, 603-617.

Barik, A. K., & Das, D. C. (2018). Expeditious Frequency Control of Solar Photovoltaic/Biogas/Biodiesel Generator Based Isolated Renewable Microgrid Using Grasshopper Optimisation Algorithm. . *IET Renewable Power Generation, 12(14)*, 1659-1667.

Chaturvedi, D., Malik, P., & Choudhury, K. (2009). Polar Fuzzy Adaptive Power System Stabilizer. *The Institution of Engineers(India), vol. 90*, (pp. 35-45).

Dahab, Y. A., Abubakr, H., & Mohamed, T. H. (2020). Adaptive Load Frequency Control of Power Systems Using Electro-Search Optimization Supported by the Balloon Effect. . *IEEE access, 8*, 7408-7422.

Gheisarnejad, M. (2018). An effective hybrid harmony search and cuckoo optimization algorithm based fuzzy PID controller for load frequency control. . *Applied Soft Computing, 65* , 121-138.

Gheisarnejad, M., & Khooban, M. H. (2019). Secondary Load Frequency Control for Multi-MicroGrids: HiL Real-Time Simulation. *Soft Computing, 23(14)*, 5785-5798.

Guha, D., Roy, P. K., & & Banerjee, S. (2018). Application of Backtracking Search Algorithm in Load Frequency Control of Multi-Area Interconnected Power System. *Ain Shams Engineering Journal, 9(2)*, 257-276.

Guha, D., Roy, P. K., & & Banerjee, S. (2018). Maiden Application of SSA-Optimised CC-TID Controller for Load Frequency Control of Power Systems. *IET Generation, Transmission & Distribution, 13(7)*, 1110-1120.

Hanwate, S. D., & Hote, Y. V. (2018). Optimal PID Design for Load Frequency Control using QRAWCP Approach. . *IFAC-PapersOnLine, 51(4)*, 651-656.

Hasanien, H. M., & El-Fergany, A. A. (2019). Salp Swarm Algorithm-Based Optimal Load Frequency Control of Hybrid Renewable Power Systems with Communication Delay and Excitation Cross-Coupling Effect. *Electric Power Systems Research, 176* , 105938.

Mohamed, M. A., Diab, A. A., Rezk, H., & Jin, T. (2020). A Novel Adaptive Model Predictive Controller for Load Frequency Control of Power Systems Integrated with DFIG Wind Turbines. . *Neural Computing and Applications, 32(11)*, 7171-7181.

Mohan, A. M., Meskin, N., & & Mehrjerdi, H. (2020). A Comprehensive Review of the Cyber-Attacks and Cyber-Security on Load Frequency Control of Power Systems. . *Energies, 13(15)*, 3860.

Pegah, O., & R., M. (2017). LMI-Based Robust Predictive Load Frequency Control for Power Systems With Communication Delays . *Power Systems IEEE Transactions on, 32(5)*, 4091-4100.

Pradhan, C., & Bhende, C. N. (2019). Online Load Frequency Control in Wind Integrated Power Systems using Modified Jaya Optimization. . *Engineering Applications of Artificial Intelligence, 77*, 212-228.

Sahel, S. S., & Boudour, M. (2015). *Application of Particle Swarm Optimization Based Neural Network to Fault Classification.* Algiers, Algeria: Electrical & Industrial Systems Laboratory-LSEI, University of Sciences & Technology Houari Boumediene.

Sambariya, K., & Nath, V. (2016). Load Frequency Control Using Fuzzy Logic Based Controller for Multi-Area Power System. (pp. 1-19). British Journal of Mathematics & Computer Science.

Saxena, S. (2019). Load Frequency Control Strategy Via Fractional-Order Controller and Reduced-Order Modeling. *International Journal of Electrical Power & Energy Systems, 104*, 603-614.

Shang-Guan, X., He, Y., Zhang, C., Jiang, L., Spencer, J. W., & Wu, M. (2020).