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Synthesis of Electric Sub-Network's Load Frequency Control Scheme to Mitigate System Collapse

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ABSTRACT

This paper was developed to underpin the synthesis of control scheme in the electricity network operation; as means of reinforcing the network within the local area or region. The methods adopted involved the use of the unit commitment strategy and proportional integral (PI) control action. A segment of the Ikeja-West Sub-network was adopted as the case study. This is because the network is the largest in the nation. So also; it accommodates three major state-of-the-art generators which are connected directly to its busbar. These are AES/Egbin, Omotosho and Olorunsogo power stations. These generators were combined in a technically proficient manner with the help of a list of crucial assumptions. This technique initially generated a load sharing formula using the governor droop-power output curve of generators. While the daily load curve was obtained by selecting the maximum peak load point over a period of time at the node of the Ikeja-West (330 kV) bus. For each load interval, frequency deviation was computed for all possible coalescence of the generators. This produced a number of generators' combinatorial values. The acceptable figures ranged from 0.0082 to 0.0182 per unit. Additionally, this was extended to the proportional integral controller so as to further reduce the frequency deviation. This correspondingly gave a series of values between 10^{-4} and 10^{-9} per unit Hz. From this, it became evident that the nominal frequency is closely maintained within the standard operating frequency of 50±0.5 Hz.

1. INTRODUCTION

The Nigeria's electricity network is old and fragile due to neglect of infrastructural upgrade for a more than twenty years until recently. Thus, there is lack of enough generation which has made it difficult for the system operators to make available the spinning reserve which is expected to be ten percent of the total system generation capacity. This is further exacerbated by the volatile loads that are often connected to the national grid. Hence, any slight system disturbance often results in grid collapse because the needed

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operating spinning reserve is not readily available. Thus, the simple approach to overcome this challenge is the introduction of the load frequency controller to the network.

The load frequency control (LFC) which is a subset of automatic generation control (AGC), has been used to regulate power system frequency over the years. Version 02 in section 15(1-3) stated the need for operating reserve as a mandate of the system operators while section 15.3.1 of the grid code emphasized the essential of maintaining the system frequency at 50 Hz. The code further gave the safe region of operation of electricity operation as follows: ±0.5% from 50 Hz (i.e., 49.75 to 50.25Hz) at least 97% of time during normal operation while for system under disturbance shouldn't exceed the range of ±2.5% from 50 Hz (i.e., 48.75 to 51.25 Hz). The Nigeria's grid code encourages the system operation to remain within the safe region of frequency deviation which in an attempt to overrule or overstep this boundary may lead to grievous damaging effects in the generating units and increasing maintenance costs. Thus, the LFC is a good approach to overcoming this challenge. The LFC is compatible with hydrogeneration, thermal generation or a combination of the interconnection of these units in the version of the hydrothermal operation (Aziz *et al.*, 2014). The LFC is crucial to the dynamic system operation in which case, it improves the stability limit of the interconnected systems by damping the low frequency oscillations (Nwohu and Sadiq, 2015).

Most power generators are equipped with speed governors which are used to influence the rotating speed of the turbines, but in practice, it is not compulsory that all the generating units with speed governors in a power system take part in AGC activity (Ramakrishna et al., 2010). The load frequency control is achieved by computing the net changes in the generation required in a system and changing the set position of the generators within their areas so as to keep the time average of the area control error (ACE) at a low value. Simply put, power generation is adjusted to match the load. Different control methods have been employed for load frequency control design, to achieve better dynamic performance. The most widely employed technique is the conventional proportional integral derivative (PID) controllers, (Sahoo and Pradhan, 2015). These controllers are simple to implement, easy to understand and having low cost. The nature of their control strategy is reliable and reported as robust for some operating conditions, (Kothari *et al.*, 1989; Sambariya and Nath, 2016).

The control of power system is quite essential for efficient system operation. Like many other interconnected power systems, the Nigerian grid system is a connection of hydrothermal networks. The gas turbines are the most widely used among turbine systems in electricity generation in Nigeria. This is due to the availability and relatively low price of natural gas in the country. More notably is the fact that the gas turbines can be started and stopped easily which makes them very useful at peak period in energy demand (Egware and Obanor, 2013). For the purpose of management and control, a large power system, like the Nigerian grid is sectioned into a number of control areas, which are interconnected by tie lines. Within the system, load demand on the power system is characterized by continual variations that do adversely impact the system's dynamical process. Hence for this reason, it is necessary to balance generated power with time varying demand, while allowing system real power losses. Therefore, control mechanisms are used to determine inputs that will result in a desired output (Aliyu *et al.*, 2004). Guillamón et al. (2020) pointed out that controller parameters should dynamically vary in line with those power system variables and at the same time keeping frequency requirement.

In a research work, Vanfretti *et al.* (2009) monitored the characteristics of the Nigerian power system and reported poor governor regulation and ineffective load shedding practices as observed from the frequency disturbance record (FDR). Due to this, during 2006 the Nigerian grid suffered twenty-one blackouts and captured a total system collapse that took place on Dec. 2, 2006. Another concern of the Nigerian system operators is the presence of low-frequency oscillations. The frequency decay trend was reported to have been caused by major losses of generation. The range of frequency variation is quite large and load shedding is done manually. It was reported that substation operators are not able to follow the control center instructions promptly which in turn affects the system behavior. Furthermore, Katende and Okafor, (2004) pointed out that the over-concentration of generation sources on a small portion of the country as a strategic problem. This gives rise to heavy losses during transmission, non-optimal load flow and relatively weak grid (Oluseyi, 2010). Some of the problems can be solved by making intelligent geographical planning for the future construction. Nonetheless, existing facilities can be maximized by proper scheduling of available generators' operation and wheeling of appropriate amount of power to designated control areas. With the need of uninterrupted power supply and continuous power system operation, one of the most challenging jobs is to decide which generator units should run at each period of time and for how long so as to satisfy the predictably varying load. The problem is interesting because in a typical power system, there are usually multiple generating units available for deployment. Unit commitment problem seeks to find a schedule and a production level for each generating unit over a given period of time (Bhardwaj et al., 2012). Unit commitment approach is considered a heuristic approach which aims to obtain the best possible solution while accommodating variations in the power system, especially when several thermal units are employed (Shayanfar et al., 2012). There are constraints to be considered in unit commitment problems. These may include online and offline reserves, minimum up time, minimum down time, crew constraints, maintenance constraints, etc. These constraints are to be considered in practice, for committing and de-committing generating units. These conditions cannot always be met, therefore ingenuous ways are devised to ensure that the necessary constraints are taken into consideration and should be used in establishing a loading pattern. The process is monitored closely for effectiveness. Further, it is possible that any one unit in a power system may supply the load demand, but there must be a combination of generating units that will be able supply the load demand (P_D) at any point in time (Krishnarayalu, 2015).

The crux of this research was to devise a means of controlling the power system at Ikeja west sub transmission area, using Unit Commitment approach and to complement this approach with proportional integral controller. The PI controllers are useful for steady state error correction. This is an extension of the simulation results conducted by (Oluseyi et al., 2019) which demonstrated the robustness of the neuro-fuzzy controller in accomplishing frequency control as compared to the fuzzy logic and proportional-integral (PI) controllers. In which case, the neuro-fuzzy controller displayed better settling time and overshoot percentage. However, defining the rules of the operation of artificial intelligent type of controller like neuro-fuzzy could be tricky. Sometimes rules are mismatched and are non-coherent. To attain stability of controller, proper modelling of the of the power system needs to be done but the Nigerian power system is not well defined to make proper modelling possible.

However, Ugwuanyi et al., (2021) pointed out that a comprehensive study of the oscillations and nature of the Nigerian power system is missing, despite its importance. Most model analyses on the Nigerian power system focus on voltage stability. There are usually no area control centers in some operating points, adequate characterization of the electromechanical oscillations is lacking, perhaps due to the continuously changing network structure or inadequate and unreliable dynamic generator data. Hence the use of unit commitment approach and the conventional PI controllers which are simple to implement, easy to understand and having low cost. The nature of their control strategy is reliable and reportedly robust in most cases and conditions. This is according to previous works (Kothari et al., 1989; Sahoo and Pradhan, 2015; Sambariya and Nath, 2016).

2. METHODOLOGY

2.1. Case Study Network

Figure 1 shows a single line diagram of Ikeja-West sub transmission station which is the case study network. Oluseyi et al. (2017) in earlier research analyzed the case study network. The nominal frequency of the network is 50 Hz ±0.5%. The 330 kV Ikeja bus bar is the central point through which power is being transmitted to other smaller stations and buses. The 330/132 kV transmission station is considered strategic and unique to the Nigerian National Grid. The station has seven (7) incoming 330 kV lines, two (2) 330 kV outgoing lines and fourteen (14) 132 kV outgoing lines. The outgoing lines are directed to step down transmission stations in the network.

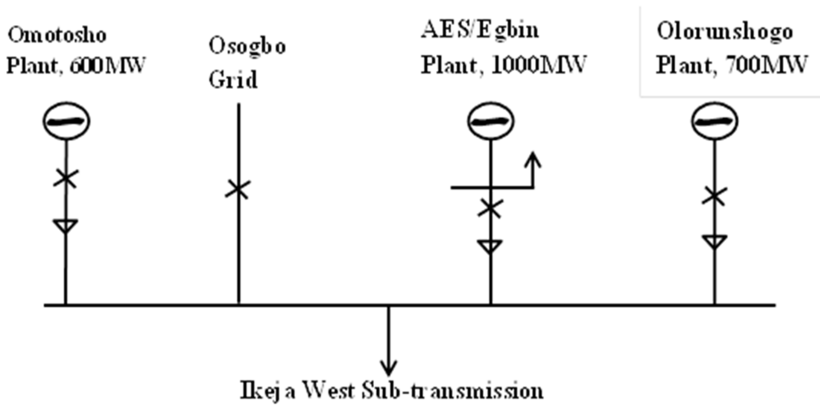

Figure 1: Structural connection of the Ikeja West sub-network

Table 1 shows the parameters and operating capacity of the generating stations. The generator parameters on Table 2 were obtained from (Saadat, 1999). The information contained in the tables were used for the computation of PI controller's constants. Also, the initial voltage droop value of generating stations used in the course of the study are represented by the vector 'd' as shown below.

$$D = [d_1 \quad d_2 \quad d_3] \tag{1}$$

where d_1, d_2, d_3 in equation (1) represent the voltage droop due to the loading effect of the demand on Egbin, Olorunsogo and Omotosho power stations respectively (see Table 2).

Table 1: Generator ratings and capacities of generating power stations

S/N	Name of generating stations	Generator type	No of generator sets	Unit generator rating (MW)	Total installed capacity (MW)	Total available capacity (MW)
1	Egbin / AES	Thermal (steam turbine)	6	220	1320	1000
2	Omotosho I	Gas turbine	8	42	336	600
	Omotosho II (NIPP)	Gas turbine	4	112.5	450	
3	Olorunsogo I	Gas turbine	8	42	650	760
	Olorunsogo II (NIPP)	Thermal (steam turbine)	6	112.5	675	

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Table 2: Operating parameters of the generating stations

Index no.	Name of generating stations	Single time constant (τ_T)	Governor constant (τ_g)	% Change in load per % change in frequency (D)	Per unit inertia (H)	Regulation (R)
1	Egbin / AES	0.2s	0.5s	0.9%	5s	0.04
2	Omotosho	0.6s	0.3s	0.9%	4s	0.04
3	Olorunsogo	0.5s	0.2s	0.6%	5s	0.05

2.2. Data for Load Forecast

The load data was collected from the systems operation log record at Ikeja West Transmission Station at Ayobo in Lagos, Nigeria. The load curve in Figure 2 represents the graphical cross seasonal load variation that is supplied from the Ikeja West sub-station for a period of twelve months (i.e., fifty-two weeks). The load curve was plotted and discretized into weekly intervals as shown in Figure 3. With these activities, it comes easy for the integration of the unit commitment within that region or time slot (to avoid load shedding) whenever the demand is mismatching the supply

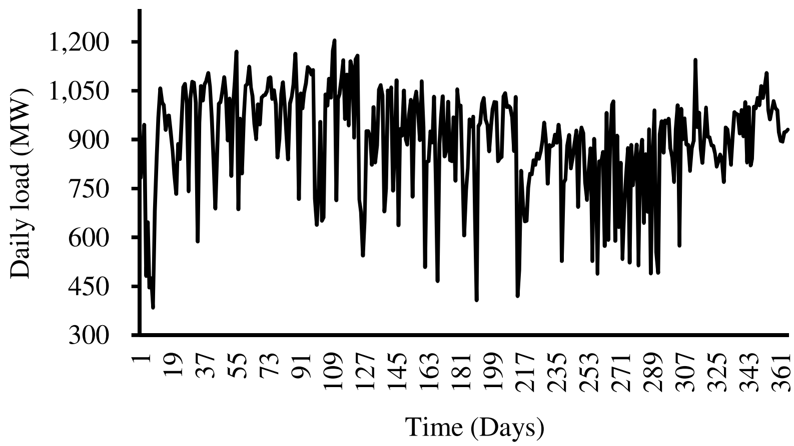

Figure 2: Daily load curve of Ikeja West sub transmission station (for a year)

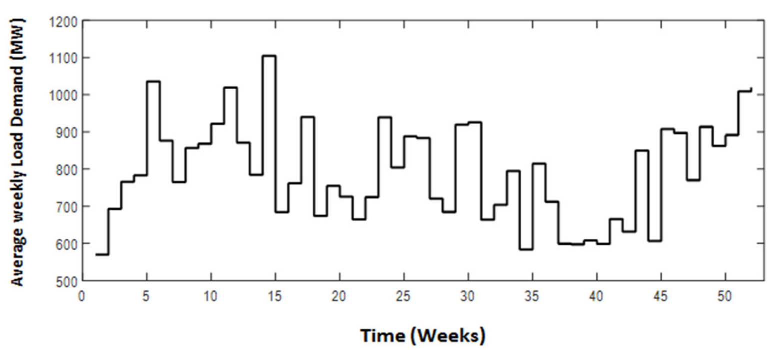

Figure 3: Weekly load curve of Ikeja West sub transmission station (for a year)

2.3. Assumptions

The frequency stabilization is the subject of interest of this research, and it would be given utmost priority while other factors will be treated as constants. Some assumptions were made in the work to cater for the less flexible constraints. These assumptions are as stated below.

i. In this study, it was assumed that there is no power interchange between the Ikeja West transmission bus and Osogbo grid control center or other control centers. Hence, input from Osogbo is not considered. Only Egbin, Omotosho and Olorunsogo generating plants are considered as the available generators.
ii. It was also assumed that the incremental fuel cost of the three generators is the same, and that the generators are operating with the same fuel efficiency. Hence cost study is exempted in this research.
iii. It is also assumed that the generating units are in good working condition, thereby requiring no shedding of load at the load bus, due to fault.
iv. It is also assumed that line losses are of insignificant value.

2.4. Methods

The methods employed in formulating a solution to load frequency fluctuation were unit commitment scheme and proportional-integral (PI) control policy. The procedure for both is explained as follows.

2.4.1. Formulation of equations

Two major equations were formulated by considering the droop characteristic curve of multiple generators operating in parallel in a power system. In Equation (2), the frequency deviation estimator is developed as below.

$$\Delta f = \frac{\sum_{i=1}^{n} P_{mi} - P_D}{\sum_{i=1}^{n} \frac{P_{mi}}{d_i}} \tag{2}$$

Where P_{mi} is the maximum generating capacity of generator, I, P_D is the load demand at a particular instant, d is the droop value of generator governor, Δf is the frequency deviation and n is the number of committed generators.

In the same vein, Equation (3) was developed as a technical strategy for load sharing amongst the committed generators.

$$p_i = (1 - \frac{\Delta f}{d_i}) p_{mi} \tag{3}$$

2.4.2. Algorithm

To establish the procedural steps involved in this study, the following steps were followed, namely:

Step 1: Obtain a load cycle data for load forecast

A twelve-month load demand log was collected for load forecast from Transmission company of Nigeria. While assuming that the power losses in transmission lines are disregarded, the power supplied by the generating sets was assumed to be the load demand on the system. The data was plotted into a graph.

Step 2: Discretization of the continuous load curve

The graph obtained in step one was discretized into fifty-two equal size widths (load intervals). The value of each load interval was taken as the average load during the interval.

Step 3: The generator power rating of the generating stations

Step 4: The theoretical possible number of combinations 'com' for the 'n' number of generating stations was calculated. From the law of combination, for 'n' different elements, the number of possible outcomes is expressed thus: Com= $2^n - 1$. For the three (n=3) generating power stations, the possible combination of the available units for use is seven. This is depicted in Table 3.

Table 3: Synthesis of the Generators connected to Ikeja West Sub-transmission network busbar

Generators	Generator combinations						
	X_1	X_2	X_3	X_4	X_5	X_6	X_7
GS_1	1	1	1	0	1	0	0
GS_2	1	1	0	1	0	1	0
GS_3	1	0	1	1	0	0	1

Zero (0) represents when the generator represented is not operational; One (1) represents when the generator represented is operational

From Table 3, it was seen that there are seven possible ways of using the three available generating units. The state X_1 implies the three generating stations (GS_1, GS_2 and GS_3) are in operation simultaneously. Combination x_2 implies the first two generating stations (GS_1 and GS_2) are deployed while the third generator (GS_3) is off, etc.

Step 5: Starting with the first load interval, the possible frequency deviations for all the possible combinations of generators were computed using Equation (2).

Step 6: The local minimum frequency deviation for selected load interval was selected. Equation (4) captures this step. This minimum frequency deviation must be in the feasible region. A feasible region occurs when the generator unit combinations satisfy the condition that the lowest sum of the generating capacity of the committed generating units is just more than the load demanded. It is the smallest generation value that can closely match the power demand PD_k at that point in time.

$$[F_{dev}]_{\min} = \mathrm{Min}\left\{\frac{\sum_{i=1}^{n} P_{mi} - P_D}{\sum_{i=1}^{n} \frac{P_{mi}}{d_i}}\right\} \tag{4}$$

Subject to the following constraint as shown in Equation (5).

$$\sum_{i=1}^{n} P_{mi} > 0.25\, PD_k \tag{5}$$

This constraint in Equation (5) was added to cater for unexpected sudden increase in power demand.

Step 7: After the computation for the local minimums were achieved, the corresponding unit combination which was responsible for the minimum frequency deviation were identified and selected to be deployed.

Step 8: The load sharing and schedule for each of the generators involved in the selected optimal combination were calculated using Equation 2.

Step 9: The computed minimum frequency deviation was compared with a specified maximum limit. If the limit is exceeded, then supplementary adjustment of droop settings is carried out to reduce the frequency deviation to a range of 50±0.5 Hz. If the limit is not exceeded, the process is terminated for that load interval and the next interval is initiated.

Step 10: The initial steps 1-9 were repeated for the other fifty-one load intervals.

Step 11: A result table containing the regulation of governor control system and generated power of all generating units in each load interval was drawn.

Step 11: A MATLAB/SIMULINK model diagram of the given network was developed, and the simulated network was used to choose the appropriate PI gain constant.

Step 12: The network was simulated for each interval. The transient and steady state response, of the frequency deviation were gotten.

Step 13: At each load interval, the appropriate gain K_i of PI controller required to restore the system frequency to its nominal value was observed and recorded.

2.4.3. Synthesis of the system frequency with the control action

After unit commitment had been used to choose possible local minimum frequency deviation, a PI controller was further used to reduce the minimum deviation so as to attain the nominal value of the network frequency. The information on Table 1 and Table 2 were inserted into Equation 5 to get the transfer function of the three generators. The range of values of the proportional constant (Ka) of the PI controllers were determined from the transfer functions of the generators as shown in Equations (6) through Equation (9).

$$T_a(S) = \frac{(1+\tau T_{a1}S)(1+T_{ga})(R_a S)}{(1+\tau T_a S)(1+T_{ga}S)(R_a s)(2H_a(s)+D_a(s))+K_a} \tag{6}$$

Each of the parameters used in Equation (5) has been named on Table 1 and Table 2.

$$T_{11}(S) = \frac{(1+0.2s)(1+0.5s)(0.04s)}{(1+0.2s)(1+0.5s)(0.04s)(10+0.9)+K_{11}} \tag{7}$$

$$T_{12}(S) = \frac{(1+0.6s)(1+0.3s)(0.04s)}{(1+0.2s)(1+0.5s)(0.04S)(8+0.9)+K_{12}} \tag{8}$$

$$T_{13}(S) = \frac{(1+0.5s)(1+0.2s)(0.05s)}{(1+0.2s)(1+0.5s)(0.4S)(8+0.9)+K_{13}} \tag{9}$$

The transfer functions of the three generating stations were derived from synthesis of the simulated diagram shown in Figure 4. The characteristic polynomials were further solved employing Routh Hurwitz polynomial and the values of the constant k_a were hypothetically found to exist within the range of values shown below.

$0 =< K_{11} =< 3.0523$

$0 =< K_{12} =< 5.555$

$0 =< K_{13} =< 3.710$

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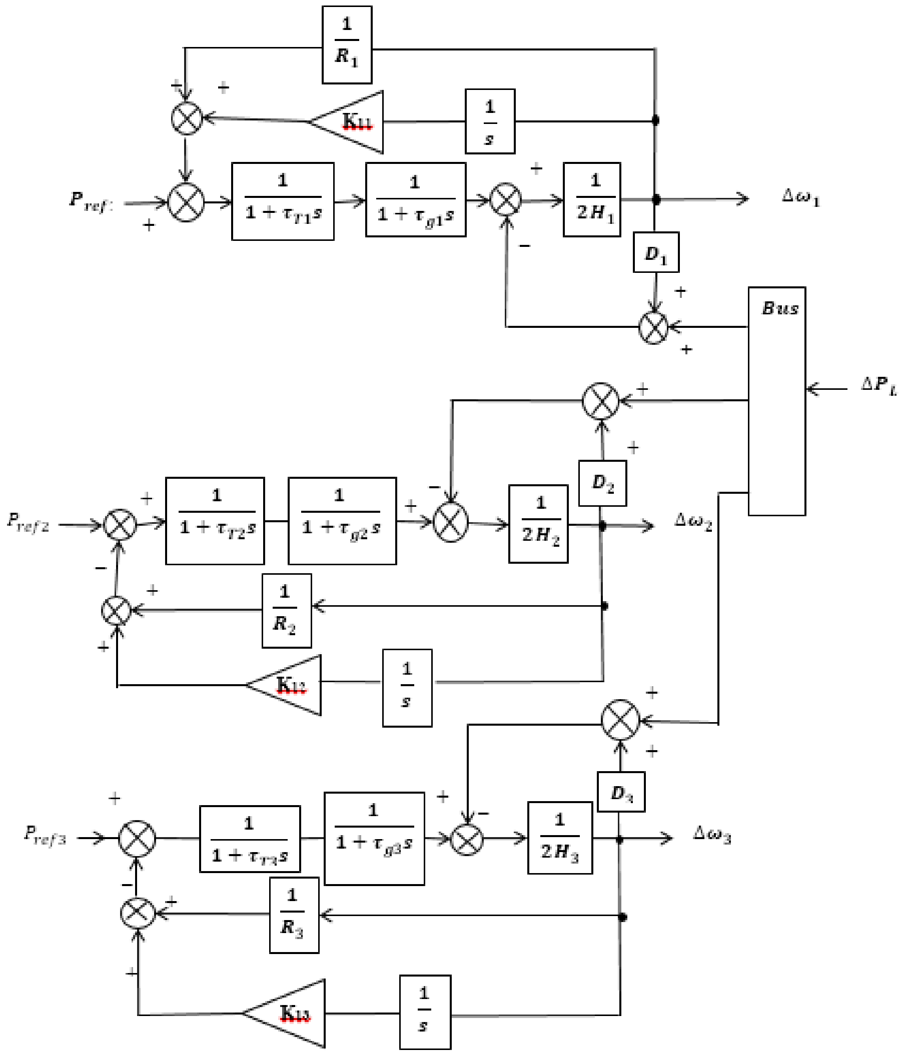

Figure 4: MATLAB/SIMULINKS block diagram for Ikeja west sub-transmission network with controller

3. RESULTS AND DISCUSSION

Table 4 summarizes the frequency deviation for each of the fifty-two load intervals (over a period of one year) after unit commitment scheme had been employed. Also presented on the table are the data of the generators to be committed at each of the intervals alongside the value of electricity that should be committed the various units in these generating stations. The system regulation (R) of the governor droop values for the generators and the proportional-integral (PI) controller constant (K) values for each of the load intervals are also provided for the synthesis.

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Table 4: Variation of system frequency deviation with PI controllers and unit commitment

Week	Ave load (MM)	Min [F_{dev}] per unit Hz	ΔP_D (MW)	Egbin power plant			Omotosho power plant			Olorunsogo power plant		
				P_1 (MW)	R_1	K_{I1}	P_2 (MW)	R_2	K_{I2}	P_3 (MW)	R_3	K_{I3}
1	569.5	0.0125	1,017.00	0.0	0	-	0.0	0	-	569.5	0.037	8
2	693.0	0.0123	936.0	693.0	0.0277	8	0.0	0.03	-	0.0	0.037	-
3	766.0	0.0094	638.0	766.0	0.0306	9	0.0	0.03	-	0.0	0.043	-
4	783.0	0.0087	848.0	783.0	0.313	8.5	0.0	-	-	0.0	-	-
5	1,035.5	0.0107	463.0	0.0	-	-	438.8	0.02	4.5	0.0	0.039	7
6	876.5	0.0160	743.0	0.0	-	-	359.9	0.02	1	0.0	0.034	8
7	765.0	0.0094	1,008.0	765.0	0.0306	9	0.0	-	-	0.0	-	-
8	856.5	0.0167	0.0	0.0	-	-	0.0	0.02	1	506.6	0.033	6
9	868.0	0.0163	776.0	0.0	-	-	0.0	0.02	0.5	512.4	0.033	6
10	921.5	0.0145	521.0	0.0	-	-	0.0	0.02	1	539.2	0.035	6
11	1,019.0	0.0113	418.0	0.0	-	-	430.6	0.02	2.6	588.4	0.038	6
12	871.0	0.0162	602.0	0.0	-	-	357.1	0.02	1.0	513.9	0.033	6
13	784.5	0.0086	953.0	748.5	0.0314	9	0.0	-	-	0.0	-	-
14	1,104.5	0.0124	403.0	690.3	0.0276	8	414.2	0.02	2	0.0	-	-
15	684.0	0.0126	1,012.0	684.0	0.0274	9	0.0	-	-	0.0	-	-
16	761.5	0.0095	1,093.0	761.5	0.0305	9	0.0	-	-	0.0	-	-
17	940.0	0.0139	640.0	0.0	-	-	391.4	0.02	2	548.6	0.036	6
18	674.0	0.0130	1,172.0	674.0	0.0270	9	0.0	-	-	0.0	-	-
19	754.5	0.0098	827.0	754.5	0.0302	9	0.0	-	-	0.0	-	-
20	725.5	0.0110	991.0	725.5	0.0290	9	0.0	-	-	0.0	-	-
21	664.5	0.0134	1,025.0	664.5	0.0266	9	0.0	-	-	0.0	-	-
22	724.5	0.0110	1,009.0	724.5	0.0290	9	0.0	-	-	0.0	-	-
23	939.0	0.0139	670.0	0.0	-	-	390.8	0.02	2	548.1	0.036	9
24	804.0	0.0184	724.0	0.0	-	-	323.8	0.02	2	480.2	0.031	9
25	888.0	0.0156	540.0	0.0	-	-	365.6	0.02	2	522.4	0.034	9
26	883.0	0.0158	658.0	0.0	-	-	363.1	0.02	2	519.9	0.034	9
27	720.5	0.0112	875.0	720.5	0.0288	9	0.0	-	-	0.0	-	-
28	684.5	0.0126	1,031.0	684.5	0.0274	9	0.0	-	-	0.0	-	-
29	919.5	0.0146	549.0	0.0	-	-	381.2	0.02	2	538.3	0.035	9
30	925.5	0.0144	583.0	0.0	-	-	384.2	0.02	2	541.3	0.035	9
31	663.5	0.0135	1,137.0	663.5	0.0265	9	0.0	-	-	0.0	-	-
32	703.5	0.0119	549.0	703.5	0.0281	9	0.0	-	-	0.0	-	-
33	794.5	0.0082	527.0	794.5	0.0318	9	0.0	-	-	0.0	-	-
34	583.5	0.0116	969.0	0.0	-	-	0.0	-	-	583.5	0.038	10
35	814.5	0.0181	499.0	0.0	-	-	329.0	0.02	2	485.4	0.031	9
36	712.0	0.0115	666.0	712.0	0.0285	9	0.0	-	-	0.0	-	-
37	599.0	0.0106	918.0	0.0	-	-	0.0	-	-	599.0	0.039	10
38	597.5	0.0107	1,061.0	0.0	-	-	0.0	-	-	597.5	0.039	10
39	608.0	0.0100	1,088.0	0.0	-	-	0.0	-	-	608.0	0.040	10
40	598.5	0.0106	925.0	0.0	-	-	0.0	-	-	598.5	0.094	10
41	665.5	0.0134	807.0	665.5	0.0266	9	-	-	-	-	-	-
42	631.5	0.0147	1,065.0	631.5	0.0253	9	-	-	-	-	-	-
43	849.5	0.0169	593.0	0.0	-	-	346.4	0.02	2	503.1	0.033	9
44	606.5	0.0101	1,007.0	0.0	-	-	0.0	-	-	606.5	0.039	10
45	907.5	0.0150	527.0	0.0	-	-	375.2	0.02	2	532.3	0.035	9
46	897.0	0.0153	466.0	0.0	-	-	370.0	0.02	2	526.1	0.034	9
47	770.0	0.0092	568.0	770.0	0.0308	9	0.0	-	-	0.0	-	-
48	913.5	0.0148	467.0	0.0	-	-	378.2	0.02	3	535.3	0.035	9
49	862.0	0.0165	756.0	0.0	-	-	352.6	0.02	2	509.4	0.033	9
50	891.5	0.0155	677.0	0.0	-	-	367.3	0.02	2	524.2	0.034	9
51	1,009.0	0.0116	552.0	0.0	-	-	425.7	0.02	2	583.3	0.038	9
52	1,019.5	0.0113	193.0	0.0	-	-	430.9	0.02	2	588.6	0.038	9

As shown in Table 4, the synthesis and analysis were carried out over a period of one year (i.e., fifty-two weeks). The average weekly load demand is also indicated on the Table, while the local minimum frequency deviation (i.e., $F_{dev,min}$) is obtained for each of the weekly intervals after unit commitment alone had been implemented. The range of frequency deviation achieved is between 0.0082 per unit Hz and 0.0182 per unit Hz. Then the synthesis of the system with the PI controller was later employed to further reduce the local minimum frequency deviation (i.e., $F_{dev,min}$) so that the network frequency will assume the nominal value. With the excursion of the frequency; then the difference between the largest and smallest value of load recorded within each load interval was noted. The load division among the variously committed generators from the three stations for each interval was shared among these generators. It should be noted that the load allocation to the various stations are indicated as P_1 for Egbin, P_2 for Omotosho and P_3 for Olorunsogo power stations. It should be noted that for each of the time intervals, the generator combination to be committed was deduced from a set of fifty-two graphs that were generated. The graphs were not captured in this report (due to space constraint), but their implication has been represented on Table 4. The graphs were used to determine or dictate the number of units of generators that are essentially needed to be committed within each time interval. Figure 5 is a typical pattern or trend of such graph with its corresponding explanation as follows.

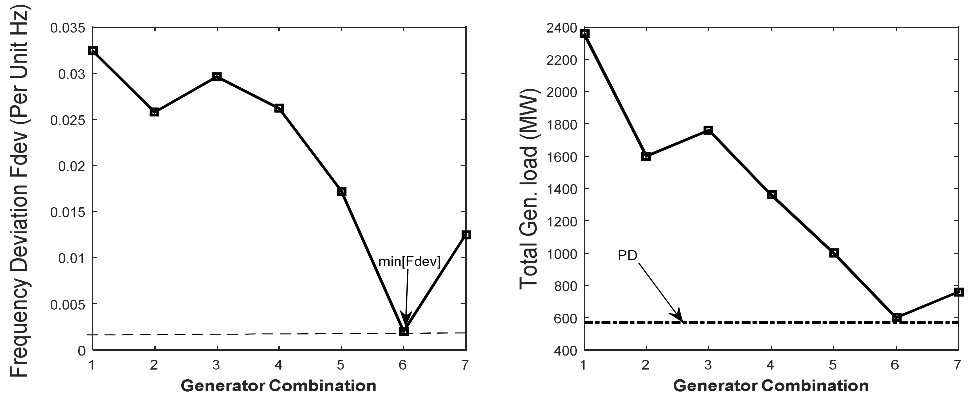

Figure 5: Determination of influence of generators' combination on the frequency deviation

From Figure 5, the horizontal line (P_D) is the load demand line which determines the choice and nature of generator combination that would be engaged. The 2-dimensional plane is divided into two parts or segments by the P_D; whereby the P_D determines the activities of the system. The feasible region exists only above the line P_D while the non-feasible region exists below line P_D. The generator operation's combination units exist in the feasible region are the practicable generator combination whose capacity is equal to or greater than the load demand at that particular time. The plotted points below the line are the impracticable generator combination for a load demand. This is because the generator(s) available for deployment in the non-feasible region cannot match the load demand at that instant in time, whereby the generator's capacity is lower than load demand.

From Figure 5, it can be inferred that all the seven generator combinations are practicable because all the plotted point are above the horizontal line P_D. This implies that the power output of the seven-generator combination is greater than the load demanded at that instant. Though all the generator combination exists on the feasible region, the seventh combination (i.e., X_7) gives the minimum frequency deviation. This is because the capacity of the seventh combination (which is, 760 MW) has the closest capacity to the demand, which is also greater than the load demand at that instant (569.5 MW). It is the supply capacity that matches the demanded load.

Therefore, for the application of unit commitment procedure, it obviously reveal the generator combination with minimum frequency deviation (i.e., $F_{dev,min}$) on the feasible region. From the foregoing; the load demand of 569.5 MW, therefore has the local minimum frequency deviation of 0.0125 per unit Hertz. From Table 4, it is only Olorunsogo generating station that is deployed for meeting the load demand. Whereby Egbin and Omotosho supported the network without any value (i.e., they were both 0 MW). This procedure was repeated for the other intervals and the results are as presented on Table 4.

The unit commitment approach was not used in isolation. Whereby the proportional-integral controllers were used to synthesize the unit commitment principle of operation in order to obtain very satisfactory results. Lastly, the control of the power system was synthesized on the SIMULINKS environment as shown in Figure 4. The responses to the synthesis were recorded as response to the load demand as shown in Figure 5. Meanwhile, Figure 6 is characterized with multiple oscillations as shown in the response before the PI controller was employed whilst Figure 7 shows the response when the controller had been introduced. The

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implementation of this procedure for the other fifty-one intervals shows similar response pattern. The results were observed with an oscilloscope. With the control actions of the PI controllers being appropriately tuned, the range of frequency deviation became much reduced. The order of the values was of the range of 10^{-4} to 10^{-9} per Hz. Hence the goal of maintaining the system's frequency at the nominal value was achieved. It should be noted that the frequency regulation parameters R_1, R_2 and R_3, as shown on Table 4, are essentially needed for the balancing of the load demand with the electric power supply from the Egbin, Omotosho and Olorunsogo generating stations respectively. This is used in the simulated power system.

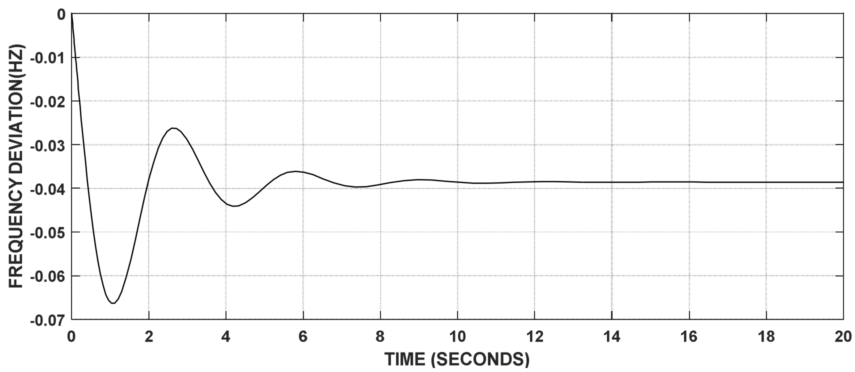

Figure 6: Typical uncontrolled response

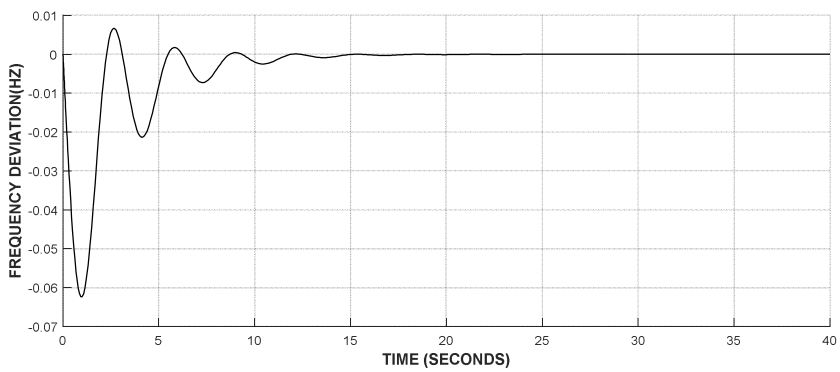

Figure 7: Typical controlled response

4. CONCLUSION

From the results presented, it can be deduced that the range of frequency deviation was within 10^{-9} and 10^{-4} H_Z, which is a slim region when compared to the grid frequency 50 ±0.5 H_Z is satisfactory. In this work, the unit commitment control policy was applied successfully to resolving the load frequency control perception. This strategy does not require a complex model to overcome the load frequency control problem. It is quite easy to understand and replicate for any dimension or complexity of electricity network. In addition, it can be applied to most power systems that have multiple generating stations with various types of turbine systems. It is necessary to note that a higher number of generating stations in a power system gives room for more flexibility and effectiveness in employing the unit commitment control strategy. Thus, it is recommended that this procedure should be extended to cover the whole Nigeria's national grid by localizing the control of the systems. This is for the purpose of providing solutions to Nigeria's electricity network's control activity and frequent system collapse that confronts the nation's grid system due to the absence of supervisory control and data acquisition (SCADA) and other relevant tools for the purpose of effective system control mechanism.

5. ACKNOWLEDGMENT

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6. CONFLICT OF INTEREST

There is no conflict of interest associated with this work.

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