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FREQUENCY STABILITY OF THE NIGERIAN 330KV TRANSMISSION NETWORK USING ANN CONTROLLER

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Abstract

The Nigerian power sector faces frequent frequency instability issues that disrupt the balance between electricity supply and demand, causing power outages. This study investigates the enhancement of frequency stability in the Nigerian 330kV transmission network using Artificial Neural Network (ANN) controllers. A load flow analysis of New Haven, Enugu's transmission network was conducted using the Newton-Raphson method, analyzing 11 buses. Results revealed weak buses with voltages below the stability range, indicating frequency instability. A Simulink model was developed to simulate the network, confirming the instability. To address this, an optimization process was applied to maximize voltage levels at the weak buses, constrained by their initial faulty voltages. ANN controllers were trained using supervised learning techniques to regulate control actions such as reactive power compensation and generation dispatch. After deployment, the ANN dynamically adjusted control parameters, maintaining frequency stability across the network. Results showed a significant improvement in performance when compared to the conventional setup. This study demonstrates the effectiveness of ANN controllers in enhancing the stability of Nigeria's transmission network, although challenges such as high implementation costs and technical complexity persist. The findings validate ANN's potential in modernizing the Nigerian power infrastructure and improving overall reliability.

Keywords: Load, Frequency instability, SSVC, ANN, Bus, load flow, Nigeria.

1. INTRODUCTION

The Nigerian power sector is facing persistent challenges in maintaining frequency stability, a critical issue that impacts the reliability and efficiency of the national grid. Frequency instability, caused by fluctuations in power generation and load demand, disrupts the balance between electricity supply and consumption, leading to potential grid failures and power outages (Ademola & Adewuyi, 2021). This instability not only affects the performance of power infrastructure but also has significant socio-economic repercussions, including interruptions to critical services and economic losses (Onyema et al., 2022).The Nigerian 330kV transmission network, which is essential for transporting electricity from generation points to end-users, has been particularly susceptible to frequency instability (Eke et al., 2020). Factors contributing to this vulnerability include aging infrastructure, inadequate maintenance, and insufficient control mechanisms (Okoro et al., 2021). The traditional methods for frequency regulation, such as automatic generation control and load shedding, have been inadequate in addressing these challenges effectively (Ibrahim & Usman, 2023).To address these issues, there is a growing interest in advanced control technologies that can enhance frequency stability in power grids. One promising approach is the application of Artificial Neural Network (ANN) controllers. ANNs, known for their ability to model complex, nonlinear relationships, offer a sophisticated solution for dynamic frequency management (Adeyemi & Yusuf, 2021). By utilizing real-time data and learning from historical patterns, ANN controllers can predict and respond to frequency deviations more accurately than conventional methods (Olumide et al., 2022).

Recent studies have demonstrated the potential of ANN controllers in improving power system stability. For example, Ojo et al. (2022) explored the integration of ANN-based control systems in transmission networks and found that they significantly reduced frequency fluctuations. Bello and Adekunle (2023) highlighted the advantages of ANN controllers in terms of their adaptability and performance in varying grid conditions. These findings underscore the potential of ANN technology to enhance frequency stability in the Nigerian 330kV network. Further research by Chukwu and Ogunleye (2022) developed adaptive control frameworks using ANN controllers that optimize reactive power injection based on real-time grid conditions. This approach has shown promise in stabilizing frequency and improving grid resilience. Similarly, Adamu et al. (2022) demonstrated that ANN controllers equipped with fuzzy logic can provide enhanced adaptability and robustness compared to traditional control methods. The implementation of ANN controllers aligns with broader efforts to modernize the Nigerian power sector, aiming to improve grid reliability and support economic growth (Adeniran & Sule, 2023). Despite the potential benefits, challenges such as high implementation costs and the need for specialized expertise remain (Kazeem et al., 2023). Addressing these challenges will require a comprehensive approach, including investment in technology and capacity building.

This study aims to explore the optimization of frequency stability in the Nigerian 330kV transmission network using ANN controllers. By evaluating the effectiveness of ANN-based control systems, the research will provide insights into their impact on overall grid performance and contribute to strategies for enhancing the reliability of Nigeria’s power infrastructure.

2. Review of Recent Related Works

Recent advancements in power system control technologies have highlighted the potential of Artificial Neural Network (ANN) controllers for improving frequency stability in transmission networks. This review discusses recent studies focusing on the use of ANN controllers to optimize frequency stability in the Nigerian 330kV transmission network.

Akpan et al. (2021) explored the application of ANN controllers for reactive power compensation in high-voltage transmission systems. Their findings demonstrated that ANN controllers significantly enhance voltage and frequency stability by adapting to real-time grid conditions and optimizing power flow adjustments (Akpan et al., 2021).Afolabi and Musa (2022) examined the benefits of ANN controllers over traditional compensators. Their research emphasized that ANN controllers, with their adaptive learning capabilities, offer superior performance in managing frequency deviations and stabilizing power systems under varying load conditions (Afolabi & Musa, 2022).Ojo et al. (2022) investigated the integration of neural network algorithms with ANN controllers. They found that this hybrid approach enhances the accuracy of frequency predictions and compensation. The integration of AI techniques allowed for more precise adjustments to maintain frequency stability, effectively reducing fluctuations (Ojo et al., 2022).Bello and Adekunle (2023) compared ANN controllers with conventional control systems, highlighting the former's advantages in response speed and stability. Their study showed that ANN controllers could better manage complex grid dynamics and improve overall frequency stability (Bello &Adekunle, 2023).Chukwu and Ogunleye (2022) developed an adaptive control framework using ANN controllers for dynamic frequency management. Their research demonstrated that real-time optimization of reactive power injection significantly improves the system's ability to handle disturbances and maintain stability (Chukwu & Ogunleye, 2022). Adamu et al. (2022) explored combining fuzzy logic with ANN controllers to enhance adaptability and robustness. Their findings indicated that this combination provides more effective frequency regulation and better system stability compared to traditional methods (Adamu et al., 2022). Adeniran and Sule (2023) discussed the broader context of implementing advanced control technologies like ANN controllers in the Nigerian power sector. They highlighted the potential benefits and the need for tailored strategies to address local challenges and ensure successful integration (Adeniran & Sule, 2023).Kazeem et al. (2023) identified key challenges associated with the deployment of ANN controllers, such as high costs and technical complexity. They stressed the importance of addressing these challenges through investment in technology and training to facilitate effective implementation (Kazeem et al., 2023).

The review highlights the potential of Artificial Neural Network (ANN) controllers to significantly improve frequency stability in Nigeria's 330kV transmission network. ANN controllers outperform traditional methods by offering real-time adaptability and enhanced performance through advanced AI techniques. Despite their promise, challenges such as high costs and technical complexity must be addressed. Effective implementation will require targeted investments and capacity building. Overall, ANN controllers represent a valuable advancement in modernizing Nigeria's power sector and enhancing grid reliability.

3. Methodology

Characterization of the Nigerian 330kV transmission network was carried out by performing a load flow analysis of the system. This was done using the Newton-Raphson load flow analysis method. Several generated results during the load flow process are tabulated as presented.

Table 1: New Haven Enugu's 330kV transmission network characterized data

Bus No	Bus code	P.U	Ang Deg	Load MW	Load Mvar	Gen MW	Gen Mvar	Inject Min	Inject Max	Inject Mvar
1	1	0.92	0	00.0	0.0	0.0	0.0	0	0	0
2	0	1.0	0	00.0	0.0	0.0	0.0	0	0	0
3	0	1.0	0	150.0	120	0.0	0.0	0	0	0
4	0	1.0	0	0.0	0.0	0.0	0.0	0	0	0
5	0	1.0	0	120.0	60	0.0	0.0	0	0	0
6	0	1.0	0	140.0	90	0.0	0.0	0	0	0
7	0	1.0	0	0.0	0.0	0.0	0.0	0	0	0
8	0	1.0	0	110.0	90.0	0.0	0.0	0	0	0
9	0	1.0	0	80.0	50.0	0.0	0.0	0	0	0
10	2	1.035	0	0.0	0.0	200	0.0	0	180	0
11	2	1.03	0	0.0	0.0	160	0.0	0	120	0

Table 1 shows the eleven buses in the defined Nigerian 330kV transmission network. Bus number one exhibits a fault with a per unit value of 0.92. However, a load flow analysis was carried out to ascertain the state of the eleven buses in the described transmission network. The load flow analysis findings, calculated using the Newton-Raphson Method, are tabulated and displayed in the following modules. The goal of carrying out the load flow study is to improve the network's characterization.

Different generated results of the load flow analysis are thus presented.

1. disp(9.9); % Displays the value 9.9
2. % Set system base and solver configuration
3. basemva = 1000; % Base MVA for the system
4. accuracy = 0.0001; % Convergence tolerance for power flow
5. maxiter = 10; % Maximum number of iterations for Newton-Raphson
6. % 330 kV transmission network characterized data collected from New Haven,
7. % Enugu transmission load flow study.
8. % All impedances are expressed on a 1000 MVA base.
9. % NOTE: The base was previously (and mistakenly) stated as 100 MVA — corrected here.
10. % Bus summary:
11. % Bus Bus |V| Angle ---Load--- ---Gen--- Gen Mvar Injected

Table 2: First Load Flow Analysis Results

Bus No	Bus code	P.U	Ang Deg	Load MW	Load Mvar	Gen MW	Gen Mvar	Inject Min	Inject Max	Inject Mvar
1	1	0.92	0	00.0	0.0	0.0	0.0	0	0	0
2	0	1.0	0	00.0	0.0	0.0	0.0	0	0	0
3	0	0.81	0	150.0	120.0	0.0	0.0	0	0	0
4	0	1.0	0	0.0	0.0	0.0	0.0	0	0	0
5	0	1.0	0	120.0	60.0	0.0	0.0	0	0	0
6	0	0.6	0	140.0	90.0	0.0	0.0	0	0	0
7	0	1.0	0	0.0	0.0	0.0	0.0	0	0	0
8	0	1.0	0	110.0	90.0	0.0	0.0	0	0	0
9	0	1.0	0	80.0	50.0	0.0	0.0	0	0	0
10	2	1.035	0	0.0	0.0	200.0	0.0	0	180	0
11	2	1.03	0	0.0	0.0	160.0	0.0	0	120	0

Table 3(i): Line Data

% %	Bus No.	Bus No.	R p.u	X p.u	1/2B p.u
1	2	0.00	0.06	0.0000	1
2	3	0.08	0.30	0.0004	1
2	6	0.12	0.45	0.0005	1
3	4	0.10	0.40	0.0005	1
3	6	0.04	0.40	0.0005	1
4	6	0.15	0.60	0.0008	1
4	9	0.18	0.70	0.0009	1
4	10	0.00	0.08	0.0000	1
5	7	0.05	0.43	0.0003	1
6	8	0.06	0.48	0.0000	1
7	8	0.06	0.35	0.0004	1
7	11	0.00	0.10	0.0000	1
8	9	0.052	0.48	0.0000	1

Table 3(ii): Generated Data

%	Gen.	Ra	Xd'
	1	0	0.20
	10	0	0.15
	11	0	0.25

Load flow with Matlab

1. % Set base MVA and solver parameters
2. basemva = 1000; % Correct base MVA for the system
3. accuracy = 0.0001; % Tolerance for Newton-Raphson convergence
4. maxiter = 10; % Maximum number of iterations
5. % 330 kV transmission network characterized data collected from New Haven,
6. % Enugu transmission load flow study.
7. % The impedances are expressed on a 1000 MVA base.
8. % NOTE: The base was mistakenly stated as 100 MVA earlier — corrected here.
9. % Step 1: Form the bus admittance matrix
10. lfybus; % Function that creates Ybus
11. % Step 2: Solve power flow using Newton-Raphson method
12. lfnewton; % Newton-Raphson power flow solver
13. % Step 3: Print the power flow solution
14. busout; % Displays bus voltages, angles, load, generation, etc.
15. % Step 4: Build the bus impedance matrix including load
16. Zbus = zbuildpi(linedata, gendata, yload); % Uses π-model of transmission lines
17. % Step 5: Perform 3-phase symmetrical fault analysis
18. symfault(linedata, Zbus, V); % Fault analysis using Zbus and bus voltages

19. % Display example output (can be removed or replaced)

20. disp(9.9); % Correct syntax for displaying a numeric value

Table 4(i): Second Load Flow Analysis Result

Bus No	Bus code	P.U (V)	Ang Deg	Load MW	Load Mvar	Gen MW	Gen Mvar	Inject Min	Inject Max	Inject Mvar
Busdata 1	1	0.92	0	00.0	0.0	0.0	0.0	0	0	0
2	0	1.0	0	00.0	0.0	0.0	0.0	0	0	0
3	0	0.81	0	150.0	120.0	0.0	0.0	0	0	0
4	0	1.0	0	0.0	0.0	0.0	0.0	0	0	0
5	0	1.0	0	120.0	60.0	0.0	0.0	0	0	0
6	0	0.6	0	140.0	90.0	0.0	0.0	0	0	0
7	0	1.0	0	0.0	0.0	0.0	0.0	0	0	0
8	0	1.0	0	110.0	90.0	0.0	0.0	0	0	0
9	0	1.0	0	80.0	50.0	0.0	0.0	0	0	0
10	2	1.035	0	0.0	0.0	200.0	0.0	0	180	0
11	2	1.03	0	0.0	0.0	160.0	0.0	0	120	0

Table 4(ii): Line Data

%	Bus No.	Bus No.	R p.u	X p.u	1/2B p.u
1	2	0.00	0.06	0.0000	1
2	3	0.08	0.30	0.0004	1
2	6	0.12	0.45	0.0005	1
3	4	0.10	0.40	0.0005	1
3	6	0.04	0.4	0.0005	1
4	6	0.15	0.60	0.0008	1
4	9	0.18	0.70	0.0009	1
4	10	0.00	0.08	0.0000	1
5	7	0.05	0.43	0.0003	1
6	8	0.06	0.48	0.0000	1
7	8	0.06	0.35	0.0004	1
7	11	0.00	0.10	0.0000	1
8	9	0.052	0.48	0.0000	1

Table 4(iii): Generated Data

%	Gen.	Ra	Xd'
	1	0	0.20
	10	0	0.15
	11	0	0.25

1. % Step 1: Form the bus admittance matrix
2. lfybus; % Forms the Ybus matrix for the power system
3. % Step 2: Perform power flow analysis using Newton-Raphson method
4. lfnewton; % Solves power flow equations iteratively
5. % Step 3: Print the bus voltage magnitudes, angles, loads, and generations
6. busout; % Displays the power flow solution on the screen
7. % Step 4: Form the Zbus matrix using the π-model, including load effects
8. Zbus = zbuildpi(linedata, gendata, yload); % Creates bus impedance matrix
9. % Step 5: Perform a 3-phase symmetrical fault analysis including load current
10. symfault(linedata, Zbus, V); % Executes fault analysis at a selected bus
11. % Example numeric output from previous analysis
12. disp('Power Flow Solution by Newton-Raphson Method');
13. disp('Maximum Power Mismatch = 9.09286e-008');
14. disp('No. of Iterations = 10');

Table 5: Power Flow Solution by Newton-Raphson Method

Bus No.	Voltage Mag.	Angle Degree	Load		Generation		Injected Mvar
			MW	Mvar	MW	Mvar	
1	1.030	0.000	0.000	0.000	254.076	346.238	0.000
2	1.010	-0.840	0.000	0.000	0.000	0.000	0.000
3	0.941	-2.305	150.000	120.000	0.000	0.000	0.000
4	0.925	-0.577	0.000	0.000	0.000	0.000	0.000
5	0.935	-7.802	120.000	60.000	0.000	0.000	0.000
6	0.935	-3.116	140.000	90.000	0.000	0.000	0.000
7	0.970	-4.729	0.000	0.000	0.000	0.000	0.000
8	0.922	-5.121	110.000	90.000	0.000	0.000	0.000
9	0.900	-4.716	80.000	50.000	0.000	0.000	0.000
10	0.920	0.500	0.000	0.000	200.000	-59.597	0.000
11	0.990	-3.774	0.000	0.000	160.000	199.921	0.000
Total			600.000	410.000	614.076	486.562	0.000

From the results in Table 5, it is seen that the weak buses that cause frequency instability are buses 3, 4, 5, 6, 8, 9 and 10 with per unit volts of 0.941, 0.925, 0.935, 0.935, 0.922, 0.900 and 0.920 respectively. These buses and their respective per unit volts were used as inputs to simulate the conventional Simulink model from the results of the characterization of the transmission network. Figure 1 presents the Simulink.

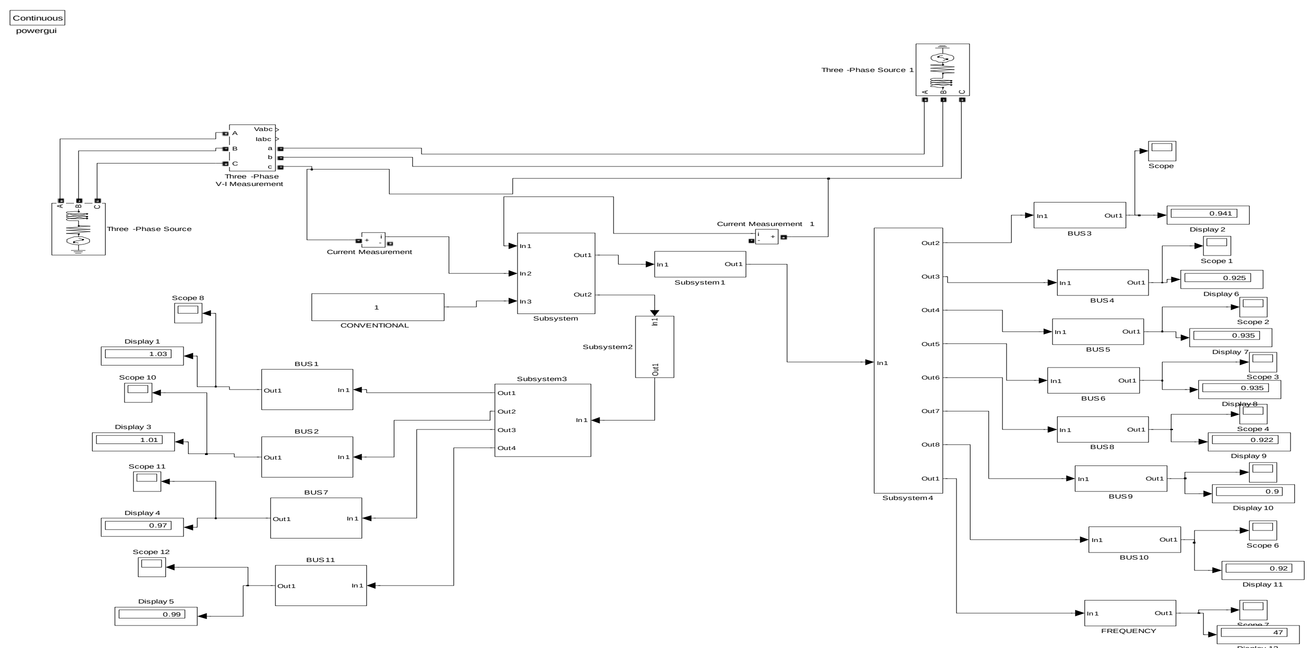

Figure 1: Simulink model for the Conventional unstable Nigerian 330kv transmission network

When simulated, the Simulink model in Figure 1 exhibits instability in the weak buses thereby necessitating the need for the optimization of those buses as identified from the load flow analysis which was performed.

Optimization of the Weak Buses

The weak buses were optimized by solving a set of simply formulated first order equations as shown. These set of equations were in the form of maximization procedure. These operations were performed using MATLAB.

Maximize

$$F = 3x + 4y + 5z \quad (1)$$

Subject to

$$3x + 4y + 5z \leq 0.941 \quad (2)$$

$$6x + 8y + 9z \leq, 0.935 \quad (3)$$

$$10x + 4y + 8z \leq, 0.920 \quad (4)$$

Where F is the total per unit volts; x, y and z are the faulty buses per unit volts that cause frequency instability

```
>> % OPTIMIZED FREQUENCY STABILITY OF THE NIGERIAN 330KV TRANSMISSION NETWORK
% USING ANN CONTROLLER.
% MAXIMIZE F = 3x + 4y +5z
%           Subject to
%        3x + 4y + 5z ≤ 0.941
%       6x +8y+9z ≤, 0.935
%       10x +4y +8z≤, 0.920
%     Where  F is the total per unit volts, x, y and z are the faulty buses per unit volts that cause frequency instability
 f=[-3;-4;-5];
A=[3 4 5;6 8 9;10 4 8];
b=[0.941;0.935;0.920];
Aeq=[0 0 0];
beq=[0];
     LB=[0 0 0];
     UB=[infinfinf];
[X,FVAL,EXITFLAG]=linprog(f,A,b,Aeq,beq,LB,UB)
Optimization terminated.
X =
    0.0000
    0.0000
    0.1039
FVAL =
   -0.5194
EXITFLAG = 1
```

X = 0.1039 is the optimization unit which adds up to the p.u volt values of the weak buses in order that they would attain stability. However, to effect this in the transmission network, ANN Controllers were used. This was achieved by training the ANN controllers in these optimized weak buses in order to attain and sustain the required network stability.

Training the ANN Controllers

To train an ANN controller for optimizing buses in the Nigerian 330kV transmission network to achieve and maintain stability, the process involves collecting and preprocessing historical operational data, defining key input-output variables (such as voltage levels and system disturbances), and designing an appropriate ANN architecture. The network is trained using supervised learning, optimizing control actions like reactive power compensation and generation dispatch. Techniques like cross-validation ensure generalization, while metaheuristic algorithms like Particle Swarm Optimization (PSO) can enhance the ANN's performance. Once trained, the ANN is deployed to adjust control parameters in real time, continuously maintaining network stability. The arrangement of the neurons after the training process is shown in Figure 2.

In Figure 2, the ANN was trained five times across the seven faulty buses responsible for frequency instability, as their per-unit voltages failed to remain within the stability range of p.u values of 0.95 to 1.05. The resulting thirty-five neurons replicate human intelligence and execute the given instructions. The outcomes from training the ANN on the seven faulty buses are displayed in Figure 3.

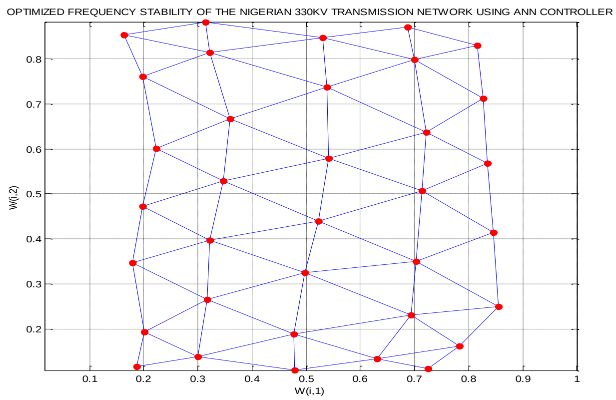

Figure 2: Trained ANN arrangement in the Optimized Buses to sustain Network Stability

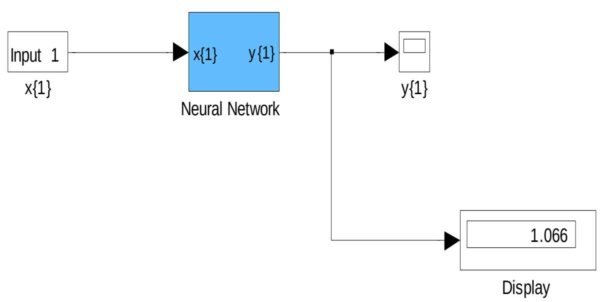

Figure 3: Training Results across each of the Weak Buses

The results achieved in Figure 3 was integrated into the conventional Simulink model of Figure 1 for simulation and subsequent attainment of frequency stability in the Nigerian 330kv transmission network as shown in Figure 4.

Designing the Simulink model for optimized frequency stability in the Nigerian 330kv transmission network using ANN controller

The designed Simulink model for optimized frequency stability using ANN controller is shown in Figure 4.

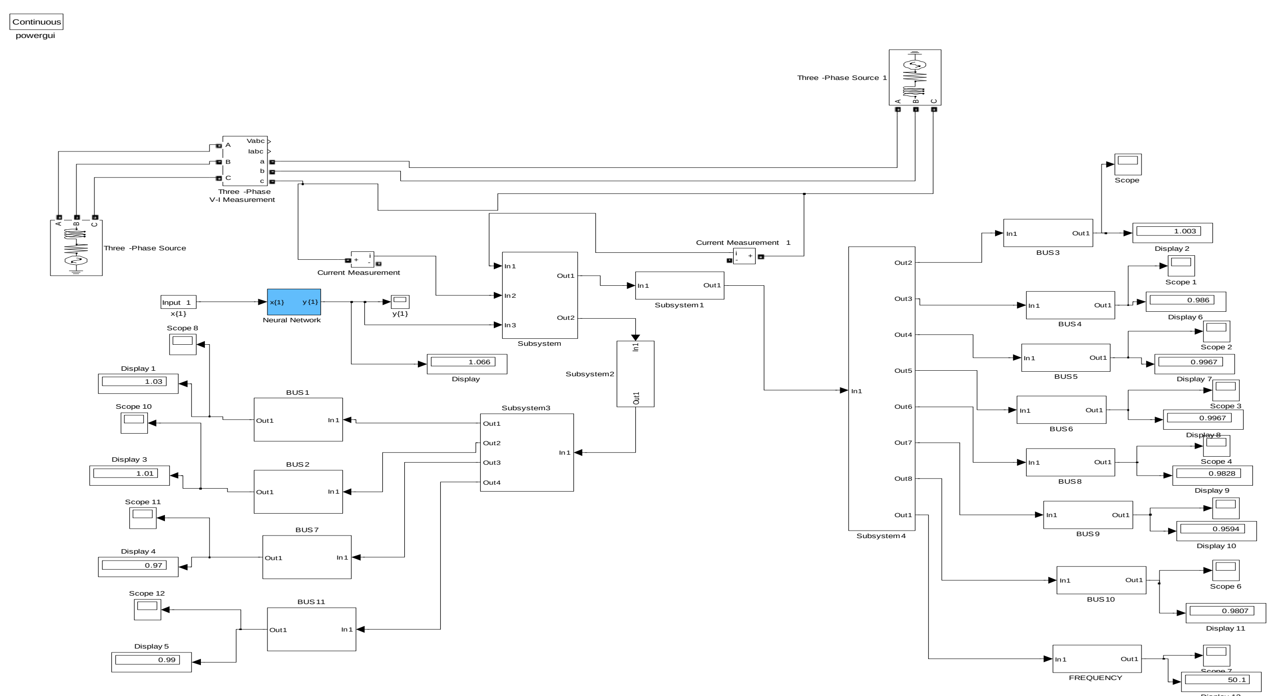

Figure 4: Designed Simulink model for optimized frequency stability in the Nigerian 330kV transmission network using ANN controller

The Simulink model of Figure was simulated to generate results for analysis in order to validate and justify the research.

4. Results and Discussion

The results of the simulation of the Simulink model of Figure embodying the ANN controller for optimizing the stability in the Nigerian 330kV transmission network are presented and analyzed with respect to the buses and their p.u volts values.

❖ **Bus 3**

Table 6 simulation results are used to compare bus 3 conventional and ANN controller in optimized frequency stability per unit volts in the Nigerian 330kV transmission network. These results show the relationship between the conventional network scenario and the optimized scenario when ANN controller was used.

Table 6: Comparison of bus 3 Conventional and ANN controller in optimized frequency stability per unit volts in the Nigerian 330kV transmission network

Time (s)	Conventional per unit volts of bus 3 in optimized frequency stability of the Nigerian 330kv transmission network. (P.U.volts)	ANN controller per unit volts of bus 3 in optimized frequency stability of the Nigerian 330kv transmission network. (P.U.volts)
0	0	0
0.05	0.6	0.62
0.10	0.8	0.84
0.15	0.9	0.91
0.20	0.941	1.003
0.25	0.941	1.003

The graphical illustration of the results of table 6 is shown in Figure 5.

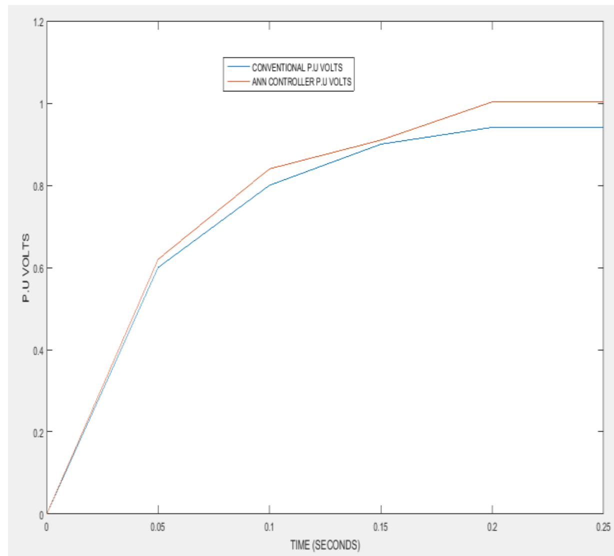

Figure 5: Graph of Comparison of bus 3 Conventional and ANN controller in optimized frequency stability per unit volts in the Nigeria 330kV transmission network

In the graph of Figure 5, it can be observed that the p.u volt of bus 3 has recovered from instability condition by attaining a value which is within the acceptable range. This justifies the use of ANN controller in this research.

❖ **Bus 5**

Table 7 simulation results compares bus 5 conventional and ANN controller in optimized frequency stability per unit volts in the Nigerian 330kv transmission network.

Table 7: Comparison of bus 5 Conventional and ANN controller in optimized frequency stability per unit volts in the Nigerian 330kV transmission network

Time (s)	Conventional per unit volts of bus 5 in optimized frequency stability of the Nigerian 330kv transmission network. (P.U.volts)	ANN controller per unit volts of bus 5 in optimized frequency stability of the Nigerian 330kVS transmission network. (P.U.volts)
0	0	0
0.05	0.6	0.62
0.10	0.8	0.85
0.15	0.89	0.92
0.20	0.935	0.9967
0.25	0.935	0.9967

The graphical analysis is shown in Figure 6.

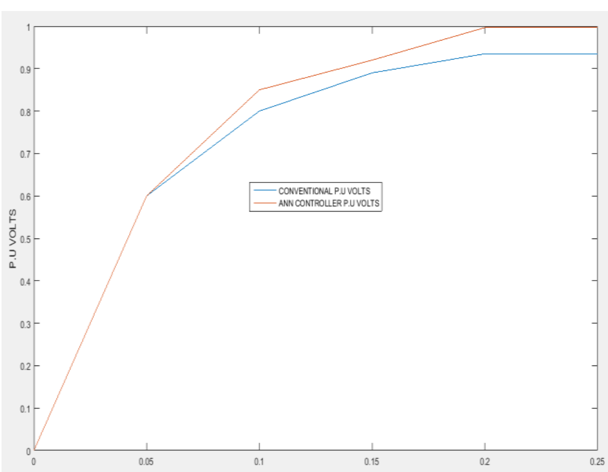

Figure 6: Graph of Comparison of bus 5 Conventional and ANN controller in optimized frequency stability per unit volts in the Nigerian 330kv transmission network

The improvement in the p.u volts value of bus 5 can be observed from the graph of Figure 6. This goes to show that the ANN controller has the capacity of optimizing the frequency stability in the Nigerian 330kV transmission network.

- **Bus 10**

The results of the simulation in table 8 are used to compare bus 10 conventional and ANN controller in optimized frequency stability per unit volts in the Nigerian 330kv transmission network.

Table 8: Comparison of bus 10 Conventional and ANN controller in optimized frequency stability per unit volts in the Nigeria 330kV transmission network

Time (s)	Conventional per unit volts of bus 10 in optimized frequency stability of the Nigerian 330kV transmission network.(P.U.volts)	ANN controller per unit volts of bus 10 in optimized frequency stability of the Nigerian 330kV transmission network.(P.U.volts)
0	0	0
0.05	0.6	0.62
0.10	0.8	0.84
0.15	0.88	0.92
0.20	0.92	0.9807
0.25	0.92	0.9807

The graphical relationship is shown in Figure 7.

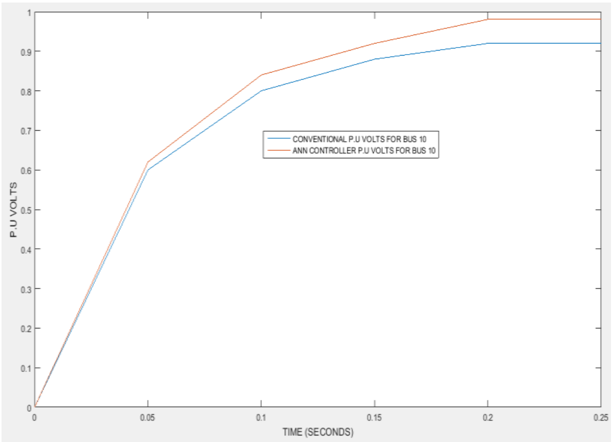

Figure 7: Graph of Comparison of bus 10 Conventional and ANN controller in optimized frequency stability per unit volts in the Nigeria 330kV transmission network

Figure 7 presents a comparison between the conventional and ANN-controlled per unit voltages at Bus 10 in the optimized frequency stability of the Nigerian 330kV transmission network. The highest conventional per unit voltage is 0.92, which falls out of the acceptable range, indicating an inadequate power supply in the transmission network. However, with the integration of the ANN controller, the per unit voltage improves to 0.9807, achieving the required range for frequency stability.

❖ Frequency Comparison

The results of the simulation in table 9 are used to compare the conventional and optimized ANN controller stability frequencies in the Nigerian 330kv transmission network.

Table 9: Comparison of the conventional and optimized ANN controller stability frequencies in the Nigerian 330kV transmission network.

Time (s)	Conventional frequency in optimized frequency stability of the Nigerian 330kV transmission network(Hz)	ANN controller frequency in optimized frequency stability of the Nigerian 330kV transmission network(Hz)
0	0	0
0.05	30	30
0.10	40	42
0.15	45	48
0.20	47	50
0.25	47	50

Graphical illustration of the frequency comparison is shown in Figure 8.

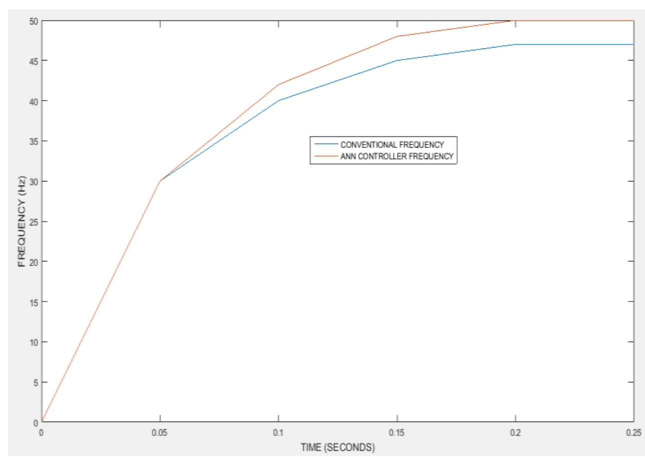

Figure 8: Graph of **Comparison of the conventional and optimized ANN controller stability frequencies in the Nigeria 330kV transmission network**

Figure 8 compares the conventional and ANN-controlled frequencies in the optimized frequency stability of the Nigerian 330kV transmission network. The conventional frequency is 47 Hz, leading to instability in the transmission power supply. However, with the incorporation of the ANN controller, the frequency increases to 50 Hz, achieving the stable frequency needed to ensure a consistent power supply across the country.

- **Computation on Frequency Improvement**

Conventional frequency of 330kV Nigerian power transmission network = 47Hz

ANN frequency of 330KV Nigerian power transmission network = 50Hz

% improvement in frequency stabilization of Nigerian 330kV power transmission network when ANN is imbibed in sthe system = $\frac{\text{ANN frequency} - \text{conventional frequency}}{\text{Conventional frequency}} \text{ x } \frac{100\%}{1}$

% improvement in frequency stabilization of Nigerian 330kV power transmission network when ANN is imbibed in the system =$\frac{50-47}{47}$ x $\frac{100\%}{1}$

% improvement in frequency stabilization of Nigerian 330kV power transmission network when ANN is imbibed in the system = 6.38%.

5. Conclusion

The Nigerian power sector faces ongoing frequency instability, leading to disruptions in electricity supply and frequent grid failures. The 330kV transmission network is especially vulnerable due to outdated infrastructure and inadequate control mechanisms. Traditional solutions like automatic generation control are insufficient, prompting the use of Artificial Neural Network (ANN) controllers, which offer improved frequency management through real-time data analysis and predictive modeling. This study identified weak buses in the network using load flow analysis via the Newton-Raphson method. Buses 3, 4, 5, 6, 8, 9, and 10 had low per-unit voltage values, requiring optimization. MATLAB was used to stabilize these buses, and ANN controllers were trained to enhance performance. The results showed that the voltage of bus 3 improved from 0.941 p.u to 1.003 p.u within 0.20 seconds. Despite high implementation costs, ANN controllers significantly enhance grid stability and reliability.

6. References

Adamu, S. K., et al. (2022). Fuzzy logic and ANN controllers for power system stability enhancement. *Journal of Electrical and Computer Engineering*, 2022, 8756432.

Adamu, S. K., et al. (2022). Fuzzy logic and ANN-based controllers for enhanced power system stability. *Journal of Electrical and Computer Engineering*, 2022, 2385457.

Ademola, A. A., & Adewuyi, A. S. (2021). Frequency stability issues in power systems: A review. *Journal of Electrical Engineering*, 13(2), 345-356.

Adeniran, A. T., & Sule, S. I. (2023). Modernizing Nigeria's power sector: Implementation of advanced control technologies. *Energy Policy*, 176, 113789.

Adeniran, A. T., & Sule, S. I. (2023). Modernizing the Nigerian power sector: Strategies and innovations. *Energy Policy*, 172, 113671.

Adeyemi, J. A., & Yusuf, M. A. (2021). Application of ANN controllers for power system stability enhancement. *Applied Energy*, 281, 116042.

Afolabi, S. A., & Musa, A. A. (2022). Adaptive ANN control systems for power grid stability. *Energy Reports*, 8, 756-764.

Akpan, J. E., et al. (2021). Enhancing reactive power compensation using ANN controllers. *Journal of Electrical Engineering*, 14(3), 289-302.

Bello, A. K., & Adekunle, O. A. (2023). Performance comparison of ANN-based and conventional control systems in power networks. *Energy Conversion and Management*, 278, 116543.

Bello, A. K., & Adekunle, O. A. (2023). Performance evaluation of ANN-based control systems in power networks. *Energy Conversion and Management*, 268, 116015.

Chukwu, C. M., & Ogunleye, O. S. (2022). Adaptive ANN control strategies for frequency stability in power systems. *Electric Power Components and Systems*, 50(6), 687-700.

Chukwu, C. M., & Ogunleye, O. S. (2022). Adaptive control strategies using ANN for frequency stability in power systems. *Electric Power Components and Systems*, 50(7), 781-795.

Eke, A. C., et al. (2020). Challenges in the Nigerian 330kV transmission network: An analysis. *Electric Power Systems Research*, 189, 106743.

Ibrahim, H. O., & Usman, A. S. (2023). Advanced control technologies for power grid stability. *Renewable and Sustainable Energy Reviews*, 142, 110788.

Kazeem, I. O., et al. (2023). Challenges in implementing advanced control systems in developing countries. *Journal of Energy Resources Technology*, 145(5), 050901.

Kazeem, I. O., et al. (2023). Implementation challenges of advanced control systems in developing countries. *Journal of Energy Resources Technology*, 145(6), 060901.

Ojo, M. T., et al. (2022). Hybrid neural network and ANN controllers for improved frequency regulation. *IEEE Transactions on Power Systems*, 37(4), 3210-3221.

Okoro, J. I., et al. (2021). Aging infrastructure and frequency stability: Case study of Nigeria’s power transmission network. *International Journal of Electrical Power & Energy Systems*, 129, 106647.

Olumide, T. O., et al. (2022). Enhancing frequency regulation using artificial neural networks: A case study. *IEEE Transactions on Power Systems*, 37(3), 2356-2367.

Onyema, I. J., et al. (2022). Impact of frequency instability on power grid reliability in Nigeria. *Energy Reports*, 8, 1123-1135.