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Steady state Power Flow improvement on Nigerian 33kV network using ANN control mechanism

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Abstract

The critical infrastructure that links the transmission system and the distribution network was the 33kV network feeders and that has always been the case in the Nigerian power system network. hence, damage on the 33kV systems means a cut off in power flow and electricity distribution to end users. Hence, to ensure functionality of the power system, ANN was introduced to improve the power quality of the system. The network utilized was a 33kV feeder in Owerri Imo state, Nigerian comprising of 7-buses and 7-lines. the system was modeled in PSAT and the simulated voltage and current signal was utilized for the configuration of the artificial neural network (ANN) model and was utilized as a control system in the power system network. to obtain the strategic location for the ANN implementation, the ANN was placed on all the lines sequentially, from the results obtained, it was seen that the optimum (minimum) active and reactive loss of 0.5552pu and 0.614pu respective at line 4. The percentage improvement achieved for the voltage profile, active flow, reactive flow, active loss and reactive loss were 12%, 19%, 22%, 18% and 21.3% respective. The paper has proved that ANN is effective in improving the steady state power quality of a 33kV power system.

Keyword; ANN; Voltage profile; Active and reactive flow; Active and reactive loss; PSAT; Optimum; Power quality improvement

1. Introduction

Electricity is delivered to the users at an acceptable and utilizable levels with adequate stability, reliability and reduced losses and the fundamental phenomenon utilize in determining the level of the requirement was the power flow analysis [27, 28,29]. power flow, which is also identified as load flow obtains the steady state condition of operation of a power system network by determining the voltage angles, voltage magnitudes, real and reactive power flow and real and reactive power losses across the buses and lines in the power system network. the aspect of the implementation of power flow considered important remains its usage in planning, security assessment, operations control of modern power systems and voltage regulations [1,2,8,36]. Hence, the quality of power flow analysis in a transmission network (especially in 33kV system) affects the voltage stability (both in steady and dynamic states), network efficiency, feeding loading and the of the power system to supply electricity to the end-users without voltage violations and electrical losses. The 33kV power system network occupies an important and critical position in emerging and developing networks because it serves as the sub-transmission or medium voltage system that links injection substations to the bulk supply points in major load centers. As the load demand increases, the network experiences little improvement in voltage profiles, increase in weka buses, rise in line losses and reduces the power quality [16, 25, 26]. The research studies caried out on the garki 33kV distribution network indicted that the control and stability of the power are fundamental for the adequate delivery of electricity to consumers and also the operation and design of the power system remains the major concern in power flow delivery [2, 9, 10]. This implied that the 33kV system is not just a passive delivery channels but an active operational zone for the continuous management of voltage profile. Reactive power and load distribution.

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Further research on the Nigerian 33kV network further indicates that poor power flow analysis are manifested due to under voltage in load buses, active and reactive power losses and under utilization of the power system equipment capacity. For instance, in the evaluation of Enugu 33kV/11kV networks using field data and ETAP application software, the 33kV system formally recorded average voltage of 0.89 per unit as a result of under voltage conditions, before the implementation of improvement measures that led to voltage improvement of 0.99 pu with the losses reduced from 2.28% to 1.47% [. These findings show the common challenge in the 33kV network especially when the reactive control and power support are inadequate. The occurrence of voltage drops and increase in power losses weakens the overall power flow performance of the power system network [34,35].

Formal methods utilized for solving power flow issues in power system network includes; adjusting the tapping of a transformer, reconfiguration of a feeder, reactive power compensation, optimal power flow determination, capacitor placement and FACT-based control mechanism. The numerical formats utilized for the determination of power flows were fast decoupled load flow and newton-Raphson flow and these flow models has remained over time the most widely used power flow models as a result of their mathematical robustness for solving non-linear algebraic behaviours [11,12,13, 14] However, in recent times, artificial intelligent and machine learning models have been utilized in the improvement of power flow parameters in high voltage, medium voltage and low voltage network.

In this paper, the use of ANN was utilized in the improvement of a real time 33kV feeder located in kaduna metropolis and power model was utilized as an objective function to the ant colony optimization (ACO) in determining the optimal location for the placement of the intelligent control tool.

2. Literature review

The ANN model system has been widely explored in the real time Nigerian power system network with the aim of improving the steady state power flow, loss reduction and voltage profile [30,31,32,33]. Though the major concentration has been on the Nigerian 330kV transmission system, the 33kV has also been the bane of state improvements in current publications. In this case, ANN is being utilized and implemented as an intelligent controller, together with converters and FACTS. Some of the ways ANN is utilized especially in the steady state power flow improvement were Loss minimization and reactive power control. For the loss minimization, [17] and [5], utilized a hybrid of ANN and UPFC for the minimization of active and reactive power loss and achieved a significant improvement when compared standalone utilization. For the reactive power control, [4] trained ANN using optimal firing angles and control signals as the output to ensure that the FACTS device utilize absorb or injects reactive power and to ensure that the power flow reshaped with low generation of error and ensure quick adaptation. [4] utilized ANN and PSO enhanced DVR control devices to achieve a significant amount of voltage stability and the PSO had a fast conversion of 65%. This was achieved on an IEEE 33 bus network in Ibadan, south western Nigeria.

[24] utilized an ANN-based UPRFC FACTS for the minimization of the line losses on the 58-bus network of the Nigerian 330kV power system network. The ANN model was trained for adequate regulation of voltage stability and power flow of the system. The results obtained indicated a high level of line loss reduction and enhanced voltage profile in all the buses modeled. However, the knowledge gap lies in the inability of the integrated control mechanism in considering the dynamic voltages during line losses and other power system issues.

[17] utilized an optimized ANN-based UPFC control mechanism for the improvement of power flow performance. The method utilized a combination of ANN learning with optimization algorithms to improve the control response. The results generated showed the enhanced power transfer capability and power system stability under varying loads. It was observed that the paper lacked validation on real time power system making the model inadequate for real time implementation.

[7] applied an ANN-based dynamic voltage restorer (DVR) for the improvement of the power quality in a 33kV distribution network feeder. The method utilized involved the training of ANN models for the detection of voltage sags and carrying out voltage compensation with the DVR. The results obtained showed a high level of voltage disturbance reduction and the improvement of the power system reliability. The study carried out centered more on power quality in distribution level without considering the transmission network protection and lesser number of buses were considered meaning that the proposed control strategy would not be adequate for higher number of buses.

[10] utilized an ANN-based intelligent power flow control method with UPFC FACTS for the prediction of the optimal control actions for power system network stability. The results generated indicated a reduced power system instability and an enhanced load balancing. The paper failed to carry out a coordinated ANN-based protection framework that would manage power flow and improve the dynamics of the voltage of the network.

[1] utilized a hybrid ANN-based adaptive PI control mechanism for the AC microgrids. The procedure involves the integration of ANN with a droop control and virtual impedance techniques. The results generated showed voltage regulation improvement, stability enhancement and power sharing. The emphasis of the paper was on a lower distribution micro-grid, of which the proposed strategy would not be effective on the control of power flow parameters on a 33kV feeder.

3. Methods

The line diagram of the power system network obtained from the Owerri sub-transmission center was shown in figure 1.

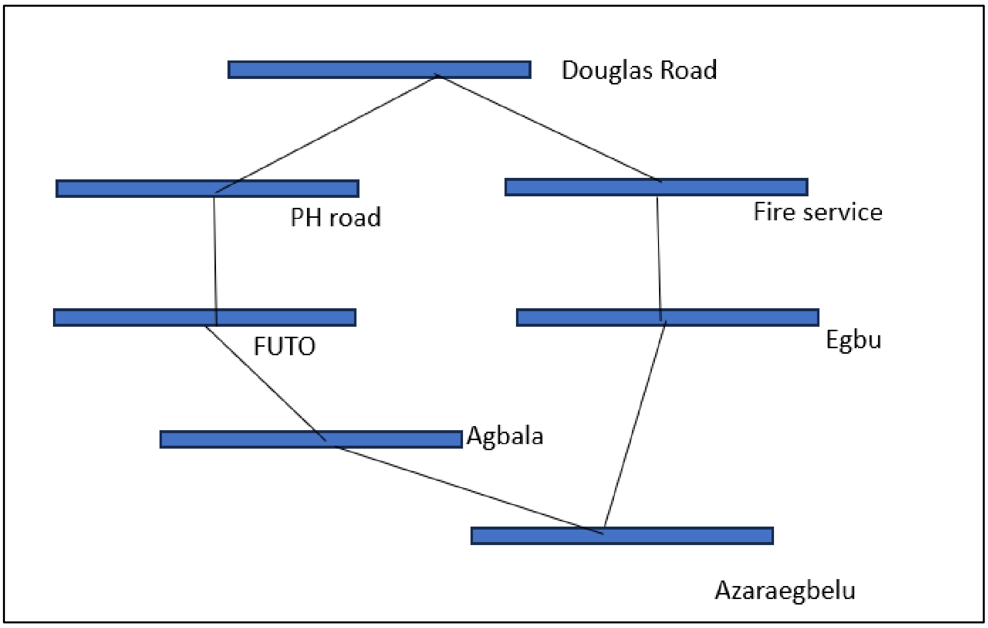

Figure 1 Line diagram of the 33kV power system network

The main feeder bus was situated in Douglas road owerri which was the main center in Imo state, south eastern part of Nigeria. And then distributed to fire service, Egbu community, the to azaraegbelu. Then from douglas road to Port harcourt road (PH road), to FUTO institution, Agbala community then to Azaraegbelu community.

The bus data obtained was presented in table 1;

Table 1 Bus data

Bus number	Bus location	Voltage (pu)
1	Douglas Rd	1
2	Fire service	1
3	PH road	1
4	FUTO	1
5	Egbu	1
6	Agbala	1
7	Azaraegbelu	1

The power system network comprised of 7 buses. The line data utilized was shown in table 2.

Table 2 Line data

Line number	From bus	To bus	Distance (kM)	R(ohm)	X(ohms)
1	1	2	5.5	0.221	0.173
2	1	3	9.3	0.016	0.271
3	2	5	4.7	0.106	0.115
4	3	4	10.2	0.226	0.183
5	4	6	11.3	0.142	0.216
6	5	7	5.2	0.083	0.323
7	6	7	11.4	0.431	0.166

Table 2 showed that there were seven lines.

3.1. Power Flow Modeling

The model of the power system network in the power system analytical tool (PSAT) was shown in figure 2.

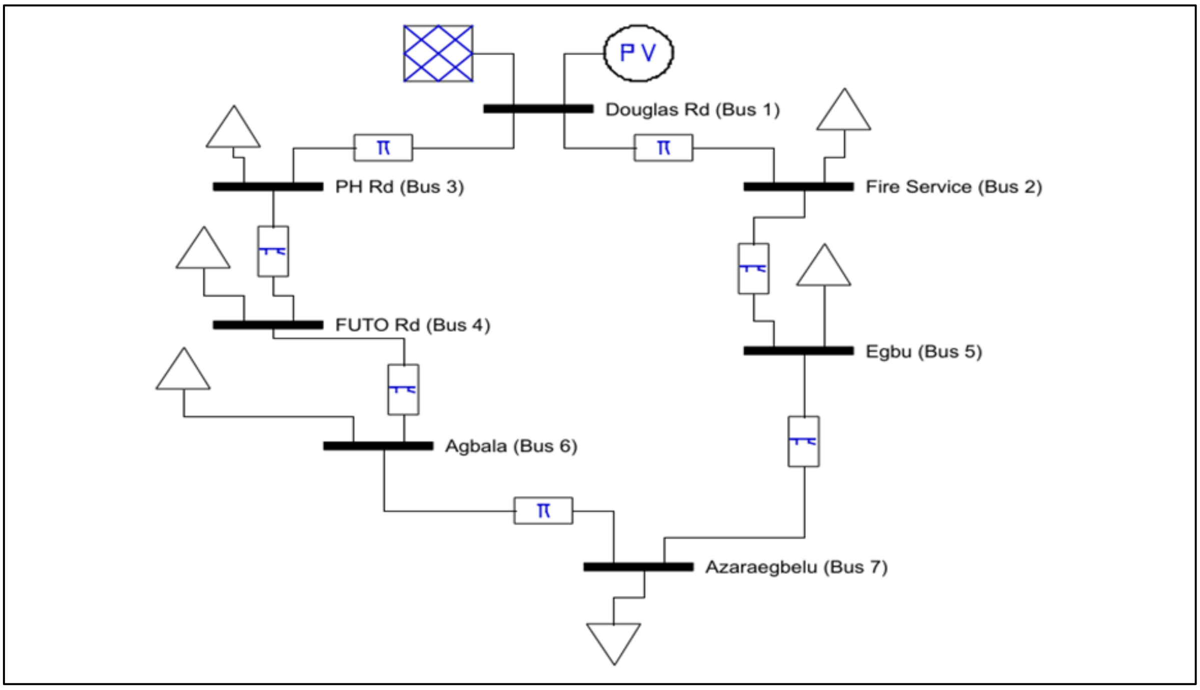

Figure 2 Power system model in PSAT

The power flow model algorithm utilized for the simulation of the power system network modeled in PSAT application shown in figure 2 was the newton-raphson algorithm. The major outcome of the model which was the active flow, reactive flow, active loss and reactive loss.

For the active power flow from bus i to bus j;

$$P_{ij} = V_i^2 G_{ij} - V_i V_j [G_{ij} \cos(\delta_i - \delta_j) + B_{ij} \sin(\delta_i - \delta_j)] \qquad (1)$$

For the reactive power from bus i to bus j;

$$Q_{ij} = -V_i^2 (B_{ij} + B_{sh}) - V_i V_j [G_{ij} \sin(\delta_i - \delta_j) + B_{ij} \sin(\delta_i - \delta_j)] \qquad (2)$$

For the active power flow from bus j to bus i;

$$P_{ji} = V_j^2 G_{ij} - V_i V_j [G_{ij} \cos(\delta_j - \delta_i) + B_{ij} \sin(\delta_j - \delta_i)] \quad (3)$$

For the reactive power from bus j to bus i;

$$Q_{ji} = -V_j^2 (B_{ij} + B_{sh}) - V_i V_j [G_{ij} \sin(\delta_j - \delta_i) + B_{ij} \sin(\delta_j - \delta_i)] \quad (4)$$

The active power loss was given as;

$$P_{loss} = G_{ij}(V_i^2 + V_j^2 - 2V_i V_j \cos(\delta_i - \delta_j)) \quad (5)$$

The reactive power loss was given as;

$$Q_{loss} = -(B_{ij} + B_{sh})(V_i^2 + V_j^2) + 2B_{ij} V_i V_j \cos(\delta_i - \delta_j) \quad (6)$$

Where P_{ij} represents the active power flow, Q_{ji} represents the reactive power loss, P_{loss} represents the active power loss, Q_{loss} represents the reactive power loss, V represents the voltage magnitude of the bus, δ represents the voltage angle of the bus, G represents the transfer conductance on the lines, B represents the transfer susceptance of the line and B_{sh} represents the half line shunt susceptance.

3.2. ANN Modeling and Allocation Strategy

Artificial neural network (ANN) was utilized for the improvement of the power flow in the power system network. for the impact of the ANN system to be maximum, it has to be strategically allocated to the system. Hence the procedure utilized was summarized in the flow chart in figure 3.

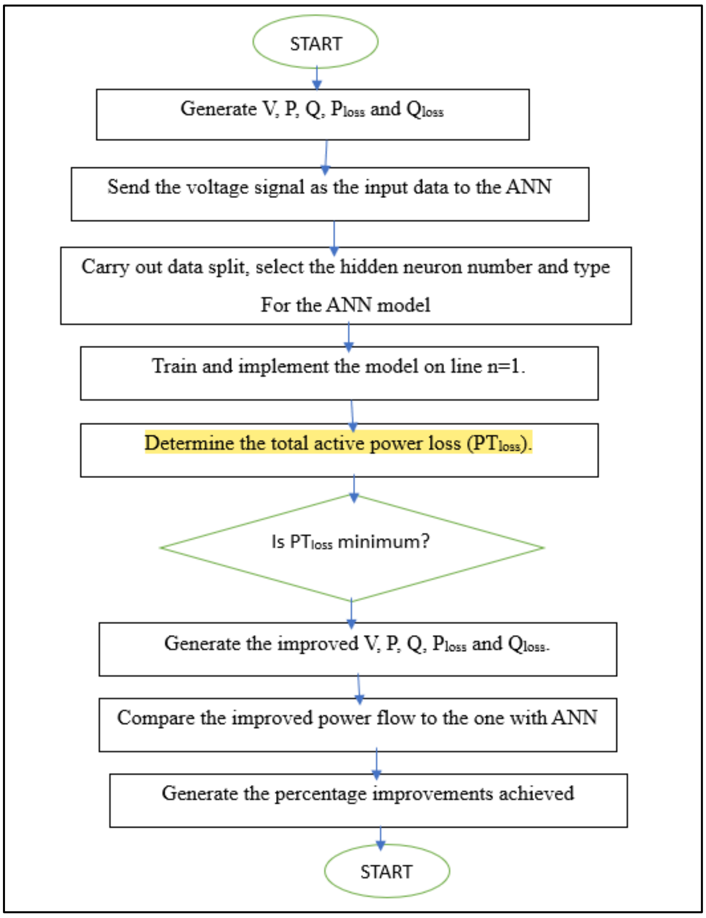

Figure 3 Flow chart of the ANN design and Allocation

The input data for the ANN was the voltage signal from lines and it was done sequentially since the voltage signals for each lines are not the same. The data was split into train, test and validation (data split) by 70%, 15% and 15% respectively. The number of hidden neurons utilized was five (5) because it was observed that at five neurons, the underfit and overfit were avoided. The ANN architecture implemented was shown in figure 4.

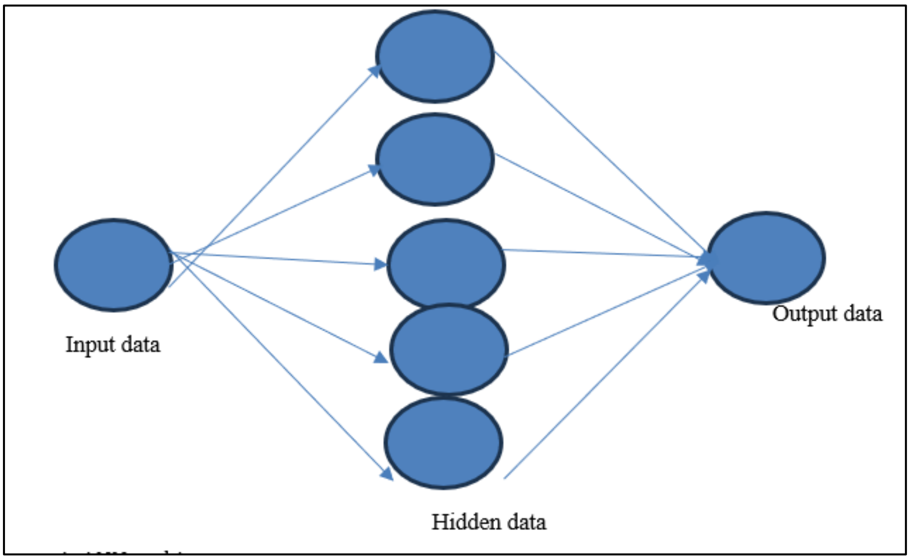

Figure 4 ANN architecture

The input neuron contains the voltage signal of each of the lines, the output neuron represents the improved voltage signal that enhances the power flows of the power system network, the hidden contains five hidden neurons with each neuron designed with log sigmod model shown in the equation below;

$$\log(x) = \frac{1}{1+\exp(-x)} \tag{7}$$

The hidden neurons links the input neuron to the output neuron after the ANN model is trained. The training the model was done using Levenberg macquart back-propagation network.

The outcome of the ANN model was implemented in each of the lines with the power flow parameters obtained at each case. But the parameter utilized for determining the strategic location for the ANN allocation was the total active power loss. But total active power loss, total power flow and voltage profile of each bus was also implemented to ensure that all the power flow parameters were improved.

4. Results

The total power loss of the system when ANN was allocated at each line was presented in the chart presented in figure 5.

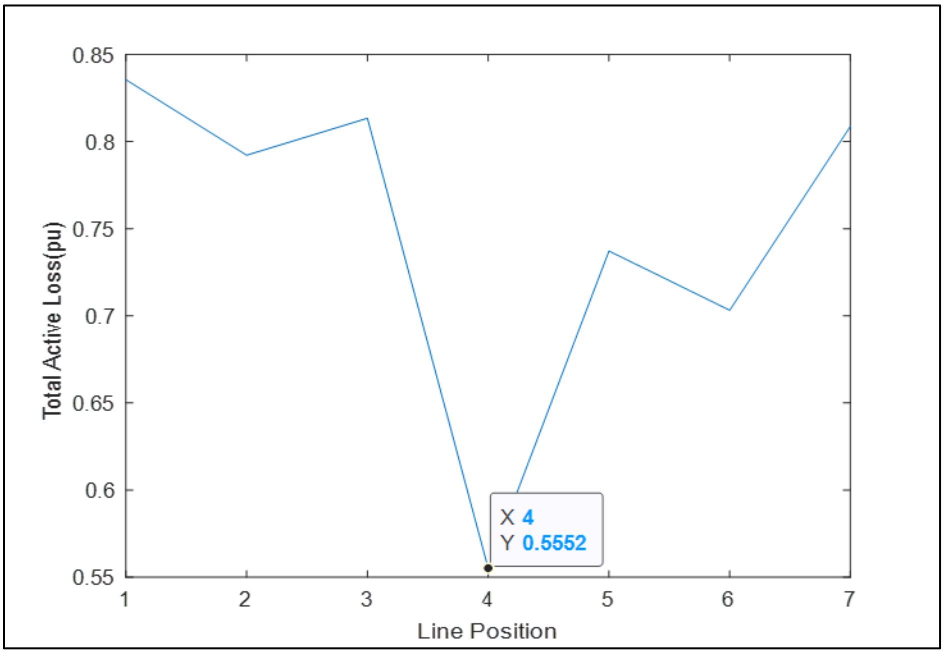

Figure 5 Total power loss for strategic location implementation

It can be seen that the total active loss was high when placed in other lines and the line with the optimum (minimized) power loss was on line 4. Hence, line 4 is considered the most strategic location for the allocation of the ANN control mechanism.

The total reactive power loss of the system when ANN was allocated at each line was presented in the chart presented in figure 6.

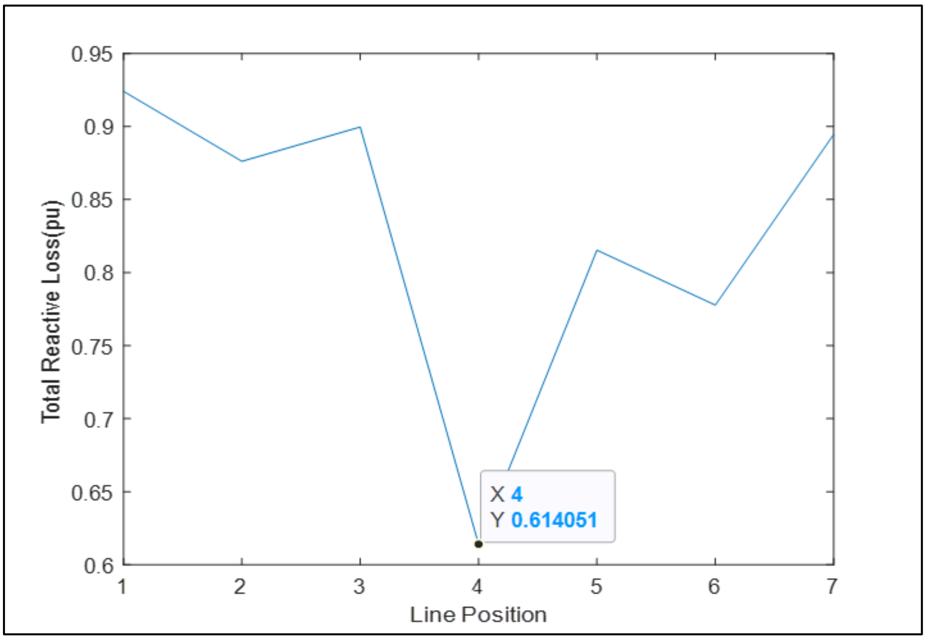

Figure 6 Total power loss for strategic location implementation

In figure 6, the total reactive loss when the ANN was placed in all the lines sequentially was shown. It was observed that the optimum (minimum) location for the allocation of the ANN control mechanism was on line 4.

Figure 5 and figure 6 showed the total active and reactive loss outcome of allocating ANN control mechanism at each of the lines. because the essence was to place the ANN model at the line with the least losses, it was seen that line 4 had the least active and reactive loss of 0.5552pu and 0.614pu, which implied that the ANN was allocated on line 4.

The impact of ANN on the voltage profile of the system was shown in figure 7.

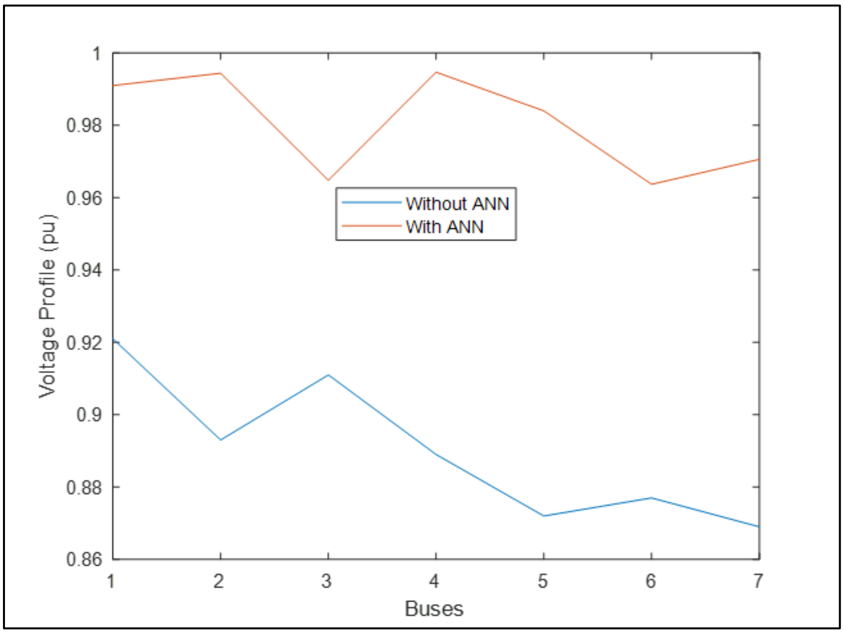

Figure 7 Voltage profile of the power system network

In figure 7, the voltage of the system without ANN allocation were below the expected threshold of between 0.95 pu and 1.05 pu. This implies that the voltage profile was low but with the implementation of the ANN system, it was observed that the all the buses exceeded the expected threshold which showed a drastic improvement when ANN was utilized.

The impact of ANN on the active power flow of the system was shown in figure 8.

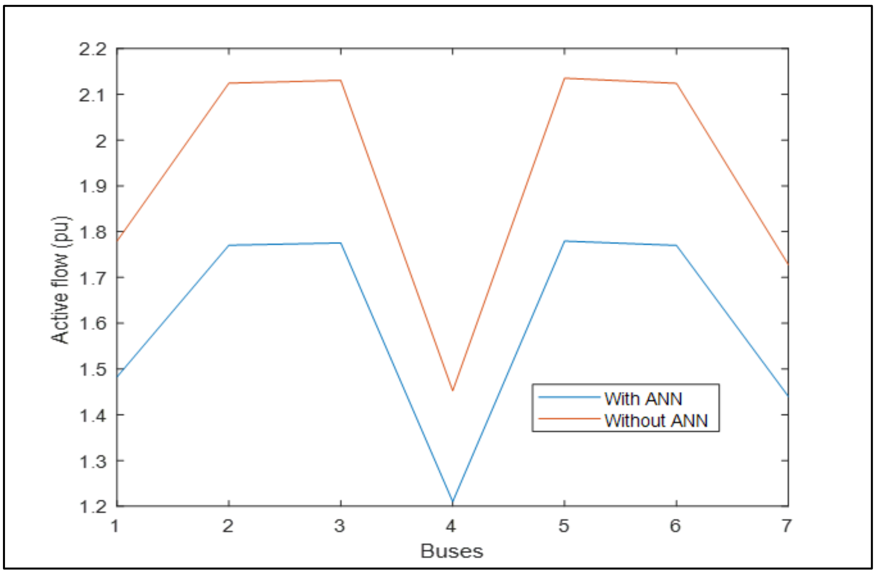

Figure 8 Active power flow of the power system network

The outcome of the active power flow analysis with the strategic placement of the ANN control was presented in figure 8. It was improvement achieved was observed as the ANN increased the amount of active power flow by mitigating the rate power flow congestion.

The impact of ANN on the reactive power flow of the system was shown in figure 9.

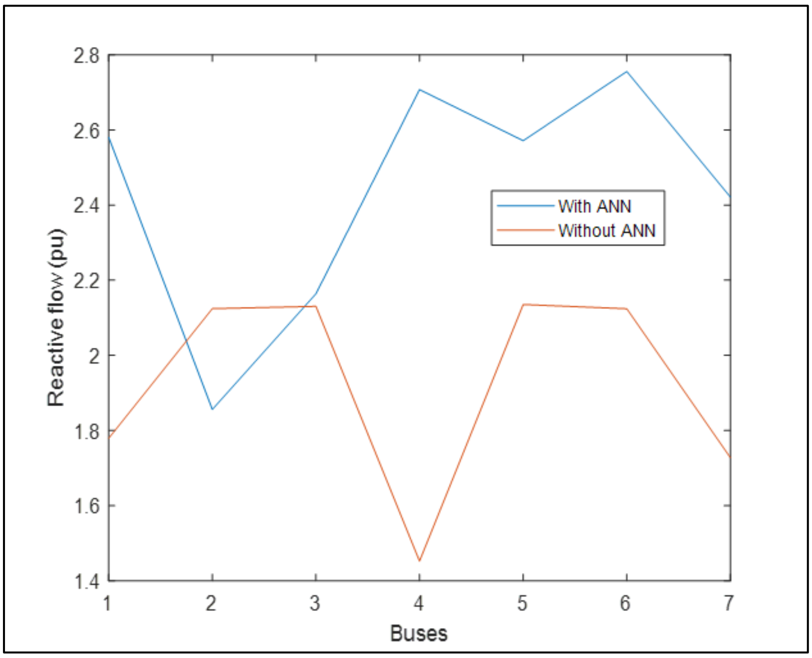

Figure 9 Reactive power flow of the power system network

In figure 9, with the exception of line 2, the strategic implementation of ANN control increased the reactive power flow of the power system network.

The impact of ANN on the active power loss of the system was shown in figure 10.

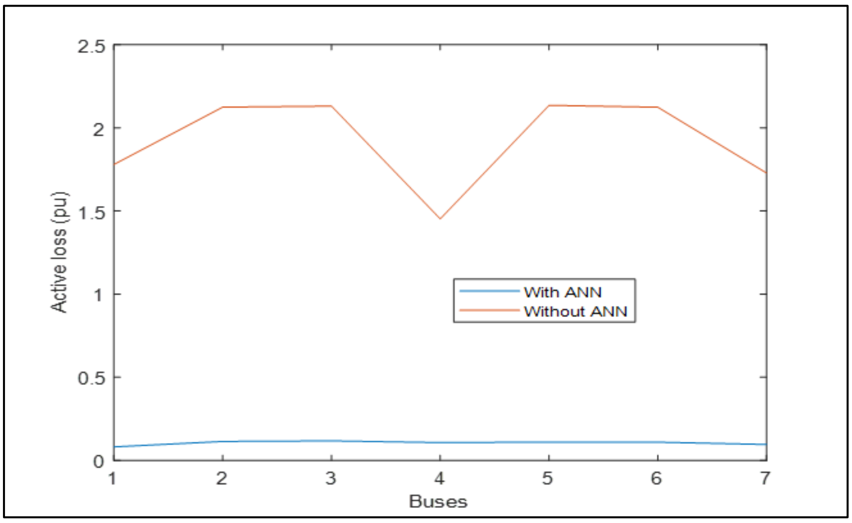

Figure 10 Active power loss of the power system network

The implementation of ANN control minimized the active power loss shown in figure 10. It was observed that active loss were all less than 0.2pu when ANN was introduced and suggested that ANN control system is effective in control active losses.

The impact of ANN on the reactive power loss of the system was shown in figure 11.

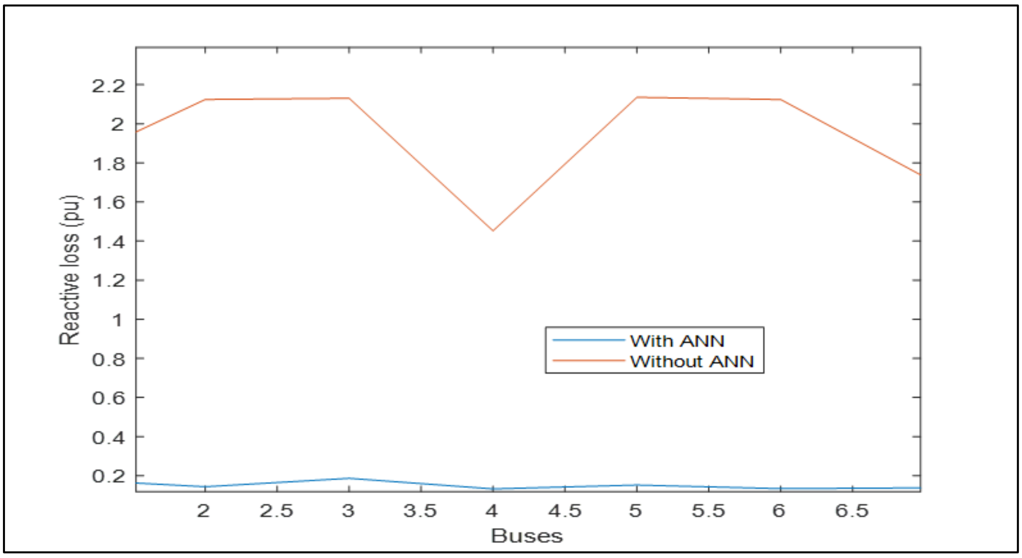

Figure 11 Reactive power loss of the power system network

The introduction of ANN control system improved the reactive losses as shown in figure 11. The reactive loss was reduced when the ANN was strategically introduced. This implies that the implementation of ANN effectively improves the power system network flow parameters.

The percentage improvement achieved for all the power flow variables were shown in table 3.

Table 3 Percentage power flow improvement achieve**d**

Power flow parameters	% improvement
Voltage profile	12%
Active Power flow	19%
Reactive power flow	22%
Active power loss	18%
Reactive power loss	21.3%

5. Conclusion

ANN was utilized for the improvement of the power flow parameters and voltage profile of the real time Nigerian 33kV power system network. the power system network was a 33kV feeder in Owerri Imo state, south eastern network. the obtained data was modeled in PSAT and simulated with the current and voltage signal generated utilized for the configuration of the ANN system with the network signals being the input data and learned signals being the output data. To obtain the strategic location of the ANN allocation, ANN model was placed on all the lines sequentially, with the total active power loss and reactive losses obtained. The minimum loss was seen on line 4 having active loss of 0.5552pu and reactive loss of 0.614pu making the line the most strategic location for the placement of the ANN system. From the power flow plots presented, the percentage improvement achieved were considered to be significant which implied that the implementation of ANN control mechanism improved the power flow of the 33kV power system network.

Compliance with ethical standards

Disclosure of conflict of interest

No conflict of interest to be disclosed.

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