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MINIMIZING LOSSES IN NIGERIA'S 330KV TRANSMISSION NETWORK USING IMPROVED STATCOM CONTROLLER

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ABSTRACT

This study presents the improvement of Nigeria's 34-bus, 330/132 kV transmission network performance through Flexible AC Transmission System (FACTS) enhancement. The FACTS is improved with a STATCOM controller integrated with Random Forest (RF) algorithm. This work investigated the Nigerian 34-Bus, 330/132kV transmission network for data collection and to measure the impact of losses on the transmission network. A simulation was carried out on an equivalent IEEE 34-bus system in MATLAB/Simulink, and the successful results justified its application to the Nigerian 34-bus network through comparative analysis between the original and optimized network, which showed clear improvements, including a reduction in voltage drop from 0.758 kV to 0.732 kV and an improvement in power factor from 0.972 to 1.006.
Keywords: FACTS; Power Losses; 330/132kV Transmission Network; Random Forest; STATCOM Controller

Keywords: Deceptive Attack Detection; Wide Neural Network; Trophallaxis Regularization; Behavioural Cybersecurity; Bio-inspired Algorithms

1. INTRODUCTION

The Nigerian 330kV power transmission network experiences significant power losses due to challenges such as reactive power imbalances, voltage instability, and line congestion. These issues contribute to reduced transmission efficiency, increased operational costs, and challenges in meeting energy demands [1]. The Nigerian 330kV transmission network, responsible for transporting electricity across long distances, suffers from both technical and non-technical losses [2]. These losses occur due to the aging infrastructure, inadequate maintenance, and operational inefficiencies, all of which undermine the overall performance of the grid [3,4]. As the demand for electricity continues to rise, there is a pressing need to address these inefficiencies to improve power quality and reliability [5]. To address this, the integration of optimized FACTS devices, which combine the advantages of FACTS technologies with machine learning techniques is proposed in this study. By optimizing reactive power flow and enhancing voltage stability, optimized FACTS devices can minimize power losses, improve the overall efficiency of the transmission network, and ensure a more reliable power supply.

2. THE PROPOSED SYSTEM

This work began with the data collection through investigation of the Nigerian 34Bus, 330KV transmission network to determine the losses on the line network. To help address this problem, optimized FACTS device made of unified power flow controller and genetic algorithm was proposed. The Static Synchronous Compensator (STATCOM) was used for control of stability on the network using random forest machine learning algorithm [8] as an optimizer. Simulation experiments were applied to implement and test the improved network with optimized FACTS on IEEE Distribution, network and then evaluated. Upon satisfactory, the model was then integrated on the Nigerian 34Bus, 330/132kV transmission network. Comparative analysis was applied to validate the work and the results obtained were discussed.

a. Data Collection

In order to gather data and assess the effect of losses on the transmission network, this study examined the 34-Bus, 330/132kV transmission network in Nigeria. Active power loss, which results from resistive heating of the line, reactive power loss, which results from inductive and capacitive effects on the line, voltage drop, which is an effect of losses, impedance, which illustrates how resistance and reactance contribute to loss, and power factor, which gauges the overall effectiveness of the transmission network, are the parameters taken into consideration for the data collection. On March 13, 2025, line data was gathered from the network based on these factors. The network administrators used the Newton Raphson approach in ETAP software to create the data at the control centre. The results of the data collected are reported in Table 1.

Table 1: Result of data collected from the 330/132kV transmission line considering losses (TCN, Nigeria)

Transmission Line	Voltage (kV)	Current (kA)	Active Power Loss (MW)	Reactive Power Loss (MVAR)	Impedance (Ω)	Line Loading (%)	Voltage Drop (kV)	Power Factor
Egbin (SB)	330	450	1.2	3.5	0.15 + j0.08	78	2.5	0.92
Akamgba	330	410	1.0	2.8	0.12 + j0.07	72	2.1	0.93
Aja	330	380	0.9	2.5	0.10 + j0.06	69	1.8	0.94
Egbin ts	132	360	0.8	2.2	0.09 + j0.05	66	1.5	0.95
Ikj-west	330	340	0.7	1.9	0.08 + j0.04	63	1.3	0.96
Benin	330	320	0.6	1.6	0.07 + j0.03	60	1.0	0.97
Sapele ps	330	300	0.5	1.4	0.06 + j0.03	58	0.8	0.98
Aladja	330	290	0.45	1.2	0.05 + j0.025	55	0.7	0.98
Delta ps	330	280	0.4	1.1	0.045 + j0.022	53	0.6	0.99
Ajaokuta	330	270	0.35	1.0	0.04 + j0.020	50	0.5	0.99
Geregu	132	260	0.3	0.9	0.035 + j0.018	48	0.45	0.99
Oshogbo	132	250	0.28	0.8	0.03 + j0.015	45	0.4	0.99
Jebba ts	132	240	0.25	0.75	0.028 + j0.014	43	0.35	0.99
Ayede	132	230	0.22	0.7	0.026 + j0.013	41	0.3	0.99
Jebba gs	132	220	0.2	0.65	0.024 + j0.012	40	0.25	0.99
Kainji gs	132	210	0.18	0.6	0.022 + j0.011	39	0.2	0.99
B.kebbi	132	200	0.16	0.55	0.020 + j0.010	38	0.18	0.99
Shiroro ts	132	190	0.15	0.52	0.018 + j0.009	37	0.15	0.99
Shiroro gs	330	180	0.14	0.5	0.017 + j0.007	34	0.13	0.99
Kaduna	330	450	1.3	3.5	0.15 + j0.07	75	2.3	0.91
Kano	330	410	1.1	2.8	0.12 + j0.07	72	2.1	0.91
Abuja	330	150	0.1	0.4	0.013 + j0.006	33	0.09	0.99
Afam	330	140	0.09	0.38	0.012 + j0.005	32	0.08	0.99
Alaoji	132	130	0.08	0.35	0.011 + j0.005	31	0.07	0.99
Onitsha	132	120	0.07	0.3	0.010 + j0.004	30	0.06	0.99
N/Haven	132	110	0.06	0.28	0.009 + j0.004	29	0.05	0.99
Makurdi	132	100	0.05	0.25	0.008 + j0.003	28	0.04	0.99
Jos	330	120	1.2	3.5	0.15 + j0.08	56	1.9	0.93
Gombe	330	110	1.0	2.8	0.12 + j0.07	71	2.1	0.93
Maiduguri	330	450	1.2	3.5	0.15 + j0.08	78	2.5	0.92
Okpai	132	60	0.01	0.12	0.004 + j0.001	24	0.01	0.99
Papalanto	132	50	0.01	0.1	0.003 + j0.001	23	0.01	0.99
Mambila	132	220	0.2	0.65	0.024 + j0.012	40	0.25	0.99
Azura	132	210	0.18	0.6	0.022 + j0.011	39	0.2	0.99
Ikot-Ekpene	132	200	0.16	0.55	0.020 + j0.010	38	0.18	0.99
Ugwuaji	132	190	0.15	0.52	0.018 + j0.009	37	0.15	0.99
Average	225.5	238.8889	0.437222	1.271389		47.91667	0.758333	0.972222

The results of the data gathered from TCN to look into network losses while taking 34-bus and 330/132 transmission lines into consideration were shown in Table 1. Several metrics were found in the data, including average power factor of 0.97, average active power loss of 0.437MW, average reactive power loss of 1.27MVAR, and average voltage drop of 0.758.

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3. PRESENTATION OF THE OPTIMIZED FACTS MODEL FOR ENHANCED POWER TRANSMISSION

The optimized FACTS control system is made of STATCOM controller optimized using random forest algorithm. The random forest algorithm is applied to monitor the state of the lines through variation in voltage to determine losses, while the STATCOM is applied to compensate for the losses and ensure an improved power system quality.

a. STATCOM Model

A STATCOM is a shunt, connected to in the FACTS device to inject or absorb reactive power in order to regulate the voltage at its connection point, especially in the bus of a transmission network. This is done by injecting capacitance if the bus voltage is low to raise voltage or absorbing capacitance if the bus voltage is high. The model of a STATCOM is with an energy storage element like capacitor which are connected to the grid through coupling reactance. The reactive power model is shown in Equation 1 as [6,7]:

$$Q = \frac{V_{bus}(V_{conv}\sin(\delta))}{X} \quad (1)$$

Where, V_{bus} is the voltage on the bus, V_{conv} is the voltage on the STATCOM converter, while δ is the phase angle difference between the bus and STATCOM and X is the coupling reactance. Then the current injected in the system is determined in Equation 2 while the converter output voltage is calculated in Equation 3 as follows:

$$I = \frac{V_{conv} - V_{bus}}{jX} \quad (2)$$

$$V_{conv} = V_{dc}.m \quad (3)$$

According to Equation 3, m is the modulation index of the power system.

b. Integration of Random Forest (RF) into the STATCOM controller

In the proposed STATCOM controller, a pre-trained random forest model is integrated to replace the traditional Proportional-Integral (PI) controller, in order to maintain voltage at the bus. The integrated model compares the measured voltage using a reference value, then automatically minimized the error by adjusting the STATCOM's reactive power output. The equations of the input vector (X) and the RF regression model are shown in Equations 4 and 5.

$$X = [V_{bus}, P_{load}, Q_{load}, I, Z, t] \quad (4)$$

Where, t= time/seasonal features of the data collected

$$Q_{ref} = \frac{1}{N}\sum_{i=1}^{N} T_i(X) \quad (5)$$

Where, Q_{ref} is the target output of the RF model in MVAR, N is the number of variables in RF, $T_i(X)$ is the prediction of the i^{th} model in the forest, given the input feature vector X, $\sum_{i=1}^{N} T_i(X)$ is the sum of predictions from all N individuals

The control loop logic at the RF-STATCOM controller shown in Figure 1 as the structure of the control system starts by collecting real-time data of voltage, load power, historical trends and time/seasonal profile as shown in Equation 4, then transforms them as the feature vector. The RF regression model shown in Equation 5 is then used to predict the optimal reactive power injection or absorption when needed to stabilize the system voltage which leads to adjustment of the Voltage Source Converter (VSC) output by adjusting the modulation index (m). Hence, the converter injects or absorbs the required Q and stabilizes the voltage as the loop continues flow. The RF-STATCOM control diagram is presented in Figure 2

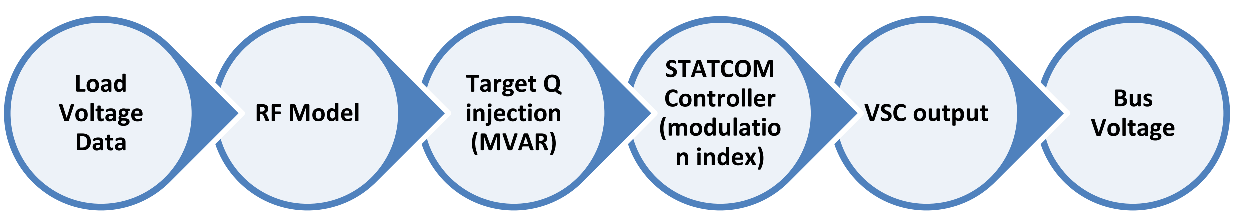

Figure 1: Structure of the Control System

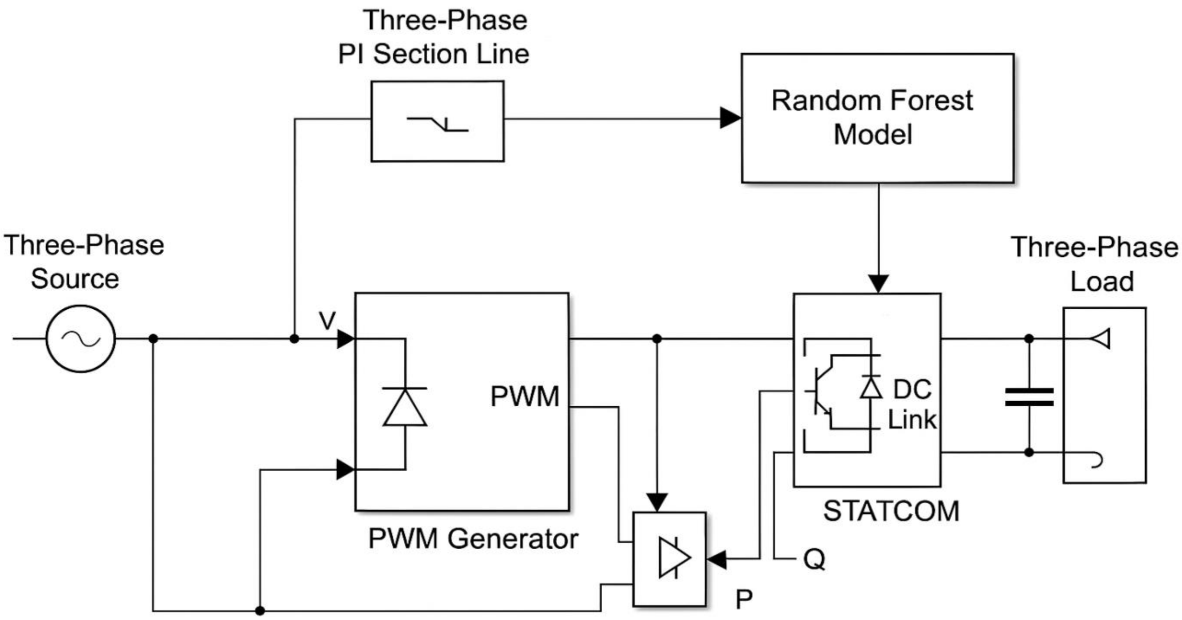

Figure 2: RF-STATCOM Controller diagram

The adoption of the RF-STATCOM controller presented in Figure 2 will help the grid to move from a grid controller by reactive (wait and fix) to a proactive and intelligently controlled grid which is particularly valuable for large, sparse grids with weak voltage support like parts of Nigeria's 330kV network.

4. SYSTEM IMPLEMENTATION

The implementation of the RF-STATCOM on the IEEE 34-bus system in MATLAB/Simulink involves a structured approach to enhance power flow control and minimize system losses. The IEEE 34-bus model is designed using standard transmission system parameters, including bus voltage levels, line impedances and power ratings. A load flow analysis is first conducted to determine power losses and voltage deviations across buses. The STATCOM is strategically placed in the FACTS at the most critical transmission lines where power losses and voltage instability are significant. The shunt and series compensators within the STATCOM are modeled using SimPower Systems components, enabling the system to regulate reactive power and improve voltage stability.

5. RESULTS OF THE SYSTEM COMPARED WITH THE INVESTIGATED NETWORK

The section presents the comparative results obtained from the investigated network and the result of the integrated RF-STATCOM. The results considering the 34-Bus 330/132kV transmission line were recorded as shown in Table 2, considering loss data such as voltage drop, and power factor.

Table 2: Comparative result of network considering losses

Transmission Line	Voltage (kV)	Current (A)	Voltage Drop (kV) in the original network	Power Factor in the original network	Voltage Drop (kV) in RF-STATCOM	Power Factor in RF-STATCOM
Egbin (SB)	330	450	2.41	0.95	2.5	0.92
Akamgba	330	410	2.03	0.96	2.1	0.93
Aja	330	380	1.74	0.97	1.8	0.94
Egbin ts	132	360	1.45	0.98	1.5	0.95
Ikj-west	330	340	1.25	0.99	1.3	0.96
Benin	330	320	0.97	1.00	1.0	0.97
Sapele ps	330	300	0.77	1.01	0.8	0.98
Aladja	330	290	0.68	1.01	0.7	0.98
Delta ps	330	280	0.58	1.02	0.6	0.99
Ajaokuta	330	270	0.48	1.02	0.5	0.99
Geregu	132	260	0.43	1.02	0.45	0.99
Oshogbo	132	250	0.39	1.02	0.4	0.99
Jebba ts	132	240	0.34	1.02	0.35	0.99

Ayede	132	230	0.28	1.02	0.3	0.99
Jebba gs	132	220	0.24	1.02	0.25	0.99
Kainji gs	132	210	0.19	1.02	0.2	0.99
B.kebbi	132	200	0.17	1.02	0.18	0.99
Shiroro ts	132	190	0.14	1.02	0.15	0.99
Shiroro gs	330	180	0.13	1.02	0.13	0.99
Kaduna	330	450	2.22	0.94	2.3	0.91
Kano	330	410	2.03	0.94	2.1	0.91
Abuja	330	150	0.09	1.02	0.09	0.99
Afam	330	140	0.08	1.02	0.08	0.99
Alaoji	132	130	0.07	1.02	0.07	0.99
Onitsha	132	120	0.06	1.02	0.06	0.99
N/Haven	132	110	0.04	1.02	0.05	0.99
Makurdi	132	100	0.03	1.02	0.04	0.99
Jos	330	120	1.83	0.96	1.9	0.93
Gombe	330	110	2.02	0.96	2.1	0.93
Maiduguri	330	450	2.41	0.95	2.5	0.92
Okpai	132	60	0.01	1.02	0.01	0.99
Papalanto	132	50	0.01	1.02	0.01	0.99
Mambila	132	220	0.24	1.02	0.25	0.99
Azura	132	210	0.19	1.02	0.2	0.99
Ikot-Ekpene	132	200	0.17	1.02	0.18	0.99
Ugwuaji	132	190	0.14	1.02	0.15	0.99
Average	225.5	238.9	0.73	1.01	0.758333	0.972222

The Table 2 presents the comparative loss analysis for the 34-Bus transmission network with RF-STATCOM as the optimized FACTS and the investigated network. The result reported an average power actor of 1.00625 for the network with RF-STATCOM and then 0.97222 as the result of the original network. The result also recorded 0.73179kV voltage drop with RF-STATCOM better than 0.75833kV recorded in the investigated network. The improvement recorded in the 3.5% improvement in enhanced network stability.

6. CONCLUSION

This study presents the improvement of Nigeria's 34-bus, 330/132 kV transmission network by integrating a Flexible AC Transmission System (FACTS). The FACTS is improved with a STATCOM controller integrated with RF algorithm. This work investigated the Nigerian 34-Bus, 330/132kV transmission network for data. Tests were carried out on the IEEE 34-bus system in MATLAB/Simulink, and the successful results justified its application to the Nigerian 34-bus network. Comparative analysis between the original and optimized network showed clear improvements, including a reduction in voltage drop from 0.758 kV to 0.732 kV and an improvement in power factor from 0.972 to 1.006. This indicates that the system achieved an enhanced voltage stability and power quality.

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