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Optimal Placement of Thyristor Controlled Series Compensator (TCSC) on Nigerian 33kV Transmission Grid to Improve Electric Power Quality.

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Abstract

This paper examined the quality of electric supply in Nigeria, especially the North Central region, and proffered a modern approach to improving the quality using Flexible Alternating Current Transmission System (FACTS) devices. Electrical energy is a product that should possess the proper quality requirements to satisfy the social, economic, and technical needs of society. The Nigerian transmission grid system was modeled and simulated in a PSAT environment as a 35-bus system. Thyristor Control Series Compensator (TCSC) is among other FACTS devices that are capable of minimizing transmission line losses and increasing the voltage profile of the buses. Genetic Algorithm (GA) optimization technique has been deployed as an effective method of placing TCSC on the Nigerian 330 kV Grid System, to control power flow and improve bus voltages.

Keywords: FACTS devices; TCSC; Transmission grid; PSAT; Genetic Algorithm; Voltage Profile

1 Introduction

The current generating capacity level in the northern part of Nigeria is less than 50 percent of the demand, and the electricity supply system serves less than 40 percent of the population. This inadequacy subjects Nigerians especially in some areas to unreliable power supply and unscheduled power outages [1]. Studies have shown that electricity challenges in Nigeria are not only in the generation, but the electricity supply industry equally faces transmission challenges. The Nigerian grid system that transverses the country is now managed by the Transmission Company of Nigeria (TCN) as part of power deregulation. For the TCN to satisfy the increased electrical power demand, and our growing technological world which is deeply dependent upon the continuous availability of electrical power, electricity market participants in TCN transferring energy between various points often drive transmission lines close to or even beyond thermal, voltage and stability limits [2]. This can lead to fluctuations in power flows through the transmission lines with effects such as increased power loss, especially in congested lines as well as cascading outages that could result in power system collapse if not managed properly. The current average available transmission capacity on the 330/132 kV transformer is 11,165 MW with 98.2% of installed capacity with an average transmission loss of 10.5% [3]. A flexible AC Transmission System (FACTS) device especially the TCSC due to its power regulation can relieve congestion in some transmission lines that are overloaded and increase the voltage profile of some buses with low voltage supply which allows better utilization of the existing grid infrastructure, and along other benefits like maintaining a healthy system devoid of voltage fluctuations [4]. Availability and access to reliable and efficient electricity contribute to the growth of the economy and improvement in the standard of living of people in developing communities in North Central with the rapid increase in population and new technological advancement. Hence the need to effectively and efficiently compensate the existing structure of a 330 kV 35-bus Electric Network using a Thyristor Control Series Compensator (TCSC) is inevitable.

2 Literature Review

The component of electric power system in Nigeria consists of generation, transmission, and distribution. The basic components of the system include power, voltage and current, and frequency. All these parameters are discussed as follows.

2.1 Electric Power

There is real, reactive, and apparent power. The Real power is measured in watts and it is the amount of energy dissipated for the work to be done, while the reactive power is that required to generate the magnetic fields to enhance the actual work done whereas the apparent power is the total power that the utility company supplies normally which is measured in MVA. Power factor (PF) is an important parameter of power quality, it helps to reduce the harmonics in the line current, thereby increasing the efficiency and capacity of power systems and reducing high customer utility bills [5].

PF is a measure that shows how efficiently electricity is being used. It is calculated by dividing the real power (the power that actually does the work) by the apparent power (the total power supplied). Another way to understand it is as the cosine of the phase angle between the current and voltage waveforms, assuming they are pure sine waves.

$$P.F = \frac{Real\ power}{Apparent\ power} \qquad [1]$$

2.2 Voltage and Current

Current and Voltage are essential quantities in electricity. Voltage serves as the cause while current is the effect. Voltage is the electrical force that drives an electric current between two points while current is the rate at which electric charge flows through a point in a circuit. Both combine to give power. There are different types of voltages namely: direct voltage (DC) and alternating voltage (AC) which correspond to types of current – direct current (DC) and alternating current (AC) respectively. The voltage in electric power transmission lines used to distribute electricity from power stations can be in several hundred times greater than the consumer voltages [6].

2.3 Frequency

Frequency meters are measured in hertz (Hz). Based on the grid code, our normal frequency level is supposed to be 50Hz. Frequency regulation is one of the most critical points in a power system. Quick response to the frequency correction within the power plant is an important issue since it prevents damage to the power transmission lines, equipment, and household appliances [7]. In a power grid system, load frequency control (LFC) also plays an essential role as it provides better conditions for power exchange and supply in trading electricity. Delays in such systems could reduce system performance and even cause parameter instability that could lead to a collapse of the grid system [8].

Table 2.3 below shows Basic Standard Value for allowed transmission system performance characteristics.

	Normal Value	Tolerable Range
Frequency	50Hz	48.75-51.25
Voltage	330 kV	313.5 (0.95 pu) – 346.5 (1.05 pu)
Power Factor	0.85	-

3 Methodology

The simulation model consists of Nigeria's 330 kV transmission grid system, thyristor-controlled series compensator (TCSC) model for power flow control in a transmission line, and the genetic algorithm for the optimal placement of TCSC. Results

3.1 The Nigeria 330kV Transmission Grid System

The 330 kV voltage level is regarded as extra-high voltage in Nigeria and is referred to as the Nigerian grid system. The Nigerian grid modeled in Power System Analysis Toolbox (PSAT) software simulated in MATLAB environment consists of thirty-five (35) buses, twenty-six (26) transmission lines, and eleven (10) working generating stations considered as at the time of this work. The Nigerian grid is made up of approximately 5,523.7 Km of 330 kV transmission lines and thirty-two 330/132 kV substations with a total installed transformer capacity of 12,688 MVA on average. The available capacity on the 330/132kV is 10,364 MVA [9]. The bus at Egbin Generating Station is chosen as the slack bus. Table 3.1 shows the installed capacity of the nine power generating stations and the type of fuel used.

Table 3.1. Electricity Power Stations of the Nigerian Power Grid

Power Stations	Fuel/Type Used	Installed Capacity (MW)
Afam	Thermal	726
Ugheli Delta	Gas	900
Sapela	Gas	1020
Ihovbor	Thermal	450
Geregu	Gas	414
Egbin	Gas	1320
Kainji	Hydro	760
Shiroro	Hydro	600
Jebba	Hydro	540
Alaijo	Thermal	960

Power Stations	Fuel/Type Used	Installed Capacity (MW)
Kano	Hydro	100

Source: PHCN (2023)

3.2 Optimization Technique - Genetic Algorithms (GA)

GA is one of optimization technique with quick and radical approach to optimization because of its independence on knowing the derivatives of the objective function. Genetic Algorithms (GA) is good for power system optimization, which offers significant advantages and better optimization performances. The basic concept is derived from the Darwin's postulation of survival of the fittest, which implies only the best individuals will be selected on the account of defined fitness level to participate with their genetic parameters in the next generation [10]. G.A only works with coding of the parameters set, where the parameters themselves are not directly involved. For a given population (candidate buses) with overall system voltage enhancement is considered suitable for location of TCSC.

3.3 TCSC Model for Power Flow Control

The real P_{ij} and reactive Q_{ij} power flows of the line connected between bus-i and bus-j having

series impedance as,

$$P_{ij} = V^2{}_i G_{ij} - V_i V_j \left[G_{ij} \cos\sigma_{ij} + B_{ij} \sin\partial_{ij} \right] \quad [2]$$

$$Q_{ij} = -V^2{}_i (B_{ij} + B_{sh}) - V_i V_j \left[G_{ij} \sin\partial_{ij} - B_{ij} \cos\sigma_{ij} \right] \quad [3]$$

Also, for $P_{ji} \wedge Q_{ji}$

$$P_{ij} = V^2{}_j G_{ij} - V_i V_j \left[G_{ij} \cos\sigma_{ij} - B_{ij} \sin\partial_{ij} \right] \quad [4]$$

$$Q_{ji} = -V^2{}_j (B_{ij} + B_{sh}) + V_i V_j \left[G_{ij} \sin\partial_{ij} + B_{ij} \cos\sigma_{ij} \right] \quad [5]$$

Where $V_i \wedge V_j$ are voltage magnitudes at bus-I and bus-j respectively.

∂_{ij} – Voltage angle between bus-I and bus-j;

G_{ij} – Conductance between bus-I and bus-j;

B_{ij} – Susceptance between bus-I and bus-j.

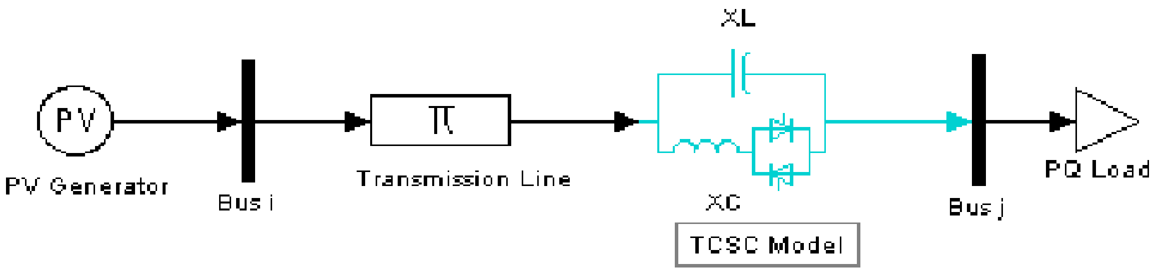

Figure 3.1 Transmission Line with TCSC

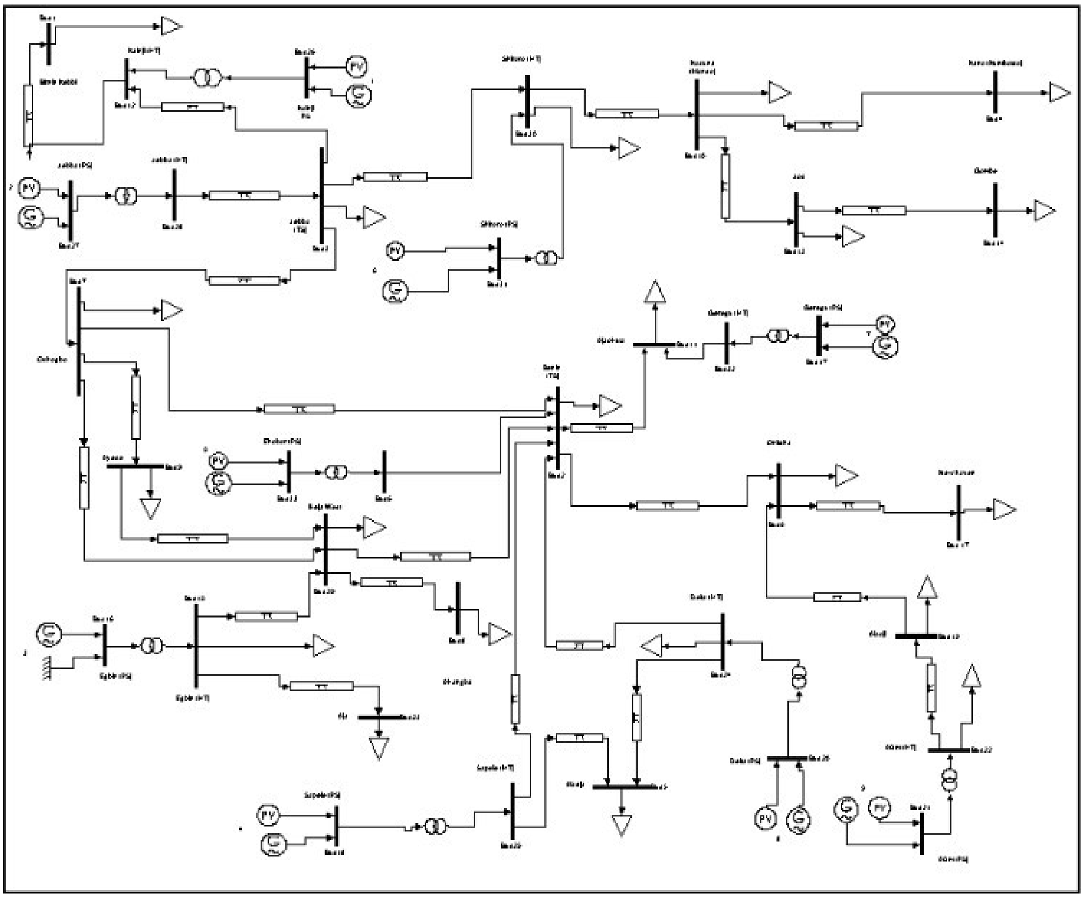

Figure 3.2. PSAT model of Nigeria Power Grid without TCSC

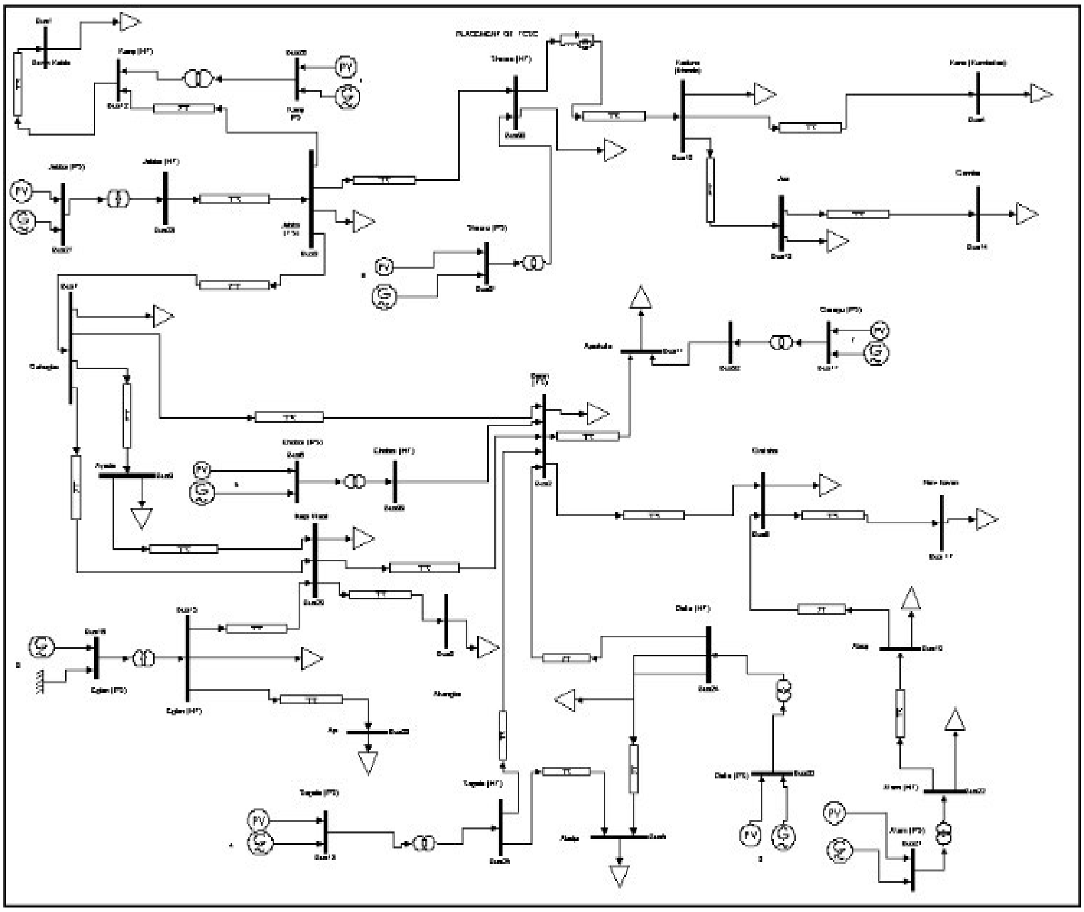

Figure 3.3. PSAT model of Nigeria Power Grid with TCSC

4 Discussion

The results show the simulation of the Nigerian grid in Power System Analysis Toolbox (PSAT) software using MATLAB environment before introducing TCSC, and after optimal placement of TCSC. The Genetic Algorithm (GA) result shows the fitness level of individual candidate buses that participated in the optimal placement of TCSC for effectiveness and efficiency.

Table 4.1 TCSC placement values for candidate buses.

Bus	Candidate Buses	Fitness Function Level
2	Bus 1_Birnin Kebbi	0.1156
4	Bus 3_Jebba (TS)	0.0711
6	Bus 7_Oshogbo	0.3848
8	Bus 11_Ajoakuta	0.1000
10	Bus 14_Gombe	0.6818
12	Bus 10_Kaduna (Mando)	0.1950
14	Bus 30_Shirro (HT)	0.9735
16	Bus 27_Jebba	0.3354
18	Bus 19_Alaoji	0.1970
20	Bus 17_New Haven	0.5699
22	Bus 32_Geregu (PS)	0.0532
24	Bus 13_Jos	0.3951
26	Bus 25_Sapele (HT)	0.1821
28	Bus 15_Kano	0.9871
30	Bus 22_Afam (HT)	0.4354

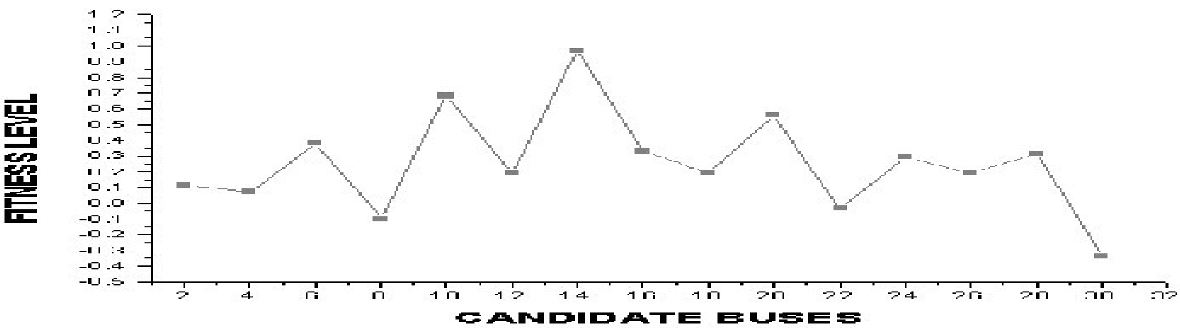

Figure 4.1 TCSC placement of candidate bus of Grid System.

Table 4.1 and figure 4.1 shows the fitness level of the candidate buses of the Transmission Grid. After coding the parameters set of the candidate buses, candidate buses show their fitness level value which implies level of real power loss and voltage enhancement on the lines. Bus 3_Jebba (TS) and Bus 15_Kano recorded least and highest fitness level value respectively. Hence, Bus15_Kano is chosen having the highest fitness value, and this will result in least overall real power loss and better voltage quality.

Table 4.2 Voltage Profile of the Buses before and after placing TCSC on Grid System

Bus	Candidate Buses	Voltage Profile of Buses Before TCSC (kV)	Voltage Profile of Buses After TCSC (kV)	% Improvement of Voltage
2	Benin (TS)_2	353.40	360.54	2.02
4	Kano_15	313.30	314.12	0.26
6	Kaduna_10	320.43	331.10	3.33
8	Ajoakuta_11	303.23	320.24	5.61
10	Jos_13	332.23	341.45	2.78
12	Gombe_14	305.56	310.25	1.53
14	New Haven_17	325.45	328.52	0.94
16	Shirror (HT)_30	351.61	360.20	2.44
18	Geregu (PS)_32	331.64	352.35	6.24

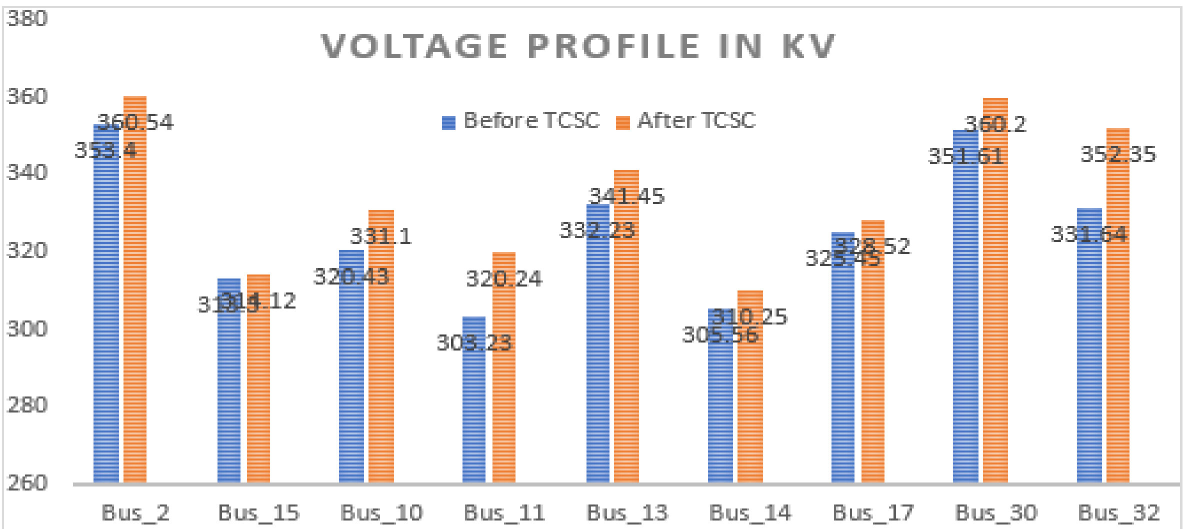

Figure 4.2 Voltage Profile of the Buses before and after placing TCSC on the Grid System

Table 4.2 and figure 4.2 shows results obtained from the simulation of power flow studies of some exposed weak buses with low voltage as a result of heavily loaded transmission lines and phase angles. On placing TCSC, some buses that violated the statutory limits of voltage were compensated. The TCSC connected in series with the transmission line changes the line reactance to allow real power flow and reactive power as voltage is in phase with the line current. This boosts the voltage in a line with voltage drop. Table 4.2 shows the improved voltage of bus_11 (Ajoakuta), bus_10 (Kaduna) and bus_32 (Geregu) significantly increased by 5.61%, 3.33% and 6.24% respectively after TCSC placed in the network. Figure 4.2 shows the overall bus affected and TCSC compensation level.

5 Conclusion

The work shows a serious improvement in the voltage profile after TCSC was installed on the Nigerian 330 kV grid system, enabling the network to be effectively used close to its thermal limit while remain stable, reduce transmission line congestion and maintains grid stability. Bus_32 (Geregu PS) and bus_11 (Ajoakuta) experienced significant improvement in the voltage level by 6.24% and 5.61% respectively thereby decongesting those line impedances to maintain voltage stability and more power flow. The TCSC improves the overall network voltage profile of the grid system by 2.79%.

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Conflict of Interest

The authors declare no conflict of interest.

Data Availability Statement

Not applicable.

AI Usage Disclosure

No generative AI tools were used.

Author Contributions

Conceptualization, **Isah Abubakar Ipemida**; methodology, **Isah Abubakar Ipemida**; analysis, all authors; writing—original draft, **Isah Abubakar Ipemida**; writing—review and editing, all authors. All authors have read and agreed to the published version of the manuscript.

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