ISSN: 2350-0328

International Journal of Advanced Research in Science, Engineering and Technology

Vol. 2, Issue 1, January 2015

Voltage Profile Enhancement of the Nigerian North-East 330kV Power Network Using STATCOM

Aribi Fughar , Nwohu, M. N., Sadiq, A. A., Ambafi, J. G.

P.G. Student, Department of Electrical and Electronics Engineering, Federal University of Technology, Minna,Nigeria.

Associate Professor, Department of Electrical and Electronics Engineering, Federal University of Technology, Minna, Nigeria.

Lecturer, Department of Electrical and Electronics Engineering, Federal University of Technology, Minna, Nigeria.

Lecturer, Department of Electrical and Electronics Engineering, Federal University of Technology, Minna, Nigeria.

ABSTRACT: The Nigerian North-East 330kV power network is characterized by low voltage and voltages outside acceptable limits that hinder quality power supply. Voltage profile of a power network provides a measure of the quality of power supply. The STATCOM is modelled and simulation is carried out in Power System Computer Aided Design (PSCAD) to enhance the voltage profile of the Nigerian 330kV Transmission Network. Ant colony algorithm is used to optimally place STATCOM on the Network. During a low voltage state on the Network, the system generates reactive power (STATCOM capacitive boosting effect). However, when the Network voltage is high, it absorbs reactive power (STATCOM inductive control effect), thus stabilizing the power network.

KEYWORDS: Nigerian 330kV, Voltage Profile Enhancement, PSCAD, STATCOM, Power Quality.

I. INTRODUCTION

Electrical energy is pivotal upon which a country's development and its economic growth revolves [1]. However, electrical energy production by means of power generation and transmission is a complex process, requiring the working of many components of the power system to ensure good power quality and reliability of supply. Complex electrical power consists of two components, the active or real power and the reactive power (imaginary power) component. Reactive Power can be described as the quantity of unused power that is developed by synchronous generators and reactive components, such as inductors or capacitors in an AC circuit or system. Imaginary power represents the product of volts and amperes that are out of phase with each other.

The amount of reactive power in an AC circuit depends on the phase shift between the voltage and the current. Reactive power provides the important function of regulating the system voltage, helping to move active power effectively through the utility grid and transmission lines to where it is required by the load [2]. Loads like electric motor and other inductive loads require reactive power for their operation.

To improve the performance of alternating current (a.c) power systems, we need to manage this reactive power in an efficient way and this is known as reactive power compensation. Reactive power is positive when it is supplied and negative when it is absorbed. There are two aspects to the problem of reactive power compensation, load compensation and voltage support. Load compensation consists of improvement in power factor, balancing of real power drawn from the supply and better voltage regulation of large fluctuating loads [3].

Voltage support consists of reduction of voltage fluctuation at a given terminal of the transmission line. Two types of compensation can be used: series and shunt compensation. These modify the parameters of the system to give enhanced VAR compensation. In recent years, static VAR compensators like the STATCOM have been developed. These quite satisfactorily do the job of absorbing or generating reactive power with a faster time response and come under Flexible AC Transmission Systems (FACTS). This allows an increase in transfer of apparent power through a transmission line,

ISSN: 2350-0328

International Journal of Advanced Research in Science, Engineering and Technology

Vol. 2, Issue 1, January 2015

and improves stability by the adjustment of parameters that govern the power system, that is, current, voltage, phase angle, frequency and impedance [4, 5].

This research therefore, intends to investigate a better way to improve the stability of the existing Nigerian North-East power system network rather than considering the need for setting up new ones, hence, the use of STATCOM as a compensator to provide a fast dynamic reactive compensation for voltage profile improvement especially during contingencies on the Nigerian North-East 330kV grid system [6].

II. THE NIGERIAN GRID SYSTEM

The Nigerian 330kV Grid System is zoned into four geographical areas in conformity with operational structure of the electric utility [7, 8]. The three hydro power stations are situated in Area 1 while Area 2 has thermal power station located in it and areas 3 and 4 have gas power stations located in them.

However, this research work focuses on the Nigerian North-East 330kV power network. The Nigerian National Grid is characterized by poor voltage profile in some parts of the network (especially in the Northern region), inadequate dispatch and control infrastructure, radial and fragile grid network, frequent system collapse, and exceedingly high transmission losses [7, 8, 9 10].

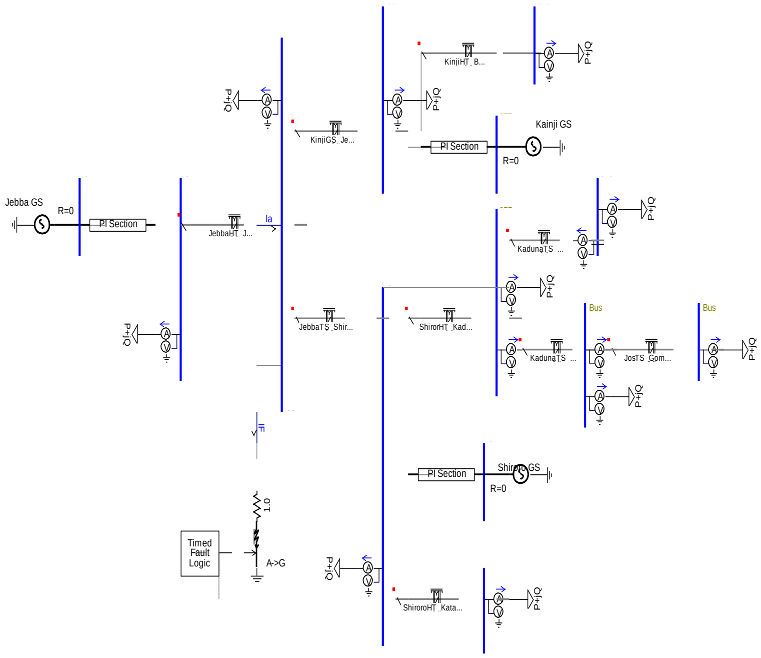


Figure 1: Structure of the Nigerian North-East 330kV **Grid System as at 2008**

III. COMPENSATION TECHNIQUE

Volt-ampere reactive (VAR) compensation is defined as the management of reactive power to improve the performance of AC power systems. The concept of VAR compensation embraces a wide and diverse field of both system and customer problems, especially as it relates to power quality (stability and efficiency) issues. Most of the power quality problems can be attenuated or solved with adequate control of reactive power and hence voltage profile improvement [5, 11]. Reactive power compensation in transmission systems also improves the stability of the AC system by increasing the active power that can be transmitted. It also helps to maintain a substantially good voltage profile at all buses of power transmission, and increases transmission efficiency, control steady-state conditions and avoid disastrous blackouts.

ISSN: 2350-0328

International Journal of Advanced Research in Science, Engineering and Technology

Vol. 2, Issue 1, January 2015

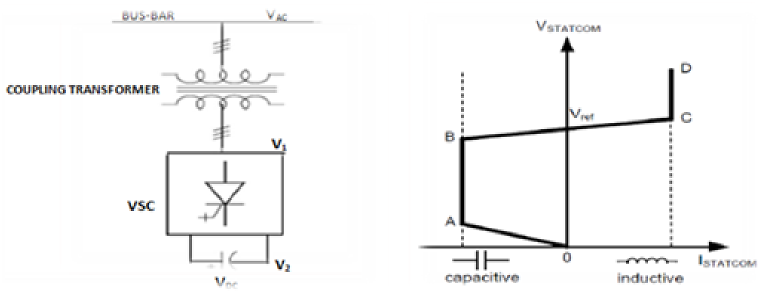
IV. STATCOM OPERATIONS

A. STATCOM Principles of Operation

With reference to Figure 2a, V_1 and V_2 are voltages of power system and that produced by the voltage source converter (VSC) respectively.
At steady state condition, V_2 produced by VSC is in phase with V_1, and in that case, only reactive power flows. If the magnitude of the voltage V_2 produced by the VSC is less than the magnitude of V_1, the reactive power flows from power system to VSC (that is, STATCOM absorbing the reactive power). If V_2 is greater than V_1, the reactive power is flowing from VSC to power system (the STATCOM is producing a reactive power). However, when V_2 equals V_1, the reactive power exchange equals zero in which case the STATCOM is said to be in a floating state.
Thus, we can say that if $V_1 > V_2$, the STATCOM is drawing a capacitive current and if $V_1 < V_2$, the STATCOM produces inductive current as shown in Figure 2b.
The amount of reactive power can be expressed as;

$$Q = \frac{V_1(V_1 - V_2)}{X} \quad \ldots\ldots (1)$$

Where: $Q =$ Reactive power, $X =$ reactance across the line transformer, V_1= the voltage of the power system and V_2 = the voltage produced by the voltage source converter (VSC)



(a) (b)

Figure 2: Shows (a) Configuration of STATCOM and (b) V-I Characteristics of STATCOM

A. STATCOM Modeling

STACTOM is always located on a load bus. The bus on which STATCOM is being placed is converted from PQ to PV. Thus STATCOM is considered as a synchronous generator whose real power output is 0 and its voltage is set to 1 p.u.
Figure 4 depicts a typical modeling of an equivalent circuit of a simple Voltage Source Converter (VSC).
The power injected into bus k by the VSC is given as;

$$P_{SC} = V_{SC} I_{SC} \quad \ldots\ldots (8)$$

The active power at bus k is expressed as;

$$P_k = V_k I^*_{sc} \quad \ldots\ldots (9)$$

Subject to the constraint

$$V_{SC\min} \leq V_{SC} \leq V_{SC\max} \quad \ldots\ldots (10)$$

Where;
$V_{SC\min}$ and $V_{SC\max}$ are the STATCOM minimum and maximum AC Voltages.
The switch-mode voltage source converter and its transformer is given as;

$$V_{SC} = V_K + Z_{SC} I_{SC} \quad \ldots\ldots (11)$$

$$Z_{SC} = (R_{SC} + X_{SC})^{1/2} \quad \ldots\ldots (12)$$

ISSN: 2350-0328

International Journal of Advanced Research in Science, Engineering and Technology

Vol. 2, Issue 1, January 2015

And $Y_{SC} = \frac{1}{Z_{SC}}$ .... (13)

$$V_K = \sum_{K=1}^{N} V_K \qquad (14)$$

Where V_K represents voltage at bus k, V_{SC} represents the voltage source converter, Z_{SC} and Y_{SC} are the coupling transformer impedance and short-circuit admittance respectively.

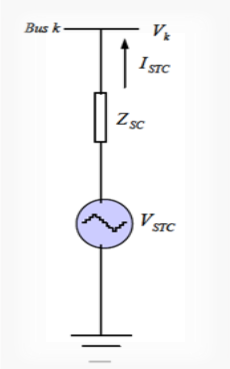


Figure 3: Equivalent Circuit of VSC

Voltage magnitude and phase angle and using the rectangular co-ordinate representation.

$$V_k = e_k + jf_k \qquad (15)$$

$$V_{sc} = e_{sc} + jf_{sc} \qquad (16)$$

$$|V_{sc}| = (e_{sc} + f_{sc})^{1/2} \qquad (17)$$

And $\delta_{sc} = \tan^{-1}\left(\frac{f_{sc}}{e_k}\right)^{1/2}$ .... (18)

V. OPTIMISATION

Ant Colony was used for the optimal placement of STATCOM using the following parameters:

A. Objective Function

This objective function is to maximize the reactive power thereby improving the voltage profile in the transmission lines.

Voltage in Power System is defined as:

$$V = X\,I^* \qquad (12)$$

But $I^* = \frac{S}{V}$ .... (13)

And $S = P + jQ$ .... (14)

$$V = X\,\frac{S}{V} \qquad (15)$$

$$V = X\left(\frac{P + jQ}{V}\right) \qquad (16)$$

In general,

$$V_K = \left[X_T\,(P_K + jQ_K)\right]^{1/2} \qquad (17)$$

ISSN: 2350-0328

International Journal of Advanced Research in Science, Engineering and Technology

Vol. 2, Issue 1, January 2015

$$0.99 \leq V_K \leq 1.00 \quad \text{where;}$$

P_K = active power of bus k; Q_K = reactive power of bus k; X_T = total reactance of all lines associated to bus k;

V_K = voltage profile of bus k; I^* = Current (Complex); K = bus under consideration [k=1, 2, 3…n]

The idea here is that any bus voltage that is within the range of V_K, could be considered acceptable. Otherwise, it is not acceptable.

VI. RESULTS

A. Simulation

The concept of simulation is to run the load flow of the Nigerian Grid System at contingency with and without STATCOM so as to determine the effect on bus voltage profile improvement. The Nigerian 330kV Transmission grid was modeled and simulated within the environment of the PSCAD/EMTDC 4.3.1 version Software and the optimal placement of STATCOM was realized by the ant-colony optimization technique.

In order to demonstrate the effect of the STATCOM on the network under consideration, certain scenarios are considered and analyzed.

B. Nigerian North-East Grid System with STATCOM

At the occurrence of a fault on the system, the three-phase fault through impedance is applied to the transmission line at Bus 10 at 250ms and subsequently, the fault is cleared in 265ms. The STATCOM is located at Bus 6 as represented on Figure 4 to be found in the appendix. The flowing time responses occurred:

ACTIVE POWER

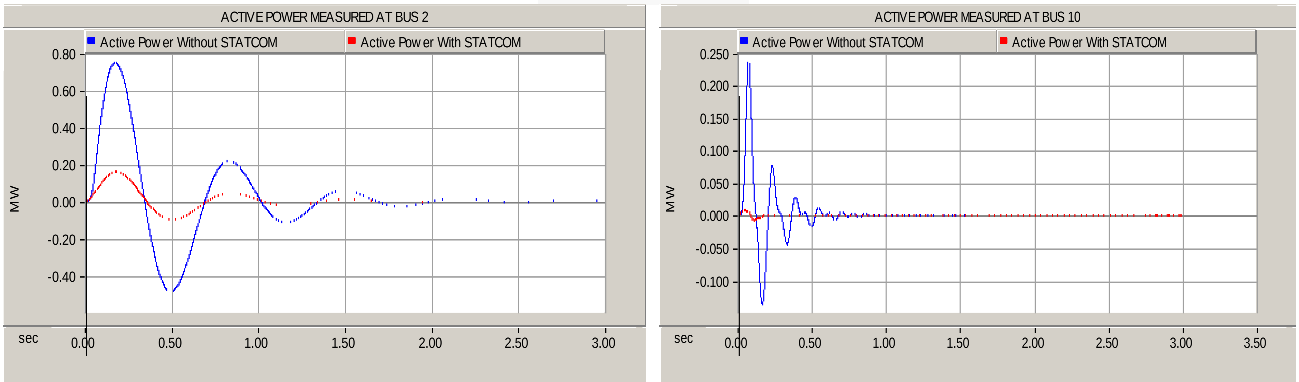


Figure 5: Analysis of Active Power

REACTIVE POWER

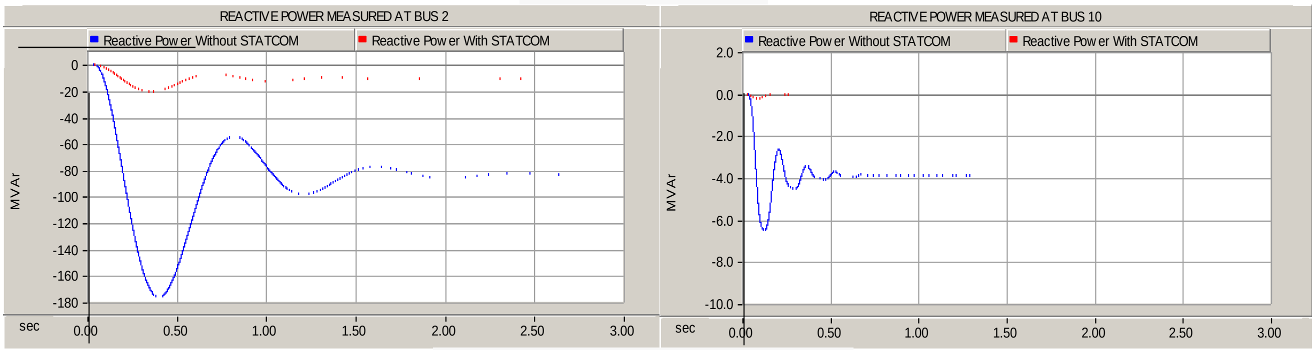


Figure 6: Analysis of Reactive Power

ISSN: 2350-0328

International Journal of Advanced Research in Science, Engineering and Technology

Vol. 2, Issue 1, January 2015

BUS VOLTAGES

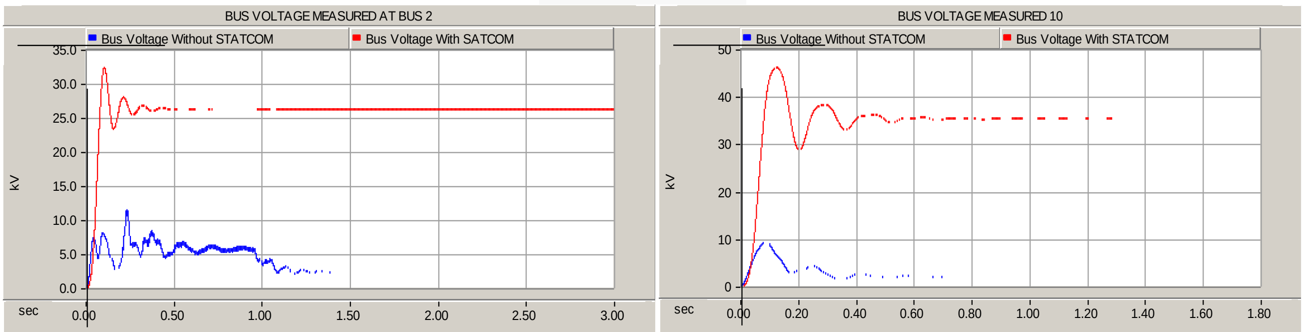


Figure 7: Analysis of Bus Voltage

FAULT CURRENT

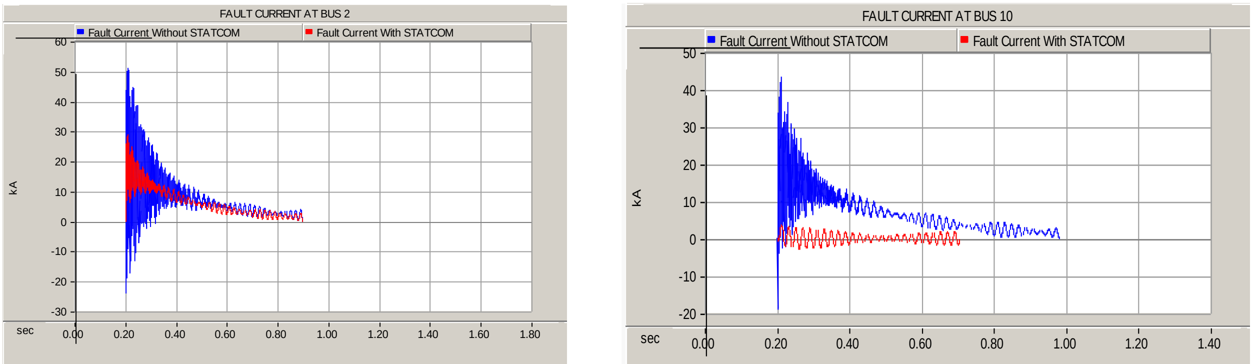


Figure 16 Analysis of Fault Current

Table 1: Bus Voltage Magnitude

BUS NO	BUS VOLTAGE WITHOUT STATCOM (p.u)	BUS VOLTAGE WITH STATCOM (p.u)	BUS VOLT WITH FAULT WITHOUT STATCOM (p.u)	BUS VOLT WITH FAULT WITH STATCOM (p.u)	EXPECTED BUS VOLTAGE (p.u)
1	1	1.0003	0.8697	1.0001	1
2	0.9242	0.9997	0.9059	0.9969	1
3	0.9969	1.0013	0.8678	1.0001	1
4	0.9848	1.0152	0.9062	1.0011	1
5	0.9515	0.994	0.8688	0.9993	1
6	0.9394	1.0061	0.8421	0.995	1
7	0.9121	1	0.8072	0.9906	1
8	0.9091	1	0.9091	0.9988	1
9	0.8939	1.0023	0.8914	0.9938	1
10	0.8667	1.0125	0.9547	0.9979	1
11	0.9667	1.001	0.7576	0.9902	1
12	0.8939	1.0004	0.9708	0.997	1
13	0.9879	1.0001	0.9077	1.0064	1

ISSN: 2350-0328

International Journal of Advanced Research in Science, Engineering and Technology

Vol. 2, Issue 1 , January 2015

VII. CONCLUSION

This research work has successfully applied the basic structure of STATCOM operating under different voltage control and its bus model on the network considered. Simulations carried out confirmed that the STATCOM is capable of providing a swift voltage support to prevent the possibility of voltage sagging or system collapse of the Nigerian 330kV network especially during fault conditions. The use of the Ant Colony Algorithm for optimal placement of the STATCOM is elucidated in this paper. The effects of STATCOM toward improving voltage profile, reactive power and transient condition minimization have been fully achieved.

REFERENCES

1. Balogun, A. Z., "The impact of natural gas pricing on electricity tariffs and supplier benefits in Nigeria", *A thesis submitted to the graduate faculty, graduate college, university of Oklahoma,* , Pp. 1-3, 2010.
2. Reactive power compensation Retrieved from http://www.electronics-tutorials.ws/accircuits/reactive-power.html 31st march, 2014. 1:13pm
3. Juan Dixon, Luis Morán, José Rodríguez, & Ricardo Domke, *"Reactive Power Compensation Technologies", State of-the-Art Review*. Electrical Engineering Dept. Santiago – CHILE. Pp. 1-15, 2010.
4. Abhijeet Barua and Pradeep Kumar, "Study of reactive power compensation using STATCOM", Department of Electrical Engineering National Institute of Technology Rourkela-769008, Orissa, pp. 1-20, 2010.
5. Ambafi, J. G., Nwohu M. N., Ohize H. O., Tola, O. J., "*Performance Evaluation of PSS and STATCOM on Oscillation Damping of a North-Central Power Network of Nigeria Grid System"*. International Journal of Engineering and Technology Vol. 2 No. 2, Pp 209-219, 2012. Retrieved from
6. *http://iet-journals.org/archive/2012/feb_vol_2_no_2/8551221326496621.pdf*
7. Sadiq, A. A., Nwohu, M., Ambafi, J., & Olatomiwa, L., "Effect of Contingency on Available Transfer Capability (ATC) of Nigerian 330kV Network. *Electrical and Power Engineering Frontier* , pp.8-17, 2014.
8. Nwohu, M.N., "Voltage Stability Enhancement of the Nigerian grid system using Flexible Alternating Current Transmission System (FACTS) devices". *PHD thesis. Abubakar Tafawa Balewa University, Bauchi, Nigeria*. Pp. 7-12, 2009.
9. Sadiq, A. A., & Nwohu, M. N., "Evaluation of Inter – Area Available Transfer Capability of Nigeria 330KV Network", *International Journal of Engineering and Technology* , 148 – 158, 2013.
10. Hernandez, M.A. Rodriguez, E. Torres, & P. Eguia, "A Review and Comparison of FACTS Optimal Placement for Solving Transmission System Issues", International Conference on Renewal Energy and Power (ICREPQ'13). ISSN 2172-038 X No.11. Bilbao (Spain), pp. 1-6, 20th to 22nd March, 2013.
11. Sadiq, A. A., Nwohu, M. N., & Ambafi, J. G., "A Comparative Study on Implementation of Genetic Algorithm (GA) and ATC to Generator Sitting in Nigerian 330kV Network", *International Journal of Engineering Sciences*. pp 350-360, 2013.
12. Juan Dixon & Luis Morán, (2005). "A Clean Four-Quadrant Sinusoidal Power Rectifier, Using Multistage Converters for Subway Applications", IEEE Trans. on Industrial Electronics, Vol. 52, No 3, June 2005.

APPENDIX

Table 2 PROBLEM PARAMETERS OF ACO

Number of ants	30
Number of Nodes/Buses	13
Minimum number of iterations before convergence	50
Pheromone decay	5%
Pheromone update	0.21
Total pheromone update	150
Percentage of visibility	>=95%

Table 3 SUMMARIZED DATA OF STATCOM

System	**Description**
Optimal System Location	Bus 6
Optimal STATCOM Size	100MVAr/40kV d.c.
Reference Voltage	1.0 pu
Percentage of Voltage Profile Increase compared to Standard without STATCOM	88.5%
Percentage of Voltage Profile Increase compared to Standard with STATCOM	97.1%
Total Percentage of System improvement	8.6%

ISSN: 2350-0328

International Journal of Advanced Research in Science, Engineering and Technology

Vol. 2, Issue 1 , January 2015

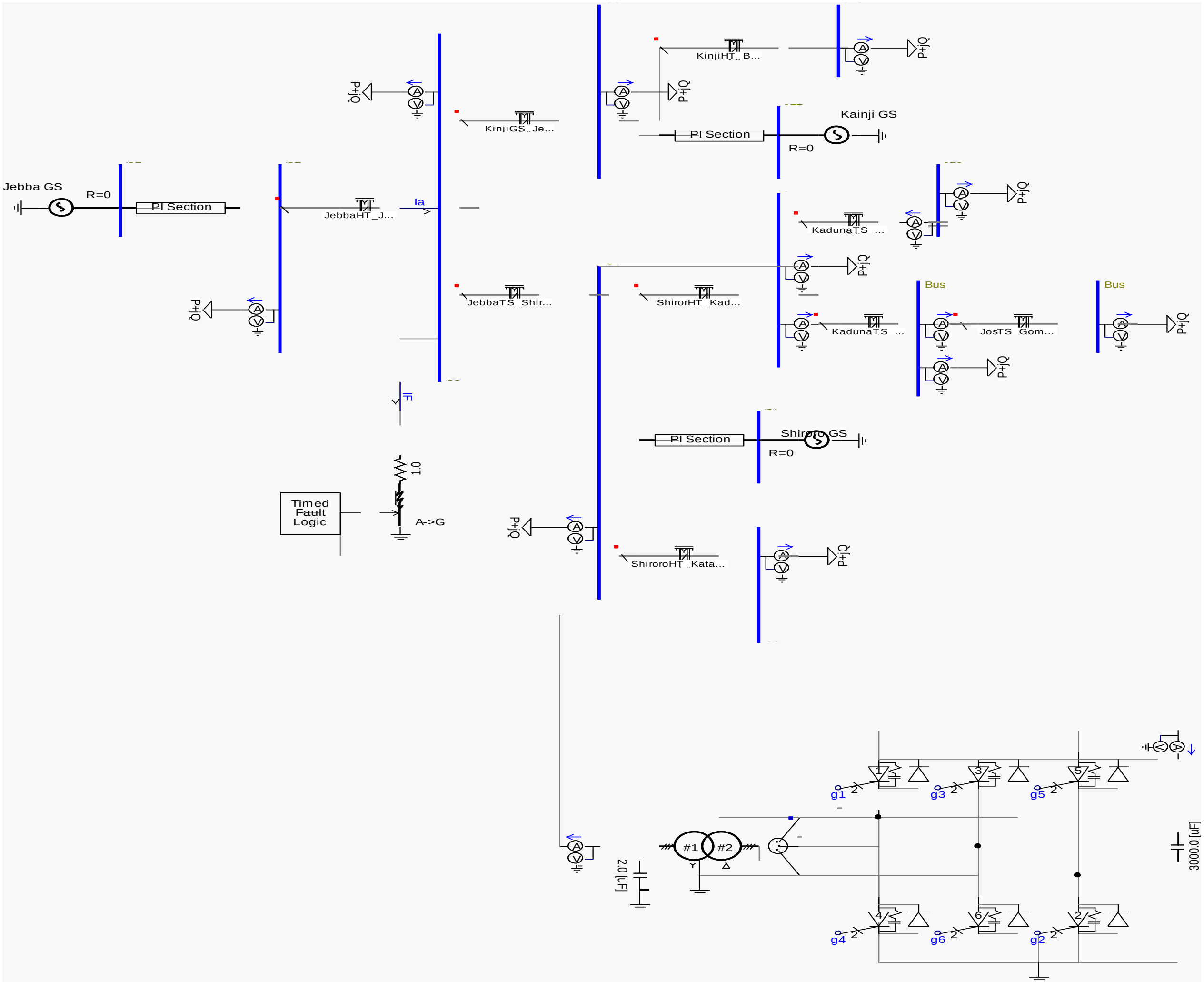


Figure 4: PSCAD representation of Nigerian 330kV Northern Region Transmission Network