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Improving Electric Power Quality In Nigerian Existing 330kv 28 Bus Electric Power Systems Using Static Var Compensator System

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Abstract

The work involved the need to, in the interim, improve on the quality of electric supply in the country by compensating the existing 28 bus Nigerian network using Static Var Compensators. This is in contrast to the long term measures of increasing the power generation capacity and expanding our transmission and distribution networks. Electrical energy is a product and like any other product, should satisfy the proper quality requirements. Nigeria as a developing country needs quality electric supply to satisfy the social, economic and technical needs of the country. But the quality of electric supply generation to satisfy these needs leaves much to be desired. This paper examined the quality of electric supply in Nigeria and proffered modern methods to improve on the quality using FACTS devices.

Key Words: *Compensation, FACTS,Violation, Existing, Quality.*

1. Introduction

The importance of electricity cannot be compared with any other utility supply since it controls, determines and affects all other sectors of a nation's economic development. The national gross domestic product (NGDP) is seriously dependent on the quality of electric supply of a particular nation. Our ever growing technological world has become deeply dependent upon the continuous availability of electrical power [1]. Increases in electric usage are necessary and desirable since electrical services are essential for a nations improved standards of living. Electricity attracts attention because it brings infrastructural development to every nation and sound national development depends on adequate provision of quality, reliable, efficient and affordable electricity [2]. President Goodluck Jonathan announced plans to develop the country's economy that include investing up to 2013 into alternative energy and power generation, transmission and distribution to raise current output. One of the objectives of the First National Implementation Plan for 'Vision 2020' is to reduce the 40 per cent of Nigerians that lack access to electricity. The successes of this aim will be achieved by the robustness of the infrastructural development of the NIPP [3].

Reliable and efficient electricity is a basic necessity and an essential intermediate input for social and economic development. Intelligent technology demands power that is free of interruption or disturbance [1]. It is essential for production of goods and services; security; leisure; and entertainment as well as the operation of modern technological systems. Availability and access to reliable and efficient electricity contribute to the growth of the economy and improvement in the standard of living of a people. Therefore, a precondition for Nigeria to achieve its aspiration of being one of the 20 biggest economies in 2020 is to generate, transmit and distribute adequate, reliable, efficient, and affordable electricity.

The electric power situation in Nigeria is so inadequate that it has held back economic development and social well-being. This has constrained the developmental aspirations of Nigeria; low quality and unreliable electricity is often cited as the biggest bottleneck to business growth in Nigeria. The current generating capacity is less than 30 per cent [4] of the demand and the electricity supply system serves less than 40 per cent of the population, mainly in the urban areas. This inadequacy subjects Nigerians mainly in rural areas to unreliable power supply and unscheduled power outages. Studies [4, 5] have revealed that electricity challenges in Nigeria is beyond generation, the electricity supply industry faces equally transmission and distribution challenges.

Nigeria needs to aggressively pursue measures that will, in the interim, avoid power system collapse and improve the integrity of the National Grid. Power generation projects generally take three to five years to complete depending on the size of the generation. The country cannot afford to wait that long for some kind of stability in their power supply [6] hence the decision to effectively and efficiently compensate the existing 330kV 28 Bus Electric network using Static Var System.

2. Components of Electric Power

Electric power generation, transmission and distribution have various parameters/components by which it is described. These include the following.

2.1. Frequency

Frequency correction is one of the most critical points in power system researches. Quick response to the frequency correction within the power plant is an important issue since it prevents damages to the power transmission lines, equipment and household appliances [7]. In a power grid system, load frequency control (LFC) plays an essential role. It provides better condition for power exchange and supply in trading electricity [8]. Delay in such systems could reduce system performance and even cause frequency or other parameter instability within the grid system.

2.2. Power Factor:

Power factor is a necessary ingredient of power quality, its correction/control is to reduce the harmonics in the line current, increase the efficiency and capacity of power systems and reduce customers' utility bill [9, 10]. Power factor (PF) is defined as the ratio of the real power (P) to apparent power (S) or cosine (for pure sine wave for both current and voltage) the phase angle between the current and voltage wave forms.

$$PF = \frac{Real\ power}{Apparent\ power}$$

2.3. Power:

Real power in watts does the real work while the reactive power is the power required to generate the magnetic fields to enable the actual work to be done where as the apparent power is the total power that the utility company supplies normally in MVA.

2.4. Voltage and Current:

Current and Voltage are two fundamental quantities in electricity. Voltage is the cause and current is the effect [11]. Voltage is the electrical force that drives an electric current between two points while current is the rate at which electric charge flows past a point in a circuit. There are different types of voltages thus: direct voltage and alternating voltage. The different types of voltages have corresponding 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.

Basic Standard Values in Nigerian Power generation, transmission and distribution system: The allowed transmission system performance characteristics are shown in table 1

Table 1: Basic Standard Values;

		Normal	Tolerable Range
1	Frequency	50Hz	48.75 – 51.25Hz
2	Voltage	330Kv	313.5 (0.95pu) – 346.5 (1.05pu)
3	Power factor	0.85	

Power Quality Disturbance: This is generally defined as any change in power (voltage, current or frequency) that interferes with the normal operation of electrical equipment [12]. These disturbances include; (i) Transients (ii) Interruptions (iii) Sag/Under Voltage (iv) Swell/Over Voltage, (v) Waveform distortion, (vi) Voltage Fluctuations and (vii) Frequency Fluctuations. The origin of most of these power disturbances starts in the lengthy grid. The long kilometer grids are most times subjected to hash weather conditions such as lighting, wind, storms, traffic accidents, equipment failure and major switching operations. The study of the power quality and ways to control them has become very necessary because of the increase in the use of electronic gadget in almost all spheres of human endeavor.

3. Simulation Model

Figure 1 shows the modelled Nigerian existing 28bus 330kV Transmission line [13]. It is made up of the following:

Capacity of 330/132kV (MVA)	3731
Number of 330kV Substations	19
Total number of 330kV Circuits	49
Length of 330kV lines (km)	4,800
Number of Control centres	1
Number of transmission lines	32
Number of buses	28
Number of Generating Stations	10

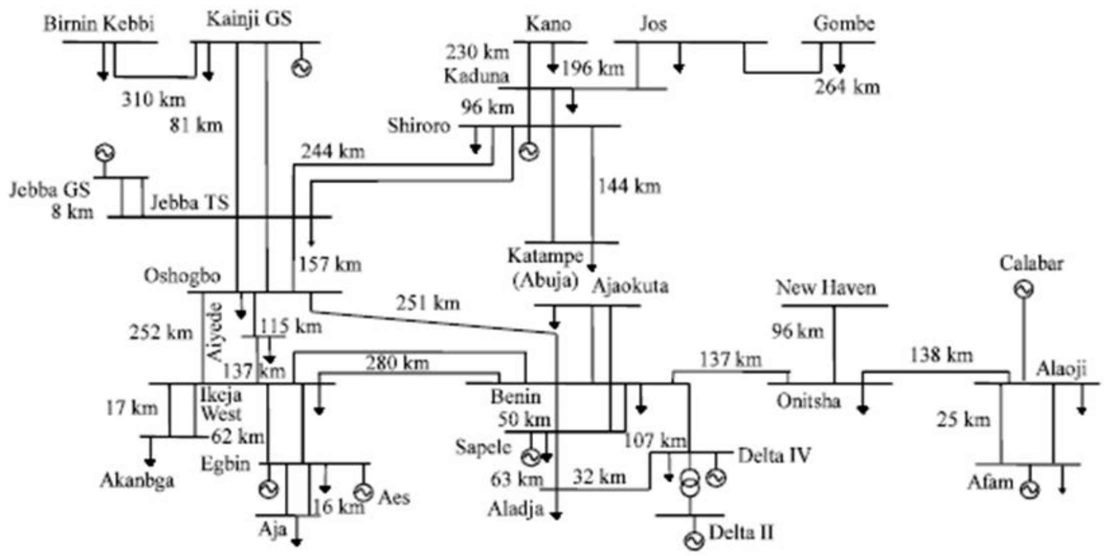

Fig. 1 Nigerian 28 bus Grid System

4. Results of Simulations at 3731MW Generation Levels

Table 2 and fig 1 show the voltage profile at each bus after the power flow analysis with generation standing at 3731MW. Details further show that there are voltage violations at bus 6 (Jos), bus 9 (Gombe), and bus 17 (Kano). These violations can be remedied using suitable voltage controlled devices such as voltage condensers (SVC). There is only one recorded thermal violation recorded on the line linking Kainji to Jebba transmission station.

Table 2: Voltage profile after the Simulation at 3731MW level.

Bus No	Bus name	Voltage (pu)
1	Kainji	1.05
2	Oshogbo	1.03
3	Benin	1.02
4	Ikeja – west	1.00
5	Aiyede	1.00
6	Jos	0.91
7	Onitsha	1.00
8	Akangba	0.99
9	Gombe	0.84
10	Abuja	1.02
11	Egbin ps	1.02
12	Delta ps	1.05
13	AES	1.00
14	Okpai	1.00
15	Calabar	1.00
16	Aladja	1.04
17	Kano	0.87
18	Sapele ps	1.02
19	Aja	1.02
20	Ajaokuta	1.03
21	New haven	0.96
22	Alaoji	0.99
23	Afam gs	1.00
24	Jebba tx	1.05
25	Jebba ps	1.05
26	Birinin keba	1.05
27	Shiroro	1.05
28	Kaduna	0.99

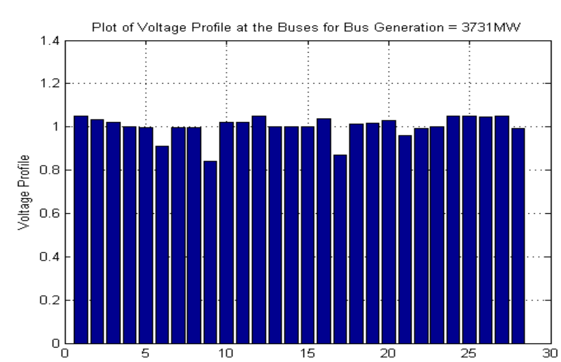

Fig 2 Bar Chart showing Voltage profile before Compensation.

4.1. Reactive Power Compensation in Nigeria 330kV 28 Bus Electric Power System Network.

System voltage depends mostly on the flow of reactive power. The long transmission lines in the Nigerian power system network generate considerable reactive Mvars which constitute serious problem in maintaining system voltages within statutory operating limits especially, during light loads periods and system disturbance. The existing 28 bus network has many reactors installed in the various locations in the power network in the country. These were taken into consideration in the simulations carried out to investigate the load flow. The status or location and values of the reactors are shown in table 3.

Table 3: Status of reactors in the existing Nigerian 330kV network.

POWER STATION	kV RATING	MVar RATING	REMARK
Kaduna	330	75	Good
Jebba	330	75	Good
Kano	330	75	Good
Gombe	330	50	Good
Oshogbo	330	75	Good
Benin	330	75	Good
Ikeja- west	330	75	Good

Source: [14].

Normally compensation modifies the surge impedance by modifying both capacitive and /or inductive reactance of the line so as to produce virtual surge impedance loading that will always equal to the actual power being transmitted. Reactive power equipment is an essential component of the transmission system [15]. It is usually used for voltage regulation, stability enhancement and for increasing power transfer. Voltage profile and stability of power transmission lines can be improved by using reactive compensation. Conventional compensation used in Nigeria 330kV network is fixed value reactors and capacitors normally controlled by mechanical switchgears. In some areas where it was very necessary to vary reactive power continuously, large generators and synchronous condensers were employed. Recently, power engineers employ latest technology known as Flexible Alternating Current Transmission System (FACTS). Flexible Alternating Current Transmission System are new devices emanating from recent innovative technologies that are capable of altering voltage phase angle and /or impedance at particular points in power systems [16].

4.2. Modeling of Static Var Systems

A static Var System (SVS) (fig 3) is an aggregation of static Var Compensators SVCs and mechanically switched capacitors (MSCs) or mechanically switched reactors (MSRs) where outputs are properly coordinated [17 – 19]. Static Var Compensators are shunt-connected static generators and absorbers whose outputs are varied in order to control specific parameters of the electric power system. SVCs are unlike synchronous Compensators. They have no moving or rotating main components hence, a SVC comprises static Var generator (SVG) or absorber devices and a suitable control device. Since SVCs have the ability to provide continuous and rapid control of reactive power and voltage, SVCs can enhance several aspect of transmission system performance and their application to date include the following;

- Control of temporary (power frequency) over voltages
- Prevention of voltage collapse
- Enhancement of transient stability
- Enhancement of damping of system oscillations.

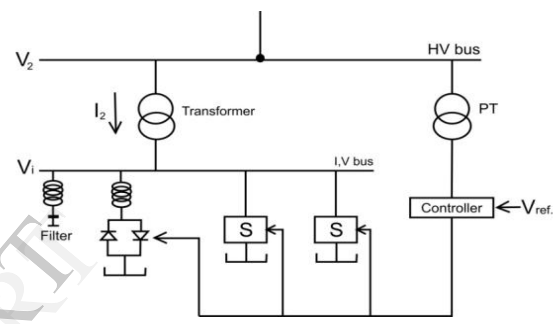

Fig 3. Schematic diagram of a typical SVS

SVS consists of a Thyristor – Controlled Reactor (TCR) and switched (thyristor or mechanical capacitors(S).

In modeling of static Var compensators, it is assumed that BSVC be the shunt susceptance of the SVC corresponding to the Mvar loading of it. This susceptance is then added to the susceptance at the particular bus. The total susceptance is given by B, a reduction in the controlling voltage V will cause the desired susceptance B to increase; this increase causes Mvar output of SVC to be enhanced. The SVC injected current into the bus is given by

$$I = -VY \qquad (1)$$

where,

$$Y = G + jB \qquad (2)$$

G maybe assumed to be zero then the MVA output of the SVC is given by

$$S = VI_{svc}^{*} \quad and \; Q = |V|^2 \, (B_{svc} + B_{Bus}) \qquad (3)$$

Table 5 Values of reactors used in the modeling and simulation of compensated 28bus 330kV Nigerian Existing power system.

POWER STATION		RATING	
STATION	BUS NO.	Kv	MVar
Jebba	25	330	75
Oshogbo	2	330	75
Ikeja- West	4	330	75
Benin	3	330	75
Onitsha	7	330	30
Aiyede	5	330	75
Akangba	8	330	75
New Haven	21	330	30
Alaoji	22	330	30
Kaduna	28	330	75
Kano	17	330	75
Gombe	9	330	100
Jos	6	330	30
Birini – Kebbi	26	330	30
Ajaokuta	20	330	30

Improvement in the quality of power generated in the system as a result of the compensation of the existing 28bus 330kV Nigeria power network can be seen in the result as stated in table 7 and fig. 4. The values of reactive power injected to the respective buses to achieve this compensation are as shown in Table 6 and the compensated model is shown in fig. 5

Table 6 Values of the new incorporated Static Vars compensators (SVC)

POWER STATION		**RATING**		**POWER STATION**		**RATING**	
STATION	BUS NO.	kV	MVar	STATION	BUS NO.	kV	MVar
Jebba	25	330	75	New Haven	21	330	30
Oshogbo	2	330	75	Alaoji	22	330	30
Ikeja-West	4	330	75	Kaduna	28	330	75
Benin	3	330	75	Kano	17	330	75
Onitsha	7	330	30	Gombe	9	330	100
Aiyede	5	330	75	Jos	6	330	30
Akangba	8	330	75	Birini – Kebbi	26	330	30
				Ajaokuta	20	330	30

4.3. Results on Incorporation of Static Var Compensator (SVC) on the Existing 28 Bus Nigerian Power System Network.

Results obtained from the power flow studies employing N-R algorithm exposed weak buses, heavily loaded transmission lines and phase angles. On incorporation of a suitable compensatory device STATIC VAR COMPENSATOR on some buses including existing ones, the hitherto weak buses were compensated. Table 6 shows the incorporation of SVC on Aiyede, Akangba, New Heaven, Alaoji, Kaduna, Kano, Gombe, Jos, Birini-Kebbi and Ajaokuta buses. The eventual results are shown clearly on fig 4 and table 7 and all the weak buses complied with statutory range of ±5% of base voltage of 330kV.

Table 7 Bus Voltages after compensation.

Bus No	**Bus Name**	**Voltage (pu)**
1	Kainji	1.0295
2	Oshogbo	1.0101
3	Benin	1.0102
4	Ikeja- West	0.9990
5	Aiyede	1.0100
6	Jos	0.9654
7	Onitsha	0.9901
8	Akangba	0.9999
9	Gombe	1.0063
10	Abuja	1.0261
11	Egbin Ps	1.0206
12	Delta ps	1.0301
13	AES	1.0000
14	Okpai	1.0082
15	Calabar	1.0000
16	Aladja	1.0276
17	Kano	1.0086
18	Sapele ps	1.0098
19	Aja	1.0302
20	Ajaokuta	1.0274
21	New Haven	0.9905
22	Alaoji	1.0000
23	Afam ps	0.9906
24	Jebba Tx	1.0236
25	Jebba Ps	1.0202
26	BiruninKebe	1.0222
27	Shiroro	1.0231
28	Kaduna	1.0041

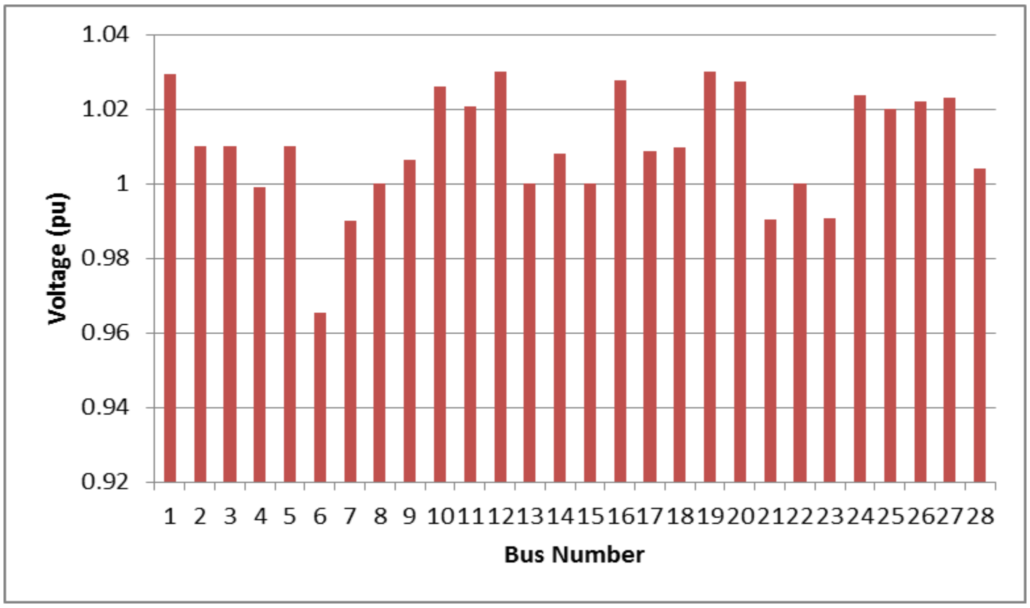

Fig. 4 Plot of voltage profile after compensation of the 28 bus Nigerian network

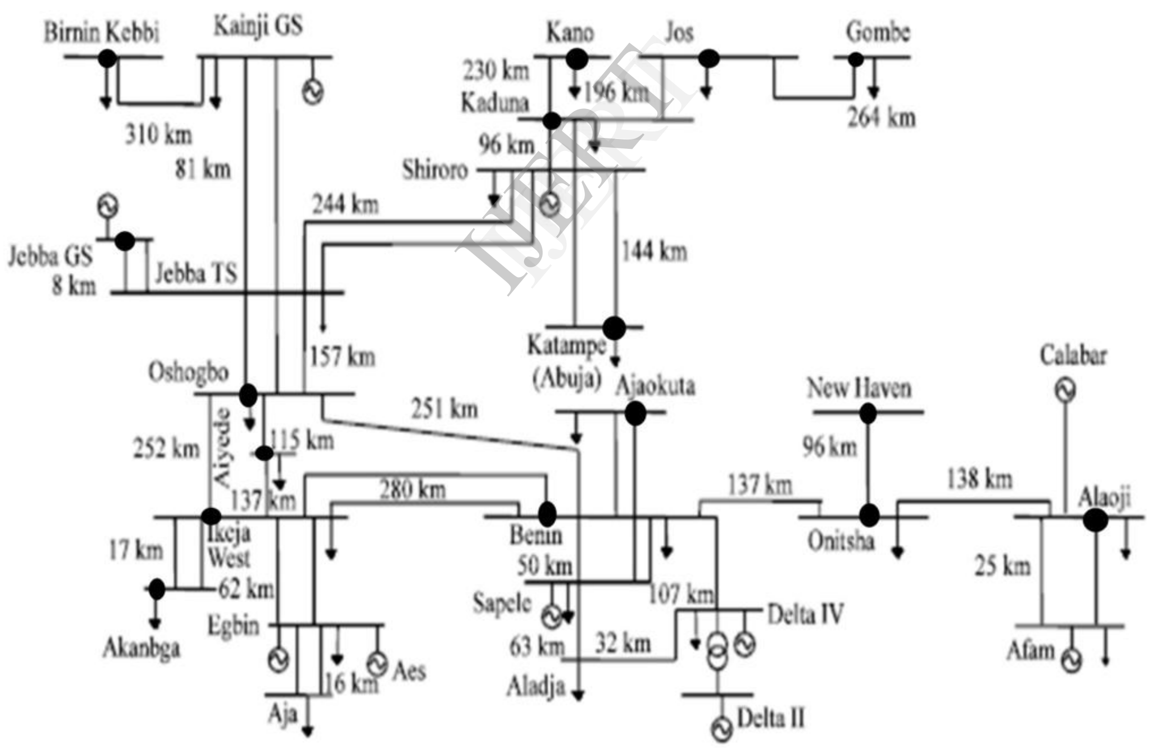

Fig 5. Model of the Compensated 28bus 330kV Nigeria Power Network (Grid)
Note: The dots (**.**) indicate compensated buses.

5. Discussion
Power flow results of the existing 28 bus power network was carried out employing Newton-Raphson power flow algorithm written in MATLAB language using the transmission line and bus parameters as obtained from the Power Holding Company Nigeria (PHCN) logbooks as shown in Appendixes 1 and 2.

It was clearly seen that some buses violated the statutory limits of voltage which has corresponding effects on the other components of power quality like the power factor and frequency. The affected buses are; bus 6 (Jos) (0.91 pu), bus 9 {Gombe) (0.84pu) and bus 17 (Kano) (0.87pu). On application of Static Var Compensators at various buses in the network, the defaulting buses maintained a voltage within the statutory limit, bus 6 (Jos) (0.9654pu), bus 9 (Gombe) (1.0063pu), bus 17 (Kano) (1.0086pu).

6. Conclusion/Recommendation

The 28bus Nigerian 330kV Power network has very low voltage drop in some buses namely Jos, Gombe, and Kano before the line was adequately compensated employing Static Var Compensators (SVC). There was a serious improvement in the voltage profile of the network after compensation. This compensation will enable the existing 28bus 330kV transmission network to be effectively used close to its thermal limit, yet it remains stable, reduce transmission line losses and maintain grid stability. It is therefore recommended that for Nigeria to attain the status of industrialized nation, aggressive steps must be taken to reform the power sector with a view to improving the electric power quality, since a stable power sector is a necessary factor for industrialization in any economy.

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