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Real - Time Voltage Stability Improvement in Electric Power Transmission Network

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Abstract

Enhancing real-time voltage stability in power system transmission network by reactive power compensation is presented in this work. The Nigerian 330kv transmission network system was used as a case study. Power flow for the network was studied and analysed in Matlab and Power System Analysis toolbox (PSAT). Total of 27 buses, 40 transmission lines and 7 generating stations of the network were considered. The base generated power were [2464.777 MW],[-1374.6861 MVar] and base load were [2381.2445 MW], [1520.9009 MVar]. The bus voltages at the base load, 120 and 125 percent of the base load without an increase in generation level were determined during the power flow simulation. At the base load, voltage recorded at Gombe, Kano and Jos buses were 0.91494 Vpu, 0.95112 Vpu and 0.95774 Vpu respectively. While at 120 and 125 percent of the base case load, voltage recorded at Kano were 0.9338Vpu and 0.9276Vpu respectively. Minimum voltage violation (Voltage Dip) were recorded at Gombe and Kano buses. Reactive compensation devices (Capacitive) were applied at these buses with voltage dip and re-simulation of power flow study showed that the bus voltages at Gombe, kano and Jos came up to 0.99132Vpu, 0.98312Vpu and 0.96764Vpu respectively.

1.0 Introduction

The basic mission of an electrical power system network is to deliver electrical energy to an end-user, safely, cheaply and neatly [1]. The form most commonly used to transport electrical energy in Nigerian is the alternating current of constant-frequency, constant-voltage. That implies that a consumer, looking back into the power system at his load port, expects the system to behave as a constant-frequency constant-voltage ac source [2]. He expects that as his load takes current or power from his port (bus) the voltage and frequency remains constant. This situation is an ideal one, it is almost impossible to design a power system in such a way that voltage and frequency remain absolutely constant whilst load varies. Nevertheless there must be a predefined voltage and frequency variation limits. Operation above or below these limits will amount to violation of the predefined limits (instability). Power system instability has become one of the greatest challenges in the power system network; this is so because, in most organized societies, an agreement is reached or a policy is made between the power supply companies and the end-user about the quality and form of the electrical energy to be supplied usually constant-frequency constant-voltage ac with a specified variation tolerance [3]. This study seeks to address the undue variation or instability associated with voltage in public power supply because every consumer desire a stable voltage supply as at when needed (real-time) for effective performance and operation of all electrical devices.

2.0 Influence of Reactive Power Flow on System Voltage Stability

Voltage control at the generator bus can mainly be achieved through generator excitation; however at other buses voltage control can be obtained by means of reactive power compensation, a clear illustration of this statement is shown in Fig.1 which shows the influence of reactive power flow on system voltage.

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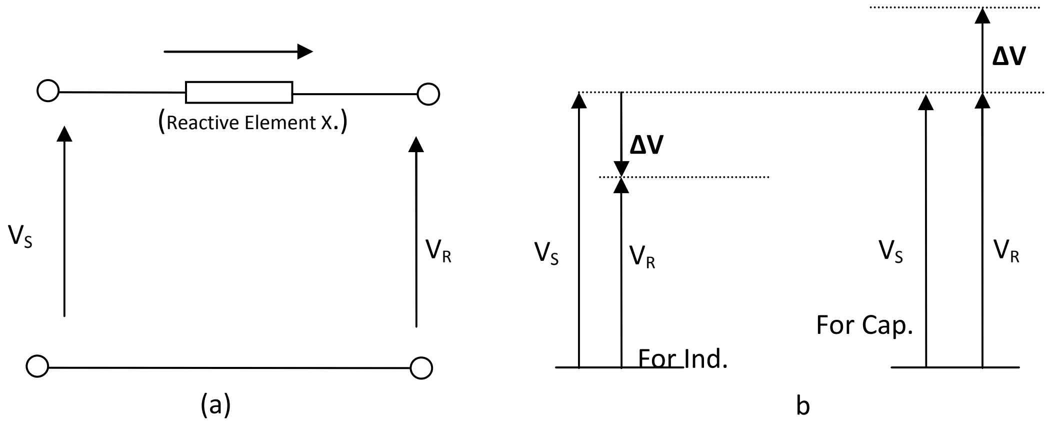

Fig 1. Influence of Reactive Power Flow on System Voltage (a) Voltage Applied Through a Reactive Element X, (b) Effect of the Reactive Element on the Supply Voltage (V_S) at the Receiving End

If the reactive element applied in the line is inductive, the change in voltage

$$\Delta V = V_S - V_R \tag{1.0}$$

Then, the receiving end voltage

$$V_R = Vs - \Delta V \tag{1.1}$$

When the reactive element applied in the line is capacitive, the change in voltage at the receiving end is

$$\Delta V = V_R - V_S \tag{1.2}$$

Then, the receiving end voltage

$$V_R = Vs + \Delta V \tag{1.3}$$

The inductive kVAr vary with the current which the line carries, whereas the capacitive kVAr vary with the system potential [4]. It is widely accepted that the power input to a system is greater than the output by a quantity I^2 R, R being the series resistance. It is not so widely realized that the same relationship exists for reactive kVAr, the input kVAr exceeding the output kVAr by an amount I^2X, where X is the series inductive reactance

3.0 Power System Stability and Voltage Control.

The stability of an interconnected power system is the ability of the system network to return to normal or stable operating condition after being subjected to some form of disturbance. Alternatively, instability means a condition denoting loss of synchronism or falling out of step from normal operating condition [5]. It has been established that for sustainable economy and technological development a satisfactory level of stability must be obtained in the energy sector. However the operators of power industries have recognized that stability consideration is an essential part of power system planning. With the current trend in globalization the demand on the Nigerian power system network is tremendously on the increase. This gives rise to continual expansion of the network, extending over vast geographical regions (urban and rural), therefore also making the network stability more difficult to maintain. It must be noted here that no matter the level of energy generated, if it has to be delivered to customers at an agreed policy, effort must be made to keep the energy at a level that is stable, safe and acceptable. This is the main objective of this research work. High voltage transmission is usually done on three phase lines. Some of the problems associated with three phase transmission system as identified by power system Engineers are listed below [5,6].

1) Voltage control at various load condition
2) Reactive power balance [voltage, transmission losses]
3) Stability problems associated with energy transfer over long distances
4) Coupling of asynchronous systems
5) Coupling of systems with different system frequencies.

Reactive power flow is primarily determined by the voltage magnitude with reactive power flowing from higher voltage bus to lower voltage bus. Real and reactive power

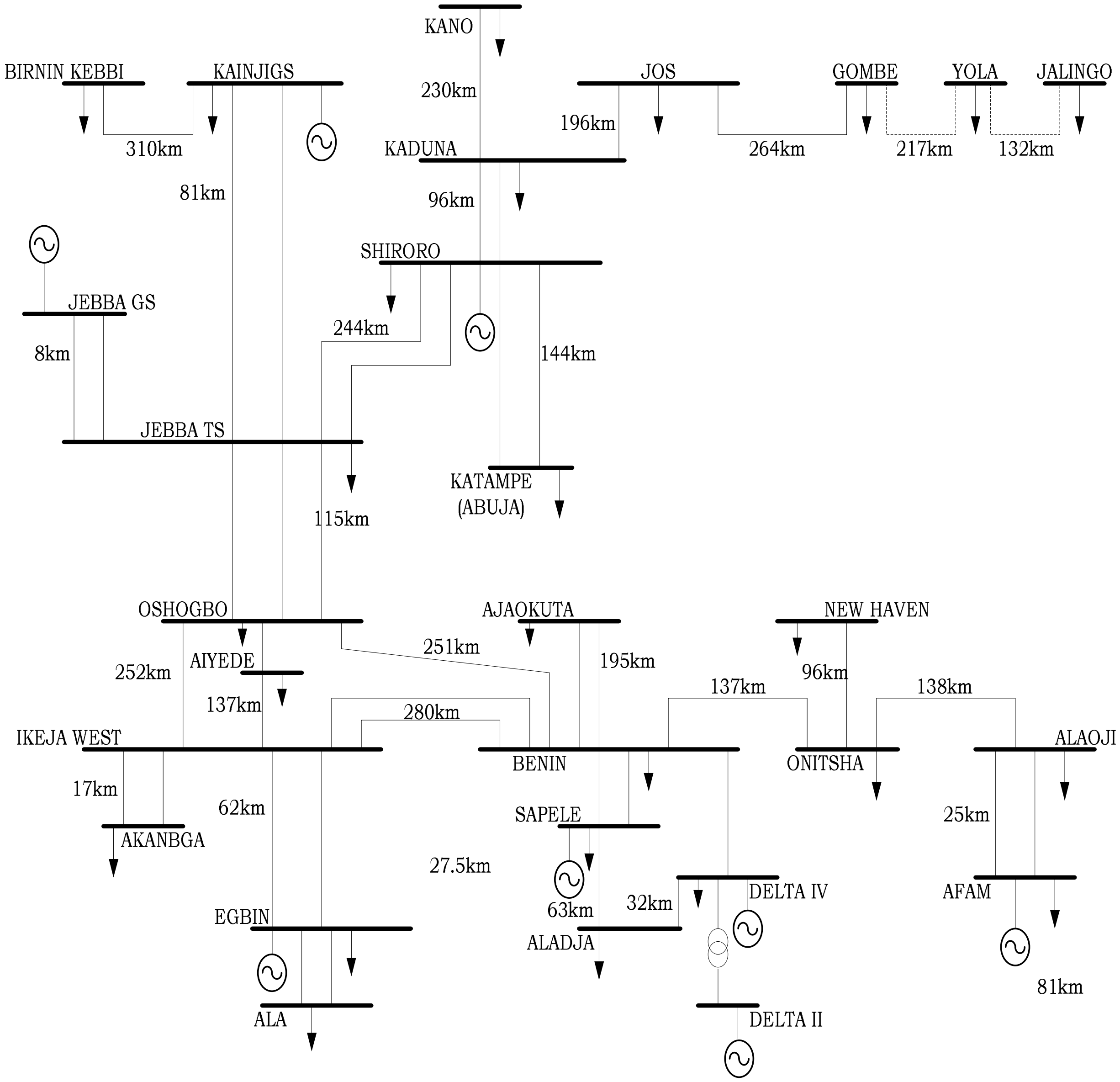

Fig. 2. Schematic Circuit Diagram of Existing 330kV Transmission lines Network.

flow, being primarily influenced by different constraints, can flow in different direction on the same line. To remedy low voltage problems in transmission network systems, the possible changes include [7]

[1] Using Tap Changing Under Load type transformer (TCUL).
[2] Increase in generator schedule voltage.
[3] System reconfiguration to shift load to less heavily loaded lines,
[4] Addition of capacitors.
[5] Use of Flexible AC Transmission System (FACTS) devices.
[6] Disconnection of shunt reactors.

The basic concept of controlling power transmission in real time assumes that means are available for rapidly changing those parameters [voltage, current, frequency and phase angle] of the power, which determine the power flow in the system network.

4.0 Problem Formulation

The major purpose of this study is to determine the minimum amount of reactive power required for compensation at a particular bus in a power system to maintain an acceptable voltage profile during contingencies such as critical outage cases or loss of a major transmission line. The system equations in this analysis are non linear, but are first linearized (approximated to a linear form) based on the approximation that for small changes [7,8]. the relationship between voltage and reactive power is linear.

Thus,

$$|\Delta Vi| \approx \sum_{j=i}^{n} Xij\Delta Qj \tag{1.4}$$

Where: $|\Delta Vi|$ = The change in voltage magnitude required to bring the voltage at bus i within desired level.

ΔQj = The change in reactive power at bus j needed to correct the voltage

Xij = The reactance linking buses i and j

Here "j" has been taken to include all the n^th^ buses.

The objective function to be minimized is the amount of reactive power to be added. i.e.

$$H = \sum_{j=i}^{n} C_j \Delta Q_j \tag{1.5}$$

where: H = Minimum corrective reactive power to be added to the system

C_j = Weighting factor at bus j. It takes into consideration the economics of varying the reactive power at the bus concerned.

n = Total number of bus where reactive compensation is to be considered.

ΔQ_j is as explained in equation (1.5).

The objective function H, therefore, provides a measure of the cost involved in the reactive compensation during any contingency.

4.1 Constraints

Normally, the corrective reactive power ΔQ_j dispatched or introduced should be such that the resulting change in the bus voltage should be greater or equal to the acceptable minimum voltage increase $|V_{\min}, i|$ and at the same time, less than the acceptable maximum voltage increase $|V_{\max}, i|$, for all changes. This is translated into mathematical form

$$\sum_{j=1}^{N} X_{ij}\Delta Q_j^{dispatched} \geq |\Delta V_{\min} i| = |V_{Hi} - V_{con,i}| \tag{1.6}$$

$$\sum_{j=1}^{N} Xij\Delta Qj^{dispatched} \leq |\Delta V \max, i| = |V_{con,i} - V_{L,i}| \tag{1.7}$$

With

$$\Delta Qj^{dispatched} \geq O \text{ for capacitive compensation} \tag{1.8}$$

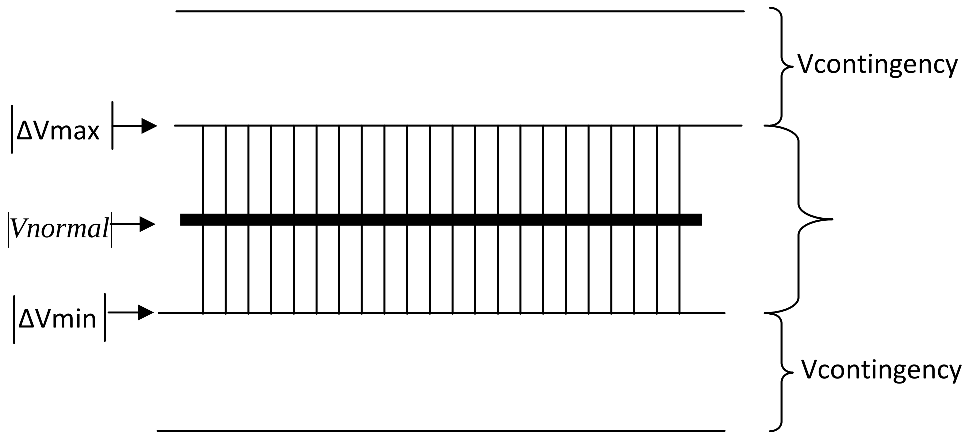

Fig.3 Statutory Voltage level and Its Acceptable Upper and lower limits

The diagrammatical representation is shown in Fig.3. It is evident that capacitive reactive power compensation is required to raise the bus voltage to an acceptable level.

5.0 Simulation and Results

Power System Analysis toolbox (P S A T 1.3.4) was used for the network power flow simulation with the following. Buses: 27 , Lines: 41, Generators: 7, Loads: 20
Number of Iterations: 4, Maximum P mismatch [p.u.] = 0
Maximum Q mismatch [p.u.] = 0 , Power rate [MVA] = 100

TABLE 1. POWER FLOW RESULTS

Bus	V [p.u.]	Phase [rad]	P gen [p.u.]	Q gen [p.u.]	P load [p.u.]	Q load [p.u.]
10: TsEgb	0.99785	-0.22945	0	0	0.8	0.6
11: Bkebi	1.0075	-0.39918	0	0	0.564	0.423
12: Osho	1.0153	-0.33444	0	0	1.449	1.0868
13: Ibdn	0.99416	-0.3065	0	0	1.33	0.975
14: Ikewst	0.99814	-0.2306	0	0	3.32	2.49
15: Akan	0.99577	-0.23322	0	0	2.28	1.71
16: Aja	0.99705	-0.23042	0	0	0.95	0.7125
17: Kad	0.99527	-0.52986	0	0	3	0.9
18: Kano	0.95045	-0.62323	0	0	1.3	0.8
19: Jos	0.95359	-0.64223	0	0	0.96	0.25
1: Sap	1.05	0	16.3803	2.6848	0	0
20: Gomb	0.90729	-0.72632	0	0	0.828	0.496
21: Ben	1.0483	-0.05717	0	0	1.242	0.933
22: Aja	1.064	-0.06771	0	0	0.65	0.4875
23: Onsha	1.0097	-0.1224	0	0	0.86	0.645
24: Aba	1.0002	-0.12235	0	0	0.748	0.42
25: Ala	1.0146	0.0076	0	0	0.2	0.15
26: Enu	0.99255	-0.14503	0	0	0.9	0.675
27: Abj	1.0258	-0.51262	0	0	1.3	0.6
2: GsJeb	1	-0.35478	0.9	-4.8543	0	0
3: GsShro	1	-0.4838	1.5	-3.244	0	0
4: GsEgb	1	-0.21981	2.2	-0.26366	0	0
5: Afam	1	-0.11691	0.72	-0.17466	0	0
6: Kaij	0.998	-0.3454	2.3	-3.1054	0	0

7: Del	1	0.01244	0.7	-4.6747	0	0
8: TsJeb	1.007	-0.35701	0	0	0.079	0.0593
9: Tsshro	1.0045	-0.4866	0	0	1.096	0.822

Minimum voltage limit violation at bus 20: Gomb [V_min = 0.94]

6.0 Summary Report

Table 2. Total Generation

Real Power [p.u.]	24.7003
Reactive Power [p.u.]	-13.632

Table 3. Total Load

Real Power [p.u.]	23.856
Reactive Power [p.u.]	15.2351

Table 4. Total Shunt

Real Power [p.u.]	0
Reactive Power (Ind) [p.u.]	0
Reactive Power (Cap) [p.u.]	0

Table 5. Total Losses

Real Power [p.u.]	0.84433
Reactive Power [p.u.]	-28.8671

Limit Violation Statistics
OF VOLTAGE LIMIT VIOLATIONS: 1
ALL REACTIVE, REAL AND APPARENT POWER FLOWS WITHIN LIMITS.

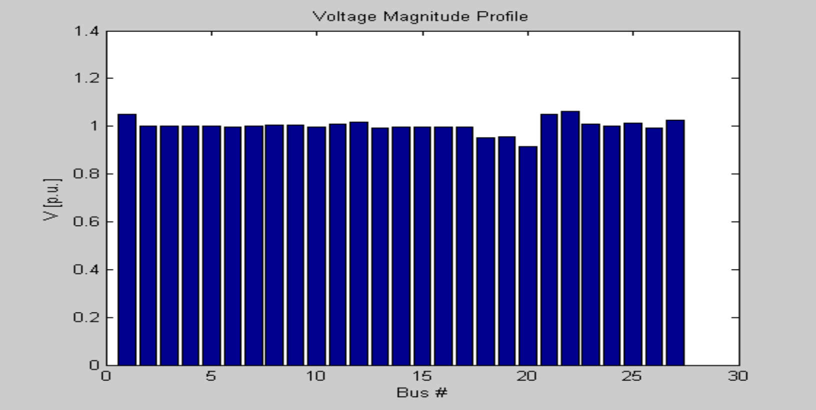

Fig.4 Voltage profile at 100% base case load

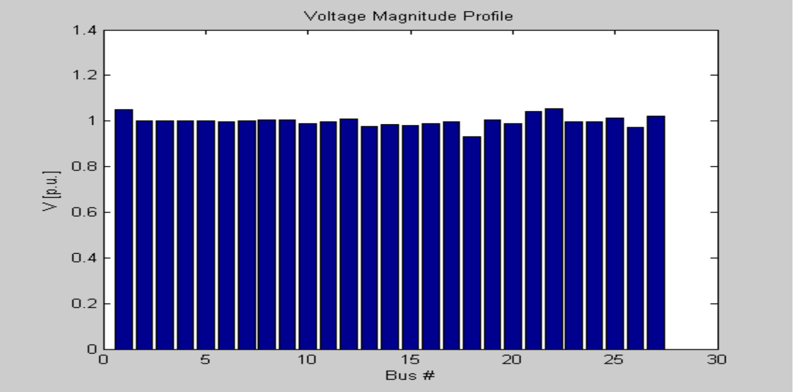

Fig.5 Voltage profile at 120% of base case load

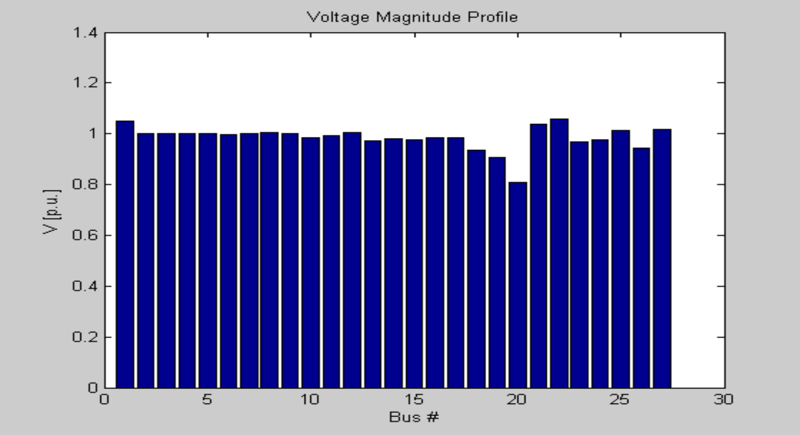

Fig.6 Voltage profile at 125% of base case load

Conclusion

The system voltage Stability profile analysis carried out revealed that minimum voltage violation occurred at Gombe bus (0.94Vpu) at the base case loading, and low voltages were recorded at Kano and Jos . The per unit values of the voltages are 0.952V and 0.953V, this is an indication of under generation that characterize the network. The system became more unstable with increased loading at the 120% and 125% of the base load without corresponding increase in generation. Further increase can lead to complete system collapse. Smaller units of generating stations evenly distributed and interconnected should be considered instead of large generating station at a location, the collapse of such a station will adversely affect the entire system. This work has been able to identify locations in the network where voltage violation could occur as a result sudden increase in load without corresponding increase in generation which in turn has its effect on the distribution network. Capacitive compensation device introduced at the Gombe bus during the re-simulation normalized or returned the voltage magnitude to an acceptable voltage level, however, it was observed that compensating devices are not adequate in the system this also leads to high voltage drops and large power losses .

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