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Transient Stability Improvement on Jos – Gombe 330kV Line Using Static Var Compensator

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Authors' contributions

This work was carried out in collaboration between both authors. Author JFU performed literature search, designed the framework and wrote sections 1, 2 and 3 of the first draft. Author MAA wrote sections 4 and 5 of the first draft and also reorganized the manuscript. Both authors read and approved the final manuscript.

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ABSTRACT

In this paper, the result of a study carried out to determine the impact of static VAr compensator on voltage profiles and reactive power flow in the Nigerian 330kV transmission grid network is presented. The research seeks to mitigate the challenge of high reactive power on Jos – Gombe 330kV single circuit transmission line. The high reactive power is produced in that axis as a result of low industrial demand in the North-Eastern region of Nigeria which results in low-inductive loading of the long transmission line that spans from Jos to Gombe and its extension to Yola, Damaturu and Maiduguri. The study also performed optimal placement of the static VAr compensator in the area where it can influence the voltage at the static VAr compensator device connection point by controlling the reactive power flow through the grid. This was accomplished by modeling the existing 330kV Nigerian network in DIgSILENT PowerFactory. The result is an improved power stability on the line between Jos and Gombe. The voltage tolerance with the approved Nigerian Grid Code and compliance was ensured. Also, the static VAr compensator was proposed over reactors due to the fact that it is dynamically switched.

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1. INTRODUCTION

Nigeria experienced a total number of 135 system collapses and 60 partial system collapses from January 2010 to September 2018 [1]. Majority of these collapses have been as a result of voltage instability. Voltage instability problem is associated with reactive power imbalance. There is heavy shortage of power generation to meet the load requirement especially in the North-East. This has resulted in construction of very long transmission lines linking the generating stations in the South to the small loads in the North as the major load centers are in the Southern part of the country. As a result, excessive reactive power is developed by these lines leading to high voltage at the receiving end of the line. The Jos – Gombe line is a 264km single circuit 330kV transmission line [1,2]. Due to the excessive reactive power developed on this line, a reactor has been installed at Gombe 330/132/33kV substation to suppress the high voltage usually recorded at the substation. This voltage problem still persists especially with the recent energization of the 180 km Gombe – Damaturu 330 kV and 260 km Damaturu – Maiduguri 330 kV transmission lines. This increase in voltage occurring at the receiving end of a long transmission line above the sending end voltage is called Ferranti effect [3]. The Ferranti effect on Jos – Gombe line is as a result of the light load flowing through the line and the non-reactive nature of the load. The capacitive line charging current produces a voltage drop across the line inductance that is in-phase with the voltage at Jos. Therefore, both line inductance and capacitance are responsible for the Ferranti effect on Jos – Gombe 330kV single circuit line. Installing a static VAr compensator (SVC) at the receiving end of the line (Gombe) will help to reduce the Ferranti effect on that line [2,3]. The SVC is expected to absorb the excess reactive power generated during the light load condition and thus help in stabilizing the voltage of the Jos – Gombe 330kV transmission line [3]. The scope of this work covers power system transient stability improvement on Jos – Gombe 330kV transmission line using SVC. The data used for this work are actual equipment parameters and were obtained from Transmission Company of Nigeria (TCN). In this work, the use of SVC device for controlling reactive power has been modeled with DIgSILENT Power Factory, and the result obtained. If deployed, this presents potential to help the utility companies minimize voltage stability issues especially in the North-East where there is serious generation deficiency.

2. RELATED LITERATURE

Various literature on improving transient stability of transmission lines and the power system have been reported. The findings from various reviewed papers show that Flexible Alternating Current Transmission System (FACTS) devices improve the stability of power system networks by injecting or absorbing reactive power to support voltage, hence enhancing stability of the network. In this work, the SVC is used to solve the reactive power challenges associated with the lightly loaded Jos – Gombe 330kV single circuit. This line is very important because it is the only line linking the rest of the system to the North-Eastern Nigeria. Any harm on this line potentially renders that part of the country in total blackout. There is zero on-grid generation in the North-East of the country. SVC was preferred over reactors due to the fact that it is a switched shunt and is excellent for the dynamic nature of the Nigerian power system particularly the critical North-Eastern Network.

3. EXPERIMENTAL DETAILS

3.1 Transient Stability

Transient stability is one of the main indices used to assess the security of a power system and it is the ability of the power system to return to equilibrium when subjected to a disturbance [4]. The stability of the power system can be improved by the use of FACTS. FACTS is based on electronic switching converters and dynamic controllers used to further improve power transfer capacity, stability, security, reliability and power quality of interconnected systems [5]. FACTS devices have been identified as cost-effective in improving the transient stability of a power system without the need of constructing new transmission lines [6]. The SVC is effective for transient stability improvement as it controls the reactive power output. It is usually installed at the midpoint of a transmission line or at the ends of the line through a coupling transformer [2 - 7].

3.2 SVC Load Flow Models

The SVC as part of flexible AC transmission system device family, is an electrical device providing fast-reactive power on high-voltage transmission network system. The SVC, as the name implies, has no moving parts. It is an automatic impedance matching device, designed to bring the system closer to unity power factor [8,9]. SVC is a shunt-connected static var generator whose output is adjusted to exchange capacitive or inductive current so as to maintain or control specific parameters [8]. SVC increases power transfer during low voltage conditions, reduces the adverse impact of faults on the lines, improves network stability, maintains a smooth voltage profile and continuously provides reactive power and mitigates active power oscillations under different network conditions [9,10].

3.3 Power System Stability

Power system stability is the property of a system that enables it to remain in equilibrium state under normal operating conditions and to regain an acceptable state of equilibrium, after being subjected to a major disturbance [11]. The reactive power appears when the voltage and current waveforms are not in phase. Since reactive power does not travel far, it becomes necessary to produce reactive power wherever it is needed which is why compensation devices are connected close to the load centers [11]. Stability problems can be grouped into three basic types namely; steady-state stability, dynamic stability and transient stability; (a) Steady-state stability is the ability of the power system to regain synchronism after small disturbances such as gradual power changes [5]. (b) Dynamic stability is concerned with small disturbances lasting for a long period of time with the inclusion of automatic control devices [12]. (c) Transient stability involves determining whether or not synchronism is maintained after the system has been subjected to major disturbance. This severe disturbance may be due to loss of generation, sudden loss of load or fault on the power system [13 -16].

3.4 Voltage Profile Analysis for Selecting SVC Location

The voltage profile of the existing 330kV Nigerian grid network was analyzed and the selection of the location for connecting the SVC was identified based on the voltage profile of the 330kV buses. A load flow study was conducted and it was observed that the Jos – Gombe 330kV single circuit transmission line is the only link of 330kV bulk power supply to the North-Eastern part of the country. In reality, typical voltage values in the North-East are in the range of 350 – 492 kV. The existing 330kV Nigerian network was modeled and the research carried out using PowerFactory Simulation tool [6].

3.5 System Study for VAR

3.5.1 Compensator ratings

The steady-state studies have been carried out in order to examine the effect of SVC on the voltages at each of the substations. The results of the studies are presented in the load flow tables (Tables 1 and 2). This research work considered a range of +/- 120 to +/- 130 MVAR size of SVCs at all the substations in the study scenarios.

Table 1. SVC device is connected at Jos 330kV bus

JOS 330kV bus			
S/N	**Bus**	**130 MVAR**	**120 MVAR**
1	JOS	343.2	345.8
2	YOLA	398.1	402.8
3	GOMBE	396.2	400.6
4	DAMATURU	411.6	416.4
5	MAIDUGURI	426.7	431.8

Table 2. SVC device connected at Gombe 330kV

Gombe 330kV bus			
S/N	**Bus**	**130 MVAR**	**120 MVAR**
1	Jos	317.4	323.0
2	Yola	287.0	302.8
3	Gombe	293.5	307.8
4	Damaturu	297.0	313.3
5	Maiduguri	306.9	323.9

4. RESULTS AND DISCUSSION

4.1 Study Scenarios

The study scenario for the placement of SVC in tackling the high voltage problem is grouped into three scenarios; (a) Scenario 1: this is the base case and it consists of the existing transmission network without connecting SVC at any of the buses; (b) Scenario 2: this consists of the base case and the proposed SVC placed at Jos 330kV bus-bar considering the existing 330kV Jos – Gombe single circuit transmission line; (c) Scenario 3: this consists of the base case and the proposed SVC at Gombe 330kV bus-bar considering the existing 330kV Jos – Gombe single circuit transmission line.

4.2 Load Flow Analysis

In this work, a base case was established to represent the transmission system conditions expected without the SVC device connection. The result of the load flow shows that most of the 330kV buses in the grid are within the acceptable voltage limits. However, the voltage profile around the area under consideration was not healthy as most of the bus voltages were out of the normal operational limits.

4.2.1 Scenario 1: Without connection of SVC device at either Jos or Gombe 330kV buses

The scenario 1 is the base case and it consists of the existing transmission network with bus-bar voltages as shown in Table 3. In Table 3, the numbers 1 to 5 indicate voltages at different buses.

Table 3. Bus-bar voltages of scenario 1

S/N	Bus bar	Voltage (kV)	Voltage (p.u)
1	Yola	458.7	1.39
2	Damaturu	471.9	1.43
3	Maiduguri	491.7	1.49
4	Gombe	452.1	1.37
5	Jos	379.5	1.15

Fig. 1 depicts the network base case (scenario 1). It was established to represent the transmission system conditions expected without the SVC device connection. The result of the load flow shows that most of the 330kV buses in the grid are within the acceptable voltage limits. However, the voltage profile around the area under consideration was not healthy as most of the voltages were out of the normal operational limits. The buses shown in red color in Fig. 1 have their voltages outside the normal operation range as stipulated by the grid code. Table 3. is the bus-bar scenario of voltage levels of Fig. 1. The load flow study results show the existing network configuration in this axis. The load flow analysis showing the resulting effect without SVC on the Jos 330kV bus with the voltage decay around Gombe, Yola, Damaturu and Maiduguri 330kV.

4.2.2 Scenario 2: Connection of SVC device at Jos 330KV bus

Fig. 2, which depicts the network of scenario 2, assumes that SVC device will be in service and

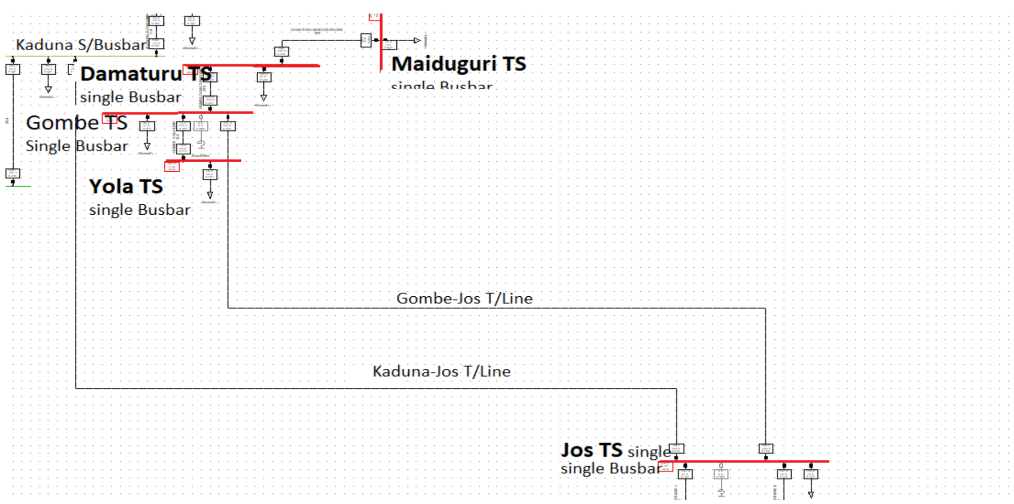

Fig. 1. Base case load flow diagram representing the transmission network

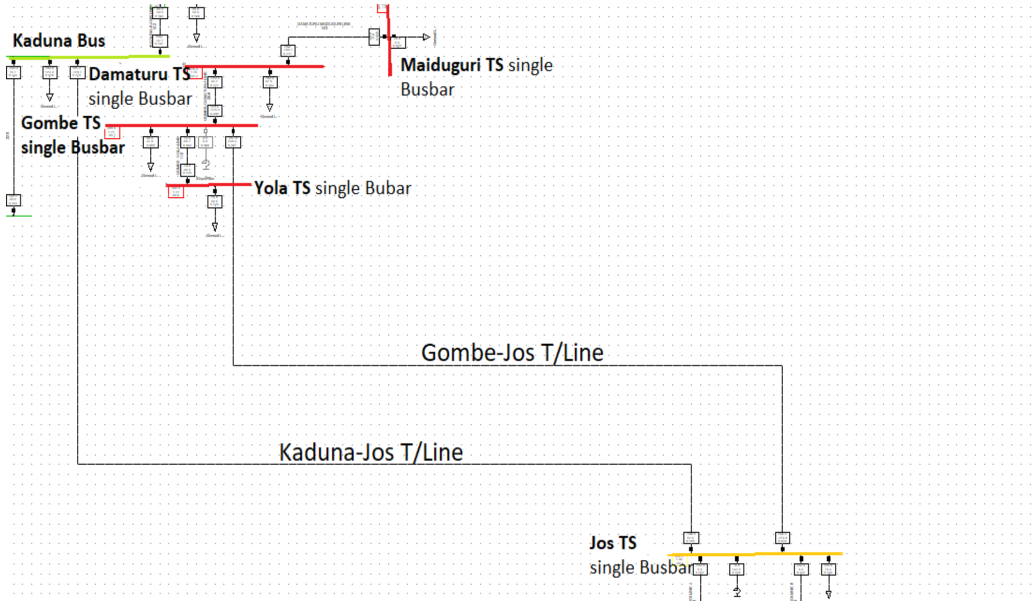

Fig. 2. Load flow diagram showing a very minimal effect of SVC at Jos bus-bar (Yellow color)

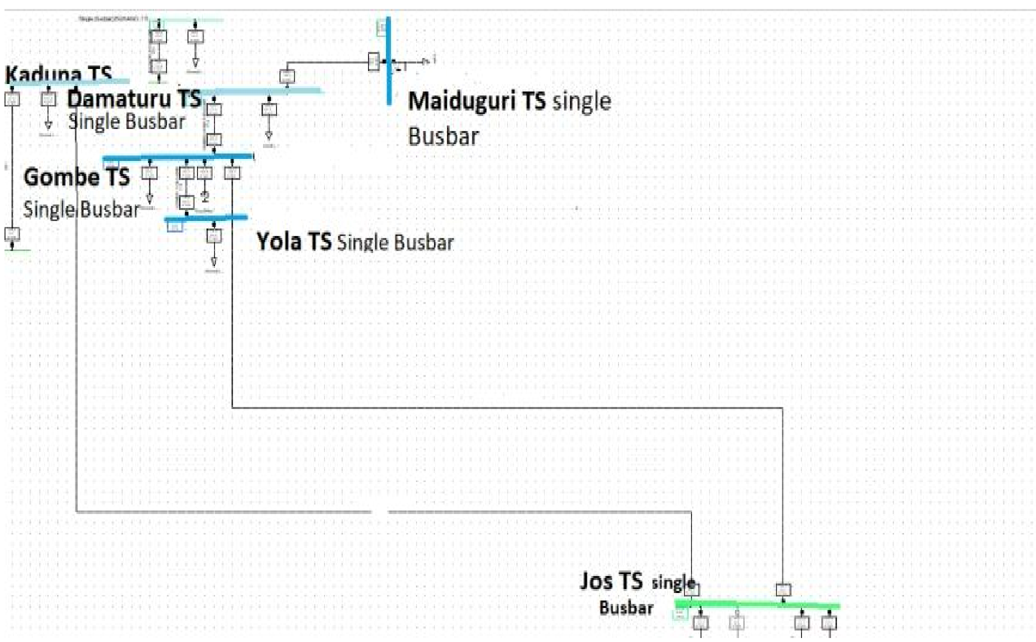

Fig. 3. Scenario 3 load flow diagram

connected at the Jos 330kV bus-bar. The load flow study results show the existing network configuration in this axis. Based on the result of the load flow analysis the effect of the SVC was very minimal only having effect on the Jos 330kV as in bus 5 (Table 4). The voltage decay around Gombe, Yola, Damaturu and Maiduguri 330kV buses still persisting (Table 4).

4.2.3 Scenario 3: Connection of SVC device at Gombe 330kV bus

Fig. 3 represents scenario 3 showing the SVC device connected to Gombe 330kV bus. The load flow study results show the existing network configuration in this axis. The load flow results indicated in green colors show significant improvement as SVC device is connected at Gombe 330kV bus and the voltage profile of the other buses connected to it indicates acceptable voltage operational limits.

Table 4. Bus-bar voltages showing the connection of SVC in Jos 330kV

S/N	Bus bar	Voltage (kV)	Voltage (p.u)
1	Yola	402.8	1.22
2	Damaturu	416.4	1.26
3	Maiduguri	431.8	1.31
4	Gombe	400.6	1.21
5	Jos	345	1.05

Table 5. Bus-bar voltages showing the connection of SVC in Gombe 330kV

S/N	Bus bar	Voltage (kV)	Voltage (p.u)
1	Jos	323.0	0.98
2	Yola	302.8	0.92
3	Gombe	307.8	0.93
4	Damaturu	313.3	0.95
5	Maiduguri	323.9	0.98

The outcome of scenario 3 shows that by connecting the SVC device at Gombe 330kV bus, it will properly influence the voltage by controlling the amount of reactive power flowing through the grid.

5. CONCLUSION

In this paper, the voltage problems associated with the network in the North-Eastern part of the country was studied and a static VAr compensator was used to control the amount of reactive power leading to voltage acceptable as required by the grid code. Three study scenarios were considered in the analysis namely: scenario 1, scenario 2 and scenario 3 respectively. Scenario 1 represents modeling of the existing 330kV Nigerian network without connection of the SVC. Scenario 2 represents connection of the SVC at Jos bus while scenario 3 represents connection of the SVC at Gombe bus. The development of the different scenarios was to determine the best place to install the SVC. From the result, placing the SVC at Gombe bus was most beneficial as the voltages were all within acceptable limits as stipulated in the grid code. This research shows that the stability improvement of the voltage level and reactive power flow in the 330kV transmission grid model was achieved with placement of SVC at Gombe.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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