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Technical Losses Reduction on the Nigerian National Grid

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ABSTRACT

For more than 30 years, the Nigerian National Grid has been beleaguered with 715 total incidences of voltage collapse. Regrettably, the control measures adopted by the Transmission Company of Nigeria, for technical losses minimization and voltage profile enhancement are ineffective when mostly desired. The study developed a model for losses minimization in the Nigerian 330 kV transmission grid. Simulation using fast decoupled load flow analysis at steady state identified the following transmission lines with losses above 5%: Jebba-Kainji (7.405%), Abuja-Shiroro (9.805%), Benin-Oshosbo (7.17%), Sapele-Benin (5.25 %), Benin-Onitsha (9.054 %), Onitsha-Alaoji (15.57%), Oshogbo-Ikeja West (10.59%), Ikeja West – Egbin (6.636%), Yola-Gombe (5.462%), Jos-Kaduna (5.987%), Mambila-Makurdi (7.781%). But with the placement of static synchronous compensator (STATCOM) at the optimal generator bus, the technical losses were minimized as follows: Jebba-Kainji (2.14%), Abuja-Shiroro (0.61%), Benin-Oshosbo (0.25%), Sapele-Benin (0.20%), Benin-Onitsha (3.07%), Onitsha-Alaoji (0.02%), Oshogbo-Ikeja West (0.223%), Ikeja West– Egbin (0.06%), Yola-Gombe (0.00%), Jos-Kaduna (3.27), Mambila-Makurdi (2.43%). Findings from the work show that out of 34 transmission lines of the 31-bus NNG, 11 transmission lines have real power losses above 5%. The results obtained before and after the placement of STATCOM prove the effectiveness of the proposed approach on 31-Bus Nigerian 330 kV transmission system.

1. INTRODUCTION

The Nigerian National grid owned and operated by the Transmission Company of Nigeria is currently operating under heavily stressed conditions owing to various factors such as incessant outages, overloading, insufficient reactive reserves, and technical losses (Onah *et al.*, 2018a). The grid comprises a main 330 kV transmission system and a subsidiary of 132 kV around major demand centers. According to Onah et al. (2018a) there are grid issues of major concern on the Southern and northern regions of Nigeria. In the Southern region, the grid is prone to over voltages due to reactive power generation from the various power plants within the vicinity. However, in the Northern part of the country, high and low voltages are usually experienced (high voltage during light load condition and low voltage at times of heavy load condition). Some of the weakest system nodes are located in this region due to long electrical distances from generating stations. Consequently, maintaining voltage stability requires technical loss reduction using compensating device which has become a growing focus for electric power utilities. Onah et al., (2018b) observed the importance of security appraisal for network planning and expansion to minimize voltage instability in electric power network. Onah et al. (2019) observed that for more than a decade, incidences of voltage collapse of the NNG in form of partial and total collapse are now a recurrent decimal. According to the study, an intermittent occurrence of 265 times from the year 2008 to 2018 which amounts to an average of 24 times per year. According to the government-owned Transmission Company of Nigeria (July, 2019) which manages the grid, the grid suffered four total collapses in January and one each in February, April and May and 1st July 2019 making the total incidences to be 8 since year 2019 (TCN, 2019). The total incidence from year 1987 to year 2018 was estimated to be 715.

According to Weedy et al., (2012), a load flow otherwise called power flow is a power system jargon for the steady-state solution of an electrical power network. It does not essentially differ from the solution of any other type of network except that certain constraints are peculiar to power systems and, in particular, the formulation is non-linear leading to the need for an iterative or numerical solution. Hence, the complexity of NNG will require an iterative technique for the steady state solution.

According to Onah et al. (2018b), planning studies will normally be performed for minimum-load conditions and maximum-load conditions. That is examining the possibility of high voltages and investigating the possibility of low voltages respectively. Having ascertained how a network behaves under these conditions, further load flows will be performed to optimize voltages, reactive power flows and real power losses. The design and operation of a power network to obtain optimum economy is of paramount importance and the furtherance of this ideal is achieved by the use of centralized automatic control of generating stations through system control centre. In Van Cutsem, (1998), these control systems often undertake repeated load flow calculations in close to real time. Although the same approach can be used to solve all load flow problems, for example the nodal voltage method, the object should be to use the quickest and most efficient method for the particular type of problem. Radial networks will require less sophisticated methods than closed loops. In Musa, (2020), an attempt was made to assess the voltage stability of Nigerian national grid but there was no control measure adopted in the work to arrest the voltage instability in the network.

Transmission systems with reactance far greater than resistance bus bar voltages can be controlled by the injection or absorption of reactive power as observed by Weedy et al. (2012) However, controlling network voltage through reactive power flow is less effective in distribution networks where the higher circuit resistances lead to the reactive power flows having less effect on voltage and causing an increase in real power losses. Static series capacitor, static shunt capacitor, synchronous compensator, static VAr compensator and STATCOM are the compensating devices discussed in this work. Capacitors can be connected in series with overhead lines and are then used to reduce the inductive reactance between the supply point and the load. Shunt capacitors are used to compensate lagging power factor loads, whereas reactors are used on circuits that generate VArs such as lightly loaded cables. The effect of these shunt devices is to supply or absorb the requisite reactive power to maintain the magnitude of the voltage as opined by Ogbuefi et al. (2012), unfortunately, as the voltage reduces, the VArs produced by a shunt capacitor or absorbed by a reactor fall as the square of the voltage; thus, when needed most, their effectiveness drops. Also, with light network load when the voltage is high, the capacitor output is large and the voltage tends to rise to excessive levels, requiring some capacitors or cable circuits to be switched out by local overvoltage relays. Synchronous compensators are rotating machines that are very expensive and have mechanical losses.

Hence, they are being superseded increasingly by power electronic compensators such as synchronous var compensators (SVC) and static compensators (STATCOM)

In TCN (2019), three reactors were installed on the Ikot-Ekpene to Ugwuaji–Jos transmission line to mitigate the effect of voltage collapse on the grid but such approach is less effective in voltage control owing to the fact that the reactive output of reactor increases with the square of voltage. Ogbuefi and Madueme (2015) used Newton Raphson load flow analysis to obtain the voltage profiles of 30 bus NNG. The bus with voltage magnitude less than 0.95 p.u was considered as a weak bus. Again, shunt capacitor compensation was exploited but as the voltage of the capacitor reduces, the VArs produced by a shunt capacitor or absorbed by a reactor fall as the square of the voltage; thus, when needed most, their effectiveness drops. Phetlamphanh et. al (2012) presented technical losses reduction in a practical distribution network. The approach was aimed at reducing real power losses present in the network by reactive power compensation using shunt capacitor placement. The authors obtained a total loss of 8,117.4 kW after steady state simulation of the distribution network. However, the total technical losses of the distribution network were decreased by 3,846.6 kW or 47.38% after capacitor placement. Although, 47.38% of real power was reduced by compensating with banks of capacitors. But the approach is usually ineffective and time consuming for quick arrest of voltage instability in a network. To overcome the draw-backs of shunt capacitors for real power loss reduction, an exploit of STATCOM was made after steady state analysis of the electric power network. Thus, this work exploited fast decoupled load flow analysis on the account of its time of iteration to obtain the load flow analysis before inserting STATCOM to the grid for the mitigation of losses.

2. METHODOLOGY

The data was collected from the National Control Center (NCC) Oshogbo, Nigeria. The simulation was carried out with power system analysis toolbox (PSAT) embedded in MATLAB 7.5. An exploit was made in the use of fast decoupled load flow analysis based on its simulation time. The algorithm for the program is presented in the flow chart shown in Figure 1. The Simulink model of 31-bus NNG is shown in Figure 2. The network comprises 31 buses, 34 lines, 10 generators buses and 21 load buses. Egbin PV bus was chosen as the slack bus because it has the highest capacity to generate power. Bus voltages less than 0.95pu and greater than 1.05 p.u were considered as violating the voltage limits. Again, losses along transmission lines greater than 5% were seen as violations. The network model was developed in the PSAT software. Thereafter, the line parameters and the bus data were inserted at their blocks. The simulation was carried out to ascertain the transmission lines with real power loss violations using fast decoupled load flow (FDLF) analysis. The voltage instabilities arising from such violations were arrested using STATCOM. The STATCOM acted like a spinning reserve that injects reactive power to the power system to compensate for the losses along the transmission lines. At a time when the magnitude of STATCOM voltage is greater than that of the terminal voltage of Kano generator bus then the reactive power is generated by the STATCOM. However, when the magnitude of STATCOM voltage is less than the terminal voltage of Kano generator bus then reactive power is absorbed by the STATCOM, thereby stabilizing and reducing the losses at the transmission line.

A STATCOM is a power electronic device to provide reactive power or absorb reactive power depending on the difference in terminal voltage and STATCOM voltage. It comprises a voltage source converter connected to the power system through a coupling reactance (L). The VSC uses very large transistors that can be turned on and off to synthesize a voltage sine wave of any magnitude and phase. $V_{STATCOM}$ is a 50Hz sine wave kept in phase with $V_{terminal}$. If the magnitude of $V_{STATCOM}$ is greater than that of $V_{terminal}$ then reactive power is generated by the STATCOM while if the magnitude of $V_{STATCOM}$ is less than that of $V_{terminal}$ then reactive power is absorbed by the STATCOM as shown in Figure 3. A very small phase angle is introduced between $V_{STATCOM}$ and $V_{terminal}$ so that a small amount of real power flows into the STATCOM to charge the DC capacitor and provide for the losses of the converter. However, the principle of operation is that the reactive power is provided by the interaction of the two voltage magnitudes across the reactor. The DC capacitor is only used to operate the power electronics and control the ripple current.

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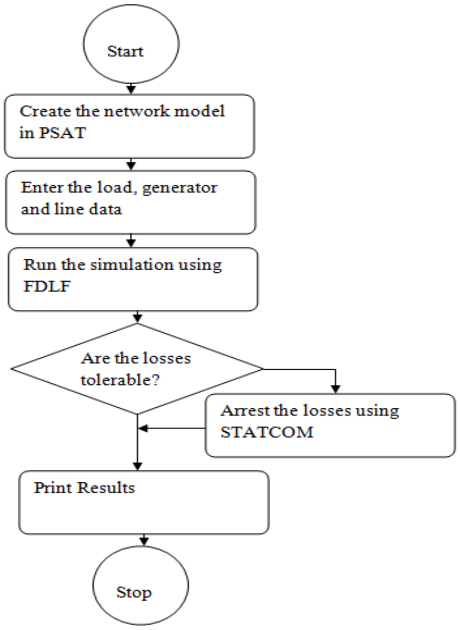

Figure 1: Flow chart for the implementation of STATCOM on NNG

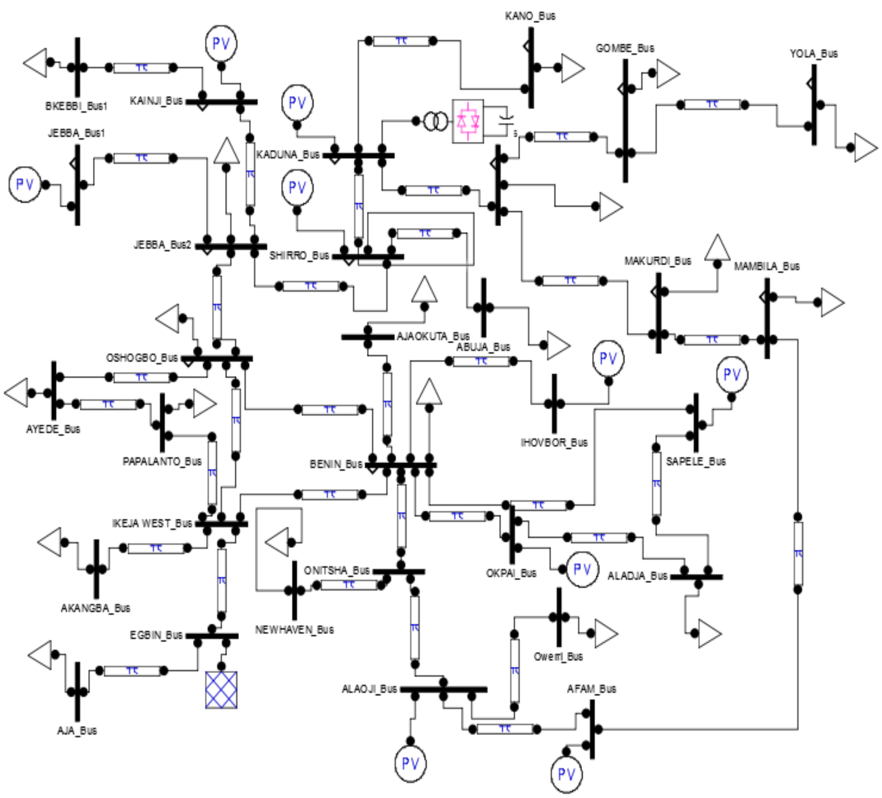

Figure 2: Simulink model of 31 buses of the NNG

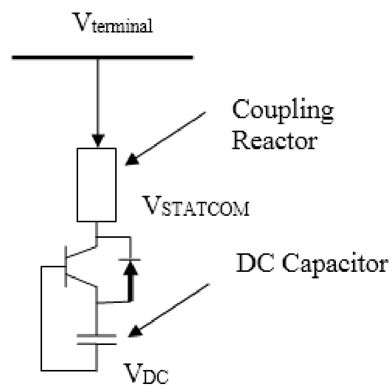

Figure 3: The structure and operating principle of the STATCOM

3. RESULTS AND DISCUSSION

For steady state analysis of the NNG, simulation was done using fast decoupled load flow analysis owing to its time per iterations. The assumption made was that a transmission line with losses above 5% is considered as violating the statutory limit. The following transmission lines with losses above 5% were identified: Jebba-Kainji (7.405%), Abuja-Shiroro (9.805%), Benin-Oshosbo (7.17%), Sapele-Benin (5.25 %), Benin-Onitsha (9.054 %), Onitsha-Alaoji (15.57%), Oshogbo-Ikeja West (10.59%), Ikeja West– Egbin (6.636%), Yola-Gombe (5.462%), Jos-Kaduna (5.987%), Mambila-Makurdi (7.781%). But with the placement of the STATCOM at various generator buses to ascertain the optimal placement, Kaduna generator bus was found to be optimal place for the installation of the STSTCOM. The technical losses were minimized as follows: Jebba-Kainji (2.14 %), Abuja-Shiroro (0.61%), Benin-Oshosbo (0.25%), Sapele-Benin (0.20%), Benin-Onitsha (3.07%), Onitsha-Alaoji (0.02%), Oshogbo-Ikeja West (0.223%), Ikeja West–Egbin (0.06%), Yola-Gombe (0.00%), Jos-Kaduna (3.27), Mambila-Makurdi (2.43%). The transmission lines with losses above 5% were seen as critical buses responsible for incessant voltage collapse scenarios observed by Onah et. al. (2019). The placement of the STATOM at Kaduna generator bus is due to radial nature of connection of the load buses which it feeds. Yola-Gombe transmission line is far from the generator bus; hence, about 5.462% was incurred at the transmission line. However, with the STATCOM placement, the losses were significantly reduced to 0.00%. As a result of the interconnections of NNG, the placement of the compensating device contributed to the minimization of losses at all the critical busses as outlined above. Shobo et al. (2020) saved 2.014 MW of real power by compensating with banks of capacitors. The current approach which has got to do with the use of STATCOM has 0.00% real power difference after the placement.

4. CONCLUSION

Findings from this study show that out of 34 transmission lines of the 31-bus NNG, 11 transmission lines have real power losses above 5%. This shows that the NNG is beleaguered by voltage instability scenarios which culminate to voltage collapse. Hence, the urgent need for real power loss reduction on the NNG. The traditional practice of the power system operators in Nigeria is to use banks of capacitors for mitigation of real power losses. The results obtained before and after the placement of STATCOM in this study proved the effectiveness of the proposed approach on 31-Bus Nigerian 330kV transmission system over the conventional practice of using banks of capacitors by a zero percent (0.00%) real power reduction.

5. ACKNOWLEDGMENT

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6. CONFLICT OF INTEREST

There is no conflict of interest associated with this work.

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