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A Review of the Applications of FACTS Devices on Nigerian 330 kV Transmission System

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Abstract: This research presents a critical review of the application of FACTS devices into the Nigerian 330 kV network for the enhancement of bus voltages and the minimization of the transmission system power loss. Available publications were critically examined with references to show these devices have been applied to power systems. This research provides vital information for power system operators and researchers on how to incorporate FACTS devices into the Nigerian power transmission system.

Key words: FACTS devices, critical review, power loss, power system, power system operators, information

INTRODUCTION

Power system the most complex system built by man consists of numerous components such as generators, transmission lines, distribution lines, transformers and variety of loads. Transmission is the link between generation and distribution. The efficiency of a power system is determined by the ability of a transmission line to optimally transfer generated power from generating stations to loads. The exponential increase in the load demand, economical and environmental constraints in transmission lines has made modern power system to be exposed to dangers of voltage instability (Sakthivel *et al*., 2011). This adversely affects the transmitted power in the network.

FACTS technology has given a new way of controlling power flows and enhancing the usable capability of transmission lines. A typical FACTS device comprises static equipment used for the AC transmission of electrical energy. It is meant for power transfer capability of power system network. The concept of FACTS was first defined by Hingorani and Gyugyi (1998). It is usually refers to as the application of high power semi-conductor devices to control different parameters and electrical variables such as voltages, impedance, phase angle, current, active and reactive powers. FACTS devices are very relevant in Nigeria power network for the improvement of the network's efficiency considering the enormous challenges inherent in the system and also the on-going deregulation/unbundling in the electricity market (Omorogiuwa and Ogujor, 2012).

The performance of an electrical power system can be evaluated using a number of power system analyses these include power flow analysis, contingency power flow analysis, fault analysis, steady and dynamic transient stability analysis, etc. FACTS devices have been incorporated in the various power system analyses to simulate the enhancement of power system behaviour (Singh *et al*., 2010; Murali *et al*., 2010; Vijayakumar, 2011; Sowjanya and Srinivasarao, 2012). In all the works, it is shown that FACTS devices have greatly improved the performances of power systems.

MATERIALS AND METHODS

FACTS devices classifications: FACTS devices are classified into 2 groups. Group 1 falls into first generation while Group 2 belongs to the second generation. The first generation FACTS devices include Static VAR Compensator (SVC) and Thyristor Controlled Series Capacitor (TCSC) while the second generation FACTS devices include Interline Power Flow Controller (IPFC), Static Synchronous Series Compensator (SSSC), Unified Power Flow Controller (UPFC) and Static Synchronous Compensator (STATCOM), etc. and each of these will be discussed briefly.

Interline Power Flow Controller (IPFC): It is a second generation FACTS device. It can either be combination of separate series controllers operating in coordinated manner or a unified controller in which the series controller provides series compensation independently for each line through the power DC link (Mahdad *et al*.,

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2007). The simple way of modelling IPFC was first reported by Nabavi-Niaki and Iravani (1996). It works only if simultaneous control is exerted on the nodal voltage magnitude, active power flow and reactive power injected from one bus to the other.

Static VAR Compensator (SVC): This is a first generation FACTS device. The SVC is conventionally used to stabilize a busbar voltage and improve dynamic oscillation in power system there by improving the voltage profile of the power system (Acha *et al*., 2002).

Static Synchronous Compensator (STATCOM): This is a second generation FACTS device. It is a regulating device based on a power electronics voltage-source controller (Mohanty and Barik, 2011; Sowjanya and Srinivasarao, 2012). The primary function of STATCOM in a power system is to increase transmission capability in a given power transmission network (Sowjanya and Srinivasarao, 2012). Usually, a STATCOM is installed to support electricity network that has poor power factor and often poor voltage regulation. It is also used for voltage stability. STATCOM provides better damping characteristics than SVC as it is able to transiently exchange active power with the system (Kumar and Nagaraju, 2007).

Thyristor Controlled Series Capacitor (TCSC): It is a first generation FACTS device. It is one of FACTS devices that is increasingly applied to long transmission lines by the utilities in modern power systems (Murali *et al*., 2010). It has various roles in the operation and control of power systems such as scheduling power flow, decreasing unsymmetrical components, reducing net loss, providing voltage support, limiting short-circuit currents, damping power oscillations and enhancing transient stability (Murali *et al*., 2010).

Static Synchronous Series Compensator (SSSC): SSSC is a second generation FACTS device. This device works in the same way as STATCOM. SSSC is able to exchange active and reactive powers with the transmission system. The primary purpose of SSSC is to control power flow in a steady-state mode. It can also improve transient stability of a power system (Murali *et al*., 2010).

Unified Power Flow Controller (UPFC): It is a second generation FACTS device. It is the most promising device within the FACTS concept. It has the ability to adjust the three control parameters, i.e., the bus voltage, transmission line reactance and phase angle between two buses, either simultaneously or independently (Mohanty and Barikr, 2011). UPFC is also the most versatile FACTS controller that can be used to improve steady-state stability, dynamic stability and transient stability (Noroozian and Andersson, 1993).

RESULTS AND DISCUSSION

Overview of Nigerian transmission system: Currently, the Nigerian transmission system consists of 5,650 km of 330 kV transmission lines with a radial system. The power system transmission capabilities inefficiency and its radial transmission nature are parts of the problems that affect the system reliability (Eseosa and Odiase, 2012). The length of the transmission lines is also another problem facing the system which result in high transmission line losses due to the long distances between generating stations and load centre (Ibe *et al*., 2009; Sule, 2010). The transmission network is characterized by irregular supply affecting the lives of its citizenry (Onohaebi, 2007).

Reference recommended the incorporation of FACTS devices in the Nigerian power system so as to significantly minimize power losses that result in widespread blackouts. Based on literatures reviewed, little work has been done in incorporating these FACTS devices for improving power system operations of the Nigerian 330 kV transmission system.

Incorporation of FACTS devices on the Nigerian 330 kv transmission system: Adebayo *et al*. (2013) researched on the application of Thyristor Controlled Series Capacitor (TCSC) for power flow analysis and voltage control of Nigerian 330 kV transmission system showed in Fig. 1. In this work the Newton Raphson iterative algorithm was used for solving the power flow problems due to its ability to converge very fast with small number of iteration. Simulation of power flow solutions with and without TCSC was done using MATLAB 7.90 based programme. Without the TCSC, voltage drops were noticed at some load bus, especially voltages at buses 9 (Ayede), 13 (New Haven), 14 (Onitsha) and 16 (Gombe) while with the incorporation of TCSC the voltage magnitudes of these buses were regulated to stay within the statutory limits. Hence, the incorporation of TCSC improved the voltage profile of the system and it enhanced the power flow in the network. Reference presented the impact of different FACTS devices such as UPFC, TCSC and STATCOM on voltage improvement and transmission loss reduction in the 330 kV transmission line network and Genetic algorithm optimization technique was also used for the power loss reduction. The network was modelled and simulated

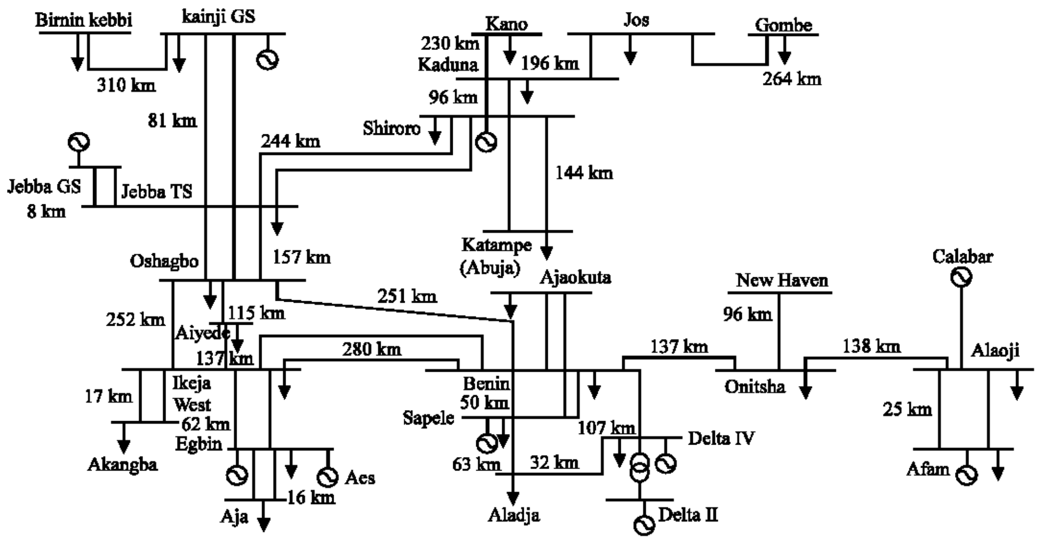

Fig. 1: Single line diagram of the Nigerian 300 kV transmission network

using ETAP 4.0 and MATLAB version 7.5. Power losses without FACTS devices were 62.90 MW and 95.80 Mvar and the weak buses per unit values were Gombe (0.8909 pu), Jos (0.9118 pu), Kaduna (0.9178 pu), Kano (0.9031 pu) and New Haven (0.9287 pu). With the incorporation of TCSC on the weak lines an improved per unit bus voltages ranging from 0.9872-0997 pu was obtained as well as power loss reduction of 44.3 MW and 78.30 MVar. Incorporating UPFC improved the per unit voltages within the range of 0.9768-0.9978 pu while STATCOM gave values between 0.9741-1.013 pu and reduced line losses to 51.8 MW and 85.60 MVar. Comparing the three FACTS devices, UPFC gave the best loss reduction of 48.64 and 27.14%. Fughar (2014) introduced the ant colony meta-heuristic technique to optimally locate STATCOM in the Nigerian 330 kV network. The ant colony optimization algorithm used the STATCOM parameters and probabilistic model to generate solutions to the problem of placing STATCOM into Nigerian network. The optimal location of STATCOM in Nigerian network showed that the bus voltage was enhanced and transmission losses were minimized. Reference researched on voltage stability improvement of power transmission system in Nigeria using TCSC and realized that without TCSC, there were voltage drops at buses Ayede (0.9892), Jos (0.9800), Kaduna (0.9810), Kainji (0.9968) and Kano (0.9992) but with the incorporation of TCSC, the voltage magnitudes of these affected buses improved as 1.1883, 1.0319, 1.0327, 1.1682 and 1.2267 respectively considering IEEE standard acceptable limits of ±10% tolerance. The results showed a considerable improvement in the voltage magnitude with the incorporation of TCSC and consequently a significant reduction in the system losses. Omorogiuwa and Onohaebi (2015), worked on the optimal location of IPFC in the Nigerian 330 kV power network using genetic algorithm optimization technique and discovered that the optimal placement of IPFC device in the network saved 50 MW of active power and the voltages of the weak buses were also improved within the allowable tolerable limits of 0.95-1.05 pu. With all these works reviewed so far, it has been demonstrated that Nigerian transmission system performance can be enhanced through the use of FACTS devices.

CONCLUSION

This research has done an in-depth review of FACTS devices placement in the Nigerian transmission system based on available literature works. It is clear from this review that only little work has be done on the incorporation of FACTS devices on the Nigerian transmission system with the literature works available. This review has clearly shown that the incorporation of FACTS devices in the Nigerian grid system will greatly enhance the voltage profile of the transmission system and minimize the unavoidable power loss of the system. It is pertinent to state that the need for research works in this field cannot be over-emphasized and should be giving great attention by concerned authorities and government. It is also necessary to practically install these devices in the Nigerian 330 kV transmission system for the desired efficiency.

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