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Power Transfer Capability Enhancement On Nigeria 330KV Lines Using Unified Power Flow Controller (Facts Device)

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***Abstract*— Electricity has become a means of livelihood as it ensures comfortability and in general increases the income of any nation. Nigeria has constantly witnessed power outages due to the increasing demand from the consumers making the power system to be stretched and poor amount of power transferred. In this study, 330kV power system data were obtained for the Nigeria 330kV South Eastern and South Southern Regions. The power system network was modeled and simulated in MATLAB environment. The lines with the least power transfer capacity were line 5 and line 6. The Unified Power Flow Controller (UPFC) FACTS device was utilized for power transfer enhancement. The results showed that UPFC improved the transfer capability of lines 5 and 6 from 0.4027pu to 0.8671pu for line 5 and 0.4027pu to 0.9291pu for line 6. Hence, it was concluded that UPFC FACTS should be utilized to enhance power transfer capability of the lines and bus station.**

Keywords*— *Power System Infrastructure, Transmission Lines, Power System Network, Transmission Line Losses, Power Transfer Capability, FACTS Vedice

I. Introduction

The development of any country is mainly anchored on the stability of its power system infrastructure. It provides a springboard for industrialization which will boost the economy of the country. Stable electricity supply in Nigeria is mandatory for economic, social and technological development. The repercussions of power interruption in the transmission system is enormous, because an outage in the transmission system can negatively affect a widespread geographical area (Ignatius K. et al, 2017).

The Nigerian power system network consist of large interconnected network that covers the whole the country. This networks are made up of high voltage substations with total transmission capacity of more than 7500 MW and over 20,000km of transmission lines. Presently, the transmission capacity is far higher than the average operational generation capacity which has fallen far below its total installed capacity. The power system infrastructure is radial and not characterized by repetitions, which has produced innate reliability issues. One of the most significant resultant effect of these under-utilization of the Nigerian power infrastructure is that transmission losses across the network is high when compared to the stipulated benchmark. This call for urgent interventions that can minimize losses and improve power capability (Amadi, 2021).

Power transfer capability of a transmission line is the amount of electric power that can be passed through a transmission network from one place to another (Gupta, 2009). The transfer capability concept of is very essential as it helps to determine system that permits inter-area transfer. Such systems are considered to be more robust than those systems that do not permit such transfer. Thus, transfer capability can be used as a rough indicator of relative system security. Transfer capability is also useful for comparing the relative merits of planned transmission improvements (Grainger J.J, Stevenson W.D, 2003). The most common solution to increasing power transfer capability is the installation of power generation station. However, it is capital intensive and takes lots of time to build, hence the need for a flexible approach towards improving power transfer capability of transmission lines (El-Hawary, 2019).

In standard AC transmission system, the amount of power that can be transferred over a transmission line is restricted by a plethora of factors, ranging from the length of the transmission line, heating effect of transmitted current, and system stability, transient stability limit, voltage limit to short circuit current limit. In an ideal transmission network, active power should be equal to apparent power such that the power factor is unity. To achieve this condition, flexible AC transmission systems (FACTS) are employed (Anyanor, K. I. et al, 2020).

FACTS which is an acronym for flexible alternating current transmission system consists of static equipment that is employed in alternating current (AC) transmission of electrical energy (Acha, E. et al, 2004; Zhang, X. P. et al, 2012). It is meant to enhance controllability and increase power transfer capability of the network. FACTS controllers are classified into four groups namely: series and shunt, for one-port controllers or combined series-series and combined series-shunt, for two-port controllers. It is generally a power electronics-based system. FACTS devices when placed in a power system enable control of active and reactive power flow and also helps to minimize transmission losses (Acha, E. et al, 2004).

In this paper , live data is obtained from the National Control Center of the Transmission Company of Nigeria, Oshogbo. Some of the weakest locations are modelled and simulated in MATLAB environment without any FACTS and subsequently, the Unified Power Flow Controller (UPFC) FACTS on those locations is investigated, to ascertain the percentage improvement in the power capacity obtainable in each case.

2.0 Review Of Relevant Literature

2.1 Electric Power System or Electric Grid

An electric power system or electric grid is known as a large network of power generating plants which connected to the consumer loads (El-Hawary, 2019). Electrical energy is a form of energy that is transferred through the flow of electron. Electrical energy is obtained by converting various other forms of energy, however, with the invention of generator, it more convenient to first convert any form of energy into mechanical energy and then convert it into electrical energy using a generator. Generators can produce AC and DC power. Nevertheless, 99% of the present power systems use AC generators (El-Hawary, 2019; Pabla, 2012).

Over the past two centuries, electrical energy has become more popular due to the flexibility of use it provides. This variety of use has brought about an ever increasing demand for electricity. Consequently, with this ever increasing demand for electricity comes the need for consistency in electricity generation so as to forestall a lapse between demand and supply. Since large amount of electricity cannot be stored for delivering this high amount of demand, the generation of electrical energy happens simultaneously with use. Apart from the varying demand for electricity that impacts the generating process, the type of load supplied also varies. These variations put many constraints and conditions and is the major reason for the complex equipment and management procedures required in power systems (El-Hawary, 2019; Electrical Technology, 2022).

The network between Generating Station (Power Station) and consumer of electric power can be divided into two parts.
i. Transmission System
ii. Distribution System

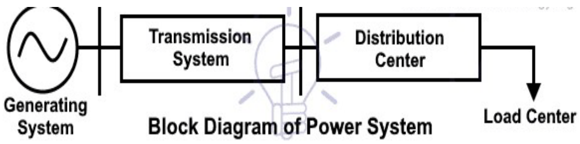

Figure 1: Block diagram of Power System, **Source**: (Electrical Technology, 2022)

It can be further categorized into primary transmission and secondary transmission as well as primary distribution and secondary distribution.

2.2 Electric Power Supply Scheme

A typical electric power system has five stages namely;

a. Generating Station
b. Primary Transmission
c. Secondary Transmission
d. Primary Distribution
e. Secondary Distribution

(Pabla, 2012; Electrical Technology, 2022)

The following parts of a typical power supply scheme are shown in figure 2.1 below.

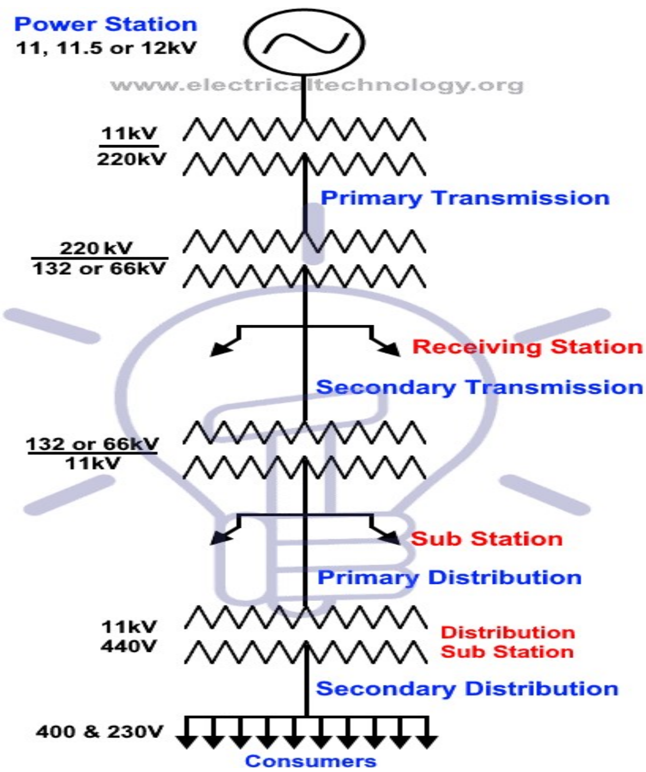

Figure 2 Typical AC Electric Power Supply Systems Scheme (Generation, Transmission & Distribution), **Source**; Electrical Technology, 2022

It is not necessary that the entire steps which are shown in Figure 2 must be included in the other power schemes, there may be differences.

In the generation, energy conversion from one form into electrical energy is done, in the transmission energy is transported to very long distance and usually using very high voltage magnitude and distribution is fulfilling the demand of the consumers at certified voltage level and it is done in terms of feeders. After these five levels, the energy must be available as the stated form in terms of voltage magnitudes, frequency and consistency (El-Hawary, 2019).

2.3 Power Generation

The generating station is where electric usually by using three phase alternators/generators. Generation is the part of power system where other forms of energy are converted into electrical energy and it is the energy source in the power system. It keeps running all the time. It generates power at different voltage and power levels depending upon the type of station and the generators used. The generators generate the power at voltage level around 11kV-20kV, depending on the capacity of the generators used and this determines the cost involved. The power plant capacity and generating voltage may be 11kV, 11.5 kV 12kV or 13kV. But economically, it is good to step up the produced voltage from (11kV, 11.5kV or 12 kV) to 132kV, 220kV or 500kV or more (in some countries, up to 1500kV) by a step up transformer. (H. Saadat, 1999; Pabla, 2012)

Presently the generating stations mainly employed all over the world are following: -

i. Thermal power plant
ii. Hydel power plant (Hydro-electric)
iii. Nuclear power plant
iv. Diesel power plant
v. Gas power plant
vi. Solar power plant
vii. Tidal power plant
viii. Wind power plant.

Electric energy is generated through these power plants at different voltage levels and at different locations depending upon the type of the plant. They are used for different purposes viz.

a. Base Load Plant: - When the plant is used to handle the base load demand on the system

b. Peak Load Plant: - When the plant is made to handle the peak load demand on the system

Accordingly, the plant is made to handle the load. This categorization is important for the quality of power that is being developed. It is also important due to the fact that the power must be generated at the same instant when the load is taking up the power. The knowledge of the type of load and approximate amount of load demand at the station determines the choice of the type of generating station (H. Saadat, 1999; Pabla, 2012; El-Hawary, 2019).

For instance, thermal plant, Hydel plant, Nuclear plant, Solar plant, Wind plant and Tidal plant are chosen to handle the base load on the system whereas Gas plants, Diesel plants are used to handle peak load demand.. Base load plants take more time in delivering the power whereas peak load plants must start very fast to supply the demand (Pabla, 2012).

3. Methodology

The major purpose of this study is to determine the power transfer capability of the FACTS devices on the power system network. The data utilized which was from the Nigerian 330kV transmission line network was obtained from the National Control Center (NCC) in Oshogbo, Osun state Nigeria.

The voltage profile in the case study dataset is given in Table 1 while the power transfer of the system without UPFC FACTS is given in Table 2.

Table 1: The case study voltage profile of the system without FACTS.

Bus number	Bus Location	Voltage profile (pu)
1	Afam	1.0000
2	Aladja	0.9640
3	Alaoji G.S	1.0000
4	Alaoji T.S	0.7773
5	Asaba	0.6884
6	Benin	0.8542
7	Delta	1.0000
8	Ihovbor	0.7921
9	New heaven	0.6884
10	Okpai	1.0000
11	Onitsha	0.7424
12	Sapele	1.0000

Table 2: The power transfer of the system without UPFC FACTS.

Line	From Bus	To Bus	Active Power (pu)	Reactive Power (pu)
1	'IHOVBOR'	'BENIN T.S'	0.5561	0.4171
2	'BENIN T.S'	'DELTA G.S'	0.4273	1.2706
3	'ALAOJI T.S'	'ALAOJI G.S'	4.4179	0.0944
4	'ALAOJI T.S'	'AFAM'	0.8498	1.7333
5	'BENIN T.S'	'SAPELE G.S.'	0.4273	1.2706
6	'DELTA G.S'	'ALADJA'	0.4027	0.3259
7	'SAPELE G.S.'	'ALADJA'	0.4027	0.3259
8	'ONITSHA T.S'	'BENIN T.S'	2.1571	0.6440
9	'NEW HEAVEN'	'ONITSHA T.S'	0.4201	0.3151
10	'ONITSHA T.S'	'ASABA T.S.'	0.4200	0.3727
11	'ONITSHA T.S'	'OKPAI G.S'	0.9666	1.9149
12	'ONITSHA T.S'	'ALAOJI T.S'	2.114	0.8770

A total of twelve (buses) were mapped out within the south-southern and south-eastern region of Nigeria. The network selected was modeled in power system analytical tool (PSAT) in MatLab and the power flow was obtained after simulating without the FACTS. Different FACTS devices were inserted in the location with the least generated or transmitted power for power transfer improvement. The FACTS utilized is the Unified Power Flow Controller (UPFC). The power system network with UPFC is shown in Figure 3.The flowchart of the procedure used for the power transfer capability analysis in this paper is shown in Figure 4.

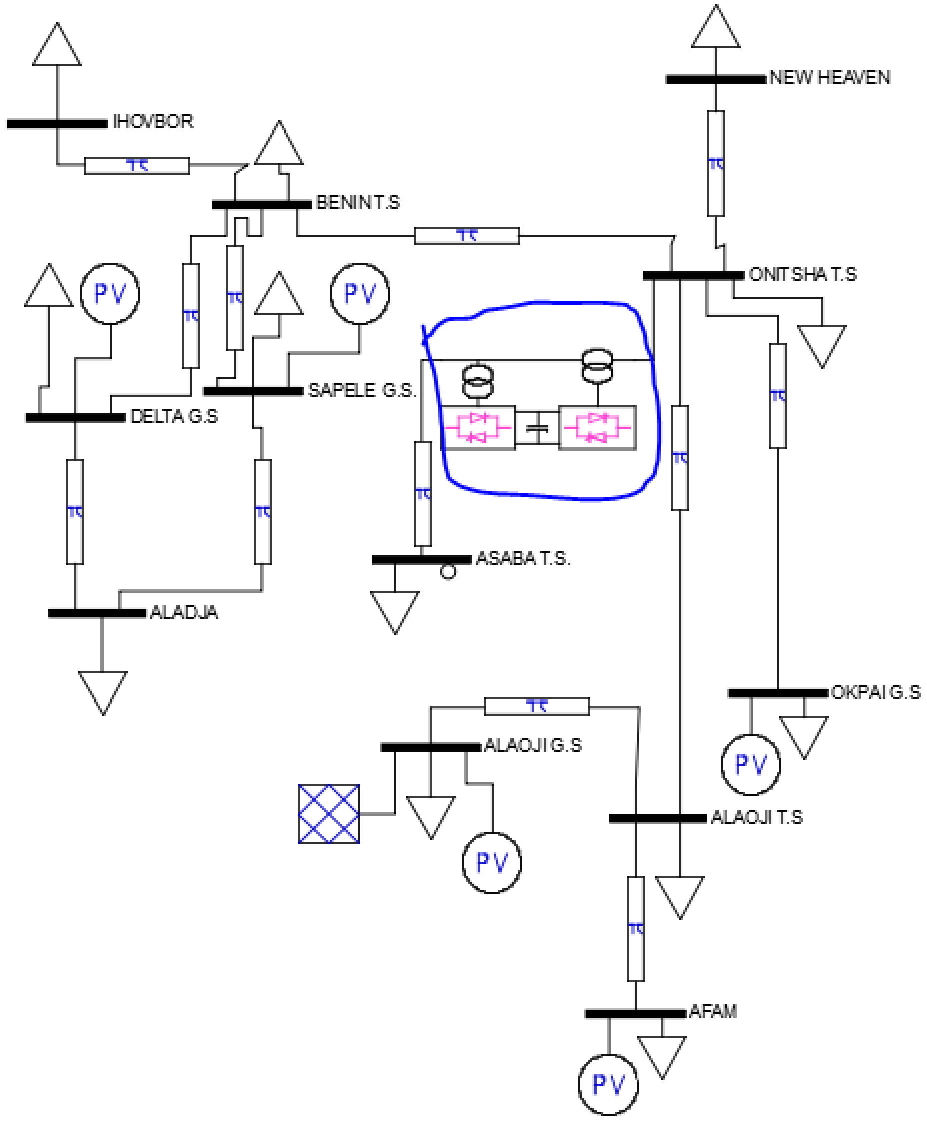

Figure 3: Power system network with UPFC

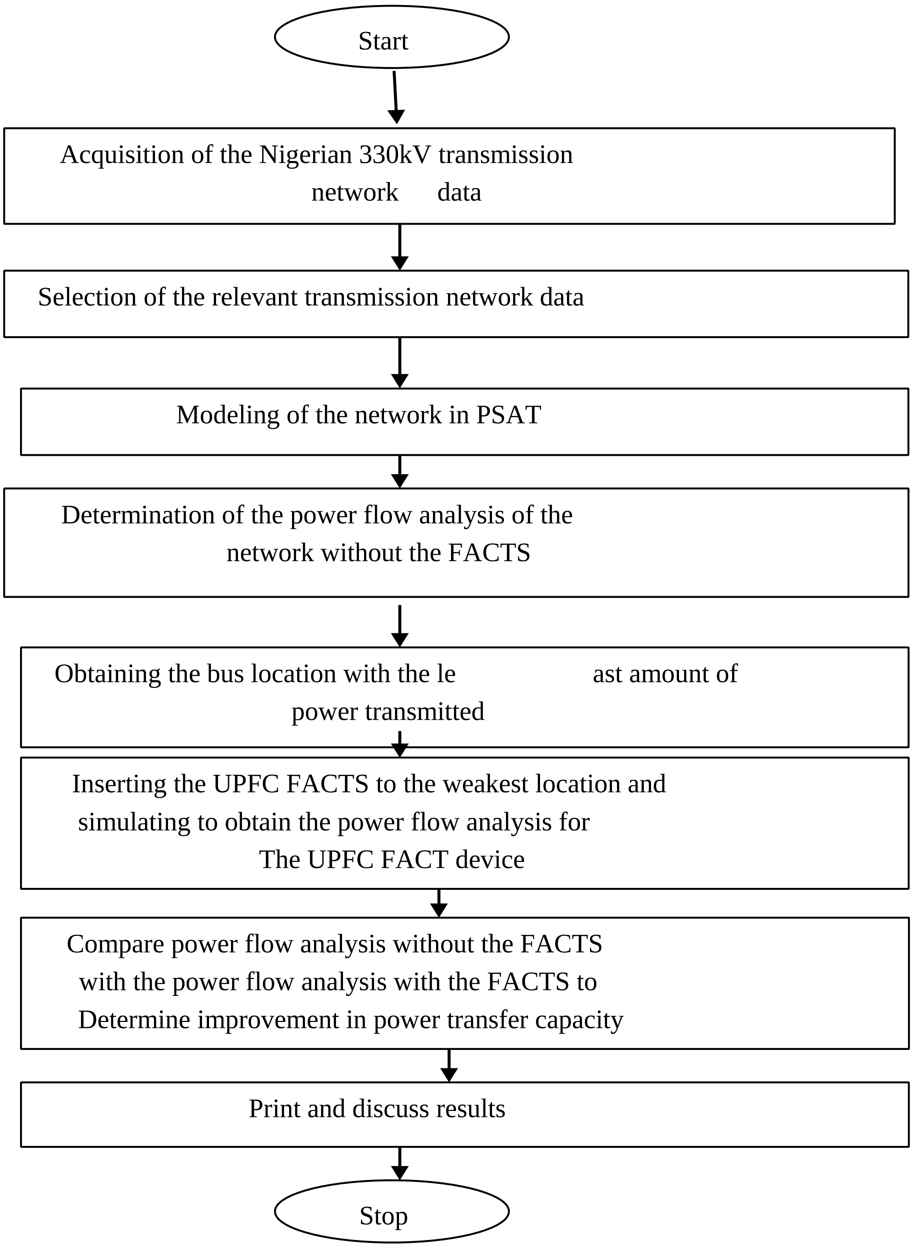

Figure 4: Flow Chart for the Power Transfer Capability analysis

4.0 Results

4.1 Power transfer capacity of the system with UPFC

The voltage profile of the power system with UPFC is shown in Table 3 and Figure 4.

Table 3: The Voltage profile of the system with UPFC.

Bus Number	Bus Location	Voltage Profile (pu)
1	Afam	1.0000
2	Aladja	0.9809
3	Alaoji G.S	1.0000
4	Alaoji T.S	0.9711
5	Asaba	0.9889
6	Benin	0.9554
7	Delta	1.0000
8	Ihovbor	0.9410
9	New heaven	0.9517
10	Okpai	1.0000
11	Onitsha	0.9818
12	Sapele	1.0000

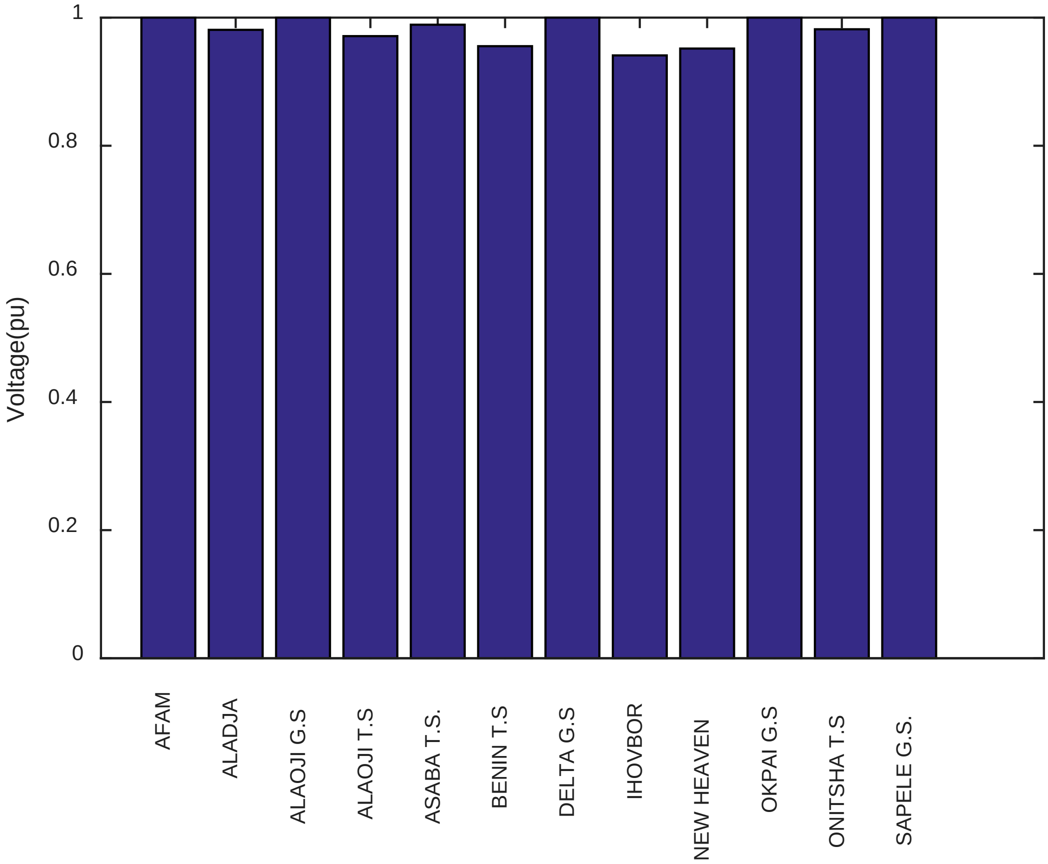

Figure 5. : Voltage profile of the buses with UPFC

From the results in Table 3 and Figure 5, there was an improvement on the voltages when UPFC FACTS was inserted especially in all the location stations. This shows the effectiveness of using UPFC for voltage improvement in power system networks.

The results on the power transfer capability with UPFC FACTS is shown in Table 4, as well as in Figure 6 and Figure 7. Amount of power transferred for line 5 and line 6 with and without FACTS are presented in Table 7

Table 4 : Power transferred with UPFC FACTS

Line	From bus	To bus	Active power (pu)	Reactive power (pu)
1	'IHOVBOR'	'BENIN T.S'	0.9973	0.7116
2	'BENIN T.S'	'DELTA G.S'	0.6895	1.4901
3	'ALAOJI T.S'	'ALAOJI G.S'	4.5091	0.2998
4	'ALAOJI T.S'	'AFAM'	0.9808	1.9776
5	'BENIN T.S'	'SAPELE G.S.'	0.8671	1.7194
6	'DELTA G.S'	'ALADJA'	0.9291	0.5781
7	'SAPELE G.S.'	'ALADJA'	0.9127	0.8113
8	'ONITSHA T.S'	'BENIN T.S'	2.2999	0.9951
9	'NEW HEAVEN'	'ONITSHA T.S'	0.6512	0.4663
10	'ONITSHA T.S'	'ASABA T.S.'	0.9519	0.6834
11	'ONITSHA T.S'	'OKPAI G.S'	0.9999	1.9931
12	'ONITSHA T.S'	'ALAOJI T.S'	2.3354	0.9109

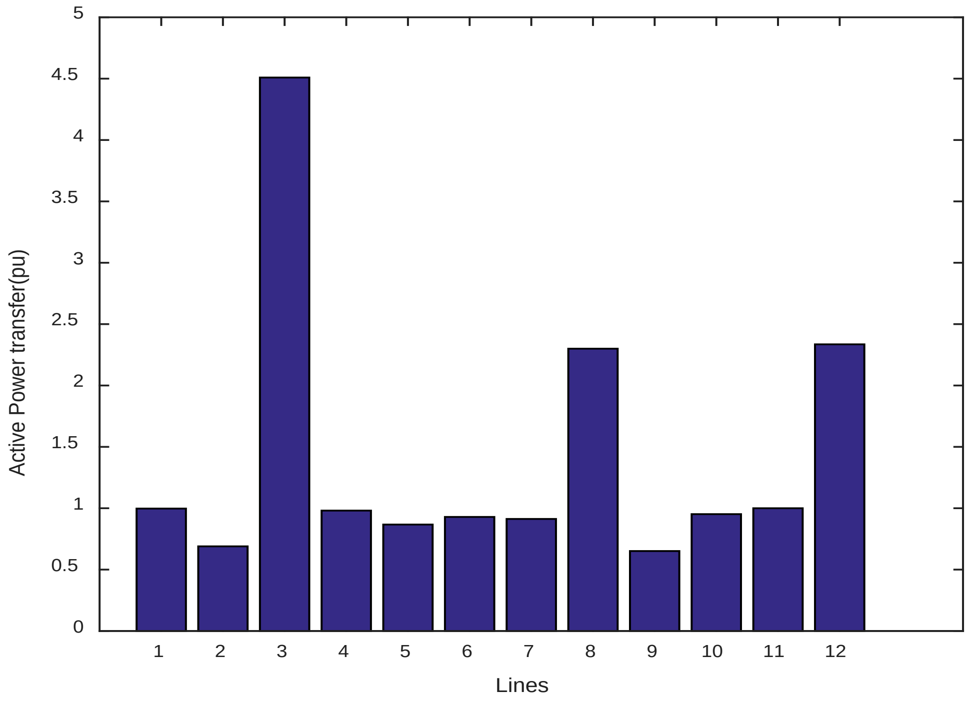

Figure 6: Active Power available with UPFC

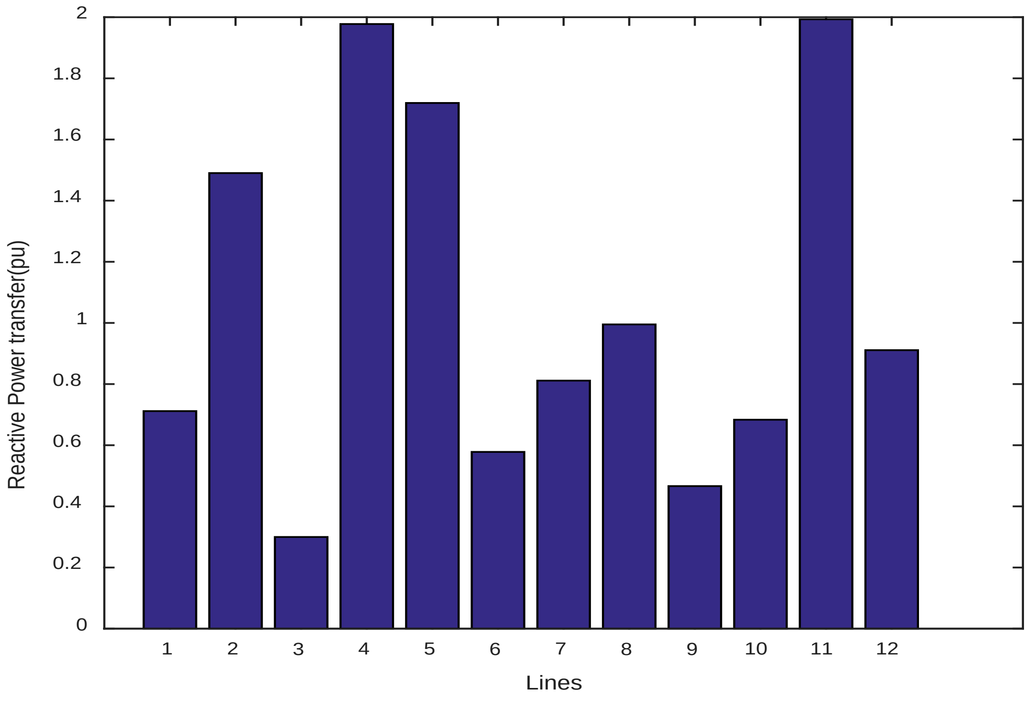

Figure 7: Reactive Power available with UPFC

The essence of the study was to determine the amount of power transferred in the south eastern and southern 330kV power system in Nigeria and compare the power transfer with and without the FACTS device and hence determine the ability of improving the power transfer of the systems by the use of the UPFU FACTS device. The voltage profile of the power system without FACTS was shown in Table 1 where it was observed that the load stations had low voltage values.

Also, the power transferred (both active and Reactive power) of the system without UPFC FACTS. Notably, Line 5 (Sapele G.S to Benin TS) and line 6 (Delta GS to Aladja) had the least transferred power capacity of 0.4027pu. This implies that the power around these lines was low and needed improvement leading to the implementation of the FACTS. The results in Table 3 and Figure 5 show the amount of power transferred with the introduction of UPFC FACTS. Also, the results on the power transfer capability with UPFC FACTS is shown in Table 4, as well as in Figure 6 and Figure 7. It was observed from the results that the UPFC device improved the power transferred on the transmission line 5 and 6 to 0.8273pu and 0.9088pu respectively, as shown in Table 7. In all, the use of the UPFC FACTS device brought about improvement in the voltage profile and the power transferred in the various lines consider3ed in the study.

Table 7: Amount of power transferred for line 5 and line 6 with and without FACTS

Line	Without FACTS	UPFC
Line 5	0.4027pu	0.8671pu
Line 6	0.4027pu	0.9291pu

5.0 Conclusion

Nigeria 330kV transmission power system network data for the south eastern and south southern part of Nigeria was obtained from the national control center Oshogbo and modeled in power system analytical tool (PSAT). The active and reactive power transferred on the transmission lines were simulated and the transmission line with the least active power transfer capability was obtained which were line 5 and line 6 having the active power transfer capacity of 0.4027pu. The UPFC FACTS was utilized in improving the amount of power transfer on the transmission lines of the network with emphasis on line 5 and lines 6. The FACTS were installed on the transmission lines connecting Asaba power station and Onitsha transmission station. On simulating the transmission power network with the UPFC FACTS the active power transfer capability value of 0.8671pu and 0.9292pu were obtained for line 5 and line 6 respectively.

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