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Psat Simulated Power Transfer Capability Analysis Of The Nigerian 330KV Power Network Using Sssc Facts Device

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Abstract— **In this paper Power System Analysis Toolbox (PSAT) simulated power transfer capability (PTC) analysis of the Nigerian 330kV power network using Static Synchronous Series Compensator (SSSC) FACTS device is presented. The study considered a 12 bus segment of case study power network comprising of buses located at the following places; Ihovbor, Benin, Sapele, Delta, Asaba, Aladja, Ontisha, Okpai, Alaoji G.S, AlaojiT.S., New-heaven and Afam. The voltage profile, as well as the active and reactive power transfer data of the case study power network segment were used PSAT to simulate the improvements that are achievable with the use of the SSSC FACTS device on the power network. The voltage profile data of the power system network without SSSC FACTS device shows that 6 out of the 12 buses have their voltage profile below the acceptable lower limit of 0.95. However, when the SSSC FACTS is applied device all the buses satisfied the minimum required voltage profile of 0.95 except the bus number 8 located at Ihovbor with voltage profile of 0.9311 after the enhancement. In any case, the bus number 8 located at Ihovbor witnessed 17.5 % improvement in the voltage profile. The highest improvement in voltage profile was noted in bus 5 located at Asaba with 42.8% improvement in voltage profile. The overall average improvement in the voltage profile of the 12 buses. Similarly, there is improvement in both the active and reactive power transfer of all the lines in the power network when the SSSC FACTS device is introduced. There is overall average improvement in the active power transfer all the lines in the power network is 54.9%, and overall average improvement in the reactive power transfer all the lines in the power network is 58.2%. In all, the use of the SSSC FACTS device has proven to be useful in improving the PTC of the case study power system network.**

Keywords— Power Transfer Capability, Nigerian 330KV Power Network, FACTS Device, Power System Analysis Toolbox (PSAT), Static Synchronous Series Compensator (SSSC)

1. Introduction

Electricity is very essential for meaningful development in any nation [1,2,3]. In many of the developing nations in Africa, it has been observed that they have very low electric power supply to demand ratio [4,5,6]. The prevailing situation in the power sector is such that current and forecasted energy demand are rarely satisfied by the national electric supply networks [7,8,9,10,11,12,13,14,15,16,17]. In addition, the demand for electricity will continue to increase because more the information and communication technology-based solutions (smart system solutions, Internet of Things, web-based solutions, mobile device solutions among others) is making the whole world to increasingly depend on technological solutions that need to be powered with electricity [18,19,20,21, 22,23, 24,25, 26,27, 82,29, 30,31, 32,33, 34,35]. Moreover, many people have advocated for augmenting the electric power generation with distributed energy generation system [36,37,38] whereby renewable energy generation from solar, wind and biomass can be used to enhance the power generation and supply index [36,37, 38,39,40, 41,42, 43,44, 45,46, 47,48, 49,50, 51,52, 53,54, 55,56, 57,58, 59,60, 61,62, 63,64,65]. However, the ability of the power transmission and distribution networks to deliver the generated electric power to the consumer is highly effected by many factors [66,67,68].

Importantly, researchers have developed different FACT devices to enhance the power transfer capability (PTC) of electric power networks [69,70,71]. In this way, the installed network can deliver more electric power to the consumers without high cost of expansion of the power network, rather the system rely on the use of low cost FACT devices. As such, this paper presents analysis of PTC enhancement of the Nigerian 330kV power network using Static Synchronous Series Compensator (SSSC) FACTS device [72,73]. The Power System Analysis Toolbox (PSAT) simulation tool is used in the analysis [74,75]. Specifically, the voltage profile, as well as the active and reactive power transfer data of the case study power network segment were used PSAT to simulate the improvements that are achievable with the use of the SSSC FACTS device on the power network. The voltage profile data of the power system network without SSSC FACTS device was compared with what is obtainable when the FACTS device is used. The study seeks to present solution in the power sector by providing useful results that can be used to enhance the PTC of the case study power network.

2.0 Methodology

2.1 The Nigerian 330kV transmission power network case study dataset

The Nigerian 330kV transmission power network dataset used was gotten from the National Control Center which is located in Oshogbo, Osun state. The transmission power network dataset was obtained in excel format and the mapped out network is shown in Figure 1. The buses selected as shown in Figure 1 includes Ihovbor, Benin, Sapele, Delta, Asaba, Aladja, Ontisha, Okpai, Alaoji G.S, AlaojiT.S., New-heaven and Afam. The selected buses formed the power system network that was modeled in power system toolbox.

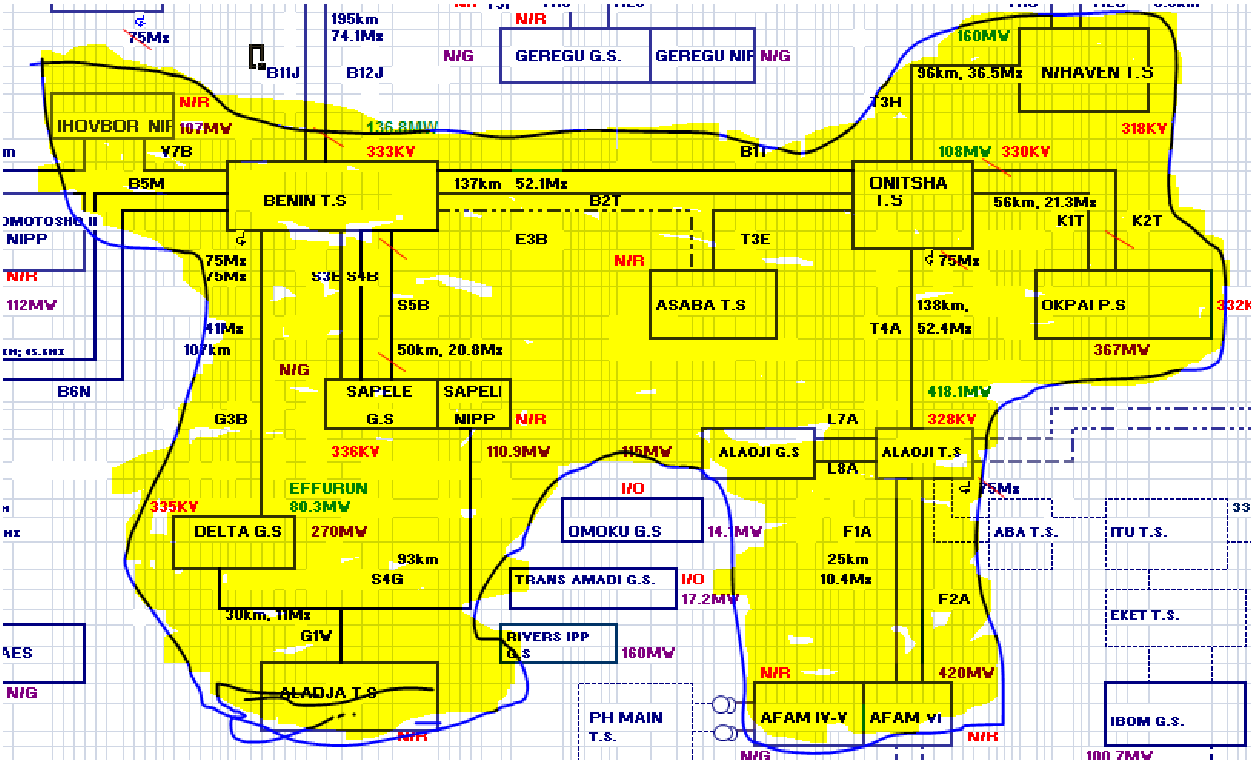

Figure 1: The mapped out area of the case study Nigerian 330kV power system network

The voltage profile data for the case study Power system network without SSSC FACTS device is given in Table 1 and Figure 2 while the power transfer data for the case study Power system network without SSSC FACTS device is given in Table 2. As presented in Table 2, the bubble chart of the active power (pu) transfer without the SSSC FACS device is shown in Figure 3 while the bubble chart of the reactive power (pu) transfer without the SSSC FACS device is shown in Figure 4.

Table 1: The voltage profile data for the case study Power system network without SSSC FACTS device.

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

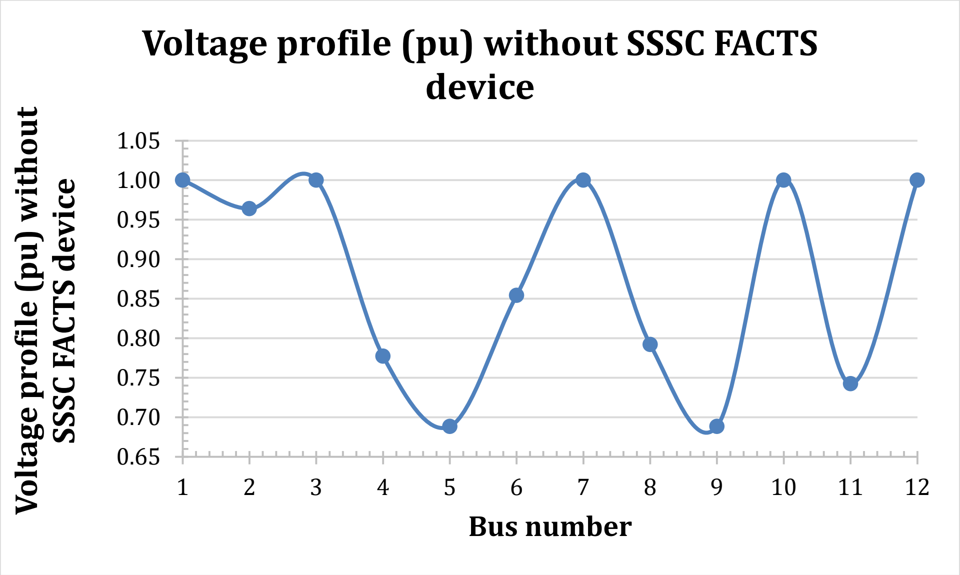

Figure 2: The bubble chart of the voltage profile data for the case study Power system network without SSSC FACTS device.

Table 2 The power transfer data for the case study Power system network without SSSC FACTS device.

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	0.644
9	'NEW HEAVEN'	'ONITSHA T.S'	0.4201	0.3151
10	'ONITSHA T.S'	'ASABA T.S.'	0.42	0.3727
11	'ONITSHA T.S'	'OKPAI G.S'	0.9666	1.9149
12	ONITSHA T.S'	'ALAOJI T.S'	2.114	0.877

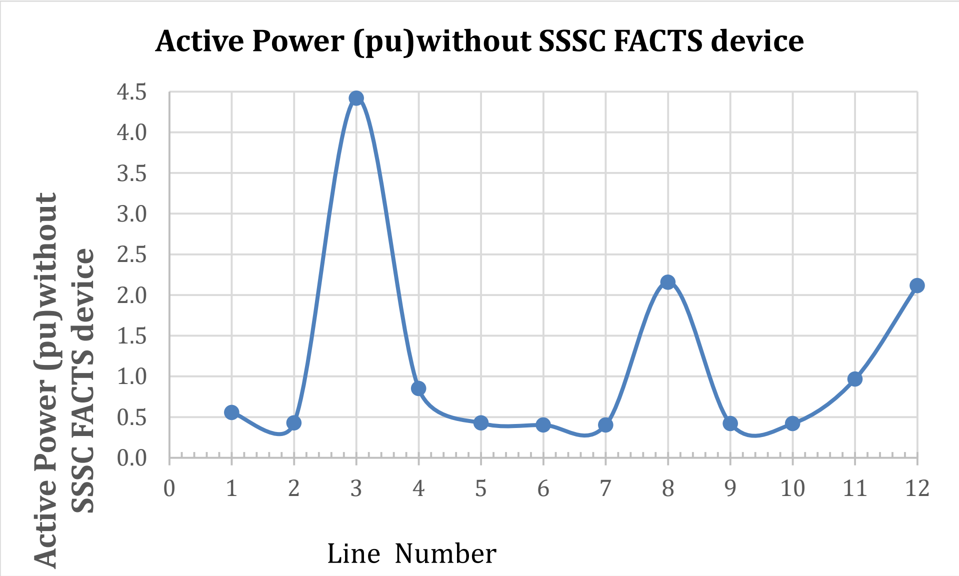

Figure 3: The bubble chart of the active power (pu) transfer without the SSSC FACS device

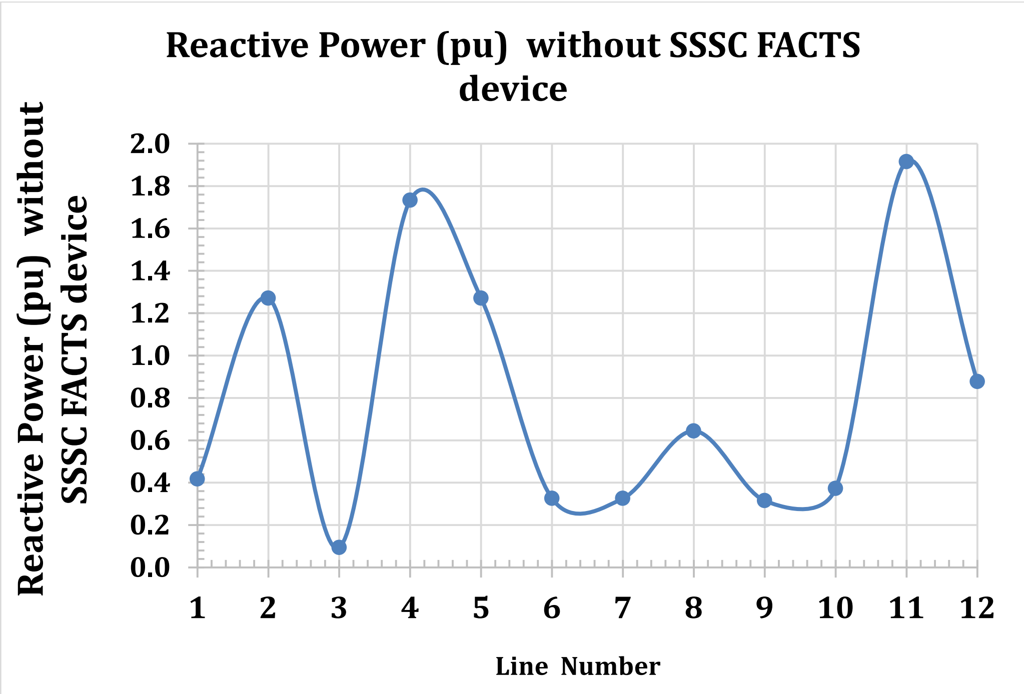

Figure 4: The bubble chart of the reactive power (pu) transfer without the SSSC FACS device

2.2 Modeling of the Power system network with Power System Analysis Toolbox (PSAT)

The modeling of the power system network was outlined in the steps below.

Step 1: Open the MatLab environment (it assumed that MatLab is already installed).

Step 2: Open the Power System Analysis Toolbox (PSAT) environment in MatLab by entering the command “psat” in the MatLab’s command window. (It is also assumed that PSAT is already installed as a MatLab tool). The PSAT environment in MatLab is shown in Figure 5. Power system analysis tool library where all the transmission network components were selected is displayed in Figure 6. The power library displayed in Figure 6 has the transmission lines, buses, loads, generators and FACTS. Only the scope block was obtained from the Simulink library. The PSAT modeling environment is shown in Figure 7. The model of the power system network of the selected region is shown in Figure 8. In Figure 8, the slack parameter was assigned to Alaoji, making Alaoji bus the slack bus. The generation station in this model includes Alaoji, Afam, Okpai, Sapele and Delta, while the transmission stations are Aladja, Alaoji (T.S), Onitsha, New heaven, Asaba, Benin and Ihovbor.

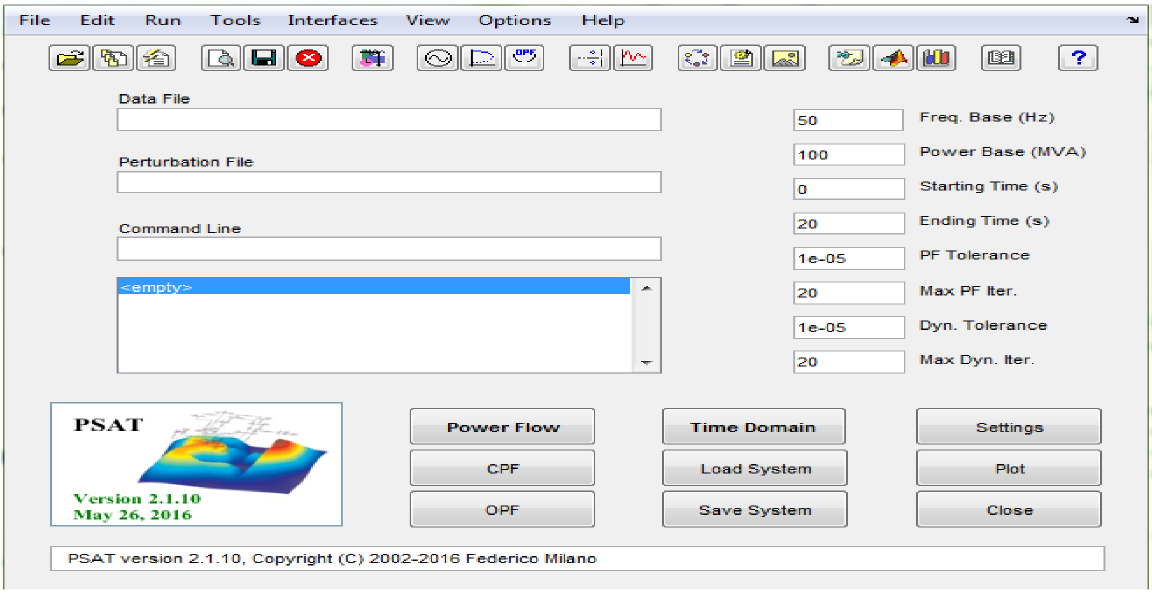

Figure 5: PSAT Environment in MatLab

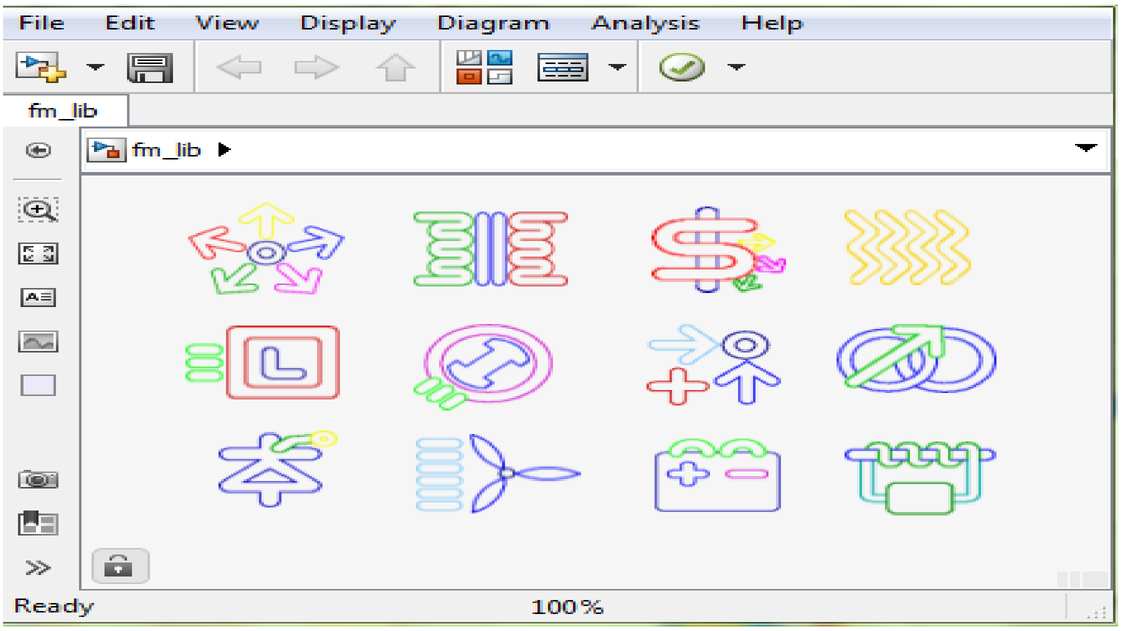

Figure 6: The Power system analysis tool library

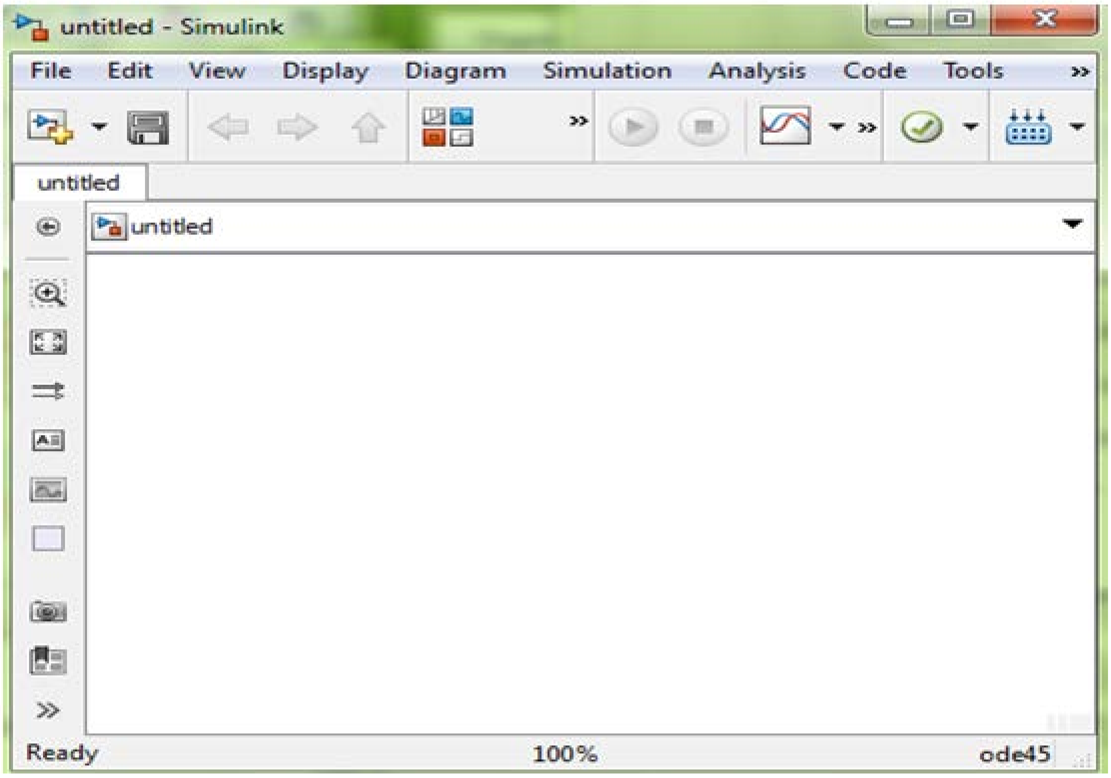

Figure 7: PSAT model library

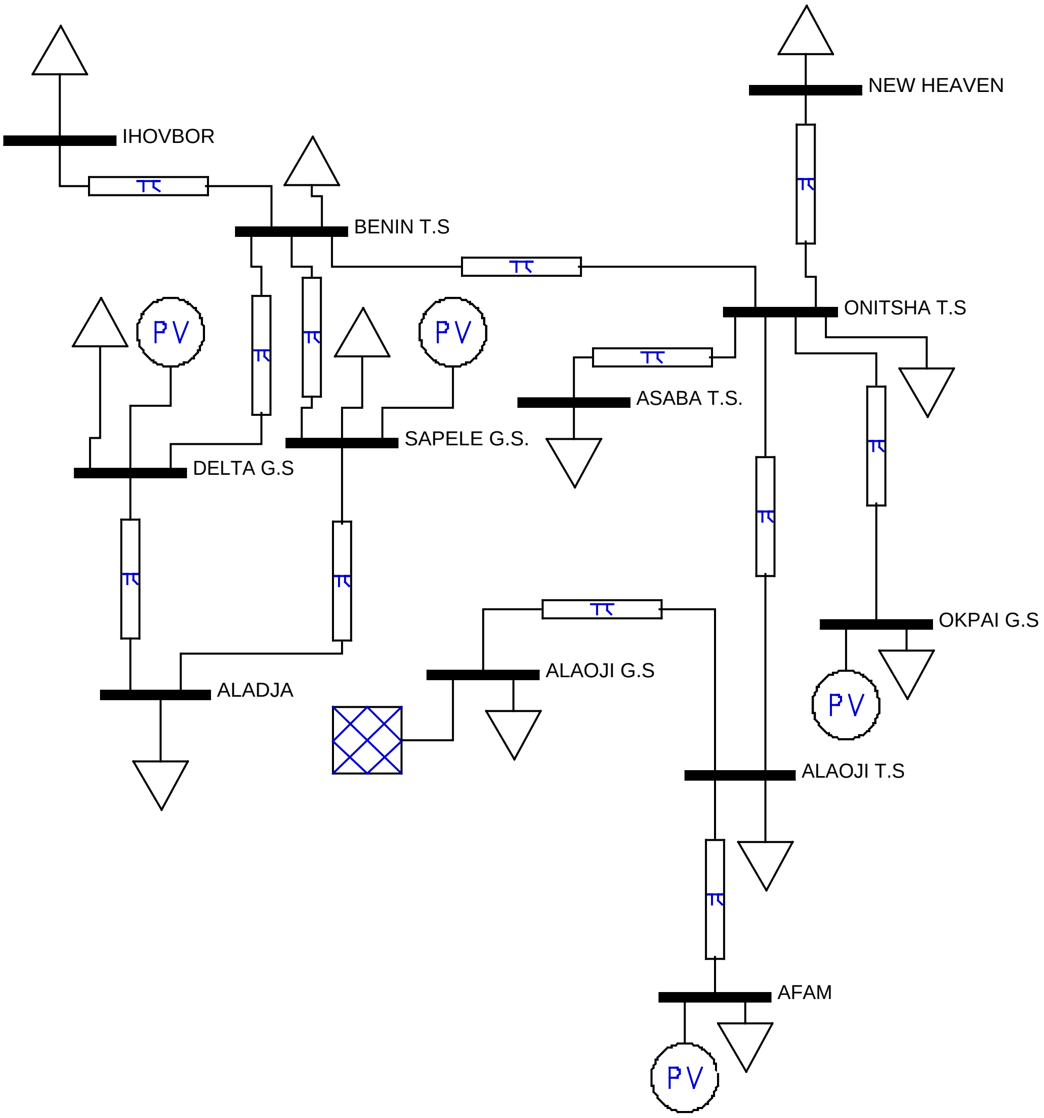

Figure 8: PSAT model of the power system network.

Step 3: Perform the PTC analysis

To achieve this, the saved model was uploaded to the PSAT environment shown in Figure 4, the 'power flow' model tab was clicked in order to enable the system perform newton-Raphson power flow analysis on the power system model. The PSAT environment indicating optimal power transfer capacity simulation completion with the conditions needed to achieve the outcome is shown in Figure 9. The screenshot in Figure 9 show that the power flow was completed in 0.56 seconds at base frequency of 50Hz and base power of 100MVA.

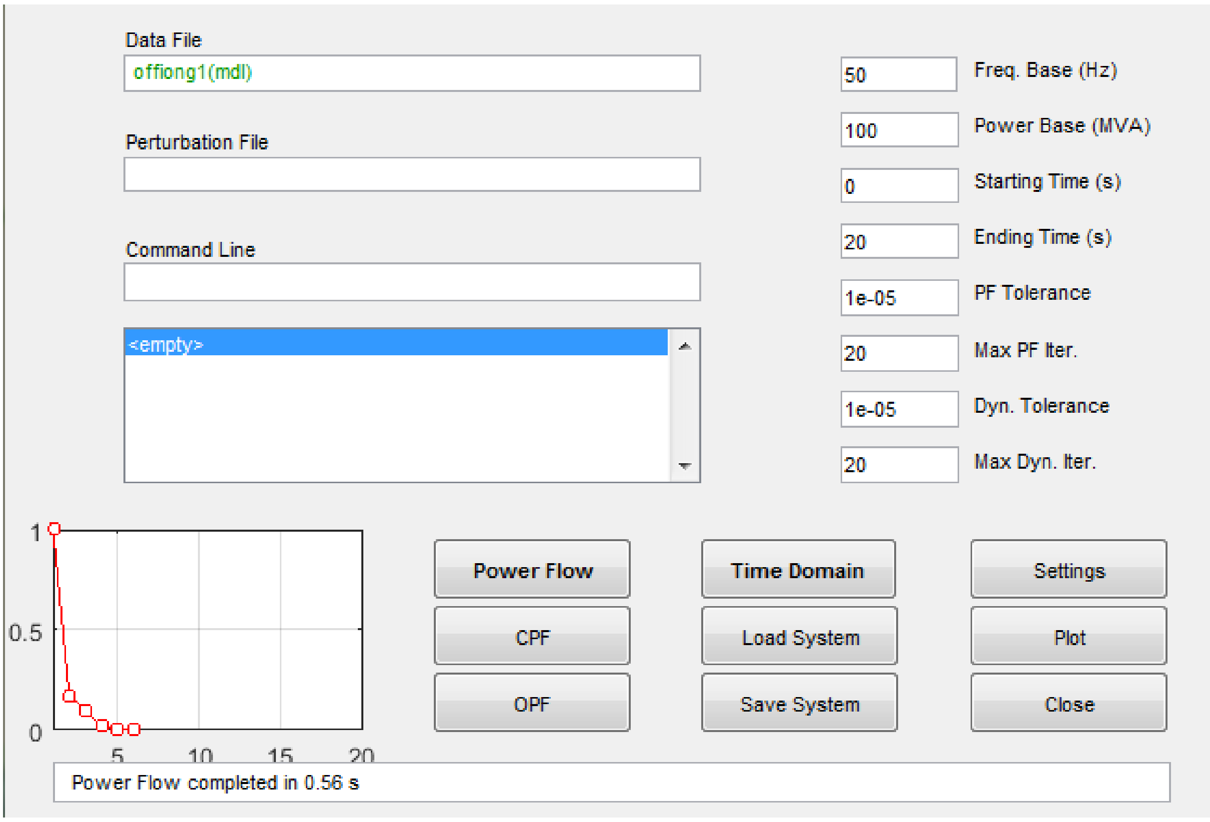

Figure 9: Completed power transfer capacity simulation

Step 4: Obtain the location with the least active and reactive power transfer on the bus(es) with the least power transfer was obtained from the load flow analysis outcome.

Step 5: Insert the FACTS to the weak bus(es): Accordingly, SSSC was inserted in the location with the least load transfer as shown in Figure 10. The results showed that Asaba transmission station had the least power transfer capacity hence, all the FACTS was inserted at the location to determine the power transfer capacity enhancement.

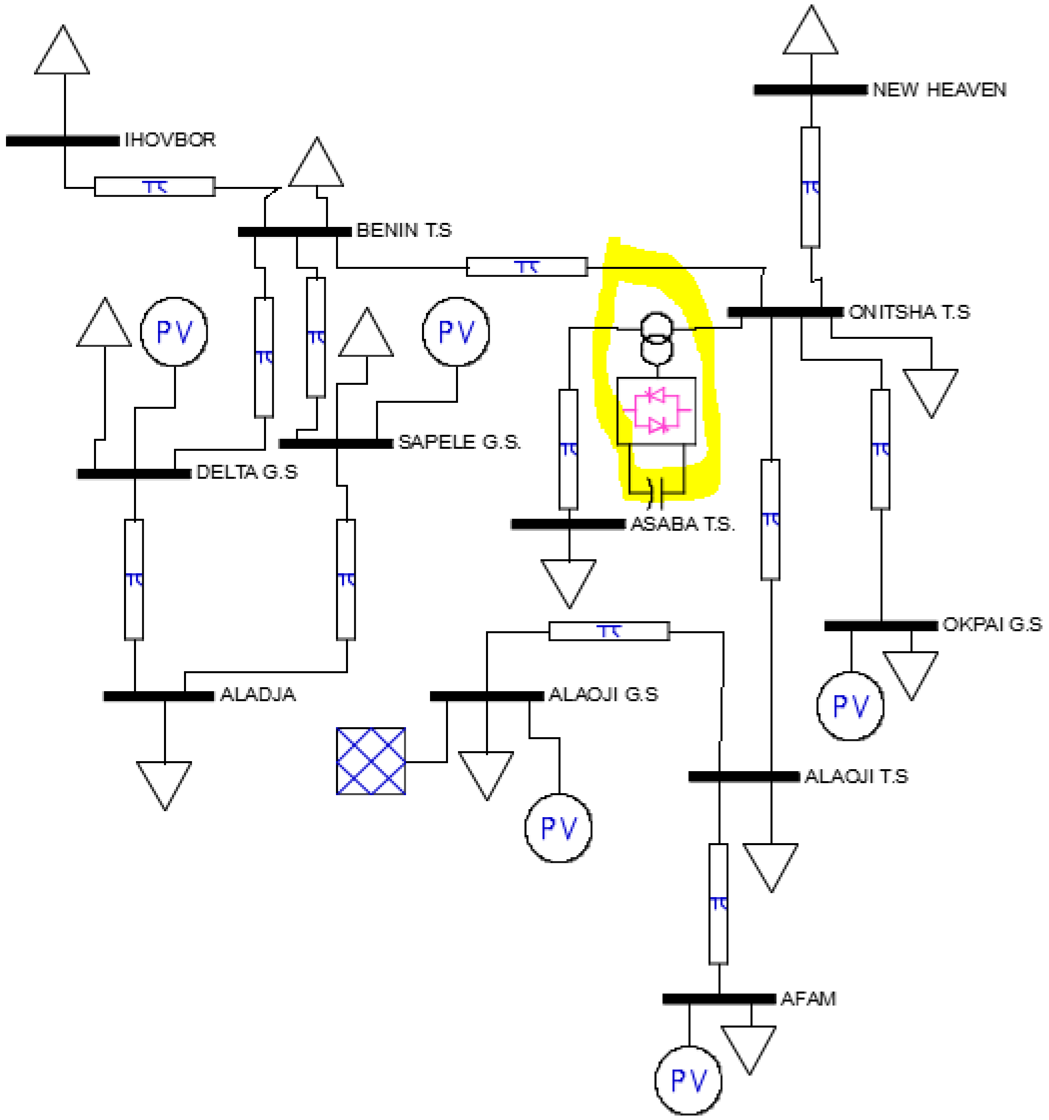

Figure 10: Power system network with SSSC

Step 6: Determine the power transfer capacity of the FACTS device utilized.

This was done by observing and determining the percentage improvement achieved on the location(s) with the least amount of power transferred in accordance with the FACTS device installed.

3. Results and discussions

The voltage profile data of the power system network without SSSC FACTS device presented in Table 1 and Figure 2 (and also in Table 3 and Figure 11) shows that 6 out of the 12 buses have their voltage profile below the acceptable lower limit of 0.95. However, when the SSSC FACTS device enhancement is conducted, all the buses witnessed improvement in their voltage profile, as shown in Table 3. Also, all the buses satisfied the minimum required voltage profile of 0.95 except the bus number 8 located at Ihovbor with voltage profile of 0.9311 after the enhancement. In any case, the bus number 8 located at Ihovbor witnessed 17.5 % improvement in the voltage profile. The highest improvement in voltage profile was noted in bus 5 located at Asaba with 42.8% improvement in voltage profile. The overall average improvement in the voltage profile of the 12 buses is 13.8%, as shown in Table 3 and Figure 12.

Table 3: Comparison of the voltage profile data for the case study power system network without SSSC FACTS device and with SSSC FACTS device.

Bus number	Bus Location	Voltage profile (pu) without SSSC	Voltage profile (pu) with SSSC	Percentage Improvement (%)
1	Afam	1.0000	1.0000	0.0
2	Aladja	0.9640	0.9714	0.8
3	Alaoji G.S	1.0000	1.0000	0.0
4	Alaoji T.S	0.7773	0.9632	23.9

5	Asaba	0.6884	0.9833	42.8
6	Benin	0.8542	0.9500	11.2
7	Delta	1.0000	1.0000	0.0
8	Ihovbor	0.7921	0.9311	17.5
9	New heaven	0.6884	0.9499	38.0
10	Okpai	1.0000	1.0000	0.0
11	Onitsha	0.7424	0.9744	31.3
12	Sapele	1.0000	1.0000	0.0
			Mean	13.8

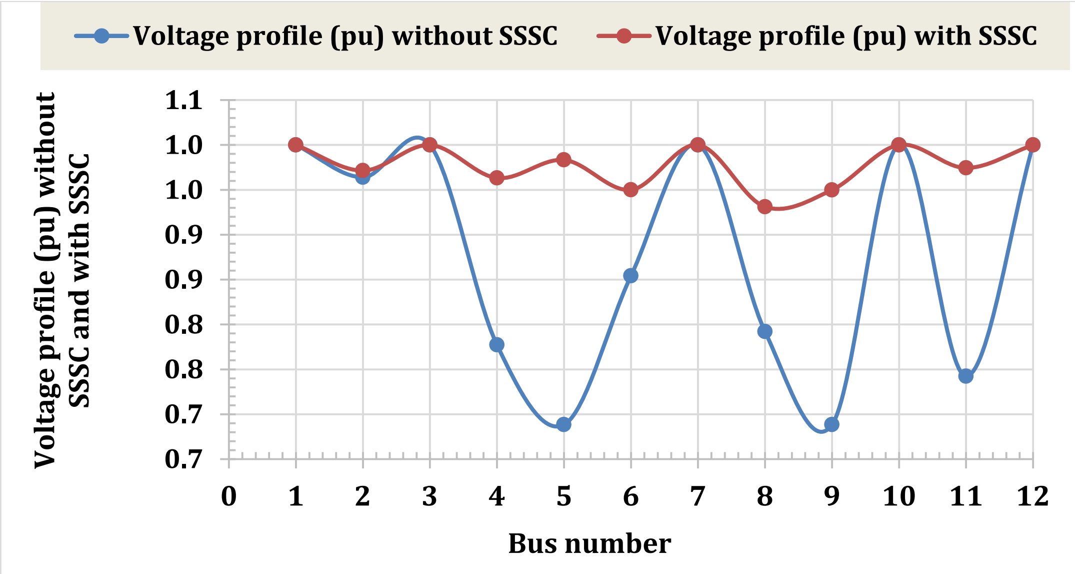

Figure 11: The bubble chart showing the comparison of the voltage profile for the case study power system network without SSSC FACTS device and with SSSC FACTS device

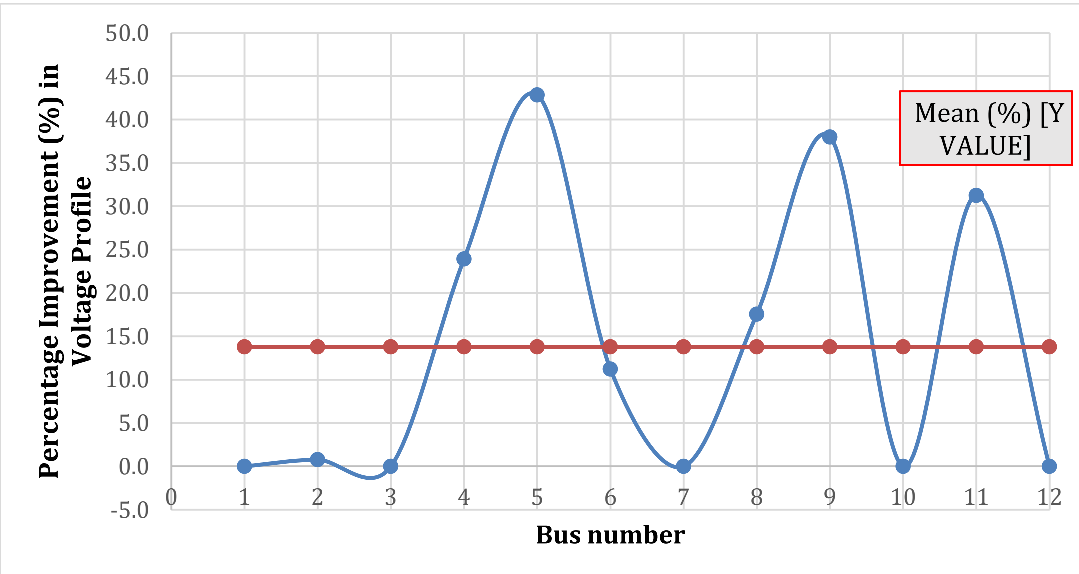

Figure 12: The bubble chart showing the percentage improvement in the voltage profile for the case study power system network when the SSSC FACTS is applied device

The active power transfer data of the power system network without SSSC FACTS device presented in Table 2 and Figure 3 (and also in Table 4 and Figure 13) shows line 6 and 7 have the lowest active power transfer of 0.4027 pu.

However, when the SSSC FACTS device enhancement is conducted, all the lines witnessed improvement in their active power transfer, as shown in Table 4 and Figure 13. Particularly, line 6 and 7 have the lowest active power transfer of 0.9088 pu and 0.8917 pu respectively after the enhancement with the SSSC FACTS device and those amount to 125.7 % and 121.4% enhancements respectively. The overall average improvement in the active power transfer all the lines in the power network is 54.9%, as shown in Table 4 and Figure 13.

Table 4: Comparison of the active power transfer data for the case study power system network without SSSC FACTS device and with SSSC FACTS device

Line	From Bus	To Bus	Active Power (pu) without SSSC	Active power (pu) with SSSC	Percentage Improvement (%)
1	'IHOVBOR'	'BENIN T.S'	0.5561	0.9523	71.2
2	'BENIN T.S'	'DELTA G.S'	0.4273	0.6335	48.3
3	'ALAOJI T.S'	'ALAOJI G.S'	4.4179	4.5112	2.1
4	'ALAOJI T.S'	'AFAM'	0.8498	0.9088	6.9
5	'BENIN T.S'	'SAPELE G.S.'	0.4273	0.8273	93.6
6	'DELTA G.S'	'ALADJA'	0.4027	0.9088	125.7
7	'SAPELE G.S.'	'ALADJA'	0.4027	0.8917	121.4
8	'ONITSHA T.S'	'BENIN T.S'	2.1571	2.2994	6.6
9	'NEW HEAVEN'	'ONITSHA T.S'	0.4201	0.6422	52.9
10	'ONITSHA T.S'	'ASABA T.S.'	0.42	0.9114	117.0
11	'ONITSHA T.S'	'OKPAI G.S'	0.9666	0.9987	3.3
12	ONITSHA T.S'	'ALAOJI T.S'	2.114	2.3314	10.3
				Mean	54.9

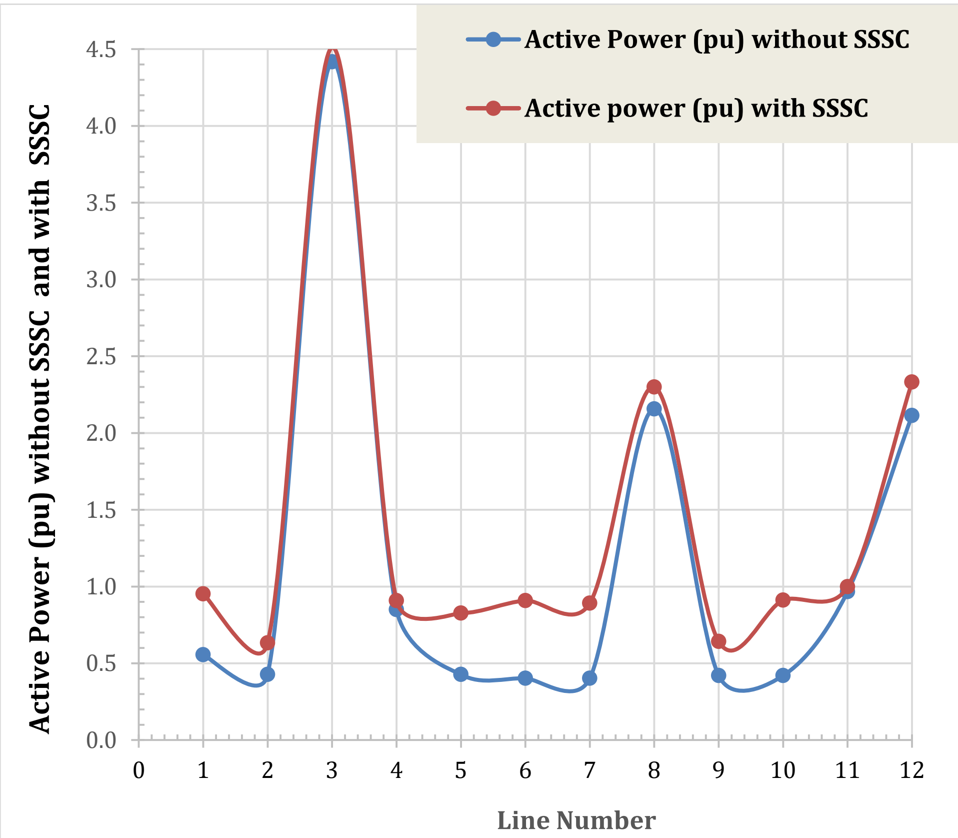

Figure 13: The bubble chart showing the comparison of the active power transfer for the case study power system network without SSSC FACTS device and with SSSC FACTS device

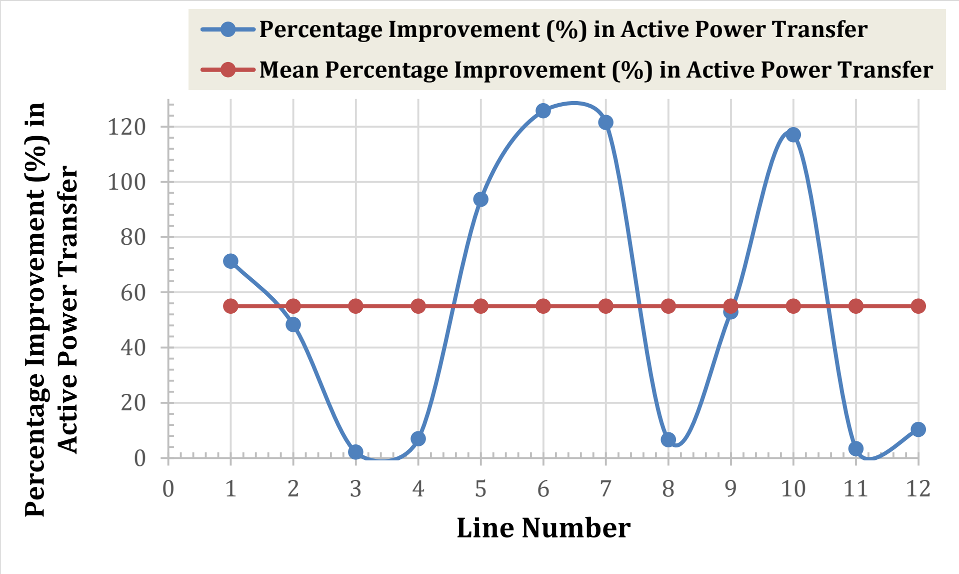

Figure 14: The bubble chart showing the percentage improvement in the active power transfer for the case study power system network when the SSSC FACTS is applied device

The reactive power transfer data of the power system network without SSSC FACTS device presented in Table 2 and Figure 4 (and also in Table 5 and Figure 15) shows line 3 had the lowest reactive power transfer of 0.0944 pu. However, when the SSSC FACTS device enhancement is conducted, all the lines witnessed improvement in their reactive power transfer, as shown in Table 5 and Figure 15. Particularly, line 3 with the lowest active power transfer of 0.2933 pu after the enhancement with the SSSC FACTS device and that amounts to 210.7% enhancement. The overall average improvement in the reactive power transfer all the lines in the power network is 58.2%, as shown in Table 5 and Figure 16.

Table 5: Comparison of the reactive power transfer data for the case study power system network without SSSC FACTS device and with SSSC FACTS device

Line	From Bus	To Bus	Reactive Power (pu) without SSSC	Reactive power (pu) with SSSC	Percentage Improvement (%) in Reactive Power Transfer
1	'IHOVBOR'	'BENIN T.S'	0.4171	0.6871	64.7
2	'BENIN T.S'	'DELTA G.S'	1.2706	1.4111	11.1
3	'ALAOJI T.S'	'ALAOJI G.S'	0.0944	0.2933	210.7
4	'ALAOJI T.S'	'AFAM'	1.7333	1.9174	10.6
5	'BENIN T.S'	'SAPELE G.S.'	1.2706	1.5664	23.3
6	'DELTA G.S'	'ALADJA'	0.3259	0.5494	68.6
7	'SAPELE G.S.'	'ALADJA'	0.3259	0.7709	136.5
8	'ONITSHA T.S'	'BENIN T.S'	0.644	0.9947	54.5
9	'NEW HEAVEN'	'ONITSHA T.S'	0.3151	0.4553	44.5
10	'ONITSHA T.S'	'ASABA T.S.'	0.3727	0.6214	66.7
11	'ONITSHA T.S'	'OKPAI G.S'	1.9149	1.9923	4.0
12	ONITSHA T.S'	'ALAOJI T.S'	0.877	0.9012	2.8
				Mean	58.2

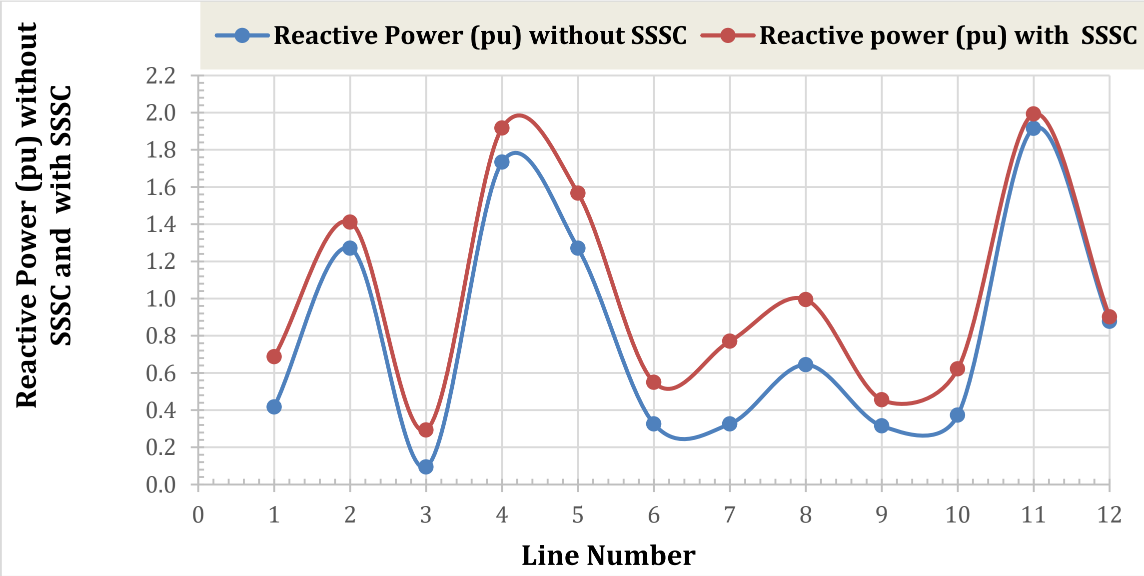

Figure 15: The bubble chart showing the comparison of the reactive power transfer for the case study power system network without SSSC FACTS device and with SSSC FACTS device

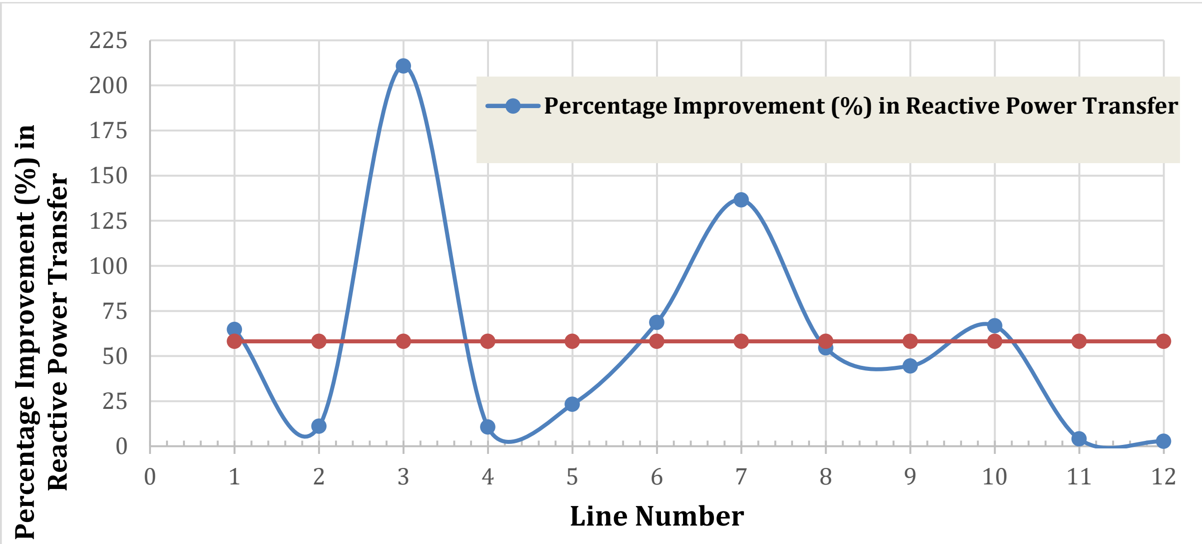

Figure 16: The bubble chart showing the percentage improvement in the reactive power transfer for the case study power system network when the SSSC FACTS is applied device

4. Conclusion

The analysis of the power transfer capability of Nigerian 330kV power network is presented. The study of the PTC of the power system network was first done without enhancement and then with enhancement using the Static Synchronous Series Compensator (SSSC) FACTS device. The study was based on voltage profile and power transfer datasets obtained for a segment of the power network that included 12 buses located at the following places; Ihovbor, Benin, Sapele, Delta, Asaba, Aladja, Ontisha, Okpai, Alaoji G.S, AlaojiT.S., New-heaven and Afam. The analysis was conducted using Power System Analysis Toolbox (PSAT) in MatLab.

The results show that there is improvement in the voltage profile of all the buses when the SSSC FACTS is applied device with an average of about 13 % enhancement in the voltage profile of all the buses. Likewise, there is improvement in both the active and reactive power transfer of all the lines in the power network when the SSSC FACTS device is introduced. There is overall average improvement in the active power transfer all the lines in the power network is 54.9%, and overall average improvement in the reactive power transfer all the lines in the power network is 58.2%. In all, the use of the SSSC FACTS device has proven to be useful in improving the PTC of the case study power system network.

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