Power Transfer Capability Enhancement On Nigeria 330kv Lines With Upfc And Sssc Fact Devices

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***Abstract*— In this paper, power transfer capability enhancement on Nigeria 330KV lines with UPFC and SSSC FACT devices is presented. In the study, Power System Analytical Tool (PSAT) in Matlab was used to evaluate and compare the achievable voltage profile enhancement, as well as power transfer capability enhancements using the Unified Power Flow Controller (UPFC) Flexible AC Transmission Systems (FACTS) device and the Static Synchronous Series Compensator (SSSC). The study was conducted using the Nigerian 330kv power network as the case study based on dataset obtained from the National Control Center in Oshogbo, Osun state. The case study dataset which has about 12 buses was modeled in PSAT and simulated in three different scenarios; without FACTS device, with the UPFC device and finally with the SSSC device. The summary of the results on the voltage profile (pu) of the buses show that the mean voltage profile (pu) of the buses without FACTS device is 0.8756 pu, with SSSC is 0.9769 pu and with UPFC is 0.9809 pu. Again, the mean percentage enhancement of the voltage profile of the buses attained with SSSC is 13.8 % while that of the UPFC is14.3 %. Essentially, the UPFC device gave about 3.6% improvement over that provided by SSSC device. The results also show that the mean percentage enhancement in the active power transfer capability of the power lines attained with SSSC is 54.9% while that of the UPFC is 60.1 %. Specifically, the active power transfer capability enhancement with UPFC is about 9.5 % better than that of SSSC device. Similarly, the results on the mean percentage enhancement in the reactive power transfer capability of the power lines attained with SSSC is 58.2% while that of the UPFC is 64.6 %. Specifically, the reactive power transfer capability enhancement with UPFC is about 11.0 % better than that of SSSC device. In all, the results show that the UPFC has better voltage profile enhancement, better active power transfer capability enhancement and better reactive power transfer capability enhancement for the overall power network considered in the study. In view of the overall results, UPFC is therefore recommended for the power network performance enhancement**

Keywords*— Unified Power Flow Controller (UPFC), Flexible AC Transmission Systems (FACTS), Nigerian 330kv Power Network, Power Transfer Capability, Static Synchronous Series Compensator (SSSC), Voltage Profile, Power System Analytical Tool (PSAT)

1. Introduction

In Nigeria, the power system industry is beset with numerous perennial challenges. The most prominent challenge is the growing energy deficit occasioned by very low energy generation, poor transmission infrastructure and very high losses coupled with fast growing energy demand [1,2,3,4,5,6,7,8,9,10,11,12,13,14,15,16,17,18,19].

Furthermore, as the days go by, advancements in technologies bring about changes in lifestyle and polices which make us to be more dependent of gadgets that require electric power [20,21,22, 23,24,25, 26,27,28, 29,30, 31, 32,33,34,35]. As such the energy deficit will still remain into the distant future. Exerts have opted for the use of various renewable energy source (such as solar photovoltaic system, biomass and wind energy system as well as hybridized combinations) in a distributed energy supply framework to enhance the energy generation in the country [36,37,38,39, 40,41, 42,43,44,45,46,47, 48,49,50, 51,52,53, 54,55,56,57,58,59,60,61,62,63,64,65,66]. In any case, improvement in the energy generation through the use of distributed energy generation system may solve the problem to some extent [67,68]. However, some problems on the transmission lines may limit the benefits of increased energy injection to the national grid. Notable problem is the limitation on the power transfer capability of the power network.

Accordingly, this paper presents power transfer capability enhancement on Nigeria 330KV lines with Flexible Alternating Current Transmission System (FACTS) devices [69,70,71]. In the study, Power System Analytical Tool (PSAT) in Matlab [72,73,74,75] is used to evaluate and compare the achievable voltage profile enhancement, as well as power transfer capability enhancements using the Unified Power Flow Controller (UPFC) Flexible AC Transmission Systems (FACTS) device and the Static Synchronous Series Compensator (SSSC) [76,77]. The study was conducted using the case study network dataset. Specifically, the active and reactive power transfer capability enhancement, as well as voltage profile enhancement with UPFC and SSSC FACTS devices are compared and the one that gives better enhancement is recommended for the case study network.

2. Methodology

In this study, the Nigerian 330kv power network map and the requisite dataset of the segment of the power network required for the study were obtained from the National Control Center in Oshogbo, Osun state. The map layout of the Nigerian 330kv power network is given in Figure 1 showing the case study segment in yellow background while the scatter plot of the voltage profile of the 12 buses plotted from the excel dataset for the case study Nigerian 330kv power network is presented in Figure 2. Again, the scatter plot of the active and reactive power transfer capabilities of the power lines plotted from the excel dataset for the case study Nigerian 330kv power network is presented in Figure 3.

Generally, the acceptable range of voltage profile (v) expressed in pu for power network buses is such that $0.95 \leq v \leq 1.05$. As shown in Figure 2, without the FACT device to enhance the power transfer capability of the power network, only 6 out of the 12 buses in the network satisfied the voltage profile requirements. Again, the scatter plot of the active and reactive power transfer data presented in Figure 3 show that without the FACTS device the minimum active power transfer occurred in power lines 6 and 7. In order to analyze the power transfer enhancement that is possible with each of the tow FACTS devices considered in the study, the PSAT tool in Matlab was used to model the Nigerian 330kv power network without the FACTS devices (Figure 4) and then with the UPFC device (Figure 5) and later with the SSSC fact device (Figure 6). Based on the models, the simulation of the power transfer capability of the power network was simulated in the PSAT for three cases, namely, without any FACTS device, with UPFC device and with SSSC device.

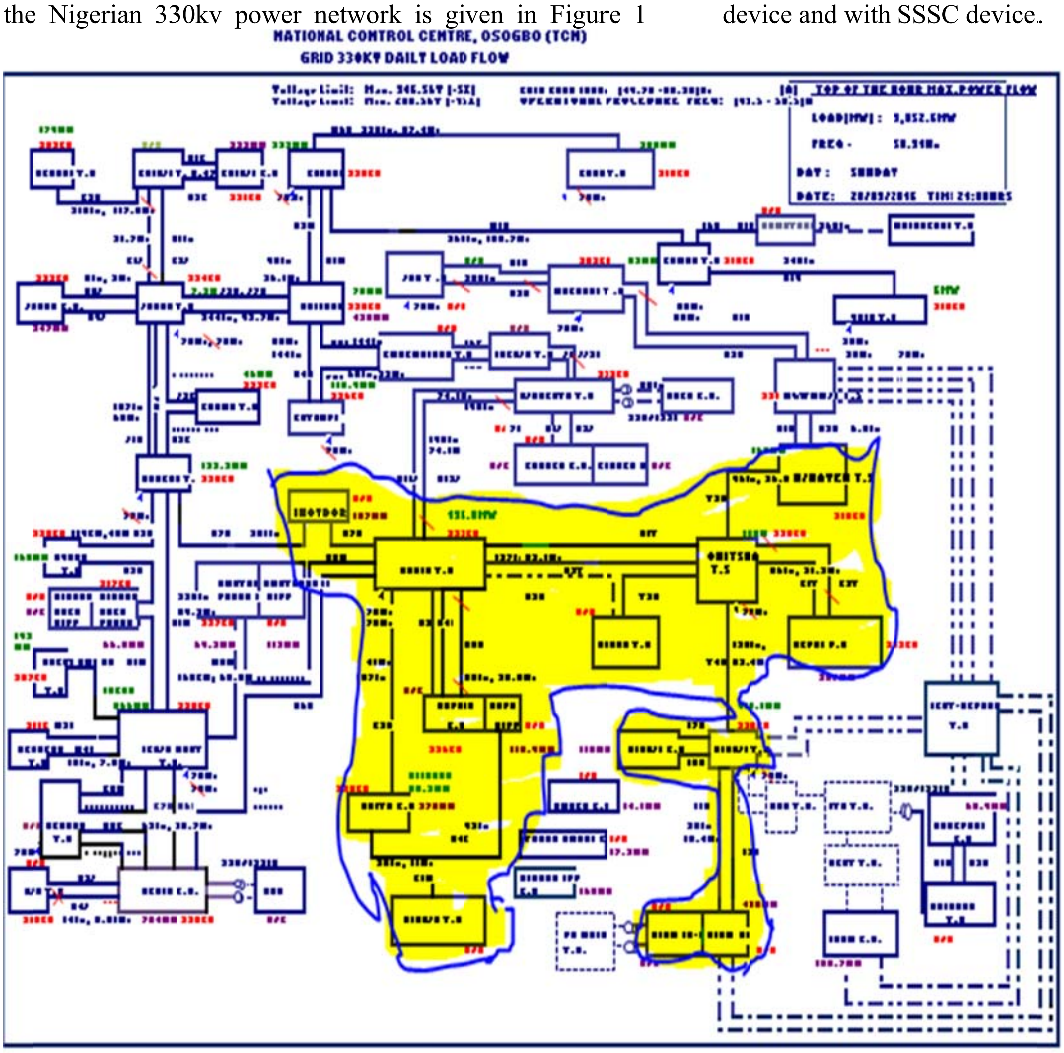


Figure 1: Nigerian 330kV power system network with the mapped out area,

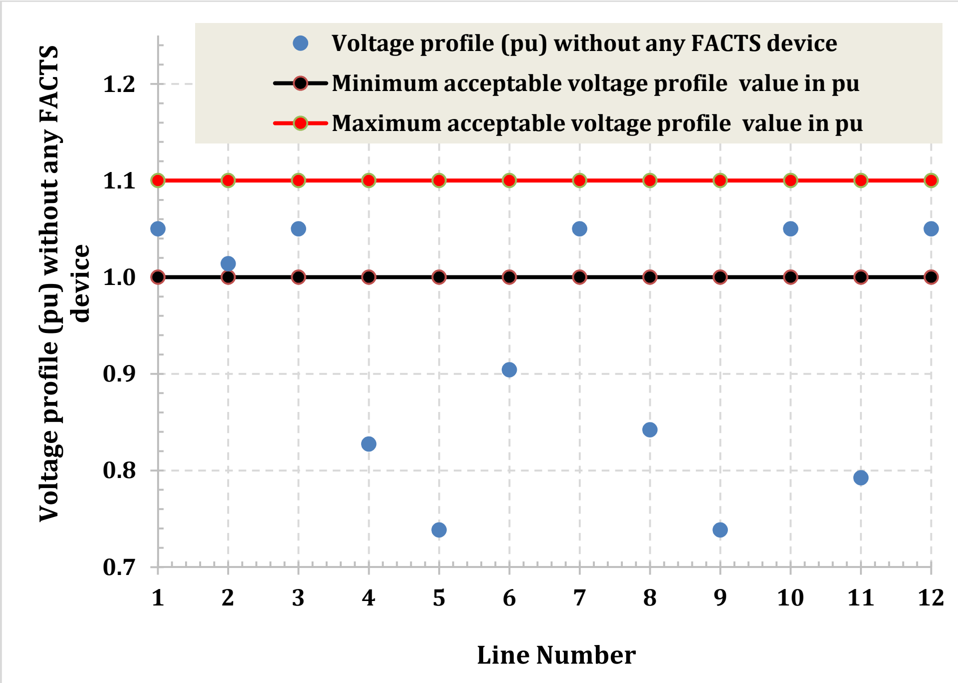


Figure 2 The scatter plot of the voltage profile of the 12 buses plotted from the excel dataset for the case study Nigerian 330kv power network

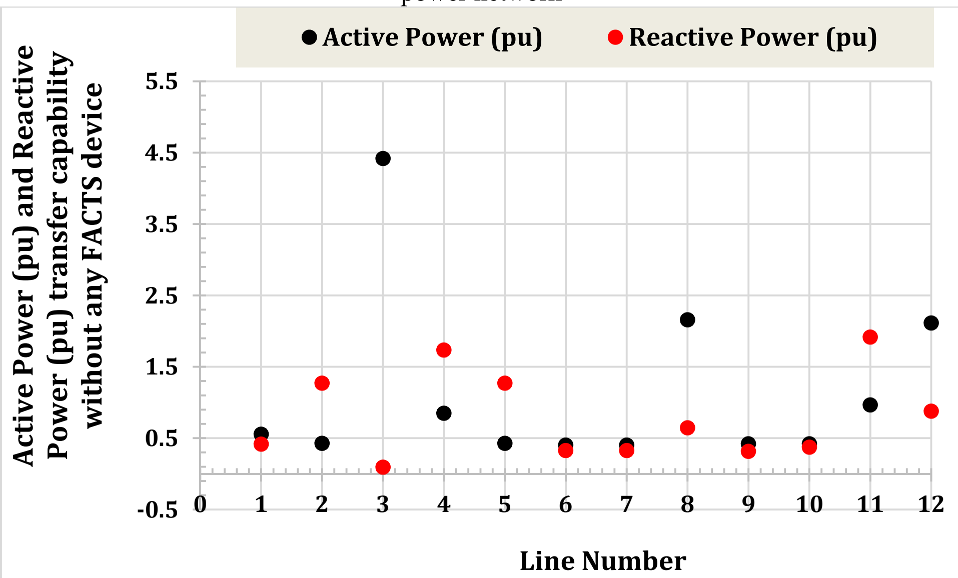


Figure 3 The scatter plot of the active and reactive power transfer capabilities of the power lines plotted from the excel dataset for the case study Nigerian 330kv power network

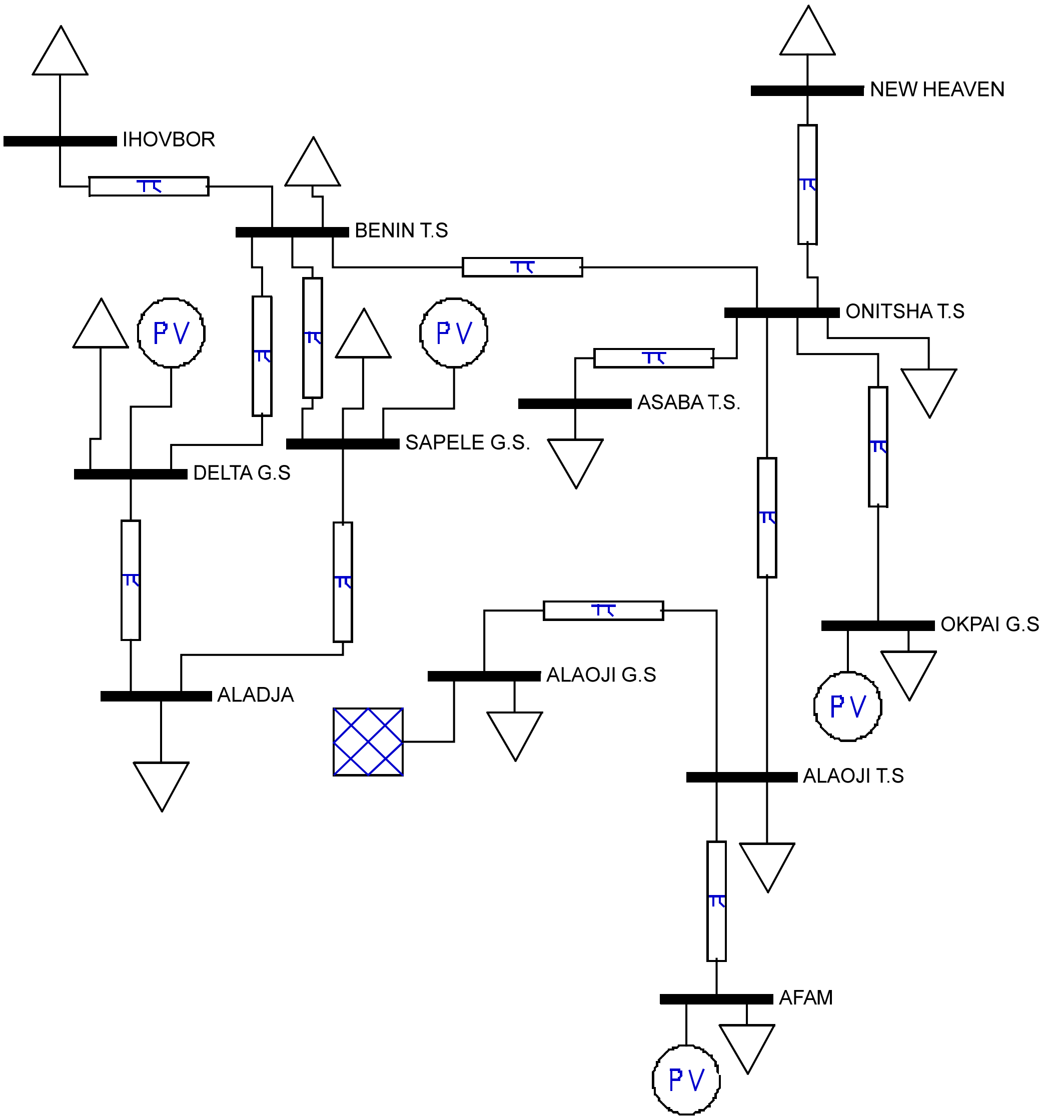


Figure 4: The model of power system network in PSAT

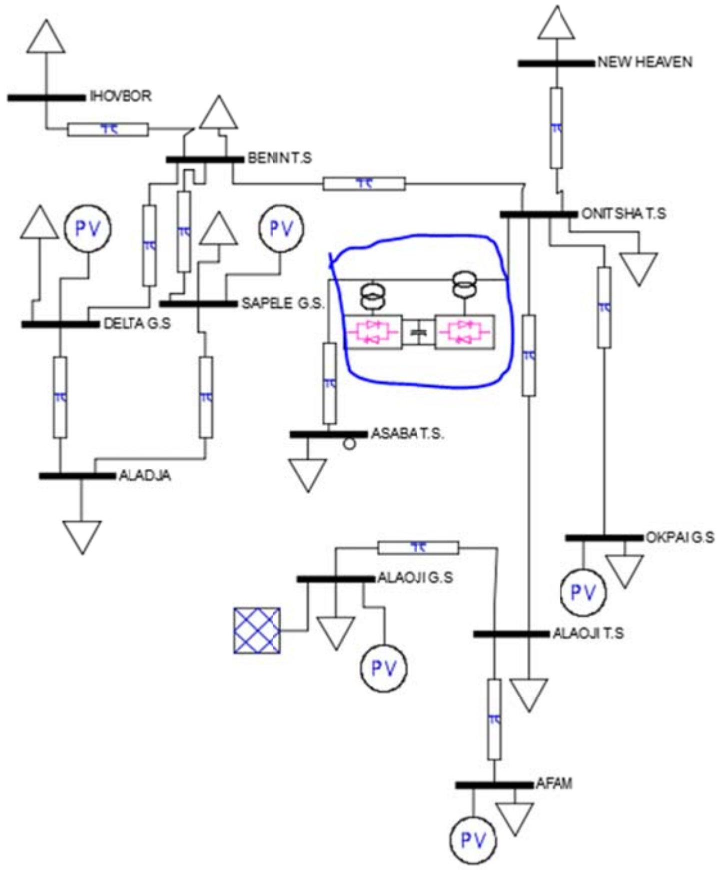


Figure 5: The PSAT model of power system network with UPFC

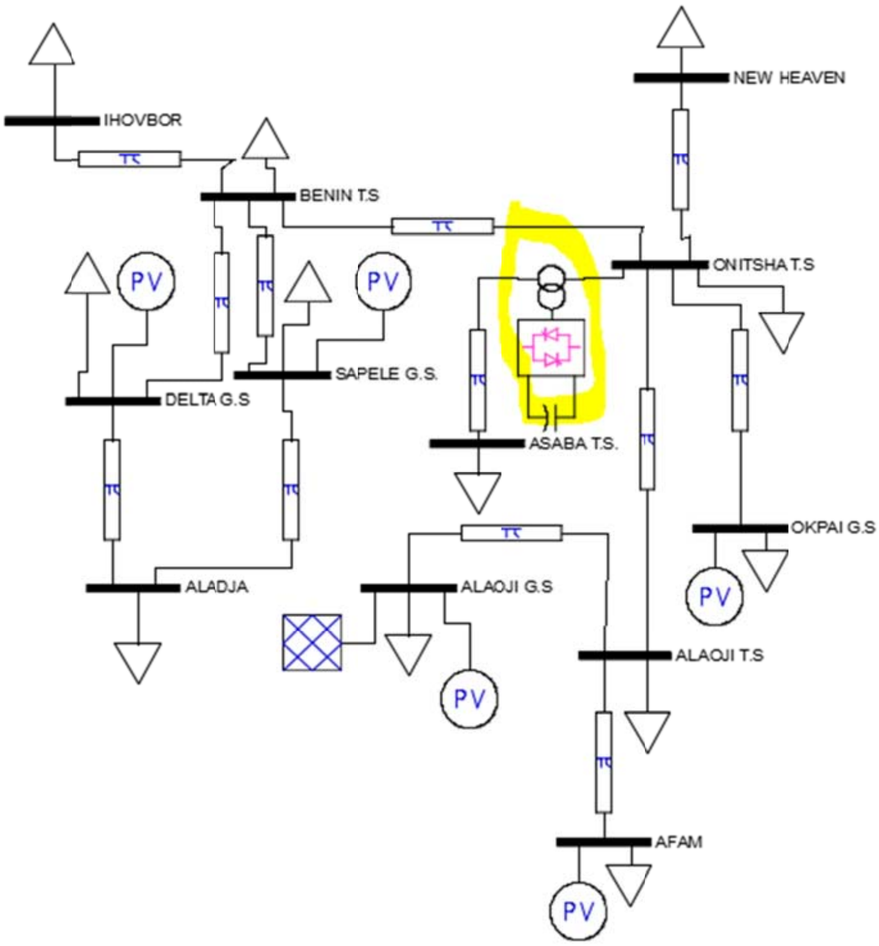


Figure 6: The PSAT model of power system network with SSSC

3. Results and Discussion

The PSAT results of the voltage profile (pu) of the buses without FACTS device, with SSSC and with UPFC are presented in Table 1, Figure 7 and Figure 8 while the percentage enhancement results for the voltage profile of the buses with SSSC and with UPFC are presented in Figure 9 and Figure 10.

The summary of the results in Table 1, Figure 7 and Figure 8 is that the mean voltage profile (pu) of the buses without FACTS device is 0.8756 pu, with SSSC is 0.9769 pu and with UPFC is 0.9809 pu. The mean voltage profile results shows that the mean percentage enhancement of the voltage profile of the buses attained with SSSC is 13.8 % while that of the UPFC is14.3 %. With the results, it is evident that the UPFC device with about 3.6% improvement over that provided by SSSC device is recommended for voltage profile enhancement for the overall power network buses considered in the study.

Table 1 Voltage profile (pu) of the buses without FACTS device, with SSSC and with UPFC

Bus number	Voltage profile (pu) without FACTS Device	Voltage profile (pu) with SSSC	Voltage profile (pu) with UPFC
1	1.0000	1.0000	1.0000
2	0.9640	0.9714	0.9809
3	1.0000	1.0000	1.0000
4	0.7773	0.9632	0.9711
5	0.6884	0.9833	0.9889
6	0.8542	0.9500	0.9554
7	1.0000	1.0000	1.0000
8	0.7921	0.9311	0.9410
9	0.6884	0.9499	0.9517
10	1.0000	1.0000	1.0000
11	0.7424	0.9744	0.9818
12	1.0000	1.0000	1.0000
Mean	0.8756	0.9769	0.9809

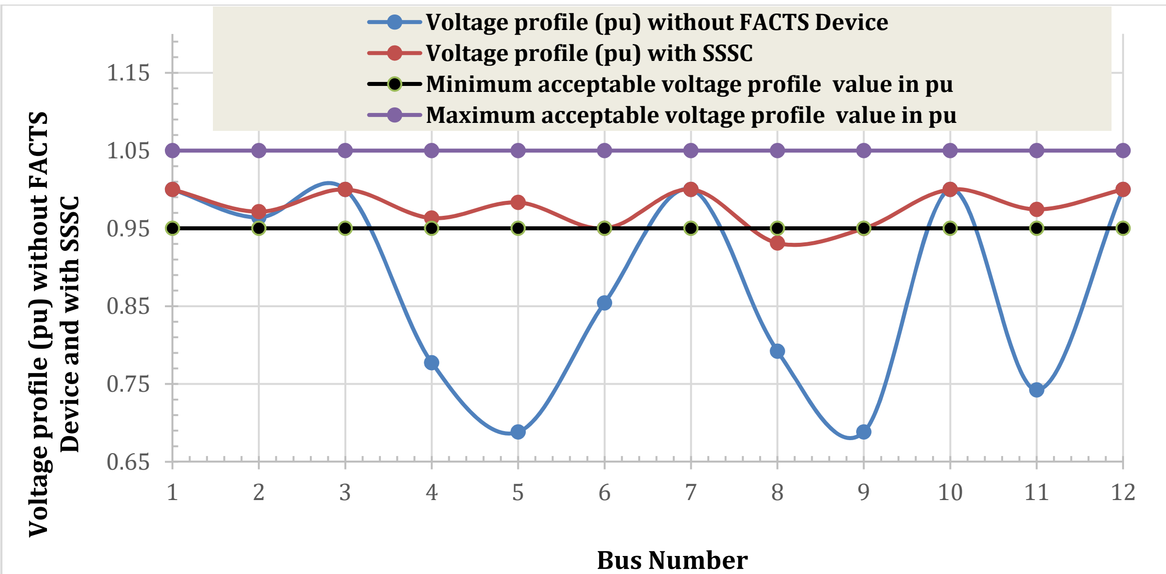


Figure 7 Voltage profile (pu) of the buses without FACTS device, with SSSC and with UPFC

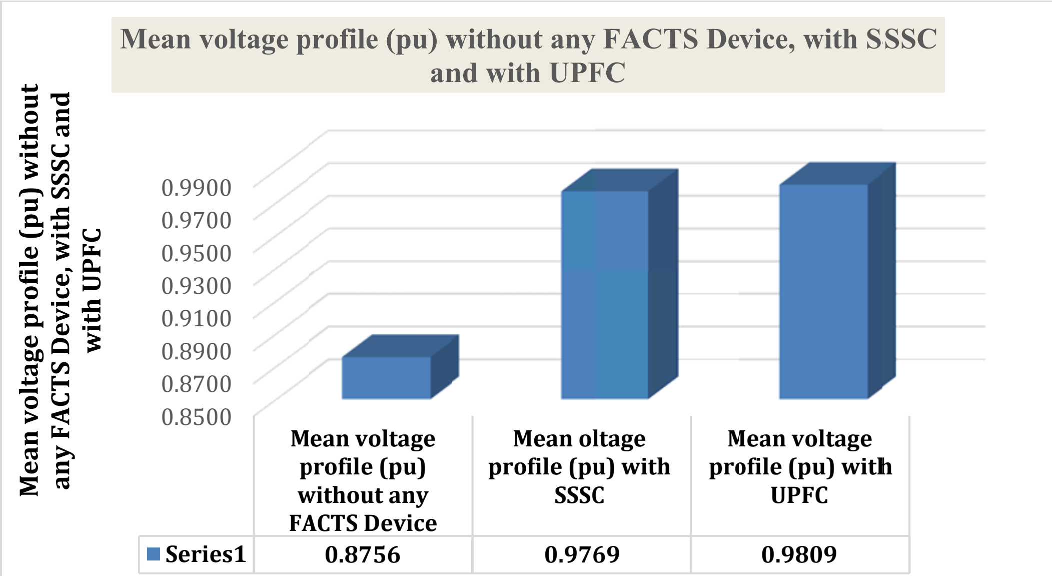


Figure 8 Mean voltage profile (pu) of the buses without FACTS device, with SSSC and with UPFC

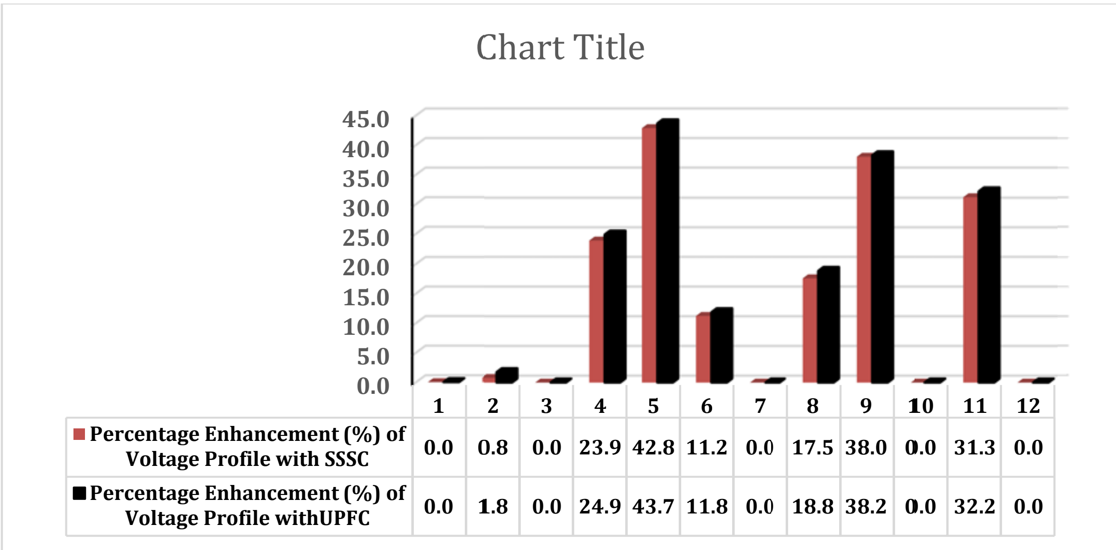


Figure 9 Percentage enhancement of the voltage profile of the buses with SSSC and with UPFC

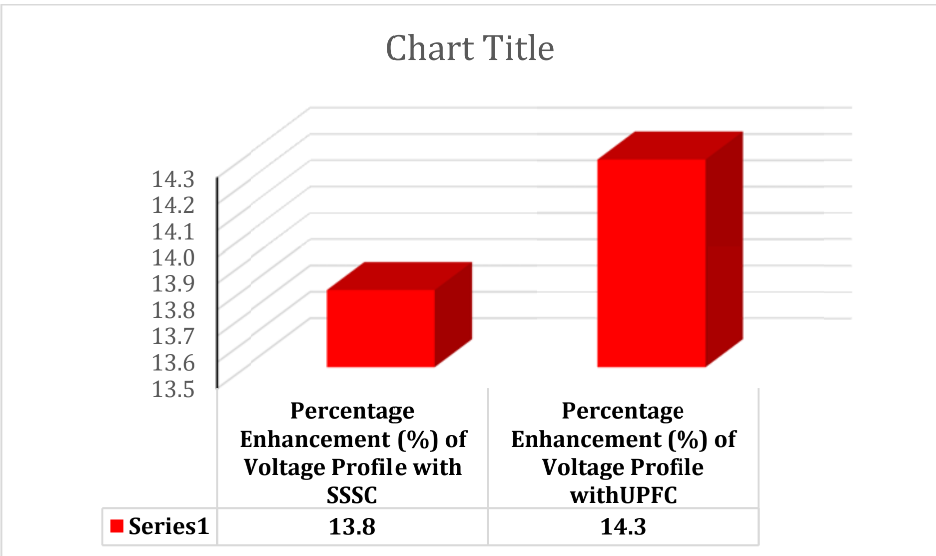
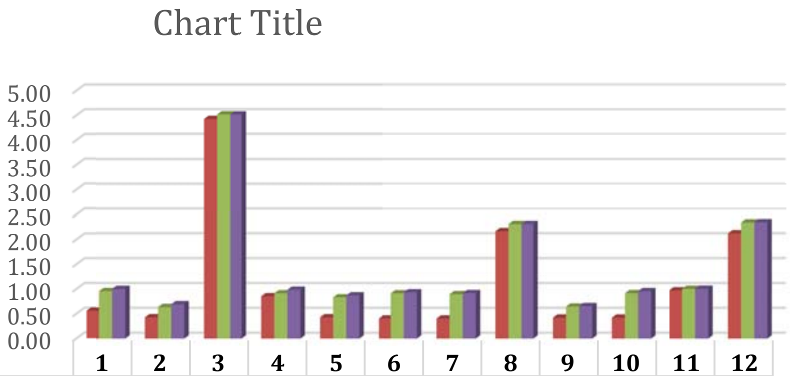


Figure 10 Mean percentage enhancement of the voltage profile of the buses with SSSC and with UPFC

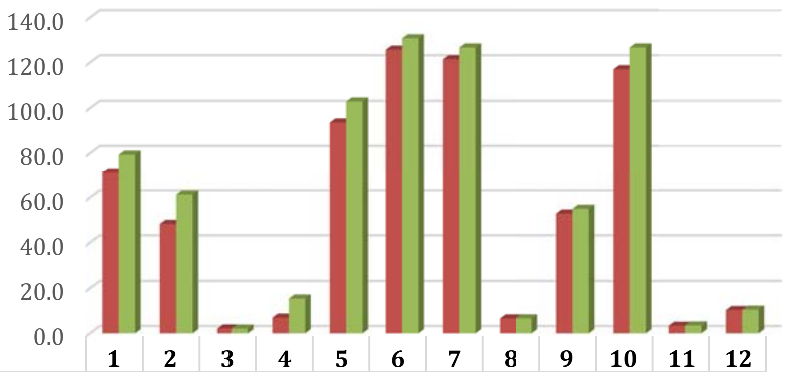
The bar chart of the active power transfer (in pu) without FACTS device, with SSSC and with UPFC are as presented in Figure 11 while Figure 12 shows the bar chart of the percentage enhancement in the active power transfer with SSSC and with UPFC. In addition, Figure 13 shows the bar chart of the mean percentage enhancement in the active power transfer with SSSC and with UPFC.

The summary of the results in Figure 11, Figure 12 and Figure 13 is that mean percentage enhancement in the active power transfer capability of the power lines attained with SSSC is 54.9% while that of the UPFC is 60.1 %. Specifically, the active power transfer capability enhancement with UPFC is about 9.5 % better than that of SSSC device. With the results, it is evident that the UPFC has better active power transfer capability enhancement for the overall power lines considered in the study.



	1	2	3	4	5	6	7	8	9	10	11	12
Active Power (pu) without any FACT Device	0.56	0.43	4.42	0.85	0.43	0.40	0.40	2.16	0.42	0.42	0.97	2.11
Active power (pu) with SSSC	0.95	0.63	4.51	0.91	0.83	0.91	0.89	2.30	0.64	0.91	1.00	2.33
Active Power (pu) with UPFC	1.00	0.69	4.51	0.98	0.87	0.93	0.91	2.30	0.65	0.95	1.00	2.34

Figure 11 Bar chart of the active power transfer (in pu) without FACTS device, with SSSC and with UPFC



	1	2	3	4	5	6	7	8	9	10	11	12
Percentage enhancement (%) in Active Power Transfer with SSSC	71.2	48.3	2.1	6.9	93.6	125.7	121.4	6.6	52.9	117.0	3.3	10.3
Percentage enhancement (%) in Active Power Transfer with UPFC	79.3	61.4	2.1	15.4	102.9	130.7	126.6	6.6	55.0	126.6	3.4	10.5

Figure 12 Bar chart of the percentage enhancement in the active power transfer with SSSC and with UPFC

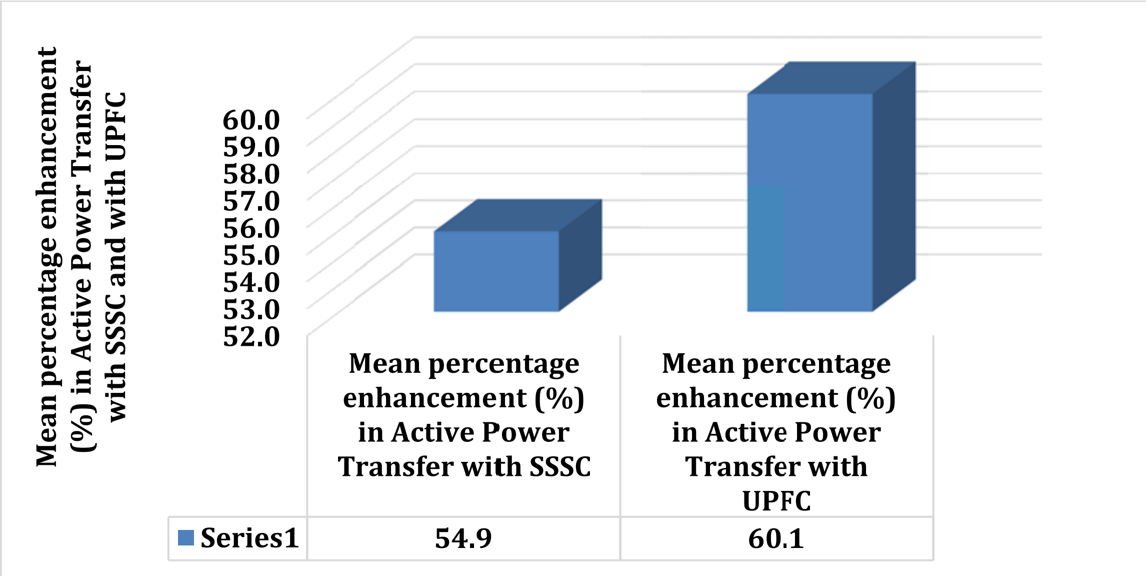


Figure 13 Bar chart of the mean percentage enhancement in the active power transfer with SSSC and with UPFC

Similarly, the bar chart of the reactive power transfer (in pu) without FACTS device, with SSSC and with UPFC are as presented in Figure 14 while Figure 15 shows the bar chart of the percentage enhancement in the reactive power transfer with SSSC and with UPFC. In addition, Figure 16 shows the bar chart of the mean percentage enhancement in the reactive power transfer with SSSC and with UPFC.

The summary of the results in Figure 14, Figure 15 and Figure 16 is that mean percentage enhancement in the reactive power transfer capability of the power lines attained with SSSC is 58.2% while that of the UPFC is 64.6 %. Specifically, the reactive power transfer capability enhancement with UPFC is about 11.0 % better than that of SSSC device. With the results, it is evident that the UPFC has better reactive power transfer capability enhancement for the overall power lines considered in the study. In view of the overall results, UPFC is therefore recommended for the power network performance enhancement.

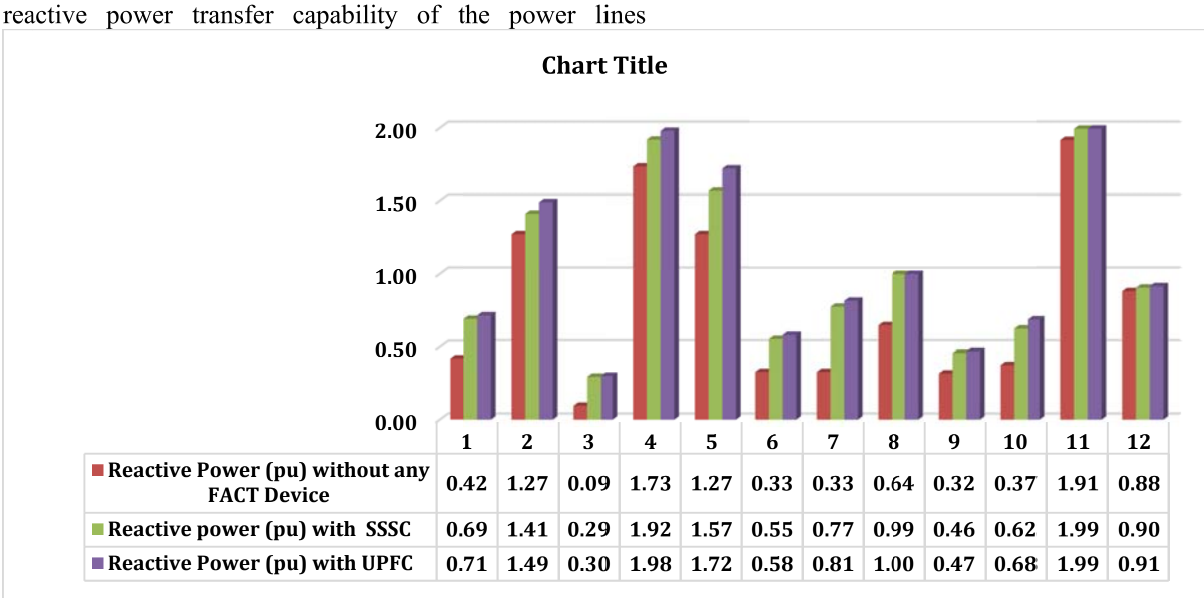
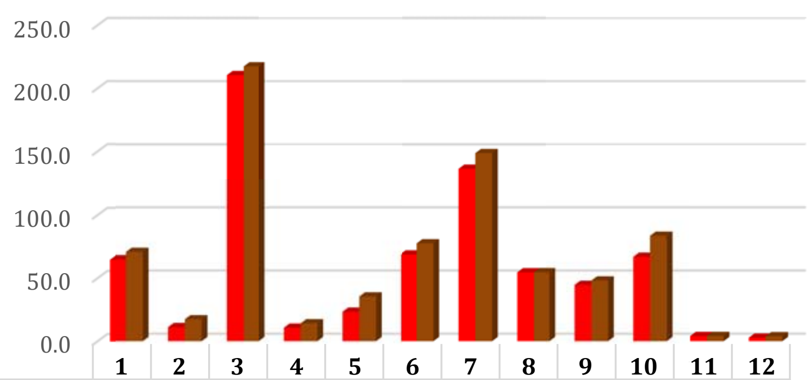


Figure 14 Bar chart of the reactive power transfer (in pu) without FACTS device, with SSSC and with UPFC



	1	2	3	4	5	6	7	8	9	10	11	12
Percentage enhancement (%) in Reactive Power Transfer with SSSC	64.7	11.1	210.7	10.6	23.3	68.6	136.5	54.5	44.5	66.7	4.0	2.8
Percentage enhancement (%) in Reactive Power Transfer with UPFC	70.6	17.3	217.6	14.1	35.3	77.4	148.9	54.5	48.0	83.4	4.1	3.9

Figure 15 Bar chart of the percentage enhancement in the reactive power transfer with SSSC and with UPFC

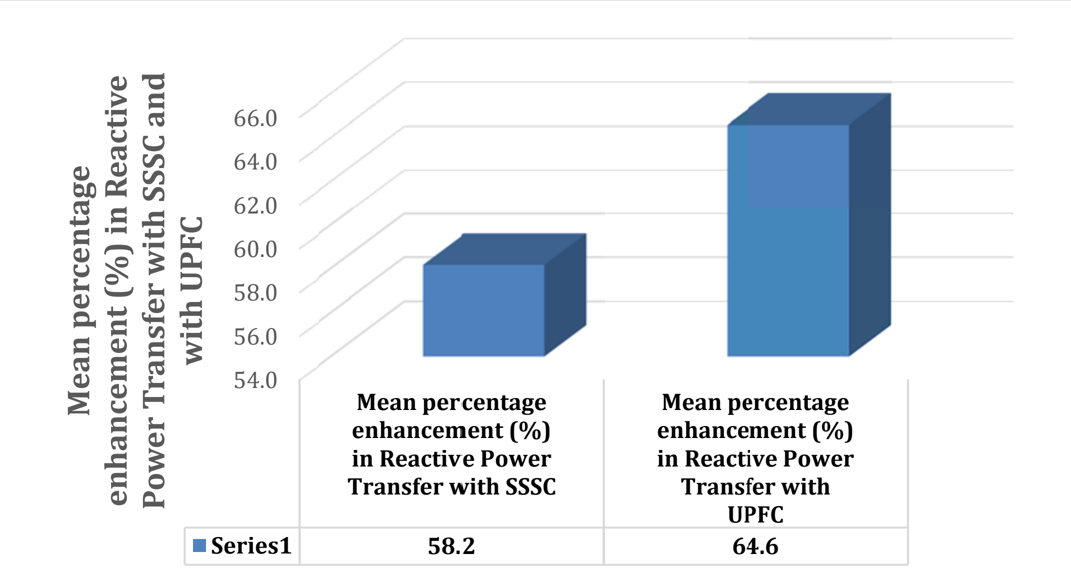


Figure 16 Bar chart of the mean percentage enhancement in the reactive power transfer with SSSC and with UPFC

4. Conclusion

Power System Analytical Tool (PSAT) in Matlab was used to evaluate and compare the achievable voltage profile enhancement as well as power transfer capability enhancements using the Unified Power Flow Controller (UPFC) Flexible AC Transmission Systems (FACTS) device and the Static Synchronous Series Compensator (SSSC). The study was conducted using the Nigerian 330kv power network as the case study based on dataset obtained from the National Control Center in Oshogbo, Osun state. The case study dataset which has about 12 buses was modeled in PSAT and simulated in three different scenarios; without FACTS device, with the UPFC device and finally with the SSSC device. In all, the results show that the UPFC has better voltage profile enhancement, better active power transfer capability enhancement and better reactive power transfer capability enhancement for the overall power network considered in the study. In view of the overall results, UPFC is therefore recommended for the power network performance enhancement.

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