American Journal of Engineering Research (AJER)
e-ISSN: 2320-0847 p-ISSN : 2320-0936
Volume-12, Issue-3, pp-51-58
www.ajer.org
Research Paper Open Access

# Power Flow Studies of 132/33/11 kV Distribution Network Using Static Var Compensator for Voltage Improvement

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***Abstract-*** *Power systems experience stress due to growing load demands and this has resulted to the implementation of reactive power injection to ensure a stable and efficient power network. To cushion this effect, this paper proposed the use of Flexible Alternating Current Transmission Systems (FACTS) technology amongst other technologies for reactive power compensation, and presents the use of Static Var Compensator (SVC) as the FACTS device for improvement of the power factor and power quality. Port Harcourt Town 132/33/11 kV substation modelled in Electrical Transient Analyzer Program (ETAP 19.0) software, was used for this analysis. Through the simulation of this network, the voltage profile evaluation through the Newton-Raphson load flow analysis method (LFA) was examined to evaluate the performance of the SVC device. The analysis results were verified and compared with permissible values included in the IEC standards. The simulation results showed the efficiency of SVC device in improving the voltage profile.*
***Keywords:*** *SVC, ETAP, Newton-Raphson, reactive power, FACTS*

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Date of Submission: 02-03-2023 Date of acceptance: 14-03-2023

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## I. INTRODUCTION

One of the common problems in power systems is reactive power compensation. FACTS devices contribute reactive power to the power network, improving the voltage stability of the network. [1]. Due to the high demand for energy, reactive power compensation aids in preventing power system overloading and collapse [2,3]. Conventional methods, such as synchronous condenser systems, have been proven effective in the past for improving power factor and supplying reactive power [4,5]. However, FACTS devices have been shown to be a more dynamic and effective tool in addressing power system instability issues, and it is able to both generate and absorb reactive power [6].

The FACTS devices are power electronic-based systems that provide improved controllability, flexibility, and reliability over the power network and have a number of benefits, including increasing the capacity of the transmission line, reducing transmission and distribution losses, amplifying adaptability, harmonic extenuation, and heightening the dynamic and static stability of the power system [7-9]. For various technologies, FACTS devices can be categorized as follows: [9]

- Shunt connected,
- series connected,
- series-series connected,
- series-shunt connected

The Static Var Compensator (SVC) is the FACTS device employed in this study for reactive power compensation, and Newton-Raphson power flow iterative technique was utilized for the load flow analysis because of its quick convergence rate and high accuracy when compared to other solution algorithms.

## II. MATERIALS AND METHOD

**Modeling of Static Var Compensator (SVC)**

One of the several FACTS devices known as SVC serves as an injector or absorber of static reactive power and is connected in parallel to the distribution network nodes. SVC is made up of a parallel combination of regulated inductors, thyristor valves, switches, and capacitor banks. It functions similarly to a variable parallel reactance that may be converted into a highly responsive device by adjusting the thyristors' firing angle [11,12].

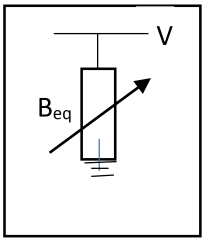


Fig. 1: Circuit model of SVC

Figure 1 depicts the equivalent circuit of the SVC. The following can be used to express the equivalent reactance to control inductor via a thyristor:

$$X_L = \frac{\pi X_L}{2(\pi-\alpha)+\sin(2\alpha)} \quad (1)$$

You may determine the parallel configuration of thyristor-controlled inductors and capacitors' SVC equivalent reactance by:

$$X_{Leq} = \frac{\pi X c X_L}{X_c(2(\pi-\alpha)+\sin(2\alpha))-\pi X_L} \quad (2)$$

The firing angle of the thyristors is indicated by α, and Xc represents the parallel capacitor reactance. Taking into account SVC equivalent susceptance, which is a result of the thyristors' firing angle, as shown in (3):

$$B_{eq} = \frac{\pi X_{L-}\, X_c(2(\pi-\alpha)+\sin(2\alpha))}{\pi X_c X_L} \quad (3)$$

The firing angle of the thyristors is a continuous function of the susceptance of SVC, unlike the capacitor, according to (3) [11].

Injection or absorbing of reactive power by SVC using (4) is calculated:

$$Q_{SVC} = -V^2 B_{eq} \quad (4)$$

In (4), V is the voltage of the node that SVC is installed.

**Substation Modelling**

The Port Harcourt Town 132/33kV substation gets power from Afam transmission station through a 132kV double circuit transmission line connected to the national grid at Alaoji-Afam transmission station. The substation consists of:

- A 132kV bus bar connected with a power source (an external grid)- a reference bus;
- 60MVA, 45MVA, and 30MVA (2) 132/33kV power transformers
- 15 MVA (3) 33/11kV power transformers.
- Six 33kV feeders, and six 11kV feeders feeding injection substations in the zone.

The base-case network employed for this investigation was modelled using the Electrical Transient Analyzer Program software, as shown in Fig. 2. (ETAP 19.0). The Port Harcourt Electricity Distribution Company (PHED) and Transmission Company of Nigeria (TCN) provided the pertinent data that was used for this research's modeling and simulation.

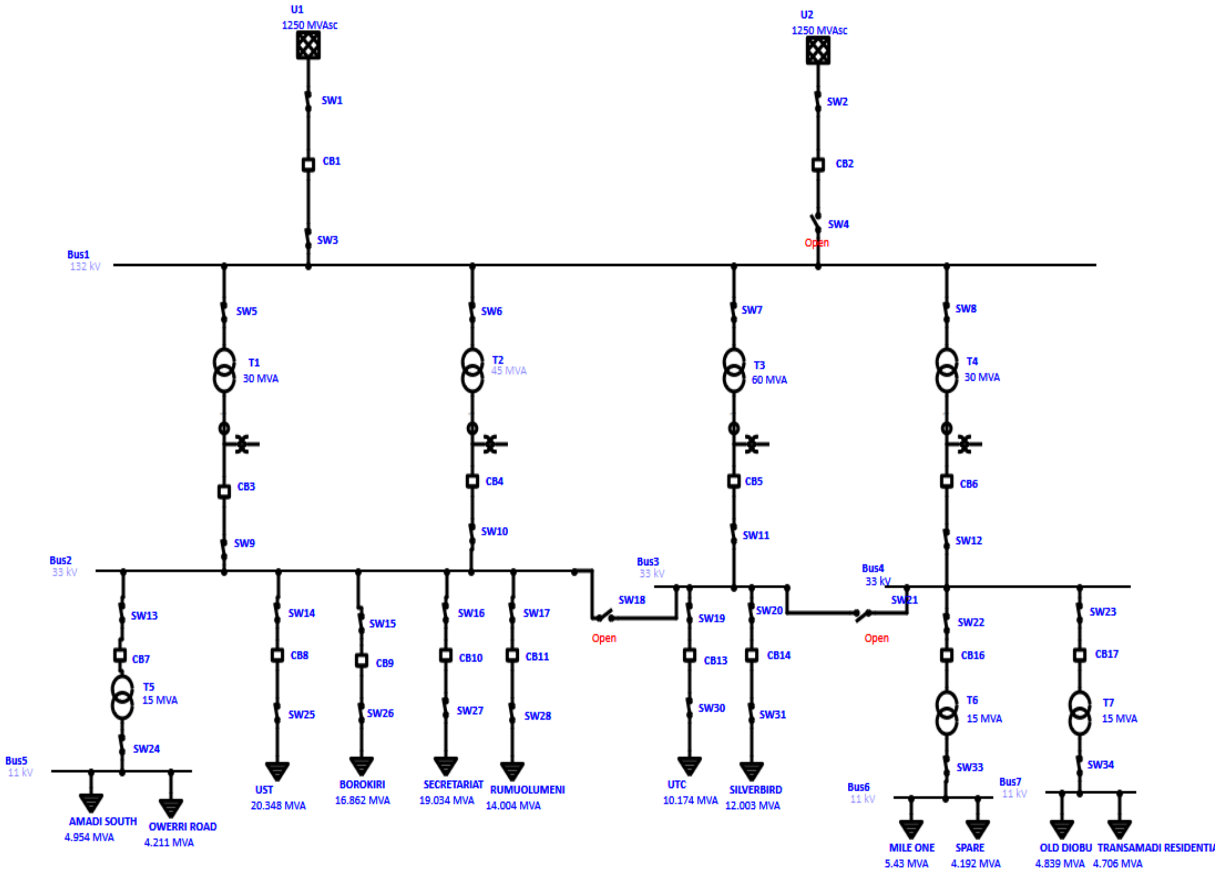


Fig. 2: The Single Line Diagram of Port Harcourt Town 132/33kV Substation

## III. RESULTS AND DISCUSSION

**Load Flow Study- Without SVC Compensation**

The load flow analysis (LFA) is a method that is frequently used for power system design and operation [13]. While conducting power system analyses, a number of studies have employed the Newton-Raphson power flow solution technique to do LFA [36–38]. Using the ETAP software's built-in Newton-Raphson power flow solution technique, a load flow study of the modeled substation was conducted. The LFA was conducted at this point in order to test the substation equipment loadings and performance under the conditions of maximum loading, without the involvement of the FACTS device (SVC). Tables 1 and 2 present the findings. It is evident from the load flow figures that the Port Harcourt Town 132/33kV substation is experiencing difficulties, including a poor voltage profile and heavily loaded transformers. The condition of the transformers after the LFA is explained in Table 1, which demonstrates that the transformers are overloaded in accordance with the power system regulation as indicated in the IEC standard 60354 requirements [14]. The IEC standard states that continuous loading of oil-immersed transformers above the threshold of 80% will shorten their useful lifetime. The findings indicate that, in comparison to T1 and T2, which are overloaded, transformers T3, T4, T5, T6, and T7 are in a better loading state.

Table 1. LFA results of the transformers – without SVC compensation

| Equipment | Ratings | % Loading |
|---|---|---|
| Transformer T1 | 30 MVA (132/33)kV | 97.8 |
| Transformer T2 | 45 MVA (132/33)kV | 97.8 |
| Transformer T3 | 60 MVA (132/33)kV | 36 |
| Transformer T4 | 30 MVA (132/33)kV | 58.8 |
| Transformer T5 | 15 MVA (33/11)kV | 50.7 |
| Transformer T6 | 15 MVA (33/11)kV | 56.4 |
| Transformer T7 | 15 MVA (33/11)kV | 55.9 |

Table 2. LFA results of the bus bars – without SVC compensation

| Equipment | Rated Value (kV) | Recorded Voltage (%) |
|---|---|---|
| Bus1 | 132 | 100 |
| Bus2 | 33 | 92.75 |
| Bus3 | 33 | 97.47 |
| Bus4 | 33 | 95.51 |
| Bus5 | 11 | 89.53 |
| Bus6 | 11 | 92.03 |
| Bus7 | 11 | 92.05 |

Table 2 shows the LFA results of the bus bars which are not very promising. The provisions of the IEC standard indicate a $\pm 6\%$ tolerance for voltage drop. As observed from the table, Bus 2, Bus 5, Bus 6 and Bus 7 violated the voltage drop limit and Bus 5 is observed to be the most overloaded bus bar in the system. Hence, this study proposes the overloaded buses to be the point of coupling for the FACTS device (SVC) and for the injection of reactive power into the network.

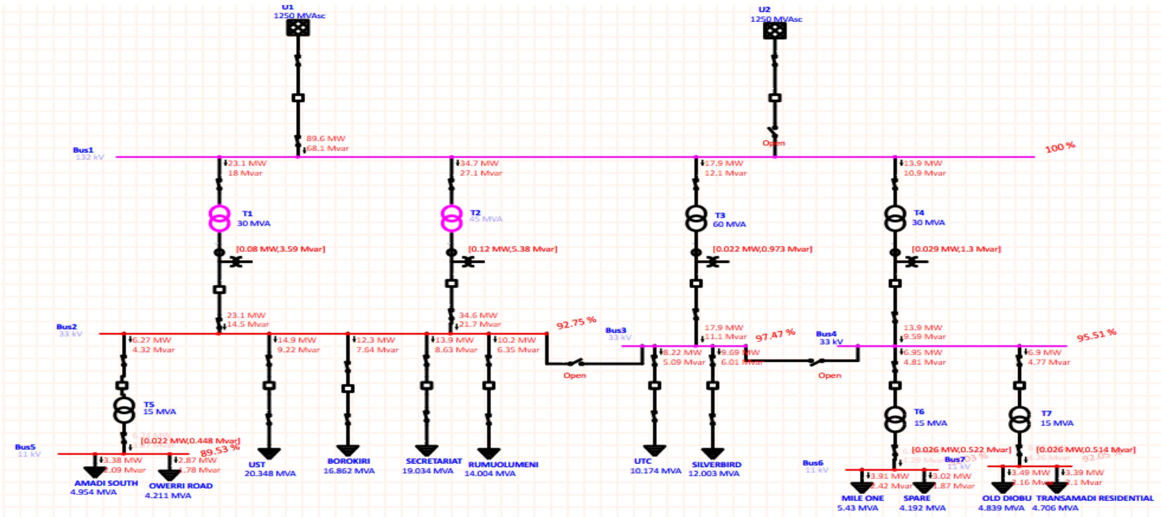

Fig. 3: LFA of the base-case network without SVC

**Load flow study – With SVC (150 MVar)**

Fig. 4 shows the installation of SVC at the weak buses; Bus 2, Bus 5, Bus 6 and Bus 7 and the results of the LFA were noted during the maximum load scenario. Tables 3 and 4 present the LFA results for the transformers and bus bars after the reactive power compensation using SVC.

Table 3. LFA results of the transformers – with SVC

| Equipment | Ratings | % Loading |
|---|---|---|
| Transformer T1 | 30 MVA (132/33)kV | 74.5 |
| Transformer T2 | 45 MVA (132/33)kV | 74.5 |
| Transformer T3 | 60 MVA (132/33)kV | 31.3 |
| Transformer T4 | 30 MVA (132/33)kV | 50.5 |
| Transformer T5 | 15 MVA (33/11)kV | 53.2 |
| Transformer T6 | 15 MVA (33/11)kV | 61.4 |
| Transformer T7 | 15 MVA (33/11)kV | 60.9 |

Table 4. LFA results of the bus bars – with SVC

| Equipment | Rated Value (kV) | Recorded Voltage (%) |
|---|---|---|
| Bus1 | 132 | 100 |
| Bus2 | 33 | 98.95 |
| Bus3 | 33 | 99.66 |
| Bus4 | 33 | 99.67 |
| Bus5 | 11 | 99.79 |
| Bus6 | 11 | 96.04 |
| Bus7 | 11 | 96.06 |

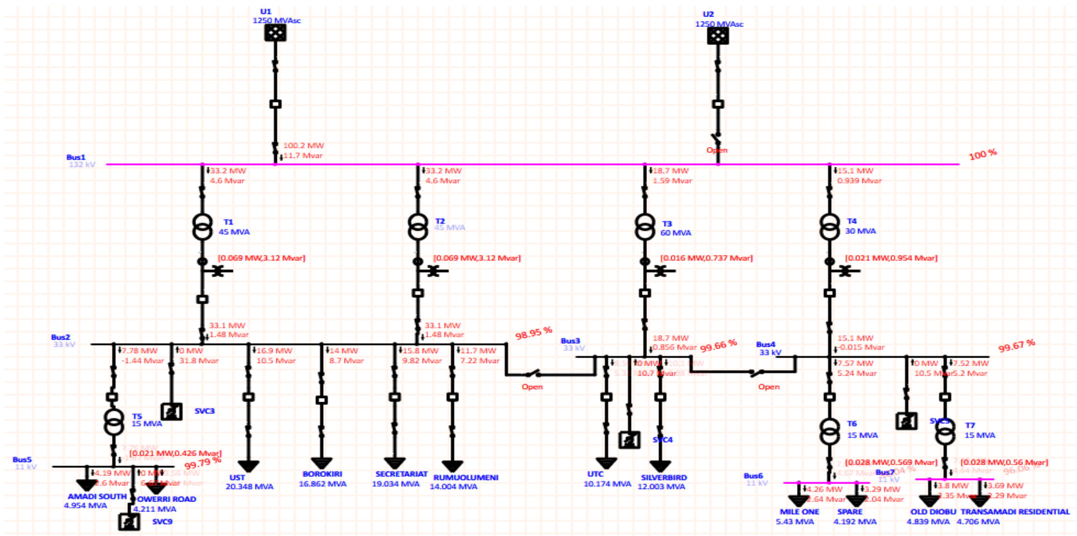

Fig. 4: LFA of the base-case network with SVC compensation

Table 5: Results of Load Flow and Losses without SVC

| S/N | ID | kW Flow | KVar Fow | Amp flow | %PF | %Loading | kW Losses | KVar Losses |
|---|---|---|---|---|---|---|---|---|
| 1 | T1 | 46280 | 46501.9 | 287 | 70.54 | 218.7 | 398.4 | 17930 |
| 2 | T2 | 69419.9 | 69752.9 | 430.4 | 70.54 | 218.7 | 597.7 | 26895 |
| 3 | T3 | 17931 | 12072.5 | 94.55 | 82.95 | 36 | 21.63 | 973.2 |
| 4 | T4 | 13882.1 | 10885.9 | 77.16 | 78.69 | 58.8 | 28.81 | 1296.4 |
| 5 | T5 | 4944.5 | 3407.1 | 127.5 | 82.34 | 40 | 17.69 | 353.7 |
| 6 | T6 | 6952.5 | 4814.6 | 154.9 | 82.21 | 56.4 | 26.1 | 522.1 |
| 7 | T7 | 6900.8 | 4774.8 | 153.7 | 82.23 | 55.9 | 25.7 | 514 |
| 8 | | | | | | **Total Losses** | 1.116 | 48.484 |

Table 6: Results of Load Flow and Losses with SVC

| S/N | ID | kW Flow | KVar Fow | Amp flow | %PF | %Loading | kW Losses | KVar Losses |
|---|---|---|---|---|---|---|---|---|
| 1 | T1 | 63656.2 | 15215.5 | 286.3 | 97.26 | 218.2 | 396.5 | 17844 |
| 2 | T2 | 95484.3 | 22823.2 | 429.4 | 97.26 | 218.2 | 594.8 | 26766.1 |
| 3 | T3 | 18744.3 | 1512.2 | 82.25 | 99.68 | 31.3 | 16.37 | 736.6 |
| 4 | T4 | 15113.1 | 898.5 | 66.22 | 99.82 | 50.5 | 21.22 | 954.8 |
| 5 | T5 | 6817.3 | 4697.5 | 149.7 | 82.34 | 55.2 | 24.38 | 487.7 |
| 6 | T6 | 7574.1 | 5245.1 | 161.7 | 82.21 | 61.4 | 28.44 | 568.7 |
| 7 | T7 | 7517.8 | 5201.8 | 160.4 | 82.23 | 60.9 | 28 | 560 |
| 8 | | | | | | **Total Losses** | 1.11 | 47.918 |

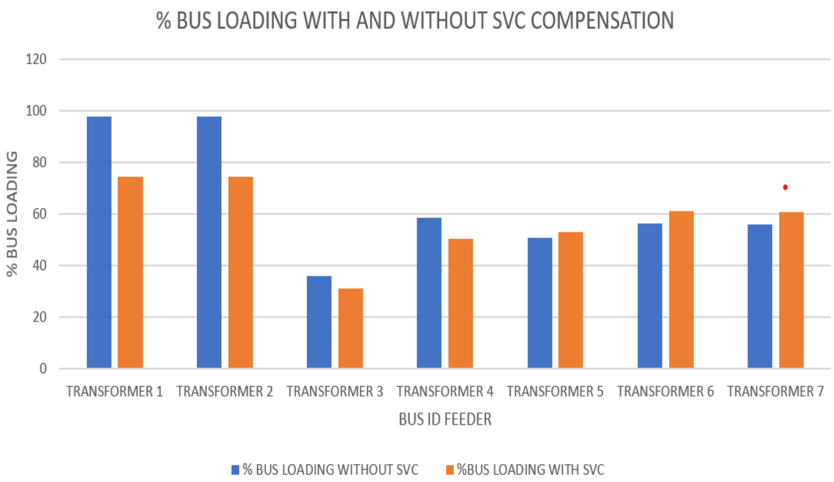


Fig 5: Chart showing % Bus loading with and without SVC

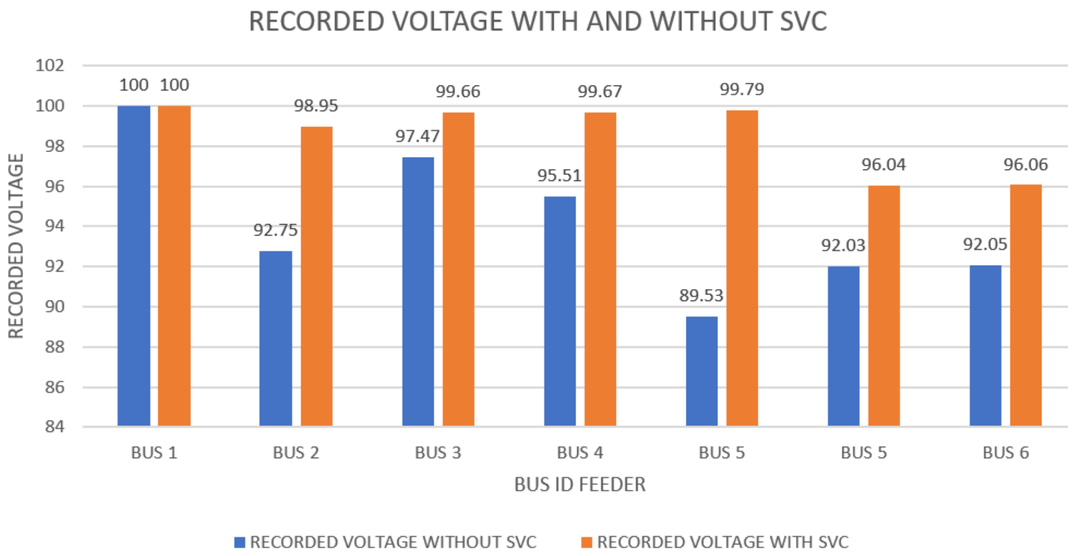


Fig 6: Recorded voltage with and without SVC

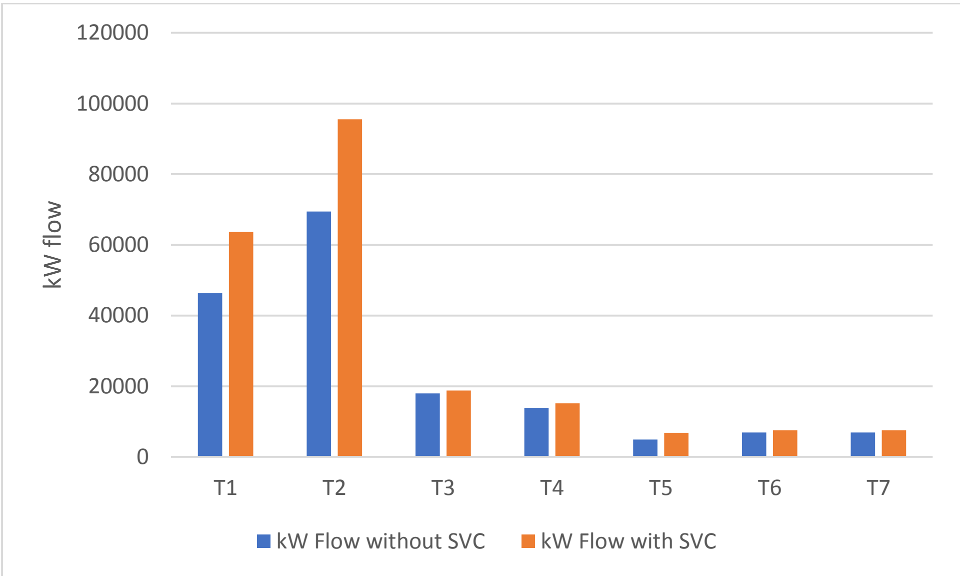


Fig. 7: kW flow with and without SVC

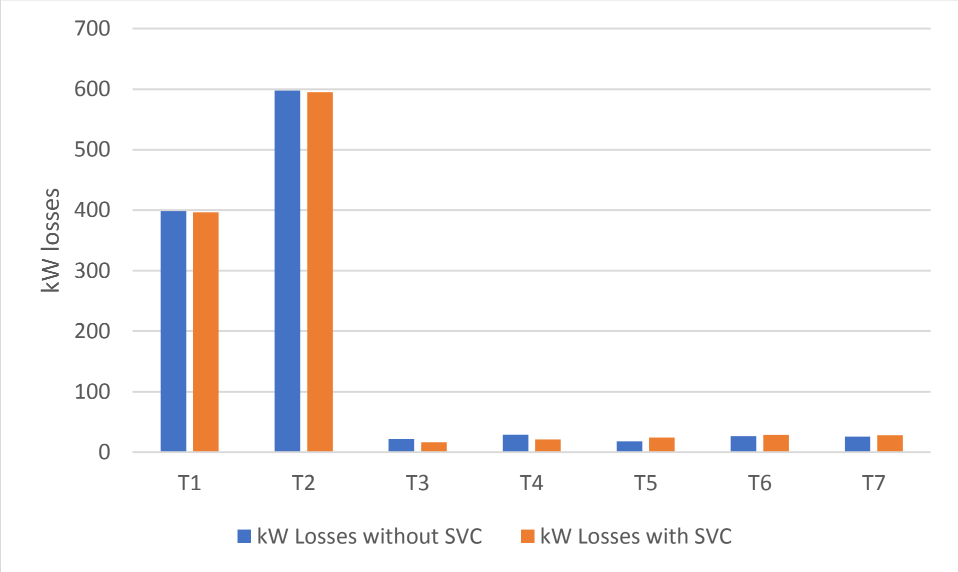


Fig. 8: kW losses with and without SVC

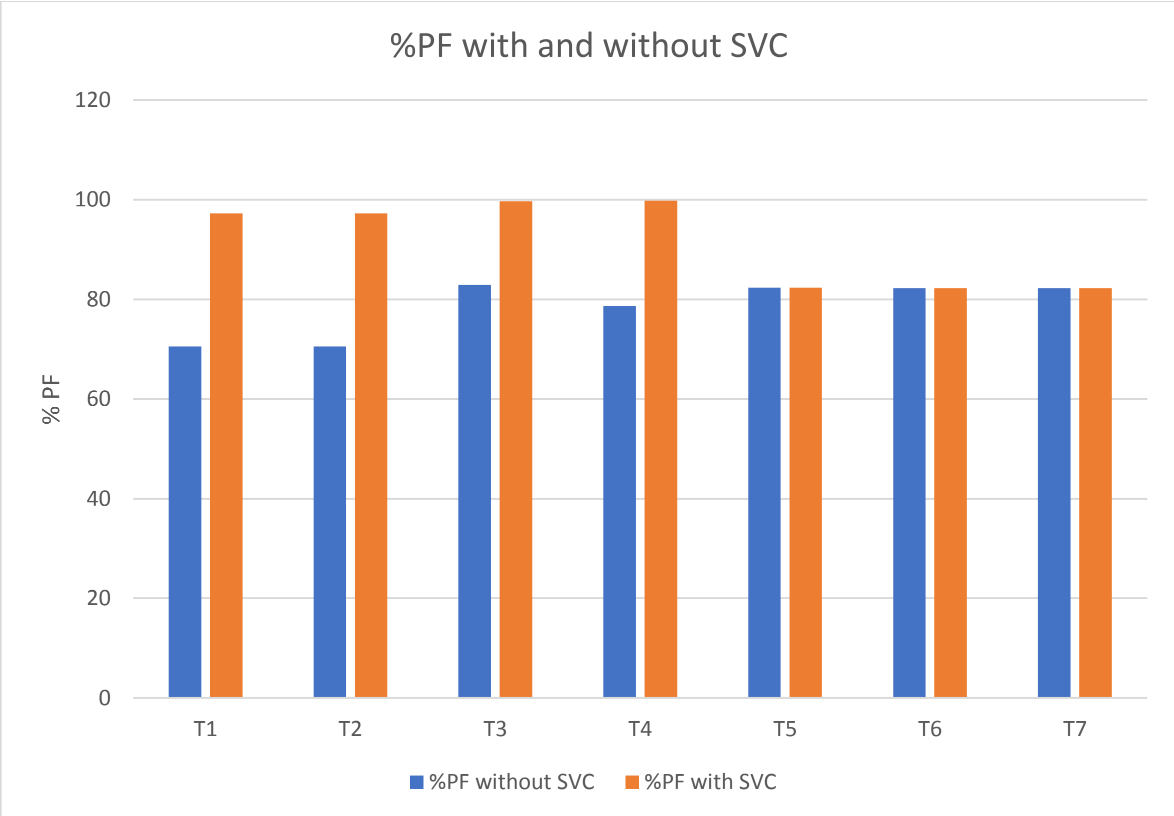


Fig. 9: % Power factor with and without SVC

After the installation of SVC, as demonstrated in tables 1 and 2, a certain improvement was seen (Tables 3 and 4) in terms of overloaded transformers; T1 and T2 which are the weak buses. Transformers T1 and T2, which were previously 97.8% loaded (without SVC adjustment), are now at 74.5% in Table 3, which represents an increase of around 23.3% in the recorded value. Table 4 displays the results of the voltage profile of the bus bars following the installation of SVC at the weak buses. The newly recorded voltage of 98.95% with SVC compensation as compared with voltage value (without compensation) of 92.75% showing 6.2% improvement for Bus 2, newly recorded voltage of 99.79% with SVC compensation as compared with voltage (without compensation) of 89.53% showing 10.26% improvement for Bus 5, newly recorded voltage of 96.04% with SVC compensation as compared with voltage value (without compensation) of 92.03% showing 4.01% improvement for Bus 6, newly recorded voltage of 96.06% with SVC compensation as compared with voltage value (without compensation) of 92.05% showing 4.01% improvement for Bus 7. Fig. 5 shows the chart for % bus loading with and without SVC. From the chart, the effect of SVC is clearly seen in the reduction of the % loading of the transformers thereby increasing the life span of the transformers. Figure 6 shows the voltage profile with and without SVC. Table 5 and 6 shows the impact of SVC in terms of % power factor, kW flow and losses. The chart shows voltage profile improvement when SVC was connected to the network.

## IV CONCLUSION

The Load Flow Analysis (LFA) is crucial for the operation of the current power system and for planning for the future. In this investigation, the base case network for load flow investigations was modeled using ETAP 19.0. The simulation was run under a peak-load scenario using the software's inbuilt Newton-Raphson power flow approach. The LFA results revealed the weak buses and overloaded transformers. By lowering their percentage loadings to a significant number and strengthening the weak buses, the SVC approach improved the overloaded transformers and produced a better voltage profile

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