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# An Improvement of Voltage Profile Using Static Var Compensators (A Case Study of New Haven 132/33kv Transmission Network)

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***ABSTRACT:*** *This research improved the voltage profile of New Haven 132/33KV transmission network using Static Var Compensators. The research study is limited to the New haven 132/33KV transmission network. The data used was the peak loads recorded for the month of April, 2018. Static Var compensators were used as the voltage regulators and hence were considered only in its voltage regulation mode. Load flow analysis have been carried out with the help of computer simulation for peak load conditions. The result show that, when the computer simulation without SVC, was done, it is observed that the voltages at the buses 1,2,3,4 are below unity. And when SVC were installed, at the buses, there was a compensation of the voltage profile to unity and it is thus enhanced. The transformer loading was also reduced with the addition of the SVC.*

***KEYWORDS:*** DIgSILENT Power-Factory, *SVC, TVC,Transmission line, Matlab/Simulink, Load flow, simulation. Thyristor.*

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## I. INTRODUCTION

Voltage ratings of the buses in the power should be within the permissible limits for satisfactory operation of all electrical equipment. Voltage of a power system network system which includes generating station buses, switching substation buses, receiving substation buses and distribution substation buses varies with the change in load. The voltage is normally high at light load and low at the heavy-load condition. To keep the voltage of the system within limits, some additional equipment is required which increase the system voltage when it is low and reduces the voltage when it is too high.

As electricity istransmitted along a transmission line, resistive and reactivepower losses are incurred and a voltage drop occurs. As an increasing amount of electricity is transferred, resistivelosses increase and increasing amounts of reactive power arerequired to support system voltages.This task of voltage control is closely associated with fluctuating load conditions and corresponding requirements of reactive power compensation.

Controlling the system voltage by the help of shunt inductive element is known as shunt compensation. The shunt compensation is of two types, i.e., the static shunt compensation and the synchronous compensation. In static shunt compensation, the shunt reactor, shunt capacitor and static VAR system are used, whereas the shunt compensation uses the synchronous phase modifier.

Voltage sag is the most common problem in heavily loaded power networks as voltage surge is a problem when the network is lightly loaded. In power networks, voltage sag is caused by imbalance in reactive power generated by the load. Voltage improvement at the receiving end is possible through a number of methods. One of the common methods is tap setting of the transformer but this has limitations related to insulation and dielectric strength.

This research work aims to study these voltage variations of the network, model a static varcompensator with the aim of improving the voltage profile [1].

## II. METHODOLOGY

The most widely used method for solving simultaneousnonlinear algebraic equations is the Newton-Raphsonmethod (NR). Newton’s method is found to be moreefficient and practical. The number of iterations required toobtain a solution is independent of the system size, butmore functional evaluations are required at every iteration.Since in the power flow problem real power and voltage magnitude are specified for the voltage-controlled buses,the power flow equation is formulated in polar form. Thisequation can be rewritten in admittance matrix as

$$I_i = \sum_{j=1}^{n} Y_{ij} V_j \quad 1$$

In the above equation, j includes bus i. expressing thisequation in polar form, we have

$$I_i = \sum_{j=1}^{n} |Y_{ij}| \, |V_j| < \theta_{ij} + \delta_j \quad 2$$

The complex power at bus i is

$$P_i - jQ_i = V_i^* I_i \quad 3$$

Substituting form equation 2 for Ii in equation 3

$$P_i - jQ_i = |V_i| < -\delta_i \sum_{j=1}^{n} |Y_{ij}| \, |V_j| < \theta_{ij} + \delta_j \quad 4$$

$$P_i = \sum_{j=i}^{n} |V_i| \, |V_j| \, |Y_{ij}| \cos(\theta_{ij} - \delta_i + \delta_j) \quad 5$$

$$Q_i = -\sum_{j=i}^{n} |V_i| \, |V_j| \, |Y_{ij}| \sin(\theta_{ij} - \delta_i + \delta_j) \quad 6$$

$$\begin{bmatrix} \Delta P \\ \Delta Q \end{bmatrix} = \begin{bmatrix} J_1 & J_2 \\ J_3 & J_4 \end{bmatrix} \begin{bmatrix} \Delta\delta \\ \Delta|V| \end{bmatrix} \quad 7$$

By running the load flow analysis using NR-method wecan find the Power flows in individual lines, bus and loss in each [1].

A.DIgSILENT Power-Factory

Power-Factory is a leading power system analysis software application for use in analyzing generation, transmission, distribution and industrial systems

Its basic functions include

- Load flow analysis
- Short-circuit analysis
- Network representation
- Network diagrams and graphic features
- Power equipment models
- Basic MV/LV network analysis etc.

## III. MODELLING OF SVC USING SIMULINK

This section presents how static var compensator is utilized to effectively control and regulate system voltage. I developed a state space model in the MATLAB/SIMULINK to show how the svc system regulates voltage when attached to a transmission or distribution system. It is modelled in its voltage regulation mode.

I. Modelling of the SVC control system

The control system of an SVC has four main components as shown in figure below

a. Voltage Measurement System
b. Voltage regulator
c. Distribution unit
d. Synchronizing Pulse generator

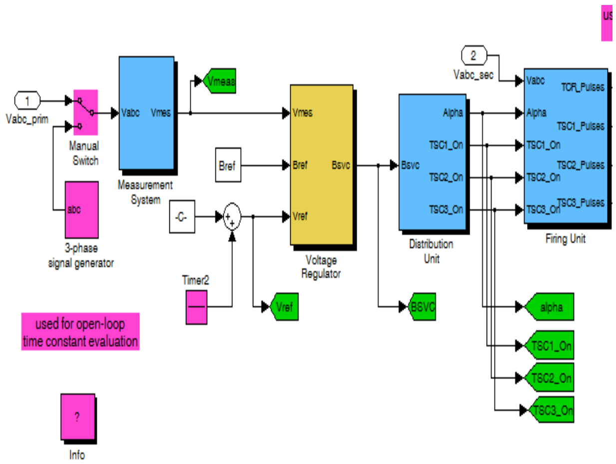


**Figure 1:** Model of the SVC control system

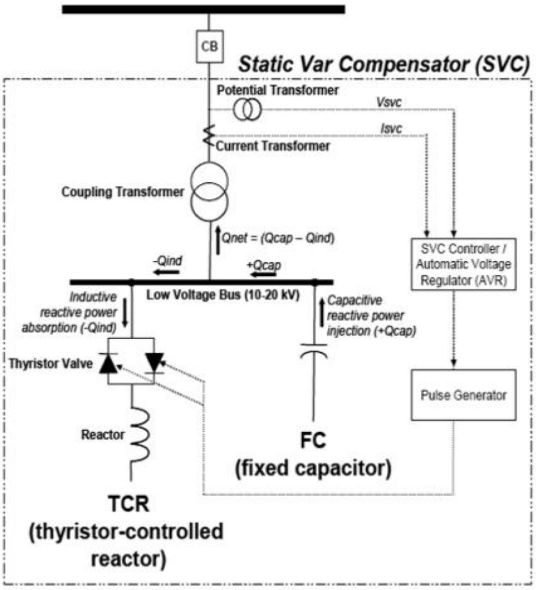


**Figure 2:**The measuring system

A measuring system measures the positive sequence of the system voltage to be controlled.

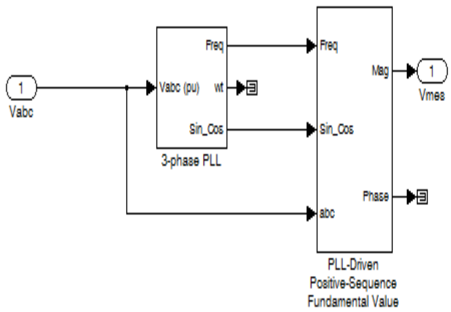


**Figure 3:** The voltage regulator

A voltage regulator uses the voltage error (difference between the measured voltage Vm and the reference voltage Vref) to determine the SVC susceptance B needed to keep the system voltage constant, Voltage regulator uses a PI regulator to regulate primary voltage at the reference voltage. A voltage droop is incorporated in the voltage regulation to obtain V-I characteristics [2].

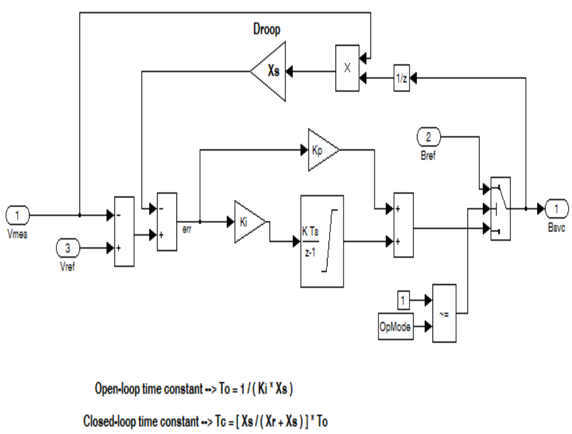


**Figure 4**: The model of the distribution unit

A distribution unit determines the TSCs (and eventually TSRs) that must be switched in and out, and computes the firing, alpha of the TCRs. Distribution unit uses the primary susceptance$B_{svc}$ computed by the voltage regulator to determine the TCR firing angle, alpha and switching of the Thyristor switched capacitor. The firing angle „alpha" as a function of the TCR susceptance if given by

$$Btcr = \frac{2(\pi - \alpha) + \sin(2\alpha)}{\pi} \quad 8$$

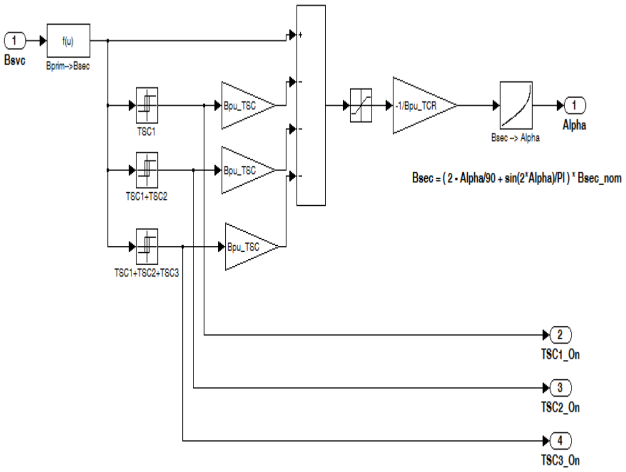


**Figure 5**: The synchronizing system

A synchronizing system using a Phase Locked Loop (PLL) synchronized on the secondary voltage and a pulse generator that send appropriate pulses to the thyristor. The pulse generator uses the firing angle alpha and the thyristor switched capacitor status from the distribution unit to generate pulses.

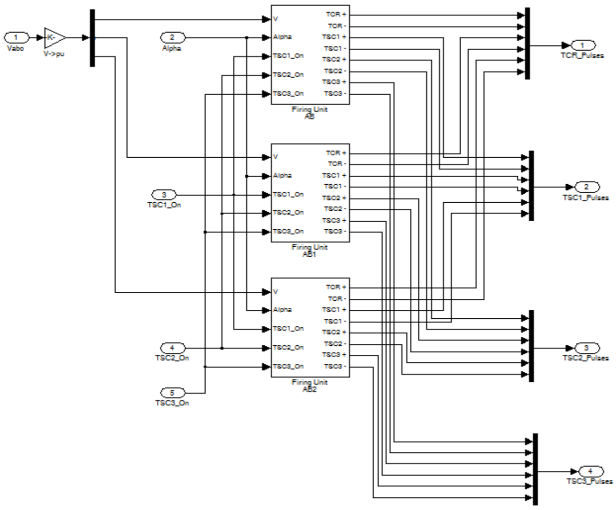

**Figure 6:**Dynamic Responses of the svc

The SVC is operating in voltage regulation mode; its response speed to a change of system voltage depends on the voltage regulator gains (proportional gains $K_p$ and integral gain $K_i$), the droop reactance $X_s$, and the system strength (short circuit level).

For an integral type voltage regulator ($K_p$=0), if the voltage measurement time constant $T_m$ and the average time delay $T_d$ due to valve firing are neglected, the closed loop system consisting of the SVC and the power system can be approximated by a first-order system having the following closed-loop time constant:

$$Tc = \frac{1}{Ki\ (Xs + Xn)} \quad 9$$

Where,
$T_c$= Closed loop time constant
$K_i$ =Proportional gain of the voltage regulator

$X_s$= Sloop reactance
$X_n$ = Equivalent power system reactance

The above equation demonstrates that you obtain faster response speed when the regulator gain is increased or when the system short circuit level decreases (higher $X_n$ values). If you take into account the time delays due to voltage measurement system and valve firing, you obtain an oscillatory response and, eventually, instability with too weak a system or too large a regulator gain.

The full completed model is shown below

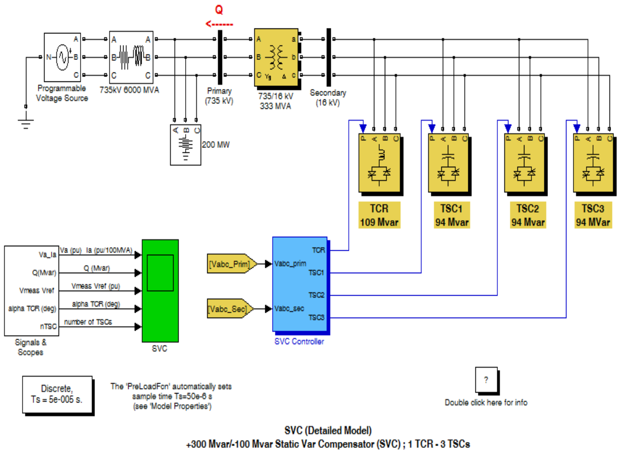


**Figure 7**: Circuit Description

A 300-Mvar Static Var Compensator (SVC) regulates voltage on a 6000-MVA 735-kV system. The SVC consists of a 735kV/16-kV 333-MVA coupling transformer, one 109-Mvar thyristor-controlled reactor bank (TCR) and three 94-Mvar thyristor-switched capacitor banks (TSC1 TSC2 TSC3) connected on the secondary side of the transformer. Switching the TSCs in and out allows a discrete variation of the secondary reactive power from zero to 282 Mvar capacitive (at 16 kV) by steps of 94 Mvar, whereas phase control of the TCR allows a continuous variation from zero to 109 Mvar inductive. Taking into account the leakage reactance of the transformer (15%), the SVC equivalent susceptance seen from the primary side can be varied continuously from from -1.04 pu/100 MVA (fully inductive) to +3.23 pu/100 Mvar (fully capacitive). The SVC controller monitors the primary voltage and sends appropriate pulses to the 24 thyristors (6 thyristors per three-phase bank) in order to obtain the susceptance required by the voltage regulator.

Each three-phase capacitor bank is connected in delta so that, during normal balanced operation, the zero-sequence tripplen harmonics (3rd, 9th...) remain trapped inside the delta, thus reducing harmonic injection into the power system. The power system is represented by an inductive equivalent (6000 MVA short circuit level) and a 200-MW load. The internal voltage of the equivalent can be varied by means of programmable source in order to observe the SVC dynamic response to changes in system voltage. The voltage source menu shows the sequence of voltage steps which are programmed. Running the simulation gives us the graph below, t is explained

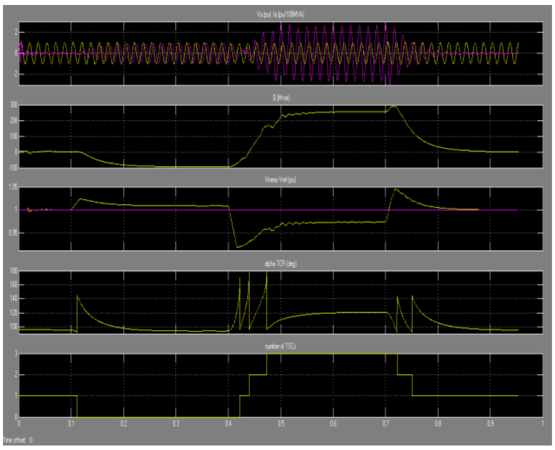

**Figure 8:** The output waveform response of the SVC when connected

The simulation was performed and the above waveforms was obtained on the SVC scope block.
The SVC is in voltage control mode and its reference voltage is set to Vref=1.0 pu. The voltage drop of the regulator is 0.01 pu/100 VA (0.03 pu/300MVA). Therefore, when the SVC operating point changes from fully capacitive (+300 Mvar) to fully inductive (-100 Mvar) the SVC voltage varies between 1-0.03=0.97 pu and 1+0.01=1.01 pu.

Initially the source voltage is set at 1.004 pu, resulting in a 1.0 pu voltage at SVC terminals when the SVC is out of service. As the reference voltage Vref is set to 1.0 pu, the SVC is initially floating (zero current). This operating point is obtained with TSC1 in service and TCR almost at full conduction (alpha=96 degrees).
At t=0.1s voltage is suddenly increased to 1.025 pu. The SVC reacts by absorbing reactive power (Q=-95 Mvar) in order to bring the voltage back to 1.01 pu. The 95% settling time is approximately 135 ms. At this point all TSCs are out of service and the TCR is almost at full conduction (alpha = 94 degrees).

At t=0.4 s, the source voltage is suddenly lowered to 0.93 pu. The SVC reacts by generating 256 Mvar of reactive power, thus increasing the voltage to 0.974 pu. At this point the three TSCs are in service and the TCR absorbs approximately 40% of its nominal reactive power (alpha =120 degrees). The TSCs are sequentially switched on and off. Each time a TSC is switched on the TCR alpha angle changes suddenly from 180 degrees (no conduction) to 90 degrees (full conduction).
Finally, at t=0.7 s the voltage is increased to 1.0 pu and the SVC reactive power is reduced to zero [3] [4].

## IV. SIMULATION AND RESULT ANALYSIS

A.New Haven Substation
There are 4 2-winding power transformers and load 9 feeders in the new haven 132/33 KV substation
TR1 – this is a transformer rated 30MVA. It supplies
- Kingsway line 1

TR2- this is a transformer rated 30MVA. It supplies
- Kingsway line 2

TR3- this transformer is rated 60 MVA. It supplies the following feeders
- Thinkers corner
- Ituku-Ozalla
- Trans-Ekulu

TR4 – this is a transformer rated 60MVA supplying
- Govt house
- Independence layout
- Emene industrial
- New NNPC

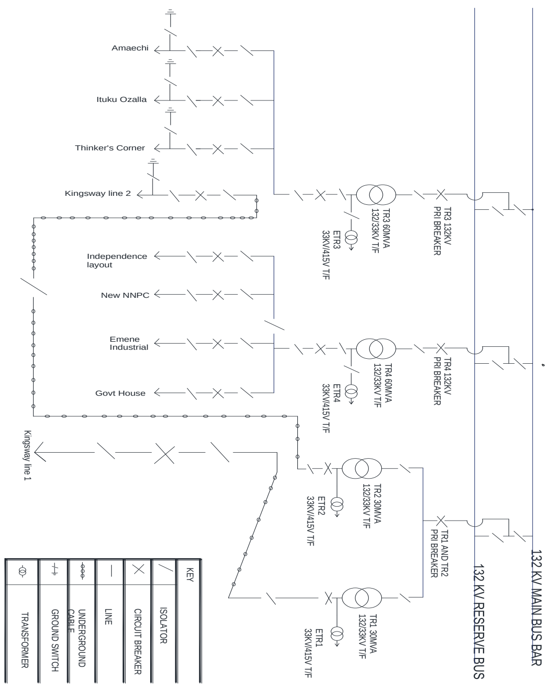


**Figure 9**: Enugu distribution circuit

To carry out load flow analysis, I made the following assumptions

- An external grid connected to the 132KV incoming bus bar is considered as then reference bus
- A nominal voltage of 33Kv at the bus bar of the receiving end
- The average temperature of the transmission line is taken to be 70 degrees Celsius
- Since the feeder length are low, they are neglected
- The system frequency is taken to be 50Hz
- The transformers have tap changers assumed to be in the neutral position
- The system is in steady state condition
- The marginal limit for voltage is 98% to 102%
- Critical limit for voltage is 95% to 105%

II. Simulation Data and Equipment Parameters

**Table 1:**New Haven Peak Load Data for April 2018

| | PEAK LOAD (MW) | PEAK LOAD (MVAR) |
|---|---|---|
| KINGSWAY LINE 1 | 13.4 | 6.5 |
| KINGSWAY LINE 2 | 16.4 | 7.9 |
| THINKERS CORNER | 15.6 | 7.5 |
| ITUKU OZALLA | 7.9 | 3.8 |
| TRANS EKULU | 6 | 2.9 |
| GOVT HOUSE | 5.5 | 2.7 |
| IND LAYOUT | 20 | 9.7 |
| EMENE INDUSTRIAL | 9.4 | 4.5 |
| NEW NNPC | 5.6 | 2.7 |

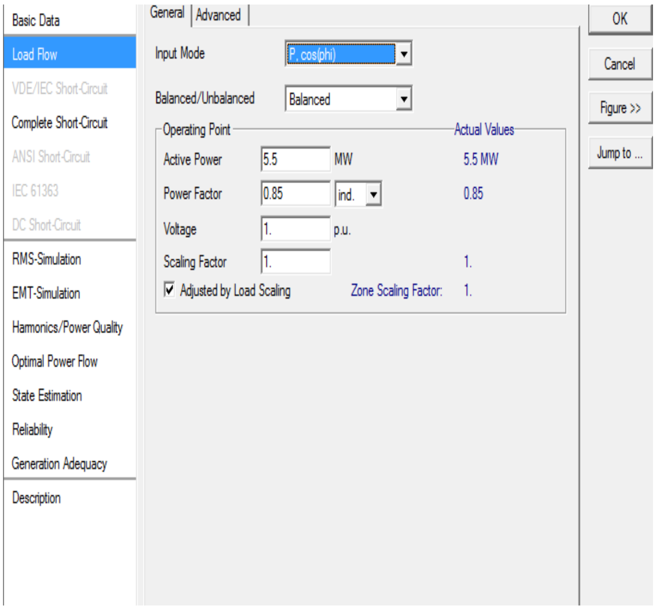


**Figure 10:** Load Parameters

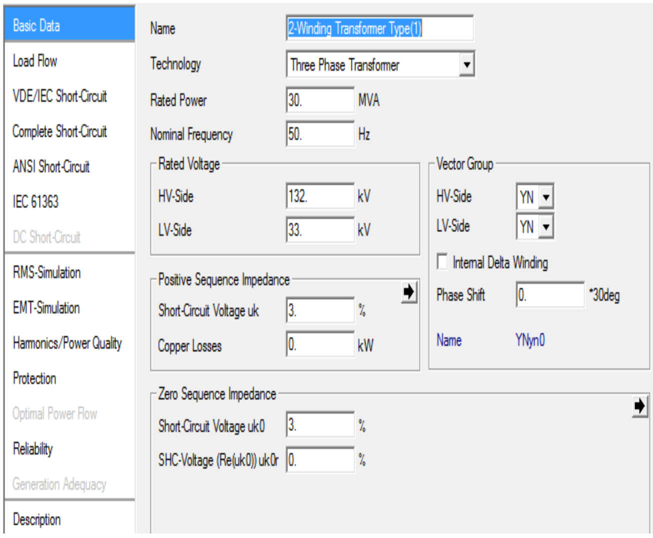


**Figure 11:** Transformer Data

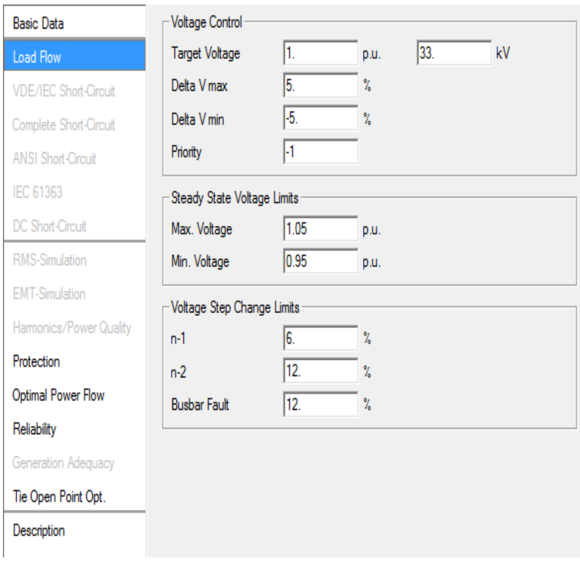


**Figure 12:** Bus Bar Data

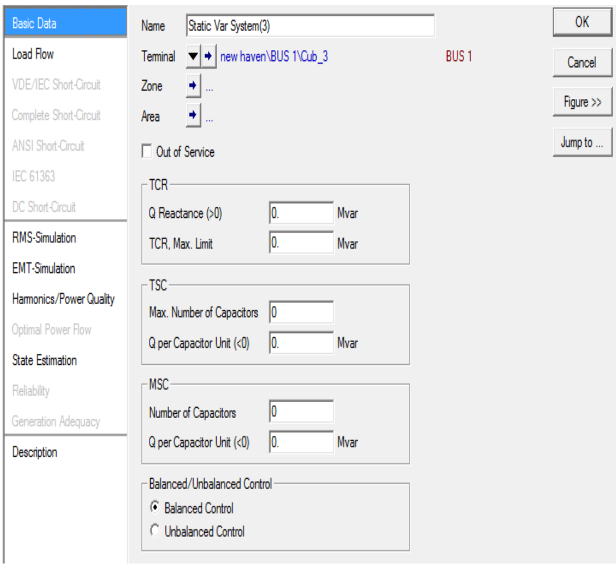


**Figure 13**: Static Var System Parameter

## V. LOAD FLOW SIMULATION AND RESULTS

A. Power-factory Load Flow of a Without Svc

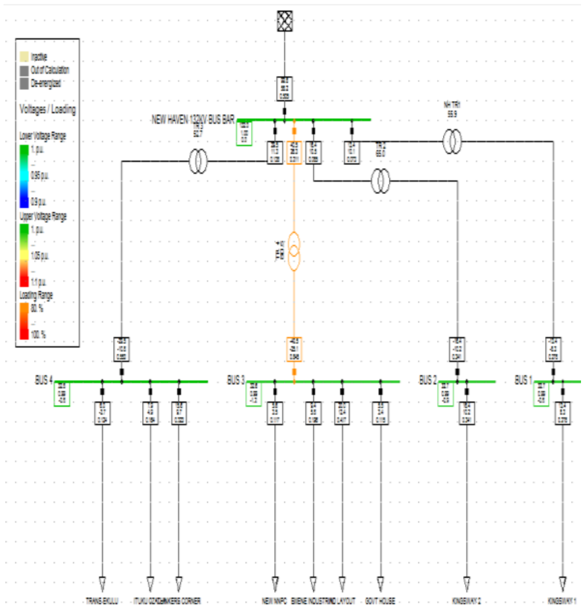


**Figure 14:**Figure Power-factory Load Flow of a without SVC

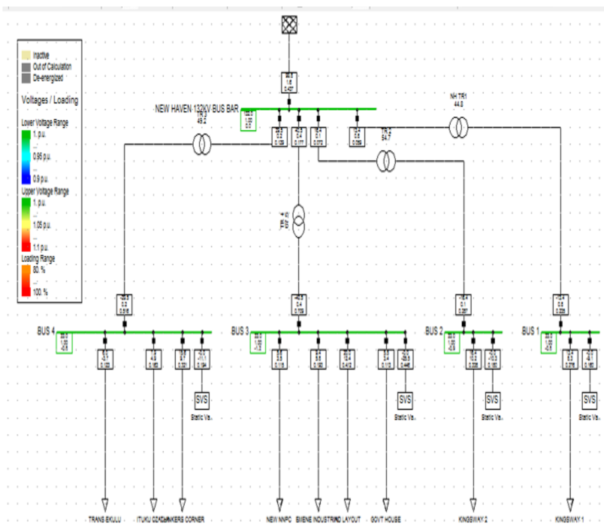


**Figure 15:** Power-factory Load Flow of a with SVC

**Table 2:** Load voltages with and without svc

| TRANSFORMER | LOADING WITHOUT SVC (%) | LOADING WITH SVC (%) |
|---|---|---|
| TR1 | 55.9 | 44.8 |
| TR2 | 65 | 54.7 |
| TR3 | 52.7 | 49.2 |
| TR4 | 80.5 | - |

**Table 3:** Recorded Bus Voltages, without svc and with svc

| BUS | BUS VOLTAGE FROM RECORDED VALUE(KV) | BUS VOLTAGE WITHOUT SVC WITH SIMULATION(KV) | BUS VOLTAGE WITH SVC WITH SIMULATION(KV) |
|---|---|---|---|
| 1 | 32.6 | 32.7 | 33.0 |
| 2 | 32.5 | 32.7 | 33.0 |
| 3 | 32.4 | 32.6 | 33.0 |
| 4 | 32.6 | 32.8 | 33.0 |

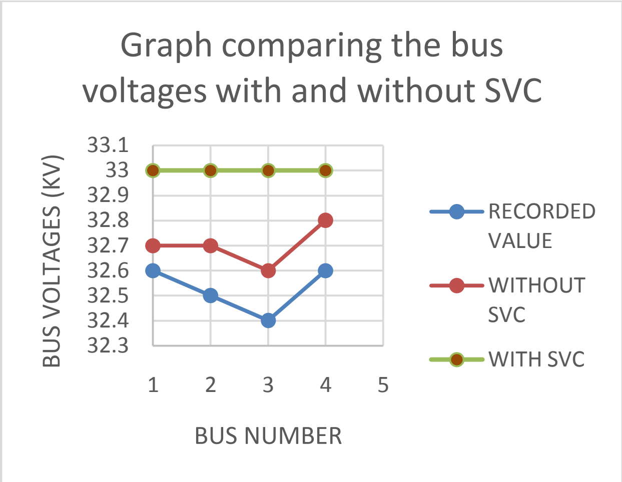


**Figure 16**: Graph comparing voltages with and without svc

**Table 4:**SVC data with respect to their various buses

| BUS | SVC DATA (MVAR) | SVC DATA (KA) |
|---|---|---|
| 1 | -9.1 | 0.16 |
| 2 | -10.3 | 0.18 |
| 3 | - | 0.194 |
| 4 | - | 0.446 |

Table of transformer loading with and without SVC

## VI. RESULT AND ANALYSIS

Load flow analysis have been carried out with the help of computer simulation for peak load conditions. In the computer simulation without SVC, it is observed that the voltages at the buses 1,2,3,4 are below unity.

When SVC were installed, at the buses, there is a compensation of the voltage profile to unity and it is thus enhanced.

The transformer loading was also reduced with the addition of the SVC [3] [5].

## VII. CONCLUSION

Considering tables 1 and 2 of the load voltage on the buses and transformer 1 to 4 respectively with and without svc, we hereby conclude that, there is a clear conviction that the installation of FACT devices on the New Haven transmission line compensates for the voltage reduction and percentage increase in transformer loading without the SVC.

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