

Active Power Loss Minimization and Bus Voltage Improvement with SVC Using Hybrid NR-PSO Technique

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ABSTRACT: This paper consists of Load flow, which is very important for any power system solution. A comprehensive study of the Newton- Raphson (NR) method of load flow analysis with and without Flexible AC Transmission System FACTS device is established. The major concerns of this paper is (1) Finding the sensitive buses, (2) Connect FACTS device (here we use Static VAR Compensator (SVC)) to those buses to minimize the losses of the system, (3) Make the voltage of those most sensitive buses constant irrespective of load on the respective buses, (4) Solve the nonlinear equation of finding firing angle of SVC to find the firing angle of the thyristors of SVC. Here sensitive buses are determined by "Load Changing Method". Optimal size of SVC is evaluated by Particle Swarm Optimization (PSO) Technique. PSO is also used to solve the nonlinear equation of finding firing angle of SVC for each optimal sizing of SVC. It is a hybrid method in which optimal value of SVC and firing angle are calculated using PSO method and load flow is done using NR method. All the programs have been implemented in MATLAB Software and the IEEE 30-bus systems have been used as case studies.

KEYWORDS: Newton-Raphson method of load flow, Flexible AC Transmission System (FACTS) device, Static VAR Compensator (SVC), Load Changing Method, Sensitive buses, Particle Swarm Optimization (PSO), IEEE 30-bus system.

I. INTRODUCTION

Today electric power plays a very important role in the life of the community and in the development of various sectors of economy. In fact the modern economy is totally dependent on the electricity. This in turn has led to increase in the number of power stations and their capacities and consequent increase in power transmission lines which connect the generating stations to the load centres. To meet the ever increasing demand it is now essential to maximize the utilization of the existing transmission system. Not only that, in transmission system it is desirable to maintain the receiving end voltage constant irrespective of load because most of the devices design to work on a constant supply voltage.

For this reason it is important to make some arrangement to the transmission system so that the losses of the transmission system get reduced as well as the voltage of the load end stay constant irrespective of load. FACTS controllers minimizes loss, enhance the voltage profile and the load ability of power systems. In this paper we use Static VAR Compensator (SVC) for several reasons. The most widely used shunt FACTS devices within power networks is the SVC due to its low cost and good performance in system enhancement. Another very important and challenging task to connect FACTS device is to find the appropriate location and the size of the FACTS. To find the most sensitive buses in the transmission system, "load changing method" is used where the given load of the test data is increased by 2%, 4%, 6%.....50% for each bus to find the variations of respective bus voltage. Here to find the most suitable size of the SVC we use Particle Swarm Optimization (PSO) technique. PSO is also used to solve the nonlinear equations to find the firing angle of SVC.

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II. RELATED WORK

To successfully implement the project it is very important to understand the concepts of each and every part of the systems. All the sources i.e. a number of books and papers were referred to undertake this projects. The book at ref [1] by D.P.Kothari & J.S.Dhillon explains the main formulation part. Here total concept of Economic Load Dispatch i.e from making of admittance matrix to exact loss formula, all have discussed in details. A basic idea as well as the algorithm for Newton-Raphson method is discussed. The whole idea of Newton-Raphson load flow analysis method is taken from the paper at ref [2] by Aditya Sharma, Manyu Saini and MdIrfan Ahmed. A comparative study between various FACTS devices are discussed in paper at ref [3] by Pavlos S. Georgilakis and Peter G. Vernados. It helps to choose SVC over other FACTS devices because of its simple construction and fast and accurate response. The firing angle concept of SVC is very important to understand for achieving the proposed goal in our project. For this a paper at ref [4] by A.Hema Sekhar & Dr.A.Lakshmi Devi, is referred. It describe the relations between firing angle and the other parameters which helps to generate the fitness functions for PSO to find out the firing angle of SVC for every sizing of it. Another paper at ref [5] by H. Amhriz-PBrez, E. Acha, and C. R. Fuerte-Esquivel, used to understand the firing angle model of SVC. The idea of "Load Changing method" of finding sensitive bus is taken from the paper at ref [6] by Pushpendra Mishra, H. N. Udupa, Piyush Ghune. As discussed before it is a hybrid project where NR method and PSO both are used to serve their purpose, a proper idea of PSO and how it works is required to understand. Ref [7] by Manjun Cai, Xuejian Zhang, Guangjun Tian, and Jincun Liu. The said paper describes the concept of PSO in very simple way. Though few changes are made to simplify the algorithms, the basic concept of PSO is taken from this paper only. All the concept of semiconductor devices used in FACTS devices are discuss in a great extend in the book at ref [8] by Muhammad H. Rashid. All the information about IEEE 30 bus system is collected from the paper at ref [9] by Dharamjit, D.K.Tanti. Ref [10] by Ahmed A. A. Esmin and Germano Lambert-Torres helps to understand the application of PSO in Power System. This paper described the use of PSO for solving the optimal distribution system reconfiguration problem for power loss minimization. In paper at ref [11] by LakshyaBhat, Anubhav Shrivastava and Shivarudraswamy, 3 method of finding sensitive buses is described and also the importance of finding the sensitive buses are stated. An idea of various FACTS devices are also taken from the paper at ref [12] by S. K. Srivastava, S. N. Singh and K. G. Upadhyay. This paper helps to understand there control features and difference of SVC from others.

III. PROPOSED METHODOLOGY AND DISCUSSION:

NEWTON-RAPHSON METHOD OF LOAD FLOW: This method was named after Isaac Newton and Joseph Raphson. The origin and formulation of Newton-Raphson method was dated back to late 1960s. It is an iterative method which approximates a set of non-linear simultaneous equations to a set of linear simultaneous equations using Taylor's series expansion and the terms are limited to the first approximation.

Load Flow equations constitute a set of non-linear algebraic equations in terms of $|V|$ in per unit and δ in radians as shown below,

$$P_i = |V_i| \sum_{k=1}^{NB} |V_k| [G_{ik} \cos(\delta_i - \delta_k) + B_{ik} \sin(\delta_i - \delta_k)] \quad (i = 1, 2, \dots, NB) \dots (1)$$

$$Q_i = |V_i| \sum_{k=1}^{NB} |V_k| [G_{ik} \sin(\delta_i - \delta_k) - B_{ik} \cos(\delta_i - \delta_k)] \quad (i = 1, 2, \dots, NB) \dots (2)$$

Where

P_i is the real power, Q_i is the reactive power, NB is number of total buses, V_i is the voltage of the i^{th} bus, $|V_i|$ is the magnitude of the voltage, δ_i is the angle of the voltage, G_{ik} is the real part of Y_{ik} ,

B_{ik} is the imaginary part of Y_{ik} , Y_{ik} is the element of the admittance bus.

These equations are expanded in Taylor's series about the initial estimate and neglecting all higher order terms, the following set of linear equations are obtained.

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$$\begin{bmatrix} H & N \\ J & L \end{bmatrix} \begin{bmatrix} \Delta\delta \\ \frac{\Delta V}{V} \end{bmatrix} = \begin{bmatrix} \Delta P \\ \Delta Q \end{bmatrix} \dots\dots\dots (3)$$

Size of the matrix = NB+ (NB-(NV+1))-1 = 2(NB-1)-NV

Where

$$H_{ik} = \frac{\partial P_i}{\partial \delta_k}, \quad N_{ik} = V_k \frac{\partial P_i}{\partial V_k}, \quad J_{ik} = \frac{\partial Q_i}{\partial \delta_k}, \quad L_{ik} = V_k \frac{\partial Q_i}{\partial V_k}$$

The new estimates for bus voltage are

$$\delta_i = \hat{\delta}_i + \Delta\delta_i \quad (i = 2, 3, \dots, NB) \dots\dots\dots (4)$$

$$V_i = \hat{V}_i + \frac{\Delta V_i}{V_i} V_i \quad (i = PQ \text{ buses number}) \dots\dots\dots (5)$$

After some iteration we get the Newton-Raphson result of Bus Voltages (V_i) and angle of the voltages (δ_i). The power loss in the line between the bus i and k is the sum of the power flows in the line from i^{th} bus and from k^{th} bus, respectively, i.e.

$$S_l = S_{ik} + S_{ki}$$

Where

l indicates the line numbers, S_{ik} is the power flows from bus no. i to bus no. k , S_{ki} is the power flows from bus no. k to bus no. i

The total transmission active power losses can be computed by summing all the line flows of the power system, i.e.

$$P_{Loss} = Re \left(\sum_{l=1}^{NL} S_l \right) \dots\dots\dots (6)$$

Where

NL is number of line

FLEXIBLE AC TRANSMISSION SYSTEM (FACTS) DEVICE: The FACTS is a concept based on power-electronic controllers, which enhance the value of transmission networks by increasing the use of their capacity. As these controllers operate very fast, they enlarge the safe operating limits of a transmission system without risking stability. FACTS can be categorized as Series Compensator and Shunt Compensator. SVC is one of the widely used Shunt Compensator and the construction and operations are discussed below.

STATIC VAR COMPENSATOR (SVC): A static var compensator (SVC) is the first generation shunt compensator. A typical SVC consists of Thyristor Controlled Reactor (TCR) and Thyristor Switched Capacitor (TSCs) or a fixed Capacitor in parallel. The output of the compensator is controlled in steps by sequentially switching of TCRs and TSCs. Figure (1) shows the basic firing angle model of SVC.

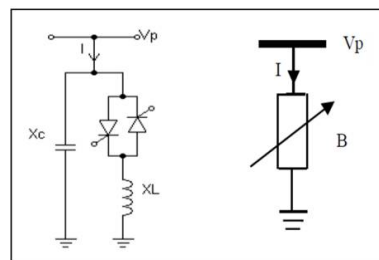


Figure 1: Basic model of SVC

From the model of SVC it is shown that a TCR and a fixed capacitor is connected parallel to each other where the susceptance (B_{TCR}) of the TCR is a function of thyristor firing angle (α).

$$X_{TCR} = \frac{1}{B_{TCR}} = X_L \frac{\pi}{2(\pi - \alpha) + \sin(2\alpha)} \dots\dots\dots (7)$$

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Or,

$$B_{TCR} = B_L \frac{2(\pi - \alpha) + \sin(2\alpha)}{\pi} \dots\dots\dots (8)$$

Where

X_L is the reactance (in per unit system) value of inductor connected to TCR

B_L is the susceptance (in per unit system) value of inductor

X_{TSR} is the value of reactance (in per unit system) of the TCR

B_{TCR} is the susceptance (in per unit system) value of the TCR

α is the firing angle (red) of thyristors connected in TCR

The SVC equivalent susceptance (B_{SVC}) can be determined by parallel operation of TCR with fixed capacitor as

$$B_{SVC} = B_C - B_{TCR} = B_C - B_L \frac{2(\pi - \alpha) + \sin(2\alpha)}{\pi} \dots\dots\dots (9)$$

Where

B_{SVC} is the SVC equivalent susceptance (in per unit system)

B_C is the susceptance (in per unit system) value of the fixed capacitor

After rearranging equation (9) we get

$$\sin(2\alpha) - 2\alpha = \frac{(B_C - B_{SVC})\pi}{B_L} - 2\pi \dots\dots\dots (10)$$

Equation (10) is a non-linear equation. To find the value of α we use Particle Swarm Optimization (PSO) for solving of the equation.

Here we use a SVC which has $B_L= 0.1pu$ and $B_C=0.06pu$

LOAD CHANGING METHOD, SENSITIVE BUSES: A bus is said to be a sensitive bus if its voltage is heavily fluctuate with load connected to that bus so sensitive bus is the one which is mostly suffered by the changes in load demands. Here Load Changing Method is used to find the sensitivity index. It is a very simple method where test system load data of each bus is increased one by one by 2%, 4%, 6%, 8%, 10%, 12% 50% and then we have compared all the results with the original power flow results of the test bus system for finding the sensitive buses.

PARTICLE SWARM OPTIMIZATION (PSO): Particle Swarm Optimization (PSO) algorithm originally is developed by Kennedy and Eberhart based on the social behaviors of animal swarms (e.g. bird blocks and fish schools). Due to the fact that PSO is a very easy, fast and powerful optimization technique, it is used for the solving of various optimization problems in electrical engineering. Here to find the most suitable size of the FACTS device we use PSO technique. PSO is also used to solve the nonlinear equations to find the firing angle of SVC. PSO is initialized by a population of random solutions with random velocities. The potential solutions, called particles, are then flows through the problem space. Each particle keeps track of its coordinates in the problem space, which are associated with the best solution or fitness achieved so far. The fitness value is also stored. This value is called *pbest*. Another 'best' value that is tracked by the global version of the particle swarm optimizer Is the overall best value, and its location, obtained so far by any particle in the population. The value is termed *gbest*. Thus at each time step, the particle changes its velocity and moves towards its *pbest* and *gbest*. At each iteration, new search points are generated from the current search points using the following equations

$$w^{k+1} = w^k * 0.99 \dots\dots\dots (11)$$

$$V_i^{k+1} = w^{k+1}.V_i^k + c_1.rand().(pbest_i^k - x_i^k) + c_2.rand().(gbest_i^k - x_i^k) \dots\dots\dots (12)$$

$$x_i^{k+1} = x_i^k + V_i^{k+1} \dots\dots\dots (13)$$

Where

$c1$ and $c2$ are the learning factors, $rand()$ is the random numbers between 0 and 1

w is inertia weight, V_i is the particle velocity, k is the iteration number

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The pbest and gbest value are updated after every iteration this processes is repeated until the convergence is obtained. For applying PSO an objective function is required to be defined. Here we apply PSO on three different objective functions to fulfill three different objects.

To find the optimal size of SVC connected to sensitive buses for improving voltage profile as well as minimizing the active power loss, total active power loss equation (equation (6)) is used as minimal objective function.

To find the optimal size of SVC connected to sensitive buses for different values of load connected to the respective buses, the below equation is used as minimal objective function.

$$Function = abs(V_{change}) \dots\dots\dots (14)$$

$$V_{change} = V - V^p \dots\dots\dots (15)$$

Where

V is the value of bus voltage when respective bus load is kept as test data

V^p is the value of bus voltage when respective bus load is increase p% of test data

To solve the non-linear equation of finding firing angle of SVC to find the firing angle of the thyristor for each sizing of SVC, a modified version of equation (10) is used as minimal objective function as shown below

$$Function = abs\left(\sin(2\alpha) - 2\alpha - \left(\frac{(B_c - B_{SVC})\pi}{B_L} - 2\pi\right)\right) \dots\dots\dots (16)$$

Table 1: The parameters of PSO we used here is

Population Size	50
Inertial Weight, w	1
Learning Factor (1), C1	1
Learning Factor (2), C2	1
Maximum number of iteration	100

IV. RESULTS AND OBSERVATION

The proposed system is applied in IEEE 30 bus systems by using MATLAB software. Newton Raphson result of voltage profile of the system with given test data is shown in figure (2)

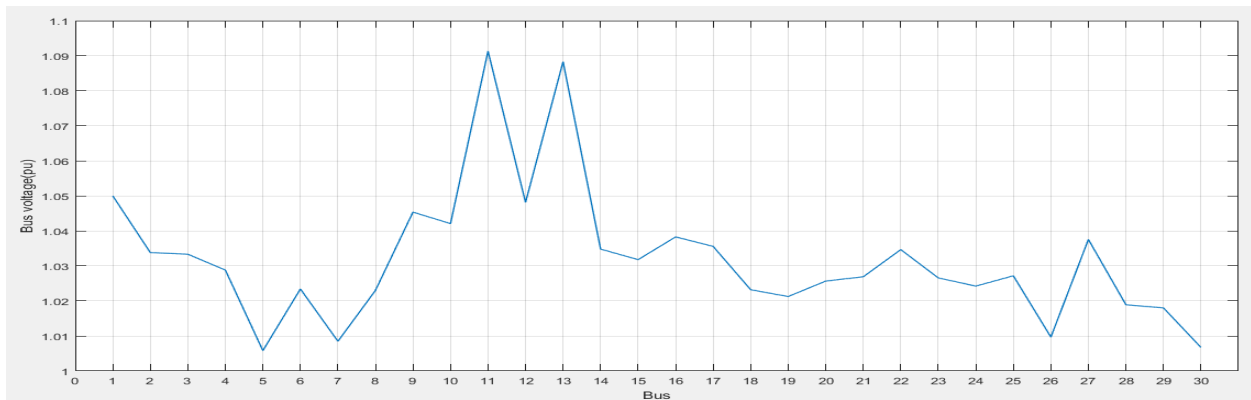


Figure 2: NR result of voltage profile of IEEE30 bus system with given test data

After obtaining the power flow results at each percentage change in load as said earlier we obtained voltage profile at each change and find the sensitive buses according to their change in voltage with load.

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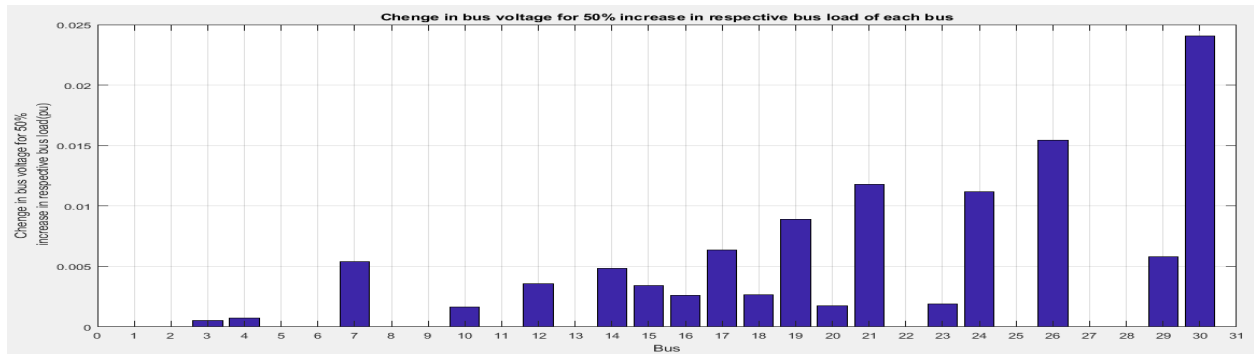


Figure 3: Sensitivity index with "Load Changing Method"

From above bar graph it is clear that 30th bus is the most sensitive bus and 26th bus is the second most sensitive bus in this system. A single SVC is connected to the 30th bus to minimize the active power losses and to improve the voltage profile and then another SVC is connected to 26th bus along with the one connected to 30th bus and observed the same as before with single SVC. The voltage profile for each case is shown in figure (4) for comparative study,

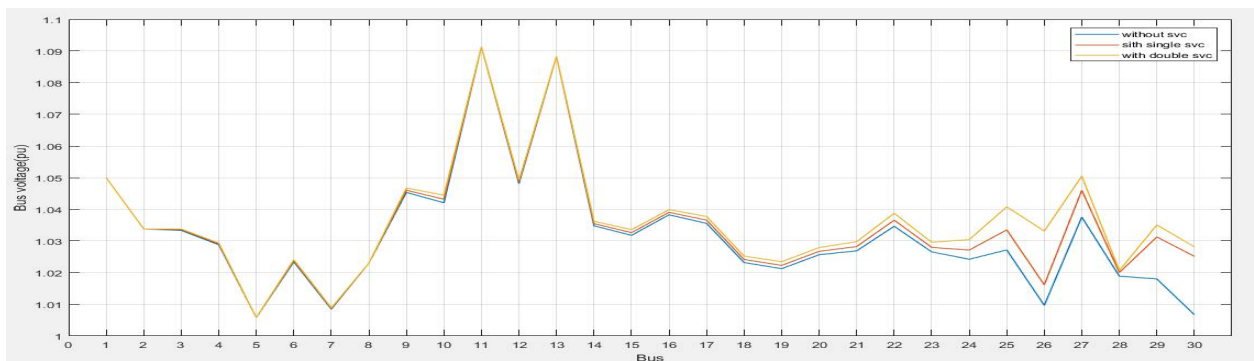


Figure 4: Voltage profile of IEEE30 bus system with and without SVC connected

From this figure (4) it is clear that the voltage profile is improved with double SVC as compared to single SVC and without SVC.

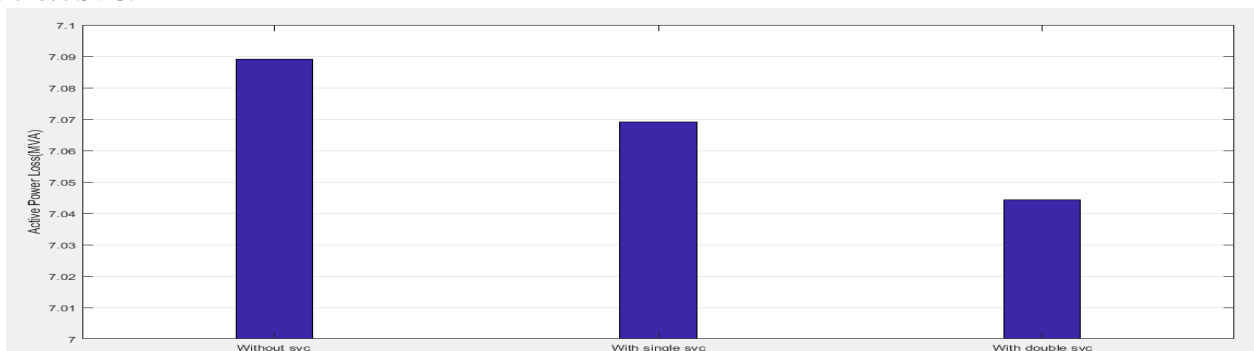


Figure 5: Comparative study of active power loss with and without SVC

This bar diagram indicates the active power loss is also minimized with double SVC connected to the system. The optimal value of SVC size for which the active power loss is minimized is obtained by PSO technique. Also the non-linear equations of finding firing angle of the thyristors of SVC are solved by PSO technique to find the firing

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angle of each sizing of SVC.

Parameters	Without SVC	With single SVC	With double SVC
Location of SVC	--	30 th bus (SVC1)	30 th bus (SVC1) 26 th bus (SVC2)
Susceptance value of SVC1 (pu)	--	0.0264	0.0219
Susceptance value of SVC2 (pu)	--	--	0.0242
Firing angle of SVC 1 (degree)	--	123.3978	120.5981
Firing angle of SVC 2 (degree)	--	--	122.0229
Real Power Loss (MW)	7.0892	7.0691	7.0443

Table 2: Comparative study of system parameters of IEEE 30 bus with and without SVC

After improving the voltage profile and minimizing the active power loss of the system our next object was to maintain the voltage of 30th and 26th buses fixed, irrespective of change in load of respective buses. By changing the susceptance value of SVC with the help of PSO we achieve that goal.

30th bus operation

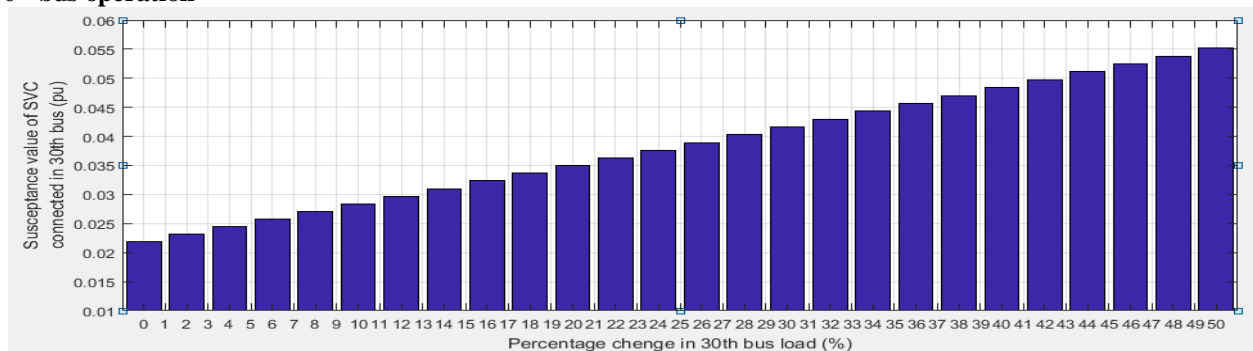


Figure 6: Susceptance value of SVC to maintain voltage constant with variable load in 30th bus

At every 2% increase in given load at 30th bus the susceptance value of SVC get increased to maintain the voltage of 30th bus constant as shown in figure (6). Initially the susceptance value was 0.0219pu to minimise the active power loss as shown before.

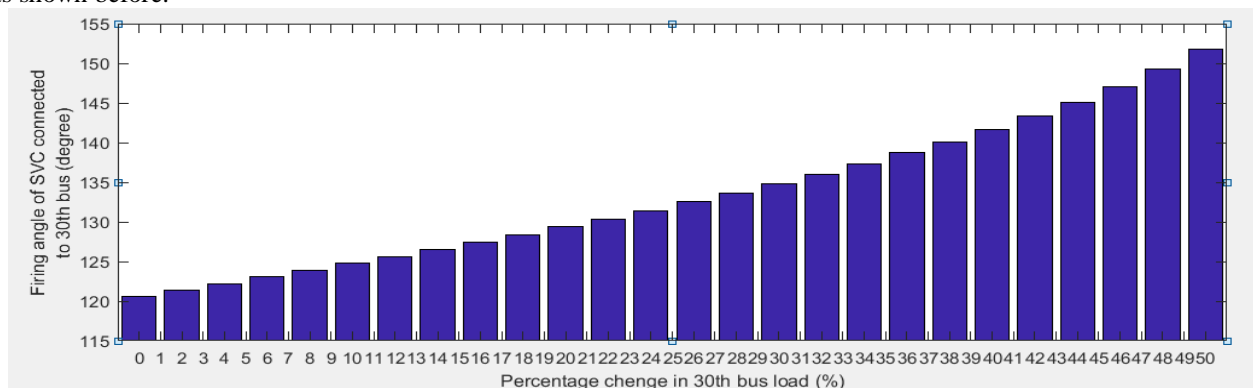


Figure 7: Firing angle of SVC to maintain voltage constant with variable load in 30th bus

To change the susceptance value of SVC, the firing angle of thyristor must also change. The firing angle with respect to percentage change of load at 30th bus is shown in figure (7).

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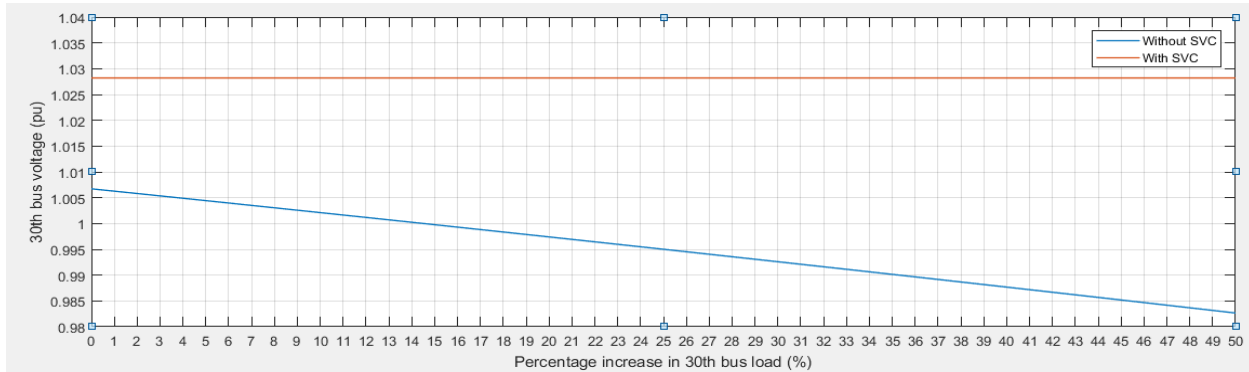


Figure 8: Change in voltage with and without SVC with variable load in 30th bus

Bus no. 30 was the most sensitive bus as stated before and the voltage waveform with respect to percentage increase in load is shown in figure (8) (blue line) and the voltage profile after connecting the SVC is shown in figure (8) (red line). From the figure (8) it can easily be observed that the voltage variation is eliminated by SVC and bus no. 30 is no longer a sensitive bus.

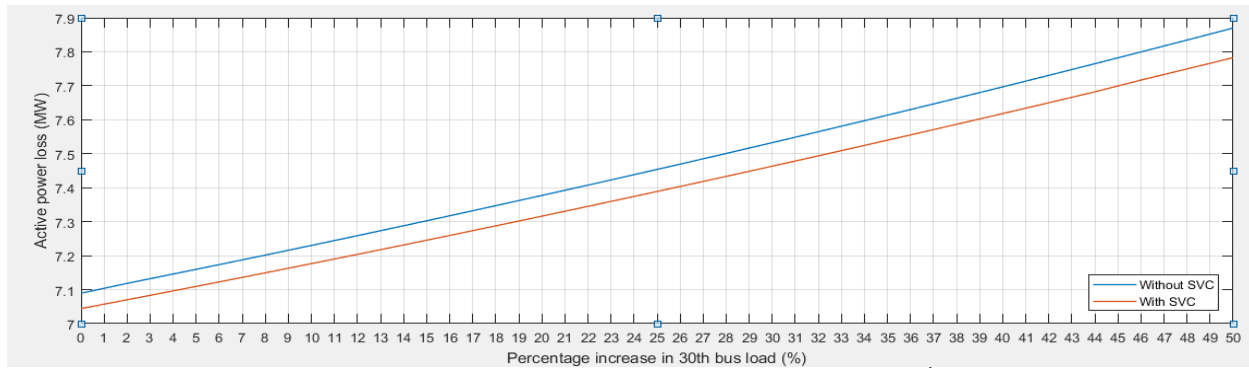


Figure 9: Active power loss with and without SVC with variable load in 30th bus

Active power loss minimization is one of the main concerns of this paper. Figure (9) shows a comparative study of active power loss of the system with and without SVC connected at 30th bus. It is easily observed that the active power loss is reduced by connecting the SVC.

26th bus operation

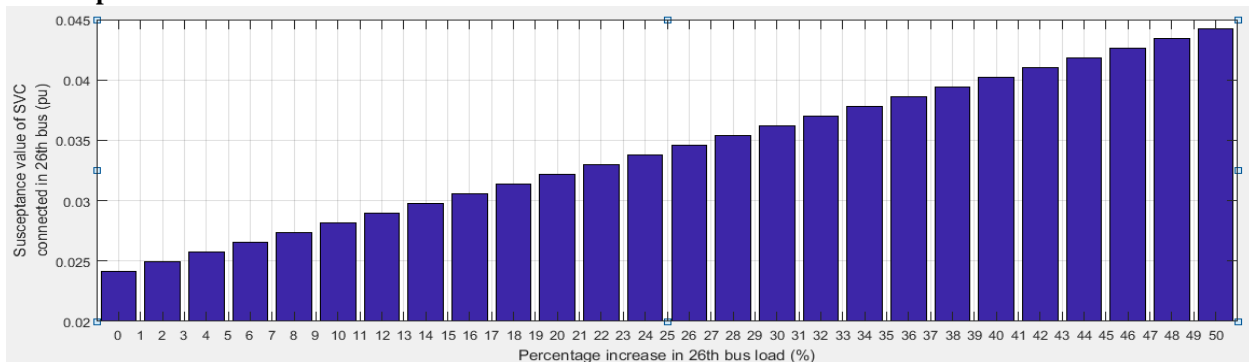


Figure 10: Susceptance value of SVC to maintain voltage constant with variable load in 26th bus

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At every 2% increase in given load at 26th bus the susceptance value of SVC get increased to maintain the voltage of 26th bus constant as shown in figure (10). Initially the susceptance value was 0.0242pu to minimise the active power loss as shown before.

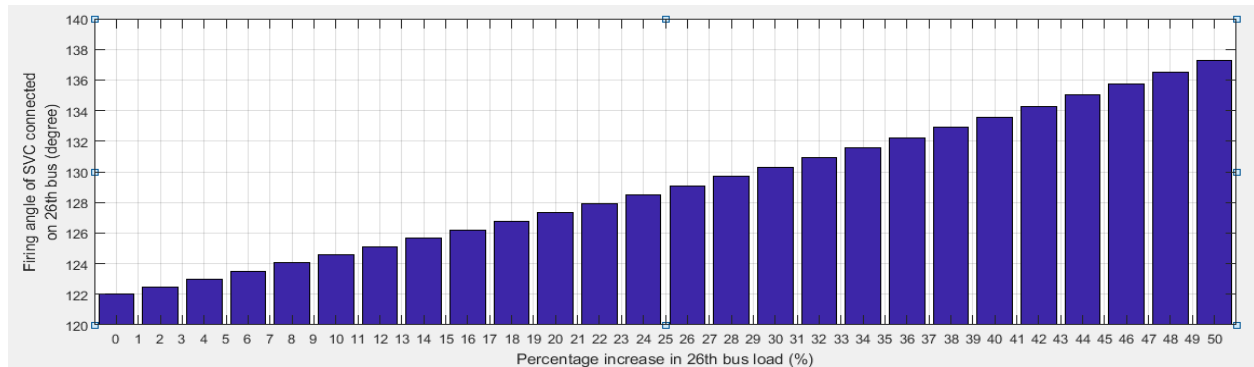


Figure 11: Firing angle of SVC to maintain voltage constant with variable load in 26th bus

To change the susceptance value of SVC, the firing angle of thyristor must also change. The firing angle with respect to percentage change of load at 26th bus is shown in figure (11).

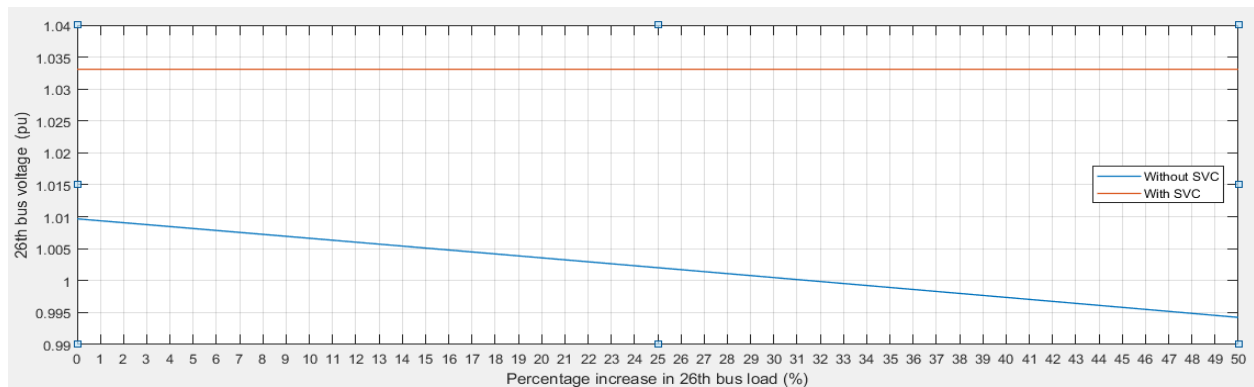


Figure 12: Change in voltage with and without SVC with variable load in 26th bus

Bus no. 26 was the second most sensitive bus as stated before and the voltage waveform with respect to percentage increase in load is shown in figure (12) (blue line) and the voltage profile after connecting the SVC is shown in figure (12) (red line). From the figure (12) it can easily be observed that the voltage variation is eliminated by SVC and bus no. 26 is also no longer a sensitive bus.

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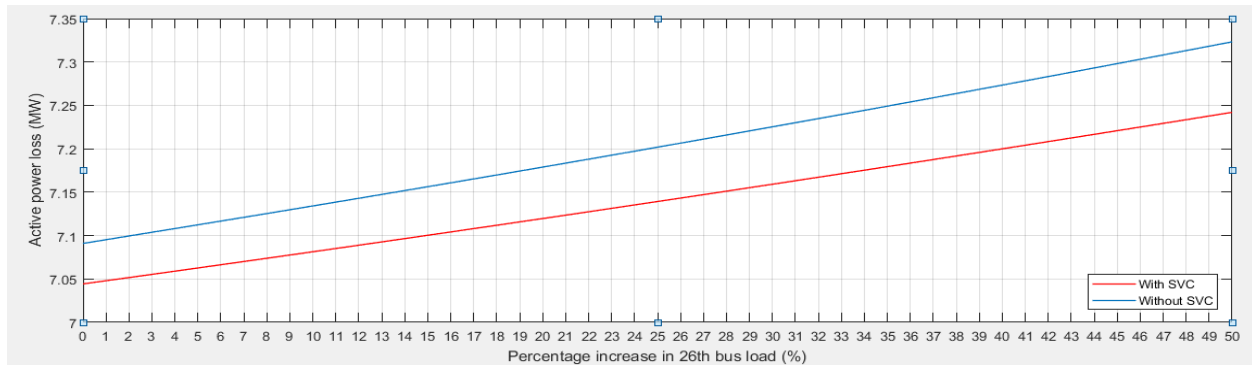


Figure 13: Active power loss with and without SVC with variable load in 26th bus

Figure (13) shows a comparative study of active power loss of the system with and without SVC connected at 26th bus. It is easily observed that the active power loss is reduced by connecting the SVC.

V. CONCLUSION

From figure (3), it is clear that 30th bus is mostly suffered due to the change in load demand followed by bus no 26th so necessary action is taken to maintain the bus voltages constant. Here we use two SVC's on each buses. We utilize the SVC's not only to make the voltage constant we use this to minimize the losses of the overall system as shown in figure (5). Figure (8) & (12) shows that the SVC's maintain the voltage constant. Figure (6) & (10) shows the respective SVC susceptance required to maintain the voltage constant. Figure (7) & (11) are the respective firing angle of SVC's. Figure (9) & (13) shows how the losses get reduced due to the SVC's.

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