ANN Based SVC FACTS Controller to Enhance Voltage Stability of Multi-Machine Power System

M.Suman, M.Venu Gopala Rao, P.V.Ramana Rao

Abstract: Voltage stability is the most vital phenomena in power systems which may be disturbed by the mismatch between the reactive power supply and demand. The occurrence of internal faults in the equipment and short circuit faults also there may be voltage collapse at the buses. Voltage stability can be improved using Static VAR Compensator (SVC) which is a shunt device. It can generate or absorb reactive power in a controlled manner such that it can enhance voltage stability of the system. L-Index method is used to determine voltage sensitivity at each bus and the bus having highest L- index value can be considered as a weak bus which is the optimal location of FACTS controller. The investigation is made to observe how susceptance in susceptance model and firing angle in firing angle model of the SVC is predicted to enhance the voltage at each bus by the artificial neural network under chaotic load. Standard IEEE 5 bus and 30 bus systems are considered as test systems and simulations are performed in MATLAB software.

Index Terms: Voltage Stability, Reactive Power control, L-Index method, Static VAR Compensator, Artificial Neural Network.

I. INTRODUCTION

Voltage instability is the major bottleneck in a modern power system that it is been a challenging issue for power system engineers for so many decades. Voltage instability leads to Voltage collapse which may in turn lead to collapse of the power system. Voltage collapse may be mainly because of the overloading of system which is highly undesirable in power systems. The primary reason for Variation in voltage is an imbalance between reactive power generation and consumption. FACTS devices facilitate a powerful solution to avert Voltage instability and voltage collapse due to their flexible and fast control. These compensators are designed with power electronic devices which are mainly used to improve the power handling capacity of the transmission lines. SVC is the combination of Thyristor Control Reactor (TCR) and Thyristor Switched Capacitor (TSC). SVC can effectively generate or absorb reactive power in a controlled manner.

In [1] different problems of voltage stability discussed and how to improve the stability described. [2] Deals with the different FACTS controllers and the improvement of the loadability limits of transmission lines. The voltage stability Index and how to determine [3] weak bus using the voltage stability index. [4] Discussed the power flow analysis and Newton Raphson power flow algorithm. [5] Presents different models of SVC and incorporating in power system. Describes the voltage stability index [6][7] and Simplified Voltage stability index. Different voltage sensitivity indices are discussed in [8]. Deals the susceptance model [9] and firing angle model [10] of SVC FACTS controller and how these models are incorporated in power system. In it was clearly given about optimal siting of FACTS controller [11][12] and also gives how different FACTS controllers to improve the voltage profile[13][14] using reactive power control.

If a right location is selected a single SVC can control voltage stability of all buses. One of the voltage stability indices L- index method is adapted to find out the critical or weak bus. If the load at the critical bus is increased beyond the rated level, then there will voltage drop at all the buses which should be compensated SVC FACTS controller. The Effectiveness of SVC Facts controller is observed using susceptance and firing angle models with increased load condition. The neural networks are designed to predict the parameters of the susceptance and firing angle models and power loss is observed with and without the SVC FACTS controller.

II. POWER FLOW SOLUTION

Load flow equations are useful for finding the best operation of existing power system and also an extension of the existing power system in a more economical way. Continuous monitoring of the power system can be possible by knowing the status of the system time to time. The unknown parameters at the buses thereby load flow of the lines and losses can be determined. Newton Raphson (NR) load flow is just like solving a set of nonlinear equations. The NR load flow method is having quadratic convergence characteristics so that it is superior to other load flow methods. This method is a more efficient method for large and complex power systems. It needs minimum number of iterations to reach convergence and the number of iterations is not depends on the size of the system. The NR load flow is run with and without the SVC FACTS controller and the performance of system will be analyzed.

III. DETERMINATION OF L-INDEX

L-index method is used to determine weak or critical bus. The bus having heighest L-index value can be consider as weak bus. Weak or critical bus is nothing but which bus effects first whenever there is a disturbance in the system. At load bus only this index can be determind as given in eqution.1

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$$L_k = |L_k| = \left| 1 - \frac{\sum_{j=1}^{N_G} C_{jk} V_j}{V_k} \right| \quad (1)$$

Number of generators is represented with NG, complex bus voltages at generator and load is given as Vj and Vk. Cjk is calculated using the equation.2

$$[C] = -[Y_{LL}]^{-1}[Y_{LG}] \quad (2)$$

Sub matrices of Y_{BUS} matrix are [Y_{LL}] and [Y_{LG}] and it can be found using

$$\begin{bmatrix} I_L \\ I_G \end{bmatrix} = \begin{bmatrix} Y_{LL} & Y_{LG} \\ Y_{GL} & Y_{GG} \end{bmatrix} \begin{bmatrix} V_L \\ V_G \end{bmatrix} \quad (3)$$

The value of L is varied from 0 to 1 and the load bus having highest value of L will be the critical bus.

IV. MATHEMATICAL MODELLING OF SVC

SVC is the combination of both TCR and TSC. Each controller can provide controllable generation and absorption of reactive power as required. SVC can absorb or generate reactive power in a controlled manner. The diagram of SVC and its voltage and current characteristics are as shown Figure 1&2.

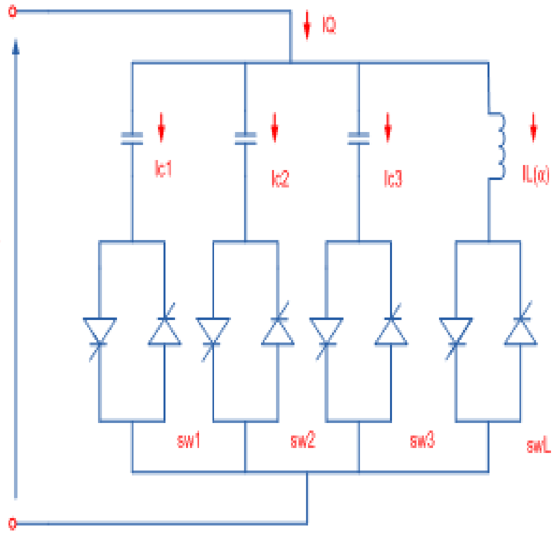

Figure1: SVC FACTS controller

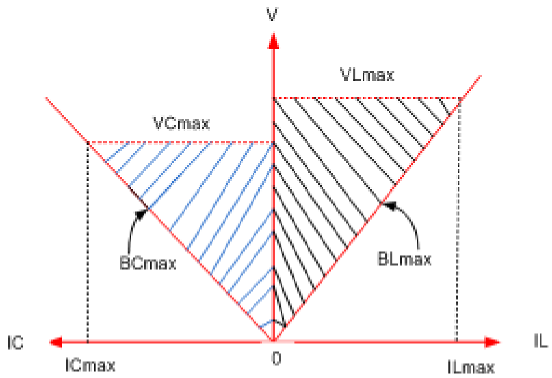

Figure 2: Volt-Amp characteristics of SVC controller

The SVC can be mathematically modeled in two ways

A. Susceptance Model

The SVC is equivalent to variable reactance with reactance or firing angle limits. The current received by the compensator is given as

$$i_{SVC}^{\cdot} = j^{\cdot} * b_{SVC} * v_k \quad (4)$$

The reactive power delivered at bus k supported by SVC is given as

$$q_{SVC}^{\cdot} = q_k^{\cdot} = -v_k^2 * b_{SVC} \quad (5)$$

The linearized equation is given by the following equation

$$\begin{bmatrix} \Delta P_k^{\cdot} \\ \Delta Q_k^{\cdot} \end{bmatrix}^{(i)} = \begin{bmatrix} 0^{\cdot} & 0 \\ 0^{\cdot} & q_k \end{bmatrix}^{(i)} \begin{bmatrix} \Delta\theta_k \\ \Delta b_{SVC} / b_{SVC} \end{bmatrix}^{(i)} \quad (6)$$

Whenever there is a change in bus voltage, the susceptance is changed until the bus voltage brings back to 1 p.u.

B. Firing Angle model

This model circumvents additional iterations where the firing angle α of the thyristors is varied until the voltage comes to 1 p.u after a disturbance. In firing angle method B_{SVC} is given by

$$i_{SVC} = j * b_{SVC} * v_k \quad (7)$$

$$b_{SVC} = b_C - b_{TCR} = -\frac{1}{x_C * x_L}\{x_L - \frac{x_C}{\Pi} * [2*(\Pi - \alpha) + \sin 2\alpha]\}$$

$$x_L = \omega * L$$

$$x_C = \frac{1}{\omega * C} \quad (8)$$

$$q_k = -\frac{v_k^2}{x_C * x_L}\{x_L - \frac{x_C}{\Pi} * [2*(\Pi - \alpha) + \sin 2\alpha]\} \quad (9)$$

From equation (9), the linearised SVC equation can be written as

$$\begin{bmatrix} \Delta p_k \\ \Delta q_k \end{bmatrix} = \begin{bmatrix} 0 & 0 \\ 0 & \frac{2 * v^2}{\Pi * x_L}[\cos(2\alpha) - 1] \end{bmatrix} \begin{bmatrix} \Delta\theta_k \\ \Delta\alpha \end{bmatrix} \quad (10)$$

V. VDESIGN OF ARTIFICIAL NEURAL NETWORKS

ANNs are mainly designed to mimic the biological neural networks. The popular architectures of ANN [15] are single layer, multi-layer and recurrent neural networks. Back propagation algorithm is used to train the multilayer feed forward neural networks. It uses the gradient descent method to get the optimized weights. The squared error is calculated using actual and targeted outputs. The randomly generated weights will be adjusted until squared error is minimized below 0.0001and the actual output is approximately equal to the targeted output. The weights are adjusted using the generalised delta learning rule or back propagation rule. The diagram of the back propagation neural networks as given

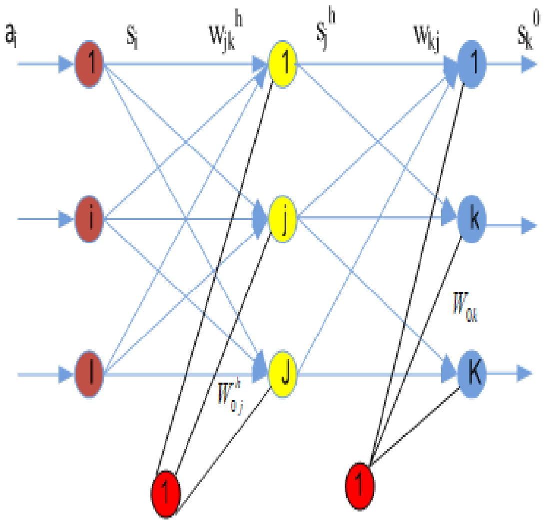

Figure.3 Multi-layer ANN

The Figure.3 is Feed forward neural network with three layers such as input, hidden and output layers which contain the I, J and K number of neurons respectively. The algorithm of the Back propagation neural network is as given below

Step1. Supply the number of input and target patterns a and b.

Step2. Consider single hidden layer having J number of neuron units as shown in Figure.1

Step3. The weighted sum or activation value of ith neuron in the input layer xi=ai

Step4. The weighted sum of the jth neuron in the hidden layer is calculated as

$$x_j^h = \sum_{i=1}^{I} w_j^k x_i + w_{oj}^h \tag{11}$$

Step5. The output of the jth neuron in the hidden layer is calculated as $s_j^h = f_j^h(x_j^h)$ (12)

Step6. The weighted sum of the kth neuron in the hidden layer is obtained as

$$x_k^0 = \sum_{i=1}^{I} w_{kj} x_j^h + w_{ok} \tag{13}$$

Step7. The output of the kth neuron in the hidden layer is obtained as $s_k^0 = f_k^0(x_k^0)$ (14)

Step8. The error term of kth output neuron is calculated as

$$\delta_k^0 = (b_k - s_k^0) * \dot{f}_k^0 \tag{15}$$

Step9. The weights between output and hidden layers are updated as follows $w_{kj}(m+1) = w_{kj}(m) + \eta\delta_k^0 s_j^h$ (16)

Step10. The error term of jth hidden neuron is given as,

$$\delta_j^h = \dot{f}_j^h \sum_{k=1}^{K} \delta_k^0 w_{kj} \tag{17}$$

Step11. The weights between hidden and input layers are updated as follows (18)

$$w_{ji}^h(m+1) = w_{ji}^h(m) + \eta\delta_j^h a_i \tag{18}$$

Step12. Determine the Squared error of lth pattern which has to be minimised is given as

$$E_l = \frac{1}{2}\sum_{k=1}^{K}(b_{lk} - s_k^0)^2$$

and total error calculates as

$$E = \sum_{l=1}^{L} E_l \tag{19}$$

Step13. Apply one by one pattern and change weights until the error is minimised.

VI. RESULT

For 5-bus and 30-bus systems L-index values are calculated. In 5-bus system, it was observed that 5th bus is having highest L- index value i.e. 0.0774 which is considered as critical bus. In the 30-bus system, there is high L-index value, i.e. 0.142 at 30th bus, so it is the optimal location of the SVC FACTS controller. L-index values for 5-bus and 30-bus are as given in Table.1 and 2 respectively

Table 1. L-Index values of 5 bus system

Bus No.	L-Index
5	0.0774
3	0.064
4	0.0397

Table 2. L-Index values of 30 bus system

Bus No.	L-index	Bus No.	L-index
30	0.142	23	0.0611
3	0.1252	21	0.0577
4	0.1038	26	0.0577
29	0.0925	10	0.0568
6	0.091	22	0.0564
7	0.0889	14	0.0546
19	0.0718	17	0.0533
18	0.0677	16	0.0499
15	0.0671	25	0.0461
20	0.0664	27	0.0424
28	0.0638	12	0.0384
24	0.0614	9	0.0347

The standard IEEE 30 bus system with 6 generator buses and 24-load buses with Artificial Neural network based SVC FACTS(ANNSVC) controller is as shown in Figure.4

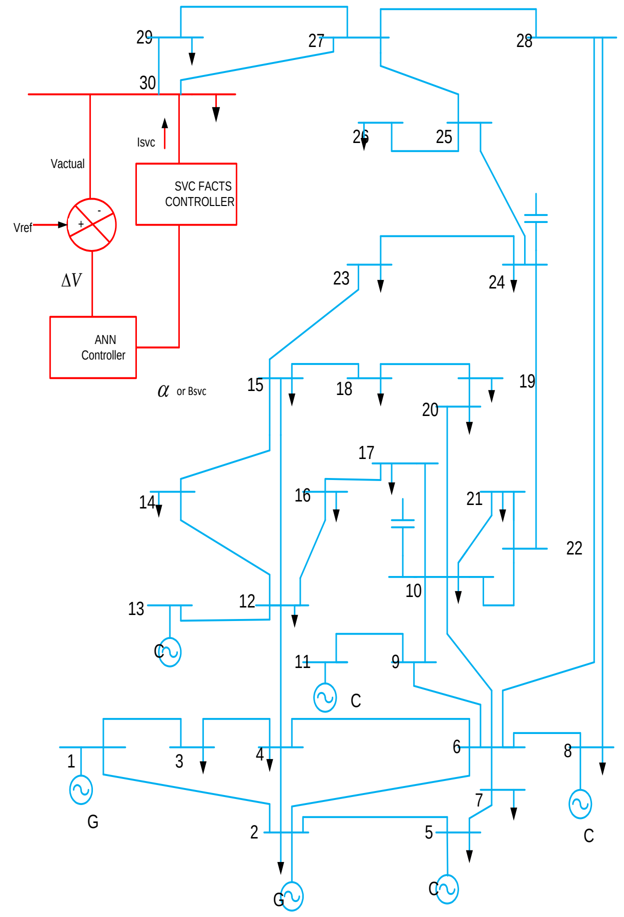

Figure.4 Standard IEEE 30-bus system with ANNSVC

Whenever there is a disturbance in load the voltage deviated from the actual value. The deviation in voltage automatically sensed by ANN controller and generates susceptance or firing angle. The SVC controller brings back the voltage at the bus when it receive signal from the ANN controller. The diagrams of the both the models are as given in Figure.5 and Figure.6

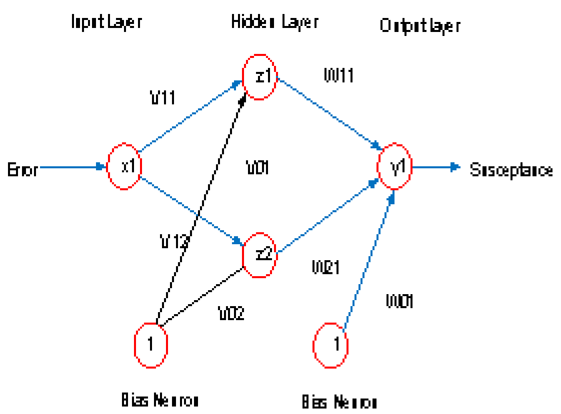

Figure.5 Neural Network to predict Susceptance

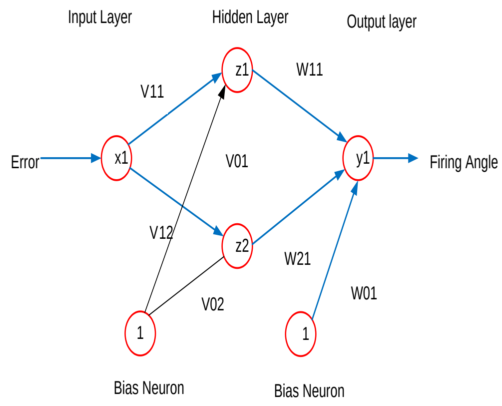

Figure.6 Neural Network to predict Firing Angle

The training time, testing time, Total number of iterations and finalized weights are as given below.

In 5-bus susceptance, ANNSVC training is done in 14873 iterations and training time is 102.061 sec and the finalized weights are as given below. The predicted weights of input and hidden layers are given by

V=[-9.3738 -11.2671]

Optimized weights between hidden and output layer neurons are given by

W=[-7.9789 -9.9637]

Finalized trained bias neuron weights are as given below

W0=[6.9245]

In 5-bus firing angle ANNSVC training is done in 102681 iterations and training time is 747.897 sec and the finalized weights are as given below. The finalized weights between input and hidden layers is given by

V=[-1.2701 -18.9372]

Finalized weights between hidden and output layer neurons are given by

W=[-14.3587 -3.5321]

Finlalized trained bias neuron weight is as given below

W0=[4.897]

In 30-bus susceptance ANNSVC training is done in 99141 iterations and training time is 1016.194 sec and the finalized weights are as given below.The inalized weights between input layer and hidden layer is given by

V=[-9.7740 -9.8296]

Finalized weights between hidden and output layer neurons are given by

W=[-8.2677 -8.3237]

Finlalized trained bias neurons are as given below

W0=[3.9402]

In 30-bus firing angle ANNSVC training is done in 86096 iterations and training time is 635.8188 sec and the finalized weights are as given below. The inalized weights between input layer and hidden layer is given by

V=[-19.1549 -1.2953]

Finalized weights between hidden and output layer neurons are given by

W=[-3.8804 -14.3376]

Finlalized trained bias neurons are as given below

W0=[4.9428]

The regression analysis which represents the effective ness of training is as shown in Figure 7,8,9 and 10.

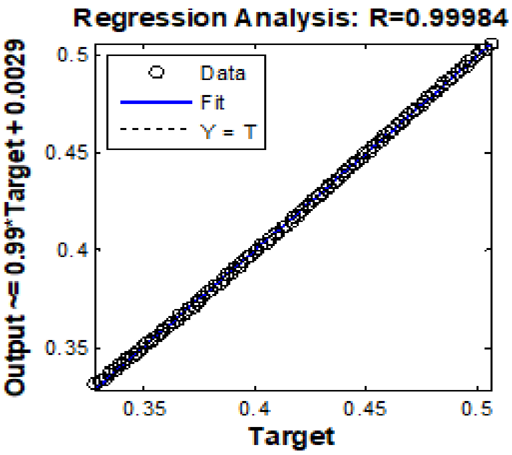

Figure.7 Regression analysis of 5-bus susceptance model

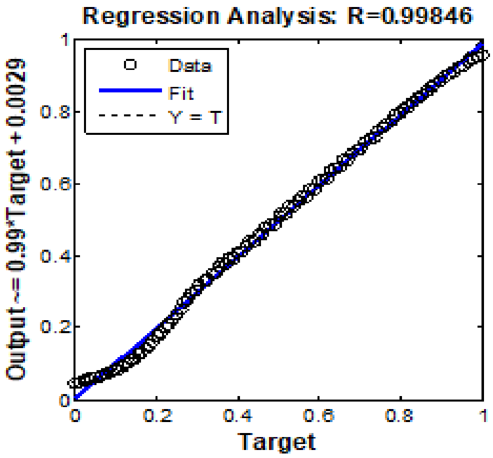

Figure.8 Regression analysis of 5-bus firing angle model

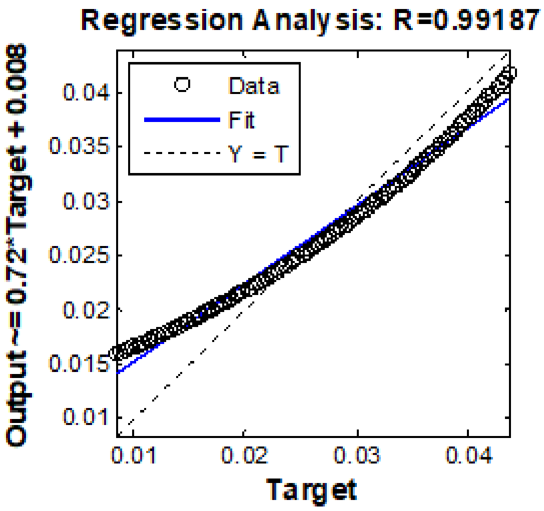

Figure.9 Regression analysis of 30-bus susceptance model

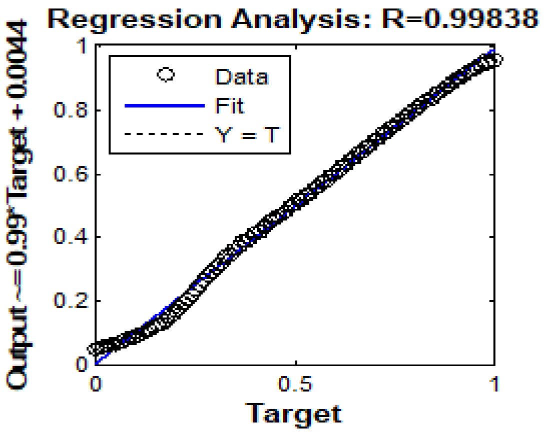

Figure.10 Regression analysis of 30-bus firing angle model

The artificial neural network once trained they can able to predict the parameters of the controller quickly and effectively. Once the parameters are generated the SVC FACTS controller brings back the voltage to the reference value which will be clearly given in the Table.3,4,5 and 6.

Table.3 Variation of bus-5 Voltages without and with SVCANN susceptance method

S.No	% change in load	Voltage at bus-5 without SVC	B_{svc} predicted by BPNN	Elapsed time(sec)	Voltage with BPNNSVC
1	10	0.9679	0.3636	0.037191	1.0001
2	20	0.9647	0.3977	0.033675	1
3	30	0.9615	0.4349	0.037630	1.0001
4	40	0.9582	0.4693	0.036354	1
5	50	0.9549	0.5058	0.027799	1.0011

Table.4 Variation of bus-5 Voltages without and with SVCANN firing angle method

S.No	% change in load	Voltage at bus-5 without SVC	α_{svc} predicted by BPNN	Elapsed time(sec)	Voltage with BPNNSVC
1	10	0.9679	136.2341	0.017560	0.9989
2	20	0.9647	136.8664	0.013862	0.9978
3	30	0.9615	137.5050	0.018404	0.9966
4	40	0.9582	138.2117	0.016394	0.9955
5	50	0.9549	138.8773	0.017156	0.9942

Table. 5 Variation of bus-30 Voltages without and with SVCANN susceptance method

S.No	% change in load	Voltage at bus-30 without SVC	B_{svc} predicted by BPNN	Elapsed time	Voltage at bus-30 with BPNNSVC
1	10	0.9896	0.0174	0.042654	1.0014
2	20	0.9848	0.022	0.031268	0.9998
3	30	0.9798	0.0279	0.030279	0.999
4	40	0.9748	0.0355	0.025433	0.9993
5	50	0.9697	0.0451	0.030342	1.0009

Table.6 Variation of bus-30 Voltages without and with SVCANN susceptance method

S.No	% change in load	Voltage at bus-5 without SVC	α_{svc} predicted by BPNN	Elapsed time	Voltage with BPNNSVC
1	10	0.9896	128.3032	0.035867	1.0000
2	20	0.9848	128.4474	0.024665	0.9999
3	30	0.9798	128.6051	0.025944	1.0001
4	40	0.9748	128.7298	0.031359	0.9992
5	50	0.9697	128.8073	0.038679	0.9966

The output voltage with and without controllers in 5-bus and 30-bus systems with diffetent models of SVC as given in Figure and Figure.

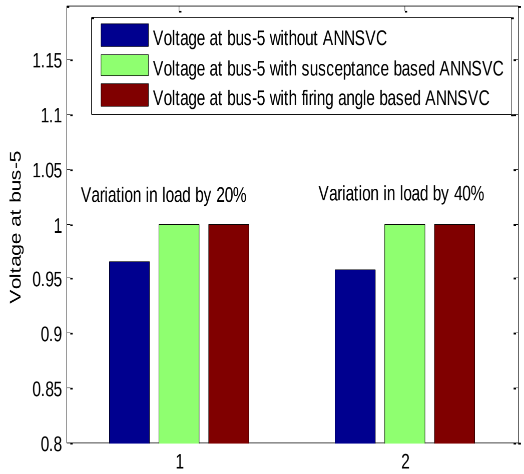

Figure.9 Variation of bus-5 volatges without and with ANNSVC when there is load change

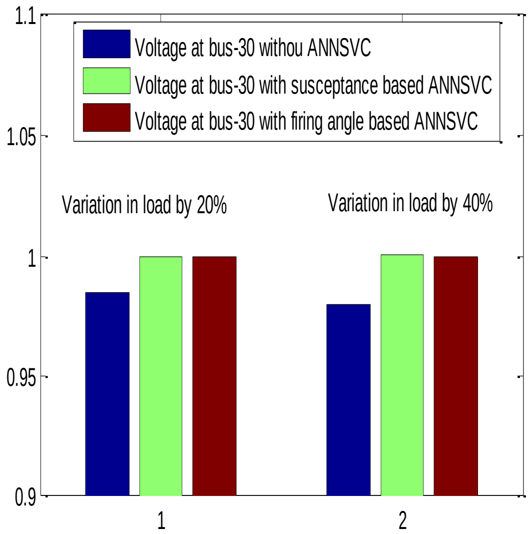

Figure.10 Variation of bus-30 volatges without and with ANNSVC when there is load change

It will be clearly observed that from the Table.7, total active power losses can be decreased with SVC FACTS controller.

Table.7 Active power los in 30-bus sytem wth and without SVC FACTS controller.

S.no	% Load variation from base value	Losses in 30-bus system without SVC Controller	Losses in 30-bus system with BPNN SVC controller	
			Susceptance model	Firing Angle model
1	10	17.0818	17.0426	17.0465
2	20	17.2938	17.2420	17.2417
3	30	17.5148	17.4615	17.4438
4	40	17.7448	17.6561	17.6562
5	50	17.9842	17.8966	17.8799

VII. CONCLUSION

It was observed that when the system is under over loaded condition there will be voltage drop from the reference level which is undesirable in the system. SVC is the Shunt FACTS controller to support the voltage profile when there is a disturbance. To determine optimal location of FACTS controller L-index method is used. According to this method it was identified that 5th bus in standard IEEE 5 bus system, 30th bus in IEEE 30 bus system are weak buses. At these weak buses SVC FACTS controller is placed. Suceptance and Firing angle methods are considered. The parameters of the SVC FACTS controller was automatically predicted accurately and quickly using artificial neural networks. The effectiveness of the controller in bringing back the voltage to reference level as well minimization of total system active power loss observed.

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