

# Dynamic Stability Enhancement of Power Transmission System using Artificial Neural Network Controlled Static Var Compensator

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## ABSTRACT

Voltage level of the system changes at the time of fault and the drop in the load voltage leads to an increased demand for the reactive power that, if not met by the power system leads to a further decline in the bus voltage. This decline eventually leads to a progressive rapid decline of voltage at that location, which may have a cascading effect on neighboring regions that causes voltage collapse. In this paper, in order to maintain system stability after faults, the transmission line is shunt compensated at its center by a 200-Mvar Static Var Compensator (SVC) in Matlab/Simulink. SVC are used to maintain the voltage within the limits. SVC will either supply the reactive power or extract the reactive power. An Artificial Neural Network (ANN) is also developed with a systematic step-by-step procedure which optimizes a criterion commonly known as the learning rule. The input/output training data is fundamental for these networks as it conveys the information which is necessary to discover the optimal operating point. It is shown that trained Neural Network developed has excellent capabilities of forecasting which can be very useful in research.

## Keywords

Artificial Neural Network (ANN), Dynamic Performance, FACTS, Matlab/Simulink, Transient Stability.

## 1. INTRODUCTION

Today's changing electric power systems create a growing need for flexibility, reliability, fast response and accuracy in the fields of electric power generation, transmission, distribution and consumption. Static Var Compensators (SVC) devices are used to improve voltage and reactive power conditions in AC systems. An additional task of SVC is to increase transmission capacity as a result of power oscillation damping. The effectiveness of this controller depends on its optimal location and proper signal selection in the power system network[9]. Flexible AC Transmission System (FACTS) is a technology based solution to help the utility industry deal with changes in the power delivery business. A major thrust of FACTS technology is the development of power electric based systems that provide dynamic control of the power transfer parameters transmission voltage, line impedance and phase angle[3]. Static Var Compensator (SVC) provides fast acting dynamic reactive compensation for voltage support during contingency events which would otherwise depress the voltage for a significant length of time[10]. The flexible AC transmission system (FACTS) controllers can play an important role in the power system security enhancement. However, due to high capital investment, it is necessary to locate these controllers optimally in the power system. FACTS devices can regulate

the active and reactive power control as well as adaptive to voltage-magnitude control simultaneously because of their flexibility and fast control characteristics. An Artificial Neural Network is a system based on the operation of biological neural networks, in other words, is an emulation of biological neural system. As its biological predecessor, an artificial neural network is an adaptive system. By adaptive, it means that each parameter is changed during its operation and it is deployed for solving the problem in matter. This is called the training phase.

## 2. SVC V-I CHARACTERISTICS

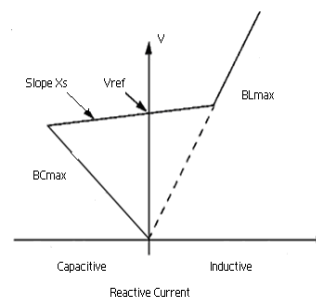


Fig 1: The V-I Characteristics of SVC

## 3. SIMULATION

### 3.1 Transient Stability with SVC

The SVC can be operated in two different modes:

- In voltage regulation mode.
- In var control mode (the SVC susceptance is kept constant).

When the SVC is operated in voltage regulation mode, it implements the V-I characteristic shown in Fig. 1.

### 3.2 SVC Operating on 700 KM T.L

A static var compensator (SVC) is used to regulate voltage on a system. When system voltage is low the SVC generates reactive power (SVC capacitive). When system voltage is high it absorbs reactive power (SVC inductive). SVC is rated as 200 Mvar

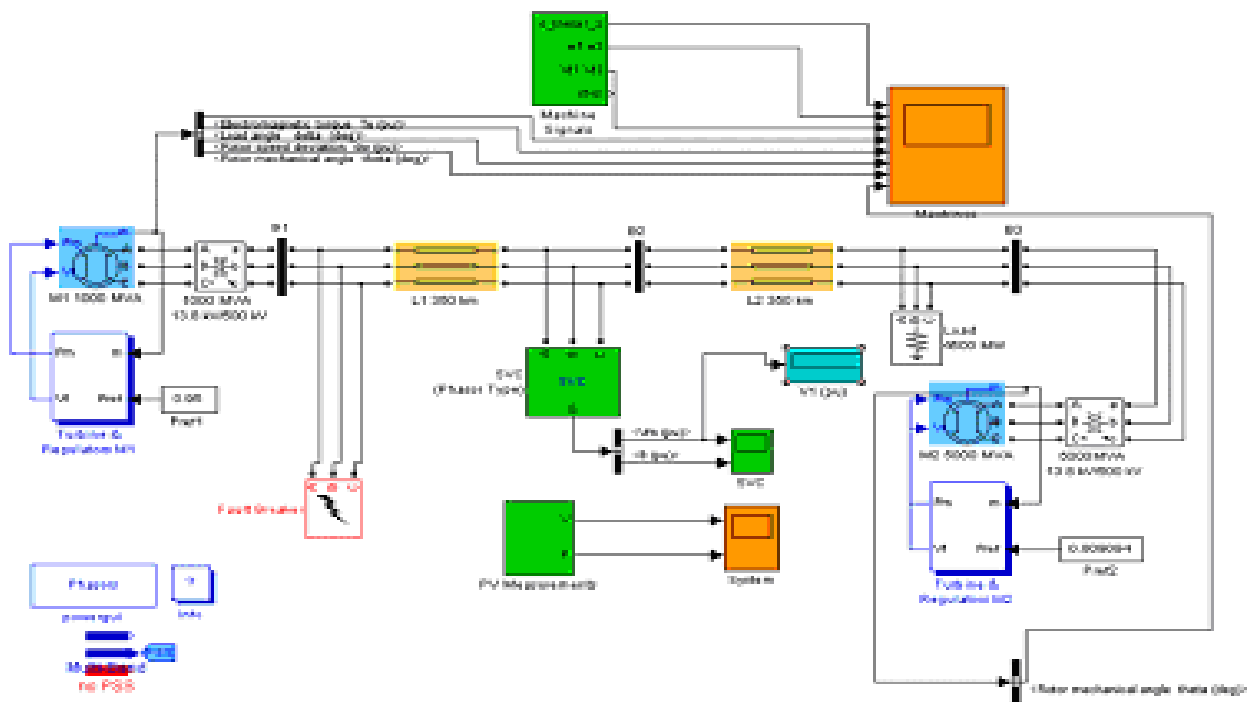


Fig 2 : SVC operating with T-G on 700 km Transmission Line in Matlab/Simulink

#### 4. ARTIFICIAL NEURAL NETWORK

Artificial neural networks born after McCulloch and Pitts introduced a set of simplified neurons in 1943. These neurons were represented as models of biological networks into conceptual components for circuits that could perform computational tasks. The basic model of the artificial neuron is founded upon the functionality of the biological neuron. By definition, “Neurons are basic signaling units of the nervous system of a living being in which each neuron is a discrete cell whose several processes are from its cell body. One can differentiate between two basic types of networks, networks with feedback and those without it. In networks with feedback, the output values can be traced back to the input values. However there are networks wherein for every input vector laid on the network, an output vector is calculated and this can be read from the output neurons. There is no feedback. Hence only, a forward flow of information is present. Network having this structure are called as feed forward networks. There are various nets that come under the feed forward type of nets. A multilayer feed forward back propagation network with one layer of z-hidden units. The Y output unit has  $W_{ok}$  bias and Z hidden unit has  $V_{ok}$  as bias. It is found that both the output units and the hidden units have bias. The bias acts like weights on connection from units whose output is always 1. This network has one input layer, one hidden layer and one output layer. There can be any number of hidden layers. The input layer is connected to the hidden layer and the hidden layer is connected to the output layer by means of interconnection weights. The bias is provided for both the hidden and the output layer, to act upon the net input to be calculated.

#### 5. TRAINING ALGORITHM

The training algorithm of back propagation involves four stages, viz.

1. Initialization of Weights
2. Feed Forward
3. Back Propagation of errors
4. Updation of the weights and the biases.

During first stage which is the initialization of weights, some small random values are assigned. During feed forward stage each input unit ( $X_i$ ) receives an input signal and transmits this signal to each of the hidden units  $Z_1, \dots, Z_p$ . Each hidden unit then calculates the activation function and sends its signal  $Z_j$  to each output unit. The output unit calculates the activation function to form the response of the net for the given input pattern. During back propagation of errors, each output unit compares its computed activation  $y_k$  with its target value  $t_k$  to determine the associated error for that pattern with that unit. Based on the error, the factor  $\delta_k$  is computed and is used to distribute the error at output unit  $y_k$  back to all units in the previous layer. Similarly factor  $\delta_j$  is computed for each hidden unit  $z_j$ . During final stage, the weight and biases are updated using the  $\delta$  factor and the activation .

x: input training vector

x: ( $x_1, \dots, x_i, \dots, x_n$ )

t: Output target vector

t: ( $t_1, \dots, t_i, \dots, t_n$ )

$\delta_k$  =error at output unit  $y_k$

$\delta_j$  =error at hidden unit  $z_j$

$\alpha$  = learning rate

$V_{oj}$  = bias on hidden unit  $j$

$z_j$  = hidden unit  $j$

$w_{ok}$  =bias on output unit  $k$

$y_k$  = output unit  $k$ .

The training algorithm used in the back propagation network is as follows. The algorithm is given with the various phases:

### 5.1 Initialization of Weights

Step 1: Initialize weight to small random values.

Step 2: While stopping condition is false, do Steps 3-10.

Step 3: For each training pair do steps 4-9.

### 5.2 Feed Forward

Step 4: Each input unit receives the input signal  $x_i$  and transmits this signals to all units in the layer above i.e hidden units.

Step 5: Each hidden unit(  $z_j, j=1, \dots, p$ ) sums its weighted input signals.

$$z_{-inj} = v_{oj} + \sum x_i v_{ij} \quad (1)$$

applying activation function

$$Z_j = f(z_{inj}) \quad (2)$$

and sends this signal to all units in the layer above i.e. output units.

Step 6: Each output unit ( $y_k$ ) sums its weighted input signals.

$$y_{-ink} = w_{ok} + \sum z_j w_{jk} \quad (3)$$

and applies its activation function to calculate the output signals.

$$Y_k = f(y_{-ink}) \quad (4)$$

### 5.3 Back Propagation of Errors

Step 7: Each output unit receives a target pattern corresponding to an input pattern, error information term is calculated as

$$\delta_k = (t_k - y_k) f'(y_{-ink}) \quad (5)$$

Step 8: Each hidden unit ( $z_j$ ) sums its delta inputs from units in the layer above

$$\delta_{-inj} = \sum \delta_j w_{jk} \quad (6)$$

The error information term is calculated as

$$\delta_j = \delta_{-inj} f'(z_{-inj}) \quad (7)$$

### 5.4 Updation of Weight and Biases

Step 9: Each output unit ( $y_k$ ) updates its bias and weights ( $j=0, \dots, p$ )

The weight correction term is given by

$$\Delta W_{jk} = \alpha \delta_k z_j \quad (8)$$

and the bias correction term is given by

$$\Delta W_{ok} = \alpha \delta_k \quad (9)$$

Therefore  $W_{jk}(\text{new}) = W_{jk}(\text{old}) + \Delta W_{jk}$ ,  $W_{ok}(\text{new}) = W_{ok}(\text{old}) + \Delta W_{ok}$  (10)

Each hidden unit ( $z_j, j=1, \dots, p$ ) updates its bias and weights ( $i=0, \dots, n$ )

The weight correction term

$$\Delta V_{ij} = \alpha \delta_j x_i \quad (11)$$

The bias correction term

$$\Delta V_{oj} = \alpha \delta_j \quad (12)$$

Therefore,  $V_{ij}(\text{new}) = V_{ij}(\text{old}) + \Delta V_{ij}$ ,  $V_{oj}(\text{new}) = V_{oj}(\text{old}) + \Delta V_{oj}$  (13)

Step 10: Test the stopping condition.

The stopping condition may be the minimization of the errors, number of epochs etc.

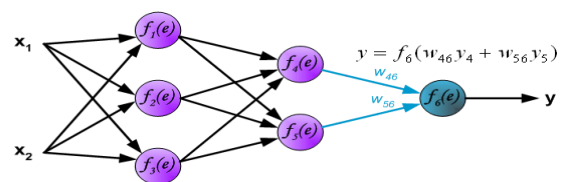
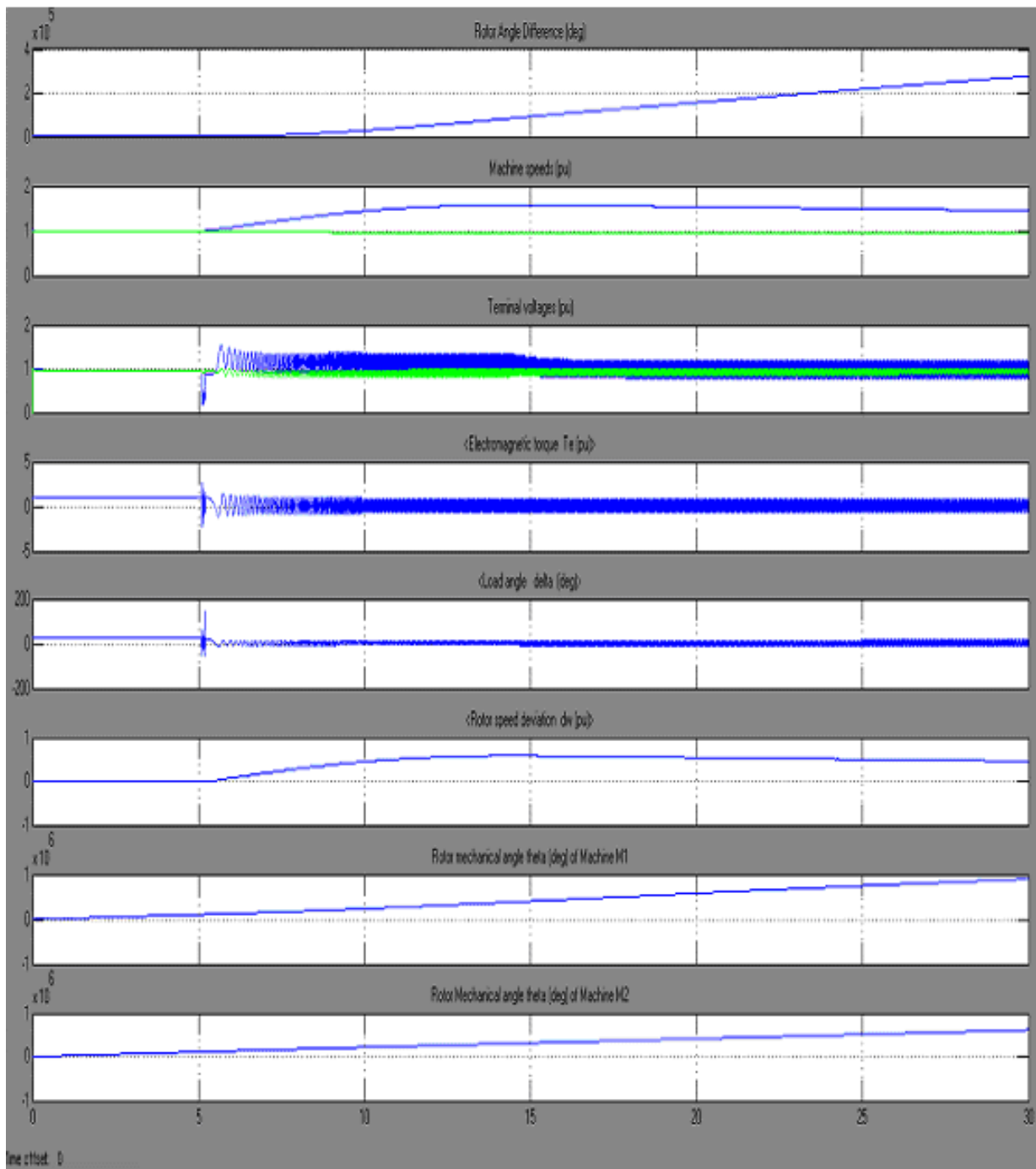


Fig 3: Feed Forward Networks



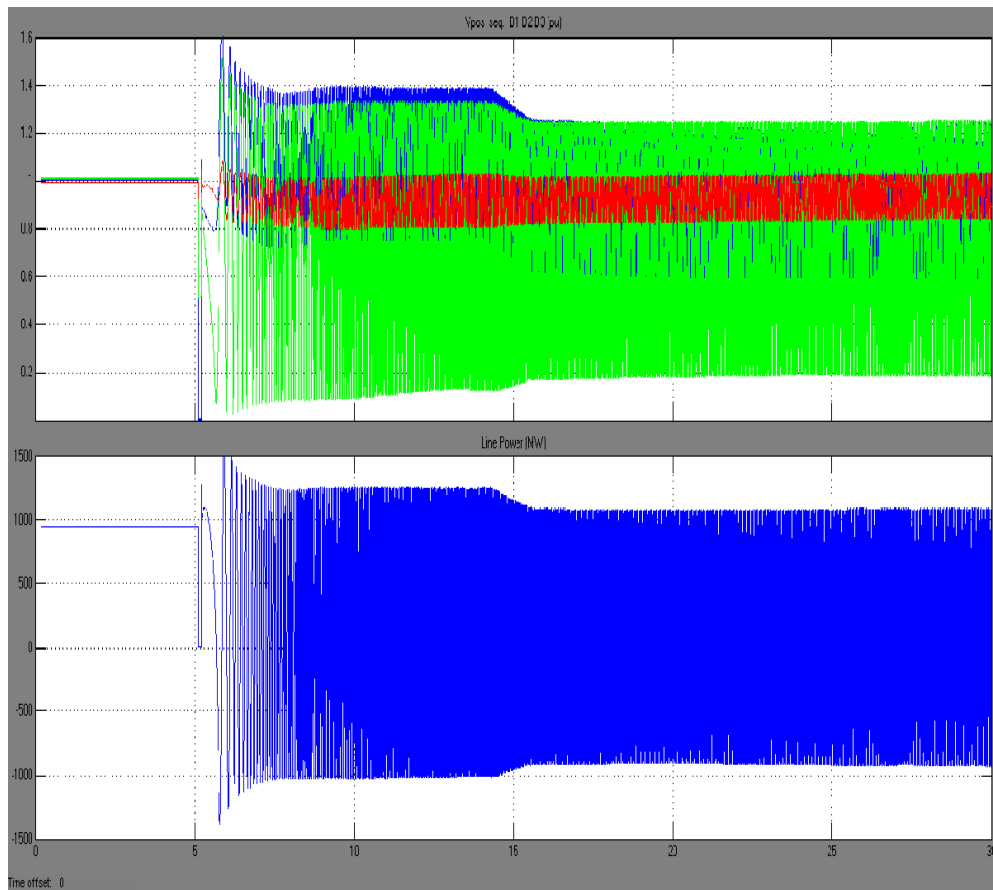
Fig 4: Back Propagation of Errors

## 6. SIMULATION RESULTS AND DISCUSSIONS

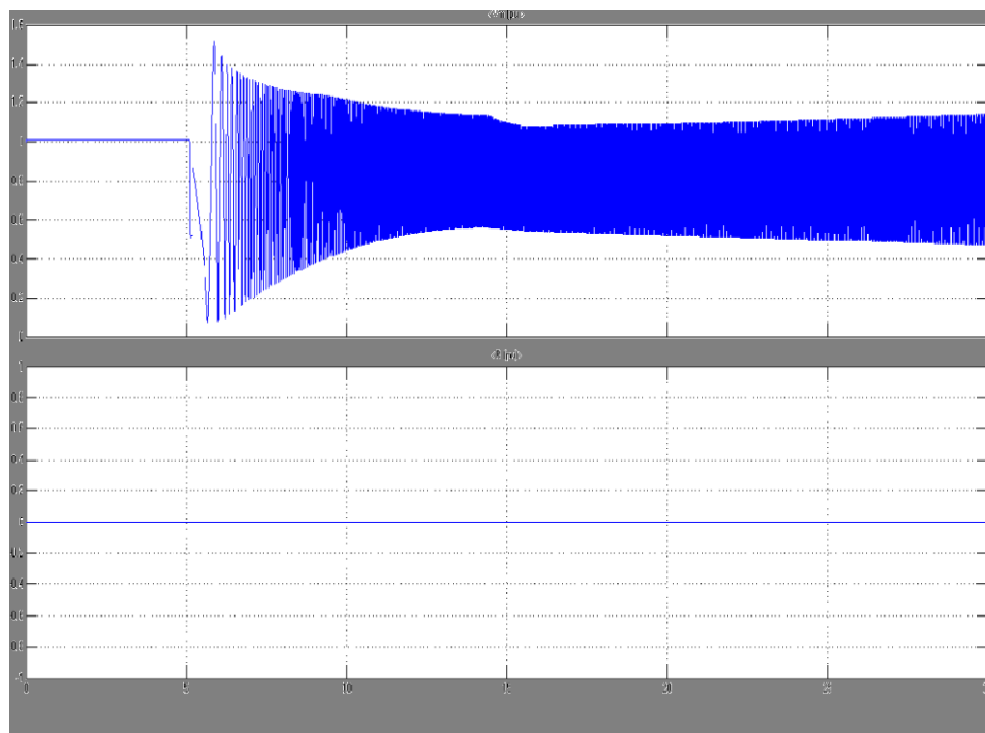


**Fig 5: Signals Observed on 'Machines' Scope Without SVC**

Now through SVC dialog box SVC is set to operate in 'Voltage Regulation' mode with  $B_{ref} = 0$ . This is equivalent to putting the SVC in service.



**Fig 6: Signals Observed on ‘System’ Scope Without SVC**



**Fig 7: Signals Observed on ‘SVC’ Scope Without SVC**

Now through SVC dialog box SVC is set to operate in 'Voltage Regulation' mode with  $B_{ref} = 0$ . This is equivalent to putting the SVC in service.

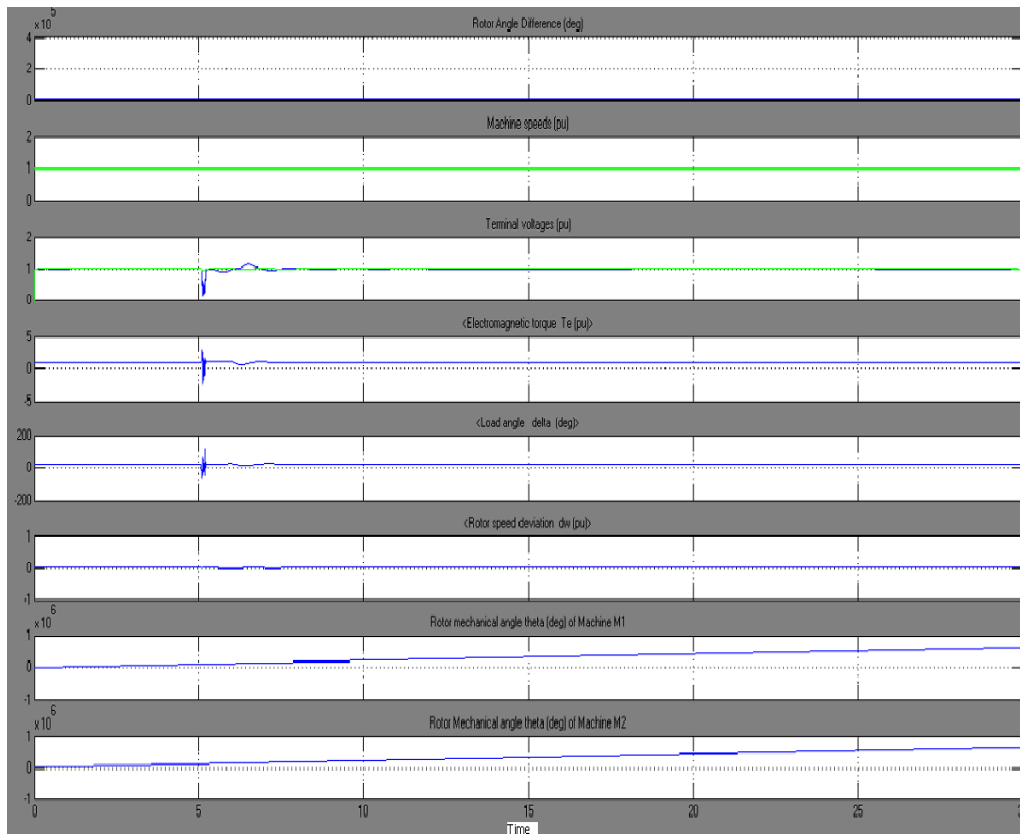


Fig 8: Signals Observed on 'Machines' Scope With SVC

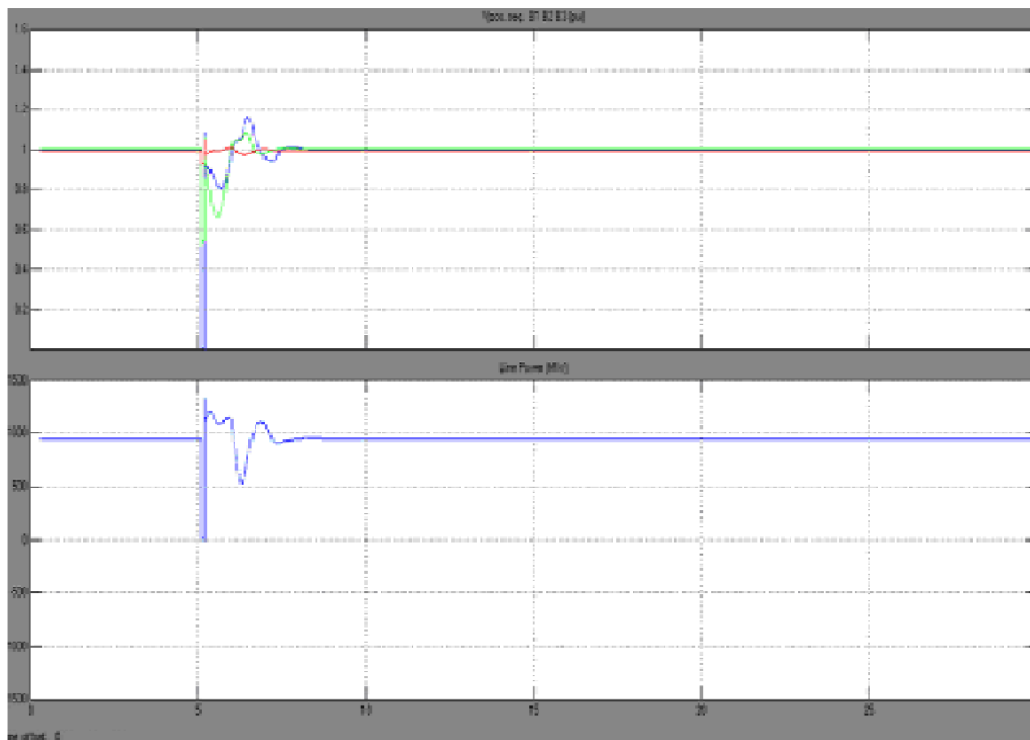


Fig 9: Signals Observed on 'System' Scope With SVC



**Fig 10: Signals Observed on ‘SVC’ Scope With SVC**

Blue colour block shown in simulation is Display Block which updates its display of the values of Voltage V1(p.u). If the values of L1 and L2 and Resistive Load are varied the values of V1(p.u) also got varied and the corresponding values of V1(p.u) is

shown by the display box. Value of V1(p.u) at 6<sup>th</sup> second is noted to train the feed-forward neural network

**Table 1. Values of V1(p.u) at different values of L1, L2 and Resistive Load**

Length of Transmission Line (L1)	Length of Transmission Line (L2)	Resistive Load (MW)	V1(p.u)
600	100	3500	1.14
650	50	4000	1.08
500	200	3500	1.17
550	150	3800	1.14
450	250	4000	1.15
400	300	3000	1.22
300	400	3200	1.20
200	500	4400	1.14
150	550	3900	1.17
100	600	3300	1.18
600	100	4200	1.09
600	100	3800	1.12
650	50	3000	1.17
650	50	3700	1.10
500	200	4200	1.12
500	200	3900	1.14
550	150	4500	1.09
450	250	3700	1.17

**Table 2. Values of V1(p.u) obtained through Matlab/Simulink and through Neural Network**

Length of Transmission Line (L1) KM	Length of Transmission Line (L2) KM	Resistive Load (MW)	V1(p.u) at 6 <sup>th</sup> second of simulation	Value of V1 obtained through NN (p.u)	Error (%)
100	600	4100	1.16	1.166	-.517
50	650	3200	1.17	1.228	-4.95
100	600	4300	1.15	1.154	-.347
150	550	4100	1.16	1.160	0
200	500	3750	1.17	1.176	-.512
250	450	3400	1.19	1.191	-.084
150	550	3100	1.19	1.222	-2.68
200	500	2500	1.23	1.253	-1.86
600	100	3100	1.18	1.169	.932
650	50	3300	1.14	1.152	-1.05
200	500	3900	1.17	1.166	.341
250	450	4100	1.16	1.148	1.03
450	250	3000	1.22	1.192	2.29
100	600	2100	1.23	1.289	-4.79
300	400	3150	1.21	1.201	.743
350	350	3650	1.18	1.164	1.35
600	100	2700	1.20	1.194	0.5
400	300	3600	1.18	1.161	1.61
130	570	2100	1.24	1.285	-3.62

## 7. CONCLUSION

Hence it can be concluded that SVC will successfully control the dynamic performance of power system and will effectively regulate the system oscillatory disturbances and voltage regulation of the power system. Simulations carried out confirm that SVC could provide the fast acting voltage support necessary to prevent the possibility of voltage reduction and voltage collapse. This paper inspects actual positive sequence voltage in a system model with or without SVC. However it is well known that these FACTS controllers have the additional advantage of being able to control “fast” system oscillations due to their quick response. Hence by properly modeling these controllers in transient stability programs, it would be interesting to determine any other possible advantages of these controllers in voltage stability studies. The presented simulation results shows that SVC is capable to power system oscillation damping successfully.

In this paper following signals i.e Rotor Angle difference (deg), Machine speeds(pu), Terminal Voltage(pu), Electromagnetic Torque(pu), Load Angle delta(deg), Rotor speed deviation dw(pu), Rotor mechanical angle(deg) theta of machine M1, Rotor mechanical angle(deg) theta of machine M2, Vpos. Seq.(pu), Line Power(MW), Vm(pu), B(pu) are observed on ‘Machines’, ‘System’ and ‘SVC’ scopes. The authors are currently working on developing appropriate models for other FACTS controllers, namely, STATCOM, SSSC, UPFC for transient and steady state stability analysis, to also analyze the advantages and disadvantages of these controllers in voltage stability studies. Value of voltage (V1) is varied by varying the values of the values of L1 and L2 and Resistive Load (MW) and then displayed at display block at 6<sup>th</sup> second as shown in Table 1. Using these values of voltage V1 a feed-forward network is trained. After the completion of training phase a Feed Forward Neural Network is developed

which can forecast a value of voltage V1 at any value of L1, L2 and Resistive Load (MW). Table 2. shows the values of voltage V1 at different values of L1, L2 and Resistive Load (MW) obtained through simulink and through Neural Network also with the corresponding values of error. It is realized that a Feed Forward Neural Network has excellent capability of forecasting the values of voltage V1 which can be very useful for further research.

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