An Artificial Neural Network Controlled SVC for Dynamic Stability Enhancement of Power Transmission System

S. JAYA LAKSHMI, Dr.V.BALAJI, S.SUBRAMANYA SARMA

Abstract— This paper reviews new approach in modern research using Artificial Neural Network. 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 was 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.

Index Terms— Electric power systems, Power system stabilizers, Artificial Neural Network (ANN), Dynamic Performance, FACTS, MATLAB/SIMULINK.

————————————— ◆ —————————————

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. After many years of research and development of controllers to damp system oscillations, many methodologies and control algorithms have been developed. Power System Stabilizers (PSS) on generators have been employed in power systems for many years and provide very effective damping of generator oscillations, but power system oscillations are still a problem in power system operation. How to fully take advantage of the resource and ability in the system to further improve overall power system stability is an active topic in recent years. Damping in the transmission paths by taking full advantage of the resources available is a viable alternative. With the rapid development in the power electronic technologies in recent years, the flexible AC transmission system (FACTS) has started to be widely used in the modern power systems. Since FACTS elements in power systems are controlled by power electronic components such as Gate Turn-off thyristors (GTOs) and Diodes, which are dynamically adjustable, FACTS equipment can also be used for system oscillation damping. Among various FACTS devices, SVCs are being used in power systems to compensate for reactive power and provide voltage support. They have the potential to be used for damping the oscillations, and work together with generator PSSs to improve the overall power system stability.

Considerable effort (Lerch,1991), (Ghandhari, 2002), (Wang, 1997,2000), (Canizares and Faur, 1999), (Armansyah, and Yorino, 2002), (Rahim, 2001), (Hiyama, 1999) has been devoted to the design of controls for SVCs to damp power system oscillations in recent years. Traditional PSS design methodology can also be used in the SVC PSS design, but it meets the same problem as in the generator PSS design. Un-

certain system parameters determine that conventional PSS design method cannot keep the desired damping function for all operating conditions. As NNs have ability to globally approach any uncertain nonlinear system, the proposed SVC controller will be based on an NN to approach the nonlinear power system. The discrete time direct control theory described in (Jagannathan, 1996, 1999) is selected to design the controller. The proposed controller needs only one neural network in comparison to the indirect control design methods that needs two: one for system parameter identification and another for control.

Overview of the proposed SVC controller is given in Section II. Selection of an NN for the controller and mathematical derivation of the discrete time direct control algorithm is demonstrated in Section III. Simulation results of the proposed controller are described in Section IV to show the effectiveness of the damping function of the proposed controller. Conclusions and future work are given in the last section.

2 OVERVIEW OF SVC CONTROLLER

Structure of an SVC controller is similar to that of a generator excitation controller. Automatic voltage regulator (AVR) is the primary control to adjust the voltage to the desired value at the system bus where the SVC is connected to support electrical power transmission. SVCs with only voltage control mode do not improve damping and in some conditions may even have negative impact on damping system oscillations. Therefore, a supplementary control should be added to the voltage controller to allow bus voltage to vary. This additional control signal can be provided through the voltage control loop. Static Var Compensator (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 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.
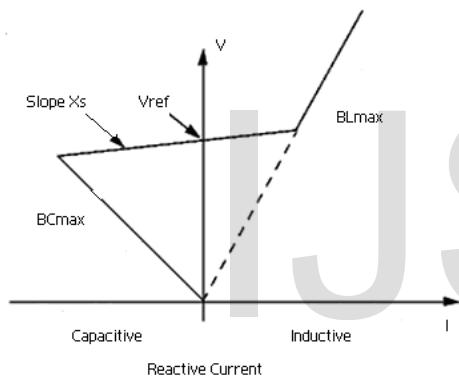
FIGURE 1. V-I CHARACTERISTICS OF SVC

SVC is basically a shunt connected static var generator/load whose output is adjusted to exchange capacitive or inductive current so as to maintain or control specific power system variables: typically, the controlled variable is the SVC bus voltage. One of the major reasons for installing a SVC is to improve dynamic voltage control and thus increase system load ability.

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

_____

• **S.JAYALAKSHMI** *is a research scholar at SCSVMV university, Kanchipuram. She is presently working as Head of the Department of EEE at Ramachandra College of Engineering, Eluru Email ID:* *jayasriram23@gmail.com*

• **Dr. V.BALAJI** *has 13 years of teaching experience. Now he is working as a principal in Spathgiri College of Engineering, Dharmapuri.*

• **S.SUBRAMANYA SARMA** *has 6 years of teaching experience in EEE Department as an Assistant professor. Presently he is working as Assistant professor in Ramachandra College of Engineering, Eluru, Andhra Pradesh. Email ID:* *sssarma.eee@gmail.com*

mode, it implements the V-I characteristic shown in Fig. 1.

3 POWER SYSTEM MODEL

This example described in this section illustrates modeling of a simple transmission system containing 2- hydraulic power plants. SVC has been used to improve transient stability and power system oscillations damping. The phasor simulation method can be used. A single line diagram represents a simple 500 kV transmission system is shown in Fig.2.
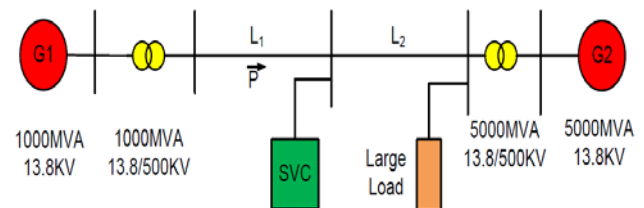

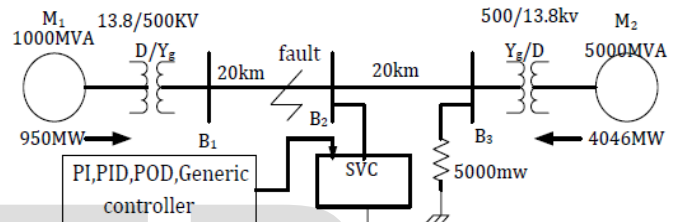FIGURE 2. BLOCK DIAGRAM OF POWER SYSTEM UNDER STUDY

Figure 3. Single line diagram of 2-machine power system with different types of SVC controller

A 1000 MW hydraulic generation plant (M1) is connected to a load centre through a long 500 kV, 40km transmission line. A 5000 MW of resistive load is modeled as the load centre. The remote 1000 MVA plant and a local generation of 5000 MVA (plant M2) feed the load. A load flow has been performed on this system with plant M1 generating 950 MW so that plant M2 produces 4046 MW. The line carries 944 MW which is close to its surge impedance loading (SIL = 977 MW). To maintain system stability after faults, the transmission line is shunt compensated at its centre by a 200 MVAR Static VAR Compensator (SVC). The SVC does not have any controller unit. Machine & SVC parameters has been taken from [5].

4 SIMULATION RESULTS (SVC WITHOUT CONTROLLER)

Two types of faults has been considered:
A. Single line to ground fault &
B. Line-Line faults.

A. Single line to ground fault:
Suppose 1-line to ground fault occurred at 0.1s & cleared at 0.2s. Without SVC, the system voltage & power becomes unstable [Fig. 5(a) & 5(b)]. But, If SVC is used but without any controller then although initial voltage damping was 5%, but after t=3.8s,the system voltage damping becomes 0.01% and system is stable [Fig.5(c)] & at 0.1s the speed deviation goes on higher
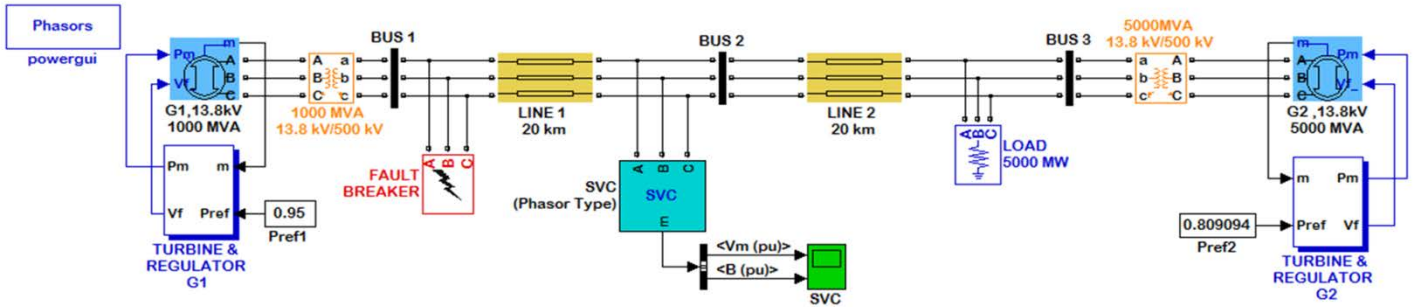
value & after clearing the fault at 0.2s machines speed deviation or oscillation is damped out gradually & dω becomes stable at 4.2 [Fig.5(d)].

During 3-phase L-L faults, If no SVC is applied then system becomes unstable But when SVC is applied then oscillation is damped out & at t=5s system voltage becomes stable & final damping becomes 0.01%,as shown in Fig.5(e).
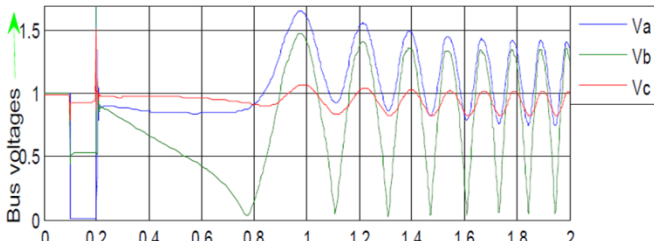

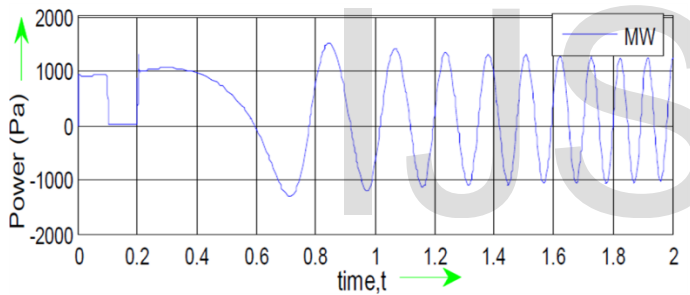Fig.5(a) Bus voltage in p.u. at faulted condition (without SVC)
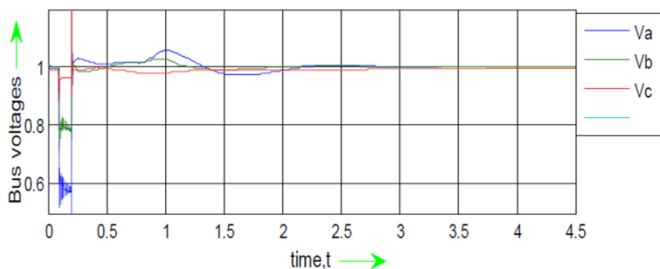

Fig.5(b) Bus power in MW at faulted condition (without SVC)

Fig.5(e) d-theta1-2 & Vm for L –L faults

5 SVC MODEL WITH PI CONTROLLER

The power system network with SVC proportional Integral (P.I.) controller is shown in Fig.6.

Fig.5(c) Output of SVC Vm in p.u for 1-phase fault (with SVC)
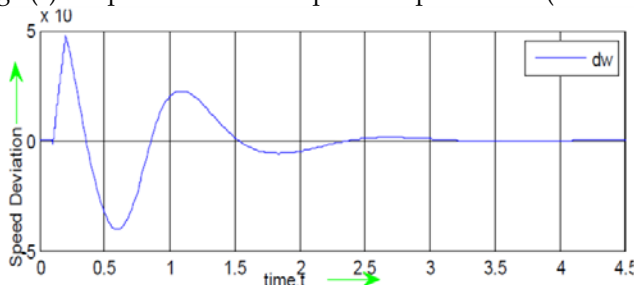
Fig.5(d) Machines speed oscillations for 1-phase fault

B. Line –Line fault:
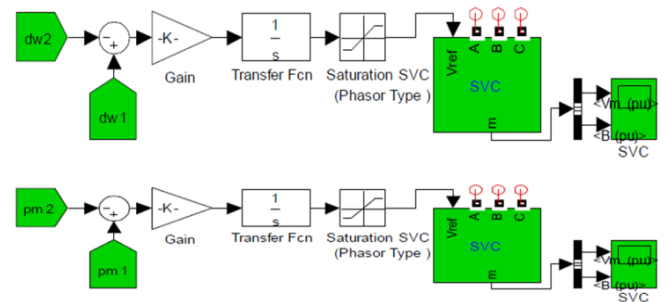
Fig. 6 Simulink diagram of SVC with P.I. controller

The angular speed deviation dω & mechanical power deviation Pm has been taken as an input parameter. When any faults occurred in the network, then both machines angular speed dω, mechanical power Pm & bus voltages will be changed & oscillated. If SVC with P.I. controller [Fig.6] is used then every network parameters become stable.

6 SIMULATION RESULTS (SVC WITH PI

CONTROLLER)

Two types of faults has been considered:
A Single line to ground fault &
B. Line-Line faults.

A. Single line to ground fault:
During 1-phase faults, after clearing the faults, the system voltage becomes stable within 3s with 0% damping [Fig. 7 (a)] & both machines speed deviation becomes stable within 3.5s [Fig.7(b)].
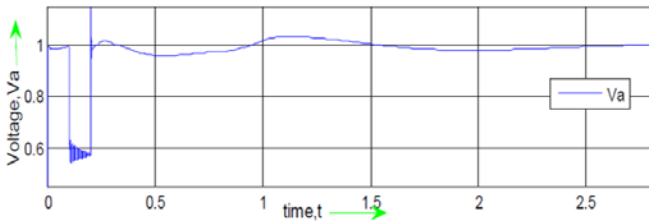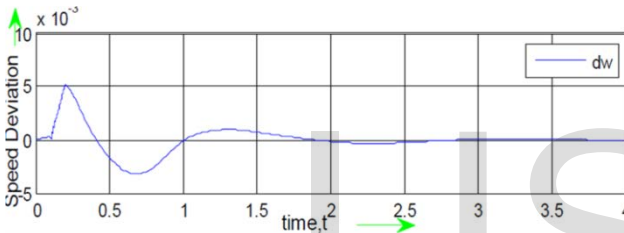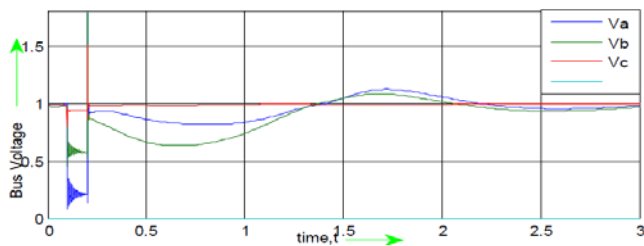

Fig.7(a) Bus voltage (in p.u.) for 1-phase fault

Fig.7(b) Machines speed oscillations for 1-phase fault

B. Line-Line fault:
During L-L faults, if SVC with P.I controller is used then the system voltage becomes stable within 3s with 0% damping [Fig. 7(c)] & machines speed deviation or oscillations becomes stable at 4.5s [Fig.7(d)].

Fig.7(c) Bus voltage (in p.u.) for L –L faults
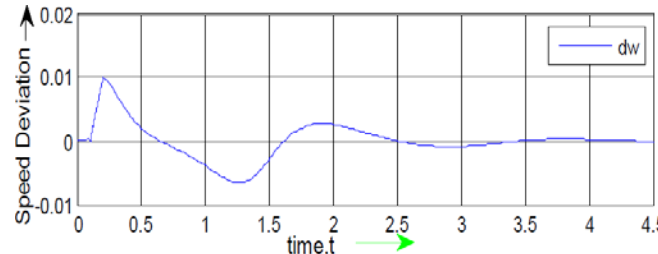
Fig.7(d) Machines speed oscillations for L-L phase fault

7 SVC MODEL WITH PID CONTROLLER

Proportional Integral Derivative (P.I.D) controller is one of the most power full controller which takes input as same as PI controller. The SVC with P.I.D controller simulink model is shown in Fig.8.
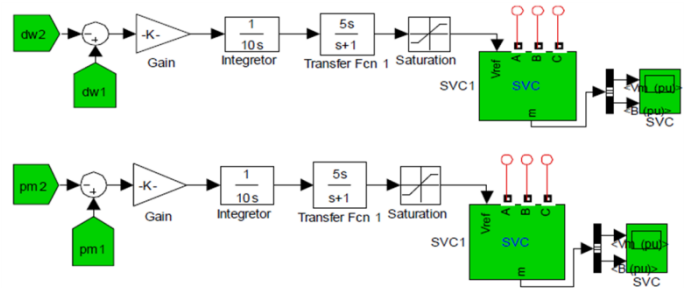

Fig.8 Simulink model of SVC with P.I.D controller

8 SIMULATION RESULTS (SVC WITH PID CONTROLLER)

Two types of faults has been considered:
A Single line to ground fault &
B. Line-Line faults.

A. Single line to ground fault:
During Single line to ground fault, if SVC with P.I.D controller is used then the system voltage becomes stable within 2.5s with 0% damping [Fig. 9(a)] & Machines speed deviation becomes stable within 3s which is shown in Fig.9(b).
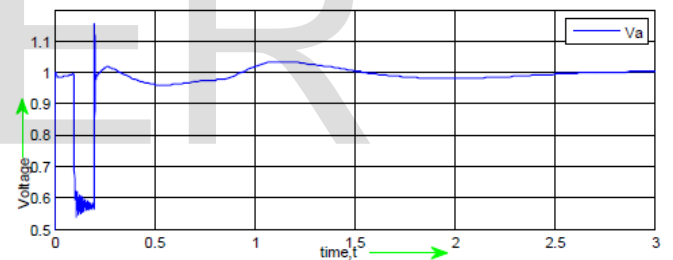

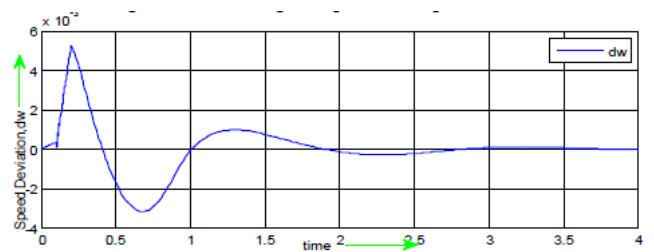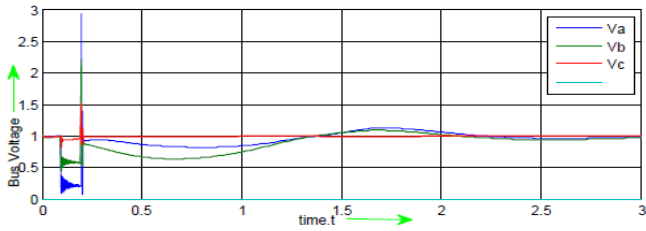Fig.9(a) Bus voltage (in p.u.) for 1-phase faults

Fig.9(b) Machines speed oscillations for 1- phase fault

B. Line-Line faults
During L-L faults, if SVC with P.I.D controller is used then the system voltage becomes stable within 2.5s with 0% damping [Fig.9(c)] & Machines speed deviation becomes stable within 3.5s which is shown in Fig.9(d).
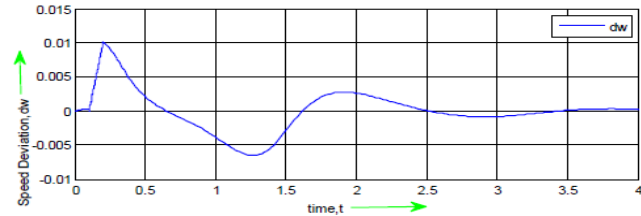
Fig. 9(c) Bus voltage (in p.u.) for L –L faults

Fig.9(d) Machines speed oscillations for L-L phase fault

9 SVC MODEL WITH POD CONTROLLER

Power Oscillation Damping (P.O.D) is a controller which externally injects Vqref to the SVC. The P.O.D controller consists of active power measurement system, a general gain, a low-pass filter, a washout high-pass filter, a lead compensator, and an output limiter. All values of the P.O.D controller has been taken from [5].
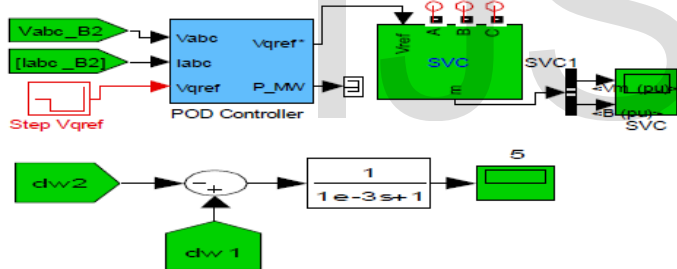

Fig.10 Simulink model of SVC with P.O.D controller

10 SIMULATION RESULTS (SVC WITH POD CONTROLLER)

Two types of faults has been considered:
   A. Single line to ground fault &
   B. Line –Line faults.

A. Single line to ground fault:
During Single line to ground fault, if P.O.D is used as SVC controller then, the system becomes stable within 2s with 0.01% damping [Fig. 11(a)] & Machines speed deviation becomes stable within 3s [Fig.11(b)].
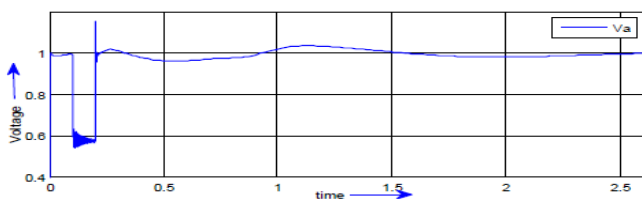
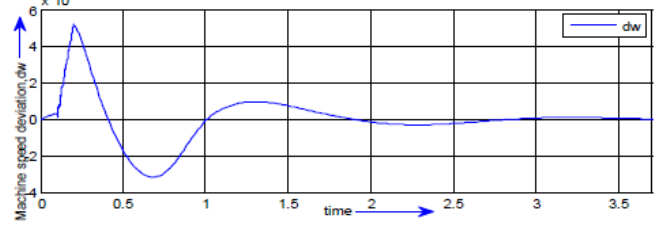

Fig.11(a) Bus voltage(B1) for 1-phase fault

Fig.11(b) Machines speed oscillations for 1- phase fault

B. Line-Line fault:
During L-L faults, Although initial damping was higher than 1-phase fault, If P.O.D is used as SVC controller then the system becomes stable within 1.5s with 0.04% damping [Fig.11(c)] & Machines speed deviation becomes stable within 2.5s with 0.04% damping [Fig.11(d)].
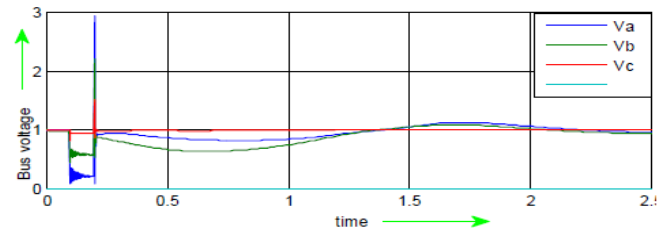

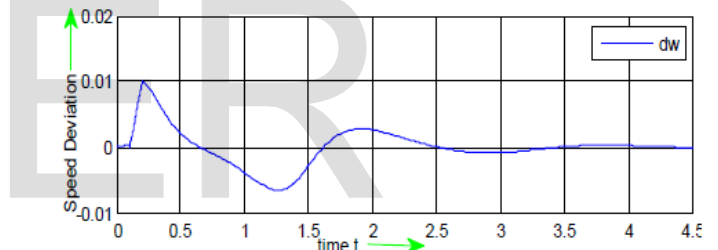Fig. 11(c) Bus voltage(B1 B2 B3) in p.u. for L-L faults

Fig.11(d) Machines speed oscillations for L-L faults

11 SVC MODEL WITH GENERIC CONTROLLER

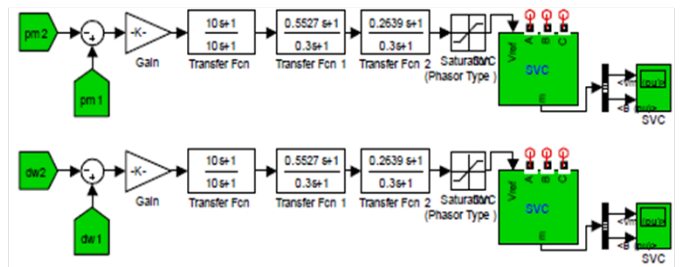The block diagram of generic SVC controller is shown in fig.12.

Fig.12 Simulink model of generic SVC controller

The input of this controller is also same as above. Tw=10, T2=T4=0.3 has been taken as constant & gain, K, T1 & T3 can be selected by properly trial & error methods. For this network, the optimum value was, K=65.49, T1=0.5527 & T3=0.2563.

12 SIMULATION RESULTS (SVC WITH GENERIC CONTROLLER)

Two types of faults has been considered:
    A. Single line to ground fault &
    B. Line –Line faults.

A. Single line to ground fault:
    During Single line to ground fault If SVC with generic controller is used then the system voltage becomes stable within 1.5s with 0.01% damping [Fig.13(a)] & Machines speed deviation becomes stable within 2s with 0.03% damping [Fig.13(b)].
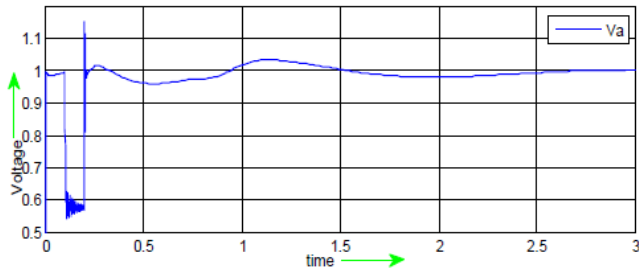

Fig.13(a) Bus voltage (B1) in p.u. for 1-phase fault
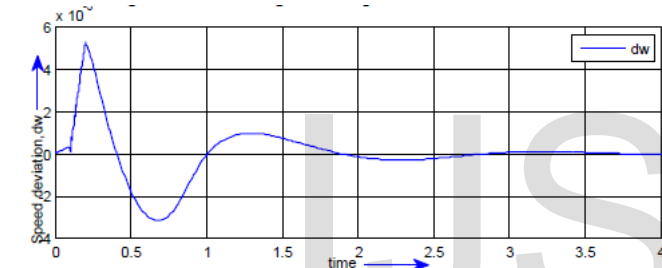

Fig.13 (b) Machines speed oscillations for 1- phase fault

B. Line-Line fault:
    During L-L faults, If SVC with generic controller is used then the system becomes stable within 1.4s with 0% damping [Fig.13(c)] & Machines speed deviation becomes stable within 2.5s with 0.02% damping [Fig.13(d)].
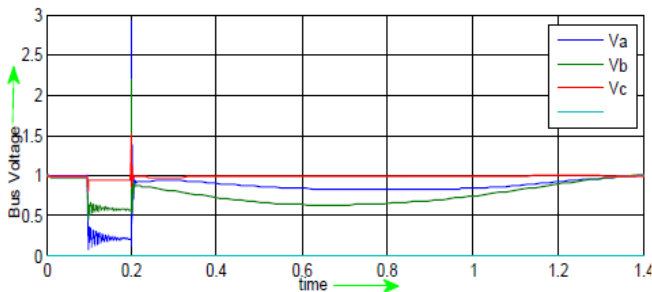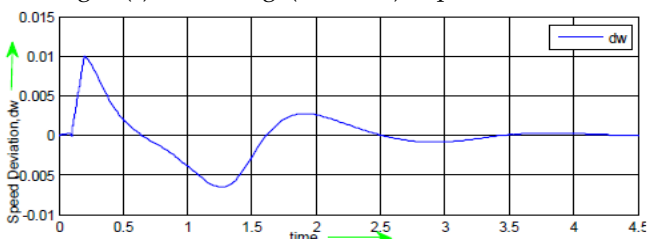

Fig.13(c) Bus voltage(B1 B2 B3) in p.u. for L-L fault

Fig.13(d) Machines speed oscillations for L-L faults

13 NN BASED SUPPLEMENTARY CONTROLLER

Comparing structures of different NNs and learning algorithms, the multilayer perceptron structure with hyperbolic tangent function as the activation function is selected for the proposed NN and a modified Delta rule is used to update the weights. Architecture of the proposed NN is shown in Fig. 14. The inputs of the NN are selected as the deviation of the generator angular speed and its two delays. There are 10 neurons in each of the first and second layers. Hyperbolic tangent function is used as the activation function of both the first and the second layers. In the third layer, the output layer, the activation function is selected as a linear function. W1, W2 and W3 are weight matrices and vector corresponding to the hidden layers and the output layer, respectively. W1 is a 3 by 10 matrix, W2 is a 10 by 10 matrix and W3 is a 10 by 1 vector.
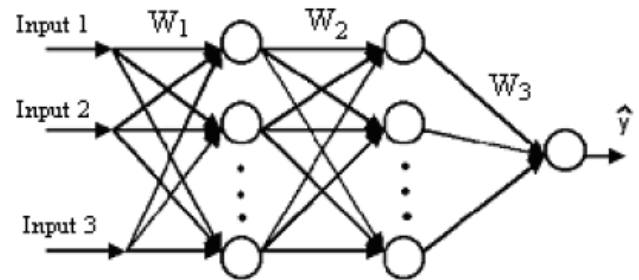

Fig. 14 Architecture of the Proposed Neural Network
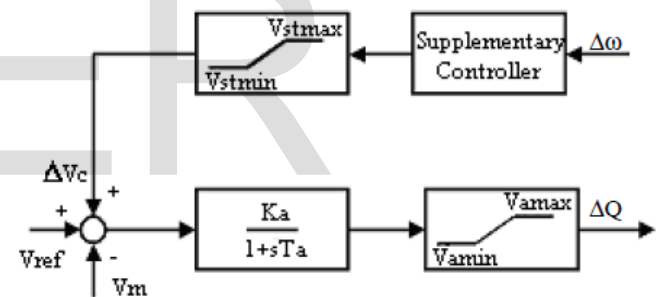

Fig. 15 SVC Controller Configuration

14 PERFORMANCE COMPARISON

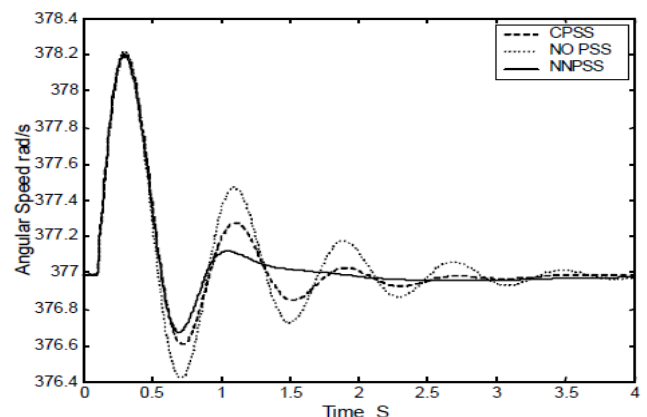The performance of different types of SVC controller taking same 500KV transmission line are summarized below:

Fig.16 Comparision of various PSS

CONCLUSION

In this paper, the voltage level of two machines power system has been improved by using SVC with different types of controller for Single line to ground fault & Line-Line faults by Phasor simulation method. Same 500KV transmission line has been simulated & observed the transient response for different types of SVC controller. Above all, SVC with Generic controller are highly efficient for voltage stability for both steady state & dynamic conditions because of having shorter voltage stability time & machine oscillation becomes damped out within very shortest time compared to other controllers. In this paper, all controller parameter has been selected by trial & error methods normally, but those parameters can be selected by Fuzzy, Neural network or Genetic algorithm techniques. Those controllers special advantage is that they can be used on any robust multi-machine power system network with very easily & cheaply. In this paper, only machines angular speed deviation (dω) & Mechanical power(pm) has been taken as input parameters of those controllers. But when any fault occurred, then voltage, current, power, mechanical power (pm), machines angular speed deviation (dω) everything will change. So, future work should be taken all of the above parameters as input parameters of those controllers & controller parameters can be tuned with any newly deigned algorithm.

REFERENCES

[1] Amit Garg ,‖Modeling and Simulation of Static VAR Compensator for Improvement of Voltage Stability in Power System ISSN: 2249-071X, Vol.2,Issue-2

[2] Ali M. Yousef ―Transient stability Enhancement of multi machine using Global deviation PSS‖ ‖ Journal of Engineering sciences, Faculty of Engineering, Assiut University, Vol. 32-No.2 April 2004 pp. 665-677.

[3] A.E. Hammad, ―Analysis of power system stability enhancement by static var compensator‖, IEEE PWRS, vol 1, no. 4, pp. 222-227B. Smith, An approach to graphs of linear forms (Unpublished work style), unpublished.

[4] Nang Sabai, and Thida Win (2008) ―Voltage control and dynamic performance of power transmission system using SVC World Academy of Science, Engineering and Technology 42 Pp. 425-429.

[5] " MATLAB Math Library User's Guide", by the Math Works. Inc.

[6] Nang Sabai, and Thida Win (2008) ―Voltage control and dynamic performance of power transmission system using SVC‖ World Academy of Science, Engineering and Technology 42 Pp. 425-429.