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A Novel Approach to Dynamic Stability Enhancement Using PID Damped ANN Controlled Static VAR Compensator (SVC)

M.Hariprasad[1], A.Hemasekhar[2]

PG Student [EPS], Dept. of EEE, SVPCET, Puttur A.P., India[1]

Associate Professor & HOD, Dept. of EEE, SVPCET, Puttur A.P., India[2]

ABSTRACT: This paper presents a novel approach to dynamic stability enhancement using PID damped ANN controlled static VAR compensator (SVC). Static VAR compensator is proven the fact that it improves the dynamic stability of power systems apart from reactive power compensation; it has multiple roles in the operation of power systems. The additional auxiliary control signals to SVC play a very important role in mitigating the rotor electromechanical low frequency oscillations. A proportional integral- derivative (PID) type controller & ANN is designed using the generator speed deviation, as a modulated signal to SVC, to generate the desired damping, is proposed in this paper. The ANN is trained using conventional controlled data and hence replaces the conventional controller. The ANN controlled SVC is used to improve the dynamic performance of power system by reducing the steady-state error and for its fast settling. The simulations are carried out for multi-machine power system (MMPS) at different operating conditions.

KEYWORDS: Artificial Neural Network, Dynamic Stability, FACTS, Power System, Static VAR Compensator

I. INTRODUCTION

The stability of a system refers to the ability of a system to return back to its steady state when subjected to a disturbance. Power is generated by synchronous generators that operate in synchronism with the rest of the system. A generator is synchronized with a bus when both of them have same frequency, voltage and phase sequence. Thus the power system stability can be defined as the ability of the power system to return to steady state without losing synchronism. Usually power system stability is categorized into steady state, transient and dynamic stability . The dynamic stability (also known as small-signal stability) is the ability of a power system to maintain stability under continuous small disturbances. These small disturbances occur due to random fluctuations in loads and generation levels. In an interconnected power system, these random variations can lead catastrophic failure. The disturbances are considered sufficiently small for linearization of system equations to be permissible. The instability of power system may lead to the steady increment in rotor angle due to lack of sufficient synchronizing torque and increasing amplitude of rotor oscillations due to lack of sufficient damping torque.

The nature of system response to small disturbances depends on a number of factors including initial operating conditions, transmission system and the type of generator excitation controls used. In today's practical power system, dynamic stability is largely a problem of insufficient damping of oscillations. Modern Power Systems are equipped with fast acting static excitation systems, as these units become a large percentage of the generating capacity; they have a large impact upon the dynamic stability of power systems. They introduce negative damping at the electro-mechanical oscillation frequencies of the machines in the range of 0.1Hz to 2.5 Hz. They make the system unstable under local and inter-area modes of oscillations. Particularly when the system is weak and with weak tie lines even a small disturbance will make the system unstable.

The purpose of dynamic stability is to examine the dynamic performance of a synchronous machine under small perturbations. Since the machine must remain in synchronism under small perturbations, it is essential to have

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positive damping for the machine. The damping torque of the synchronous machine is affected by a number of factors viz. Machine loading, excitation controls, Power System Stabilizer parameters and loads etc. Hence, a detail-linearized model is required to examine the dynamic stability. Power System Stabilizers were developed to damp out these oscillations by modulating generator excitation and introducing positive damping to the system. This is because of the fact that the above novel approaches are superior to algorithmic methods and are adaptive in nature. They also possess fast response with reduced transients and can also adapt themselves to the non-linearity in the system. The limitations of ANN based stabilizers are in its learning ability and suitable learning algorithms are required and this may even system dependent Flexible AC Transmission Systems (FACTS) are new devices emanating from recent innovative technologies that are capable of altering voltage, phase angle and/or impedance at particular points in power systems. Their fast response offers a high potential for power system stability enhancement apart from steady-state flow control. The simulated studies of FACTS devices reveal the fact that they improve the dynamic stability of power system if utilized properly.

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. The SVCs with auxiliary control signals in their voltage control loops can effectively enhance the damping of power system oscillations and improve power systems stability.

II.STUDY THE STEADY-STATE AND DYNAMIC PERFORMANCE OF A STATIC VAR COMPENSATOR (SVC) ON A TRANSMISSION SYSTEM

The SVC is a shunt device of the Flexible AC Transmission Systems (FACTS) family using power electronics. It regulates voltage by generating or absorbing reactive power. If you are not familiar with the SVC, see the Static Var Compensator (Phasor Type) block documentation, which describes the SVC principle of operation. The Static Var Compensator (Phasor Type) block of the FACTS library is a simplified model that can simulate any SVC topology. You can use it with the phasor simulation option of the Powergui block for studying dynamic performance and transient stability of power systems. Due to low frequencies of electromechanical oscillations in large power systems (typically 0.02 Hz to 2 Hz), this type of study usually requires simulation times of 30–40 seconds or more. The SVC model described in this example is rather a detailed model of a particular SVC topology (using thyristor-controlled reactor (TCR) and thyristor-switched capacitors (TSCs)) with full representation of power electronics. This type of model requires discrete simulation at fixed time steps (50 µs in this case) and it is used typically for studying the SVC performance on a much smaller time range (a few seconds). Typical applications include optimizing of the control system, impact of harmonics, transients and stresses on power components during faults.

Description of the SVC

The single-line diagram of the modeled SVC is shown on Single-Line Diagram of the SVC. It represents a 300 Mvar SVC connected on a 735 kV transmission system. This example is available in the power_svc_1tcr3tsc model. Load this model and save it in your working directory as case2 to allow further modifications to the original system. This model is shown on SPS Model of the 300 Mvar SVC on a 735 kV Power System (power_svc_1tcr3tscs).

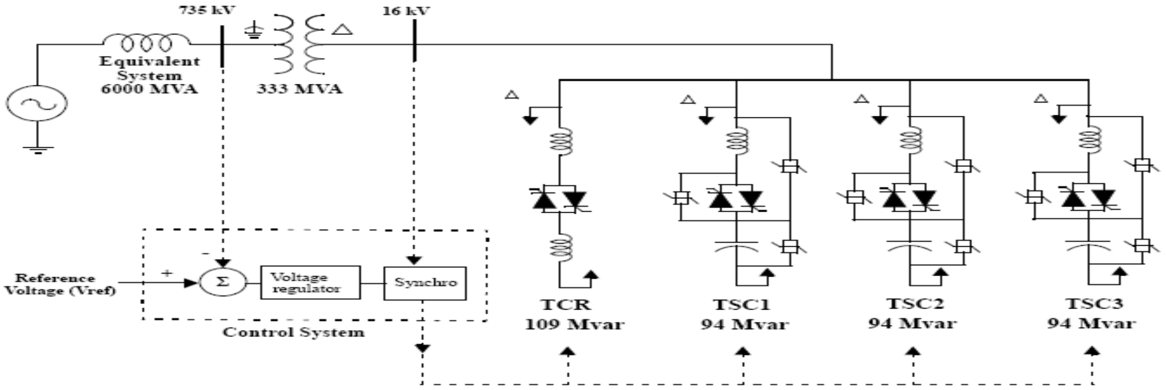

Fig .1.rep Single-Line Diagram of the SVC

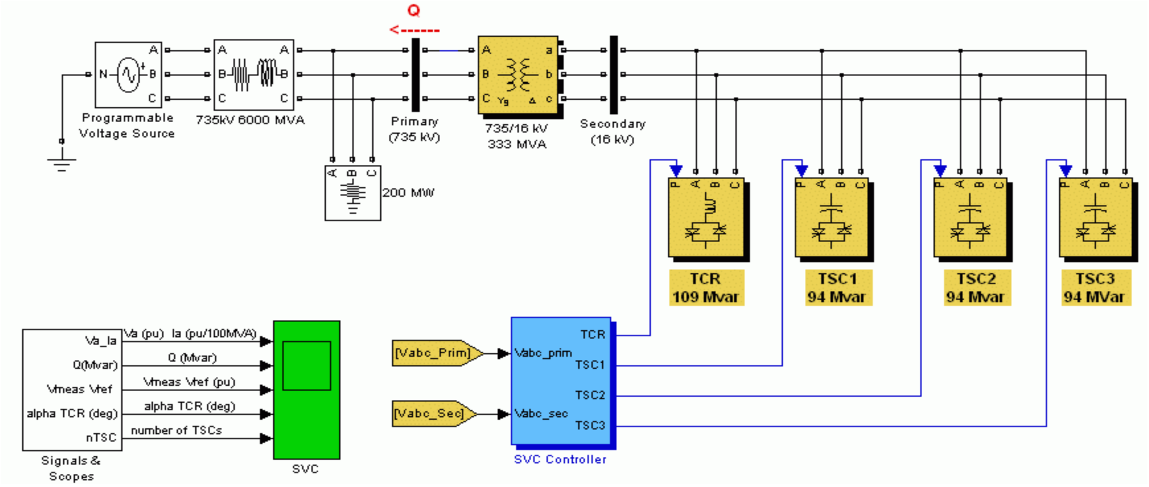

Fig .2..rep SPS Model of the 300 Mvar SVC on a 735 kV Power System (power_svc_1tcr3tscs)

III.MULTI-MACHINE POWER SYSTEM (MMPS)

The results of multi-machine power system for different case studies under operating condition 1, operating condition 2 and operating condition 3 are shown in Table 1, Table 2 and Table 3 respectively. The rotor angle fluctuations on machine 2 w.r.t. machine 1 Δδ12, rotor angle fluctuations on machine 3 w.r.t. machine 1 Δδ13, terminal voltage fluctuations on machine 2 ΔVt2 and terminal voltage fluctuations on machine 3 ΔVt3, for operating condition 1 .The rotor angle fluctuations on machine 2 w.r.t. machine 1 Δδ12, rotor angle fluctuations on machine 3 w.r.t. machine 1 Δδ13, terminal voltage fluctuations on machine 2 ΔVt2 and terminal voltage fluctuations on machine 3 ΔVt3 for operating condition 2. The rotor angle fluctuations on machine 2 w.r.t. machine 1 Δδ12, rotor angle fluctuations on machine 3 w.r.t. machine 1 Δδ13, terminal voltage fluctuations on machine 2 ΔVt2 and terminal voltage fluctuations on machine 3 ΔVt3 for operating condition 3 and different case studies are shown in Figure 5. From the results given in Table 1, Table 2 and Table 3 and responses shown Figure 1, Figure 2 and Figure 3 it is observed that the MMPS without SVC is not settling, MMPS with SVC on macnine 2 is taking large settling time. From the results it is clear that it is very much essential that the damping controlled SVC must be placed on machine 2, to reduce the settling time of rotor oscillations and also terminal voltage fluctuations, the damping controller can be conventional PID controller or ANN controller. The order of overall system will be reduced with ANN damping controlled SVC in comparison to PID damping controlled SVC. Hence the stability margin will be increased with ANN damping controlled SVC.

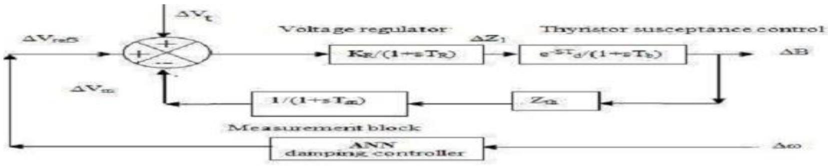

Figure 3. Dynamic modelling of SVC with additional ANN damping controller introduced in the auxiliary signals.

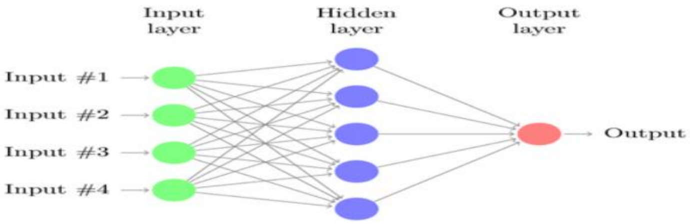

Figure 4. Philips Heffron model of MMPS with ANN damping controlled SVC

Loss reduction is the main concern in power generation and transmission. After many observations, it has been concluded that during transmission of the power, large portion of the generated power goes as losses. So to reduce the power cost, losses should be minimized. Losses generally depend upon the length of transmission as losses are high during long transmission of electricity. Transmission line conductors also play an important role determining the losses. The conductors can carry power only it is capable of, and rest power is lost during transmission to ensure that system is not overloaded. Hence, power distribution with proper conductor cables is very critical in determining the system protection.

Load balancing of power is done by open/close tie-switches in the distribution feeders. Overloading of network is maintained by transferring load from heavily loaded feeders to the less loaded feeders. Reconfiguring system is one of the main techniques for load balancing. It allows smoothening the load demands by distribution, reduced feeder losses and increased network reliability.

$[P_m – A/C]^2 + [Q_m – B/C]^2 = [A/C]^2 + [B/C]^2 - \Delta LB^S_{tm}/C$ (1.1)

Where, $A = \Sigma K_l P_l - \Sigma K_h P_h$ (1.2)

$B = \Sigma K_l Q_l - \Sigma K_h Q_h$ (1.3)

$C = K_{loop}$ (1.4)

ΔLB^S_{tm} = change in load balancing

P_m and Q_m = real and reactive power flows

K_{loop} = sum of K value from each branch

From equation 1.1,

Center of the circle = (A/C, B/C) (1.5)

And,

Radius = $[(A^2 + B^2)/C^2 - \Delta LB^S_{tm}/C]^{1/2}$ (1.6)

Now as discussed above, in zero load balancing change $\Delta LB^{S}_{tm} = 0$. So from equation 1.1,

$$[P_m - A/C]^2 + [Q_m - B/C]^2 = [A/C]^2 + [B/C]^2 \qquad (1.7)$$

IV.RESULTS AND ANALYSIS

The MMPS (WSCC 3 machine nine-bus system) is modeled as a Philips Heffron model with ANN damping controlled SVC as shown in Figure 2. The Philips Heffron model is simulated in Mat lab Simulink environment for different operating conditions and case studies like without SVC, with SVC, with PID damping controlled SVC and with ANN damping controlled SVC.

Different operating conditions are as follows:
(i) Operating condition 1: $\Delta Tm1=10\%$, $\Delta Tm2=0$, $\Delta Tm3=0$
(ii) Operating condition 2: $\Delta Tm1=0$, $\Delta Tm2=10\%$, $\Delta Tm3=0$
(iii) Operating condition 3: $\Delta Tm1=10\%$, $\Delta Tm2=10\%$, $\Delta Tm3=0$
Different case studies are as follows:
(i) No SVC and No Power System Stabilizer (PSS)
(ii) SVC on machine 2 only
(iii) PID SVC on machine 2 only
(iv) ANN SVC on machine 2 only

Table 1. Results of machine2 and machine3 for MMPS under operating condition 1

Case Studies	$\Delta\delta_{12}$		$\Delta\delta_{13}$		ΔV_{t2}		ΔV_{t3}	
	e_{ss} in pu	t_{ss} in sec	e_{ss} in pu	t_{ss} in sec	e_{ss} in pu	t_{ss} in sec	e_{ss} in pu	t_{ss} in sec
Without SVC	0.0770	NS	0.2330	NS	-0.001032	NS	0.006900	NS
SVC on m/c2	0.0662	LST	0.2182	LST	-0.000700	LST	0.005200	LST
PID SVC on m/c2	0.0412	6	0.1072	6	-0.000514	6	0.002284	6
NN SVC on m/c2	0.0412	6	0.1072	6	-0.000511	6	0.002286	6

Table 2. Results of machine2 and machine3 for MMPS under operating condition 2

Case Studies	$\Delta\delta_{12}$		$\Delta\delta_{13}$		ΔV_{t2}		ΔV_{t3}	
	e_{ss} in pu	t_{ss} in sec	e_{ss} in pu	t_{ss} in sec	e_{ss} in pu	t_{ss} in sec	e_{ss} in pu	t_{ss} in sec
Without SVC	-0.1000	NS	0.2420	NS	0.005000	NS	0.0076	NS
SVC on m/c2	-0.0700	LST	0.2820	LST	0.002500	LST	0.0079	LST
PID SVC on m/c2	-0.0375	6	0.1323	6	0.001786	6	0.0039	6
NN SVC on m/c2	-0.0375	6	0.1323	6	0.001786	6	0.0039	6

Table 3. Results of machine2 and machine3 for MMPS under operating condition 3

Case Studies	$\Delta\delta_{12}$		$\Delta\delta_{13}$		ΔV_{t2}		ΔV_{t3}	
	e_{ss} in pu	t_{ss} in sec	e_{ss} in pu	t_{ss} in sec	e_{ss} in pu	t_{ss} in sec	e_{ss} in pu	t_{ss} in sec
Without SVC	0.0900	NS	0.4520	NS	0.0052	NS	0.01220	NS
SVC on m/c2	0.0625	LST	0.5000	LST	0.0016	LST	0.01300	LST
PID SVC on m/c2	0.0045	6	0.2400	6	0.0013	6	0.00630	6
NN SVC on m/c2	0.0036	6	0.2394	6	0.0012	6	0.00628	6

NS-Not Settling, LST-Large Settling Time, e_{ss}-Steady State Error, t_{ss}-Settling time

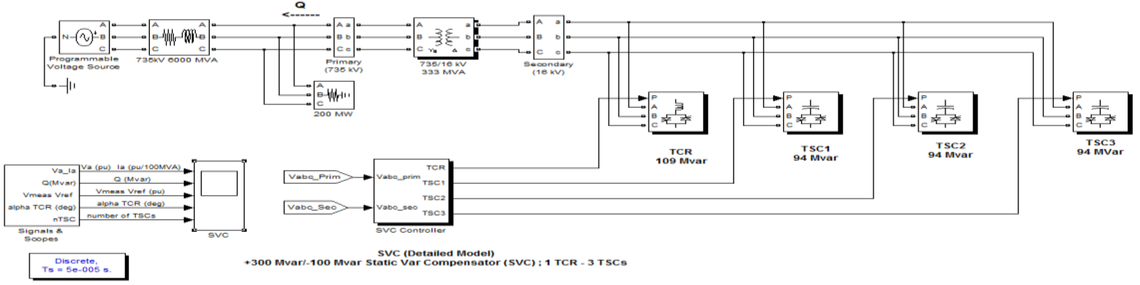

Fig 5.Multi Machine Power System with SVC

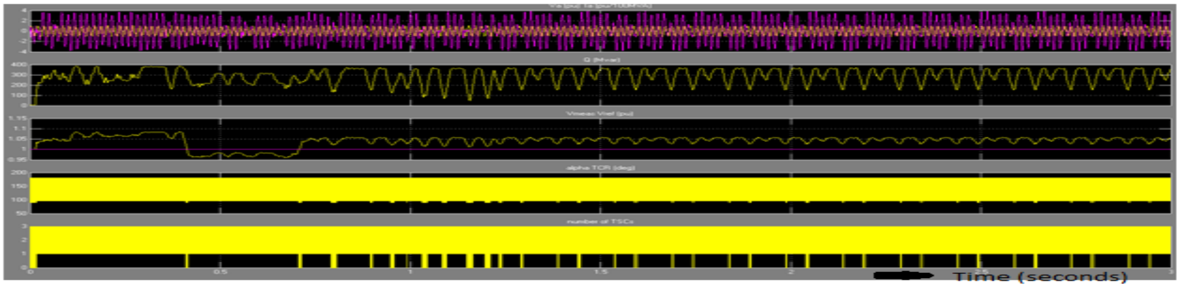

Fig 6.Simulation results of MMPS with SVC

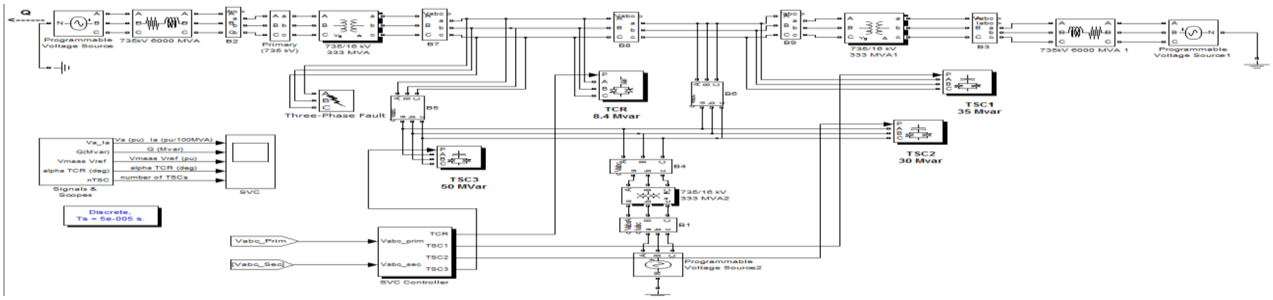

Fig .7.Simulation diagram with svc with pid controllers

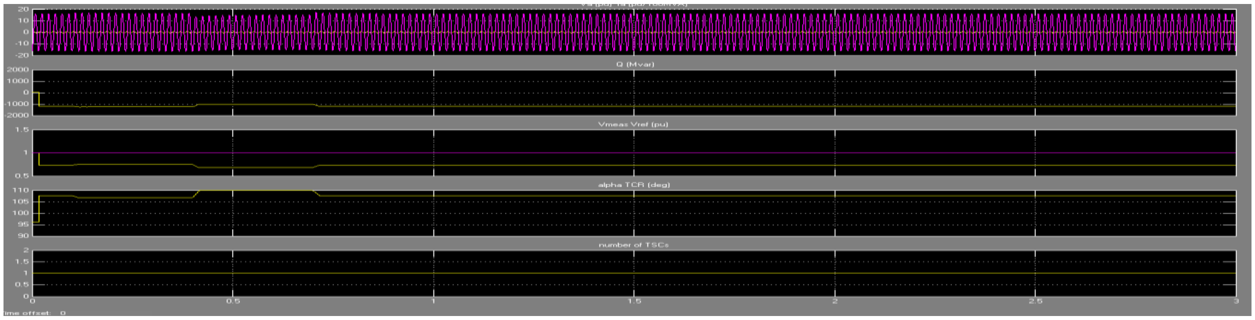

Fig .8.Simulation results with svc with pid controllers

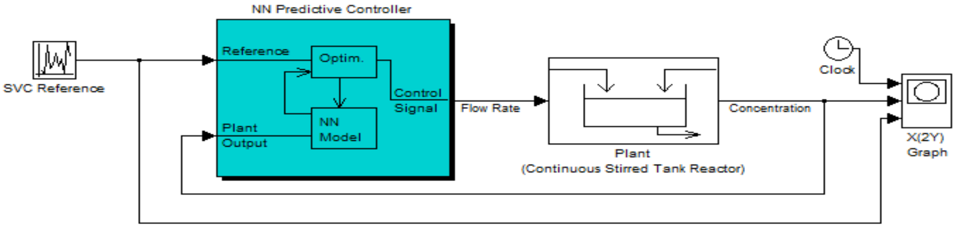

Fig 9.Svc with artificial neural networks

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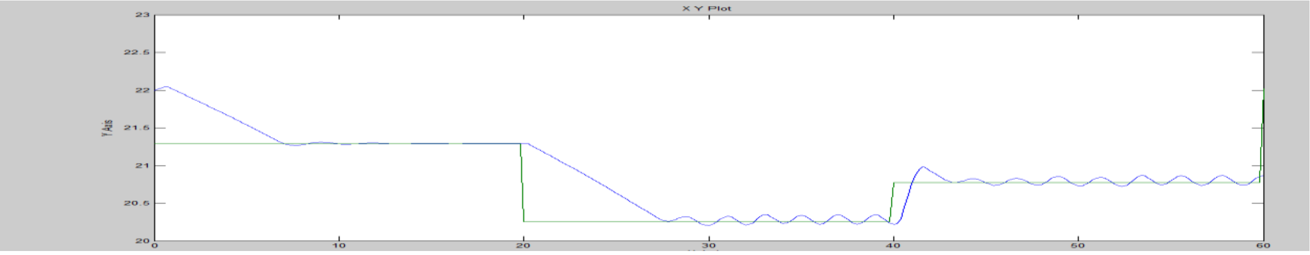

Fig 10.Svc with artificial neural networks with time & voltage

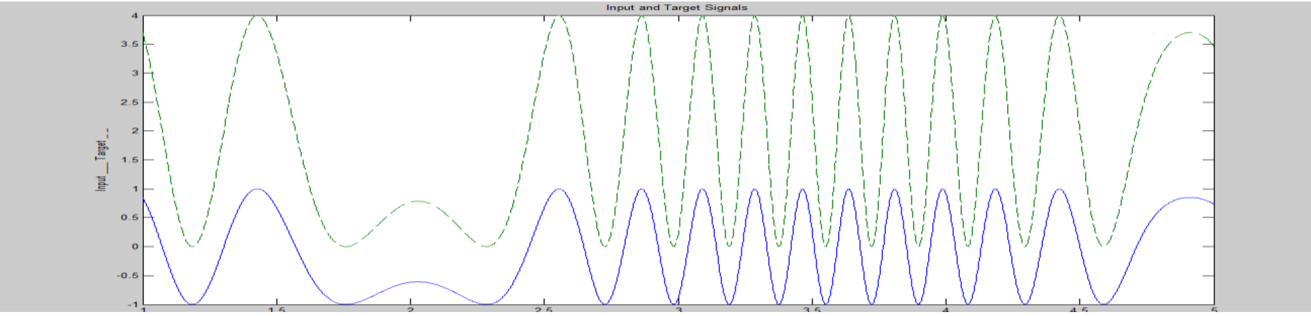

Fig 11.Svc with Artificial neural networks with time & input

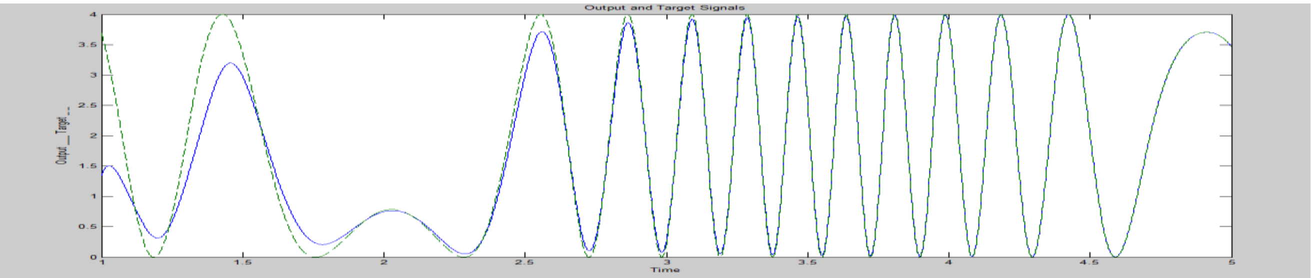

Fig 12.Svc with Artificial neural networks with time & output

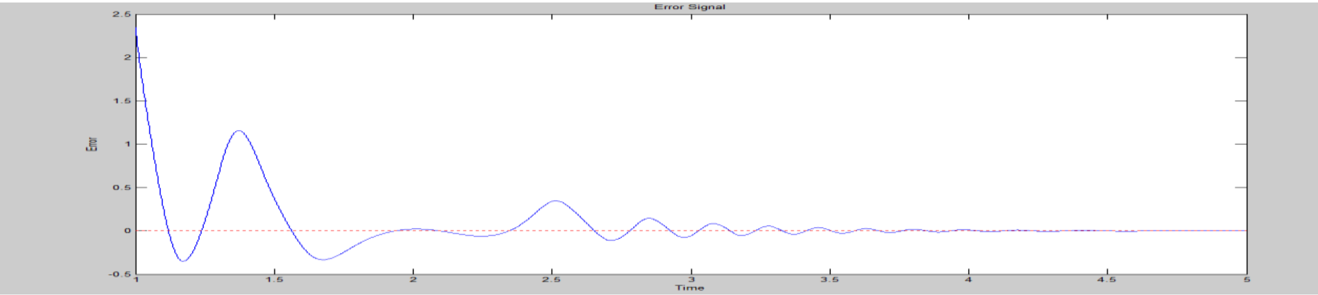

Fig 13.Svc with Artificial neural networks with time & Error

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V.CONCLUSIONS

In this paper dynamic stability of MMPS is enhanced using ANN damping controlled SVC. Apart from damping of oscillations in the generator, terminal voltages has also been reported and tested on MMPS. The conclusions are that SVC on its own is unable to damp out the oscillations and requires an additional damping controller to improve the dynamic stability of power system. The comparison of results with SVC and proposed ANN damping controlled SVC which are tested on MMPS prove that SVC with an additional ANN damping controller can mitigate the problem of dynamic stability of power system i.e. they damp out the rotor mechanical low frequency oscillations quickly. SVC placed at the terminal bus of the machine enhances the reactive power limits of the machine and also reduces the terminal voltage fluctuations effectively. . ANN controlled SVC has an added advantage of adaptability for changing operating conditions and for the non-linearity's in the system. ANN controlled SVC hence mitigate the problem of rotor electro-mechanical low frequency oscillations intelligently. In future it can be implemented for the real-time control of power system.

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BIOGRAPHY

A.Hemasekhar, he received his B.Tech (Electrical and Electronics Engineering) degree from JNTU, Hyderabad, at Sree Vidyaniketan Engineering College, Rangampet; M.Tech (PSOC) from the S.V.University college of Engineering,Tirupati. He is currently working as Associate Professor & Head of the Dept. of Electrical and Electronic Engineering, S.V.P.C.E.T,Puttur. His area of interest power systems, operation and control, distribution systems, electrical machines, power stability

M.Hari prasad he received the B.Tech (Electrical and Electronics Engineering) degree from the Jawaharlal Nehru Technological University, Anantapur in 2012 and pursuing the M.Tech (Electrical power system) from Jawaharlal Nehru Technological University, Anantapur.