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Combined Operation of SVC, PSS and Increasing Inertia of Machine for Power System Transient Stability Enhancement

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ABSTRACT

In this paper improvement of transient stability by coordination of PSS (Power System Stabilizer) and SVC (Static var Compensator) and increasing inertia of synchronous machine has been observed. Because single method is not sufficient for improving stability. For this purpose a 9 bus multi machine system has been considered. Transient stability improvement has been tested subjected to three phase fault at bus 3 after 0.5 second and fault has been cleared after 1 second. By the use of PSS, SVC and by increasing inertia method for the test system the electromechanical oscillation for generator electrical power has been reduced and the steady state power transfer has been enhanced. In this paper the Inertia of the machine is not so much increased. Because after increasing inertia of the machine rotor will be havier.so that it is kept always within limit as considering its reliability and economy. And field voltage is also kept limited.

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NOMENCLATURE

Parameter	Defintion	Parameter	Definition
Ra	armature resistance in ohm	Xd", Xq"	direct-axis,quadrature-axis synchronous subtransient reactance in percent
Xd',Xq'	direct-axis,quadrature-axis synchronous transient reactance in percent	Xd,Xq	direct-axis,quadrature-axis synchronous reactance in percent
X1	positive sequence reactance	R0,X0	zero sequence resistance.reactance
X/R	armature X/R ratio	Td0" ,Tq"	direct-axis,quadrature-axis subtransient open circuit time constant in seconds
Td0',Tq'	direct-axis,quqdrature-axis transient open-circuit time constant in seconds	H	intertia of synchronous machine
D	shaft mechanical damping term in percent	S100,S120	saturation factor at 100%,120% terminal voltage
Sbreak	per unit of terminal voltage at which the generator saturation curve skews from the air-gap line.	VSI	PSS input (speed, power or frequency) in pu
KS	PSS gain(p.u)	VSTmax, VSTmin	Maximum, Minimum PSS output(p.u)
TDR	Reset time delay for discontinuous controller(sec.)	A1,A2	PSS signal conditioning frequency filter constant(p.u)
T1,T3	PSS lead compensation time constant(sec.)	T2,T4	PSS leg compensation time constant(sec.)
T5,T6	PSS washout time constant(sec	KA	Regulator gain(p.u)

Efdmax	Maximum exciter output voltage(p.u)	KE	Exciter constant for self-excited field(p.u)
Kf	Regulator stabilizing circuit gain(p.u)	TA	Regulator amplifier time constant(sec.)
TB,TC	Voltage regulator time constant(sec.)	TE	Exciter time constant(sec.)
TF,	Regulator stabilizing circuit,Input filter time constant(sec.)	TR	Regulator Input filter time constant(sec.)
VRmax,	Maximum value of the regulator output voltage(p.u)	VRmin	Minimum value of the regulator output voltage(p.u)
SEmax	The value of excitation function at Efdmax	SE.75	The value of excitation function at 0.75 Efdmax
K	Voltage regulator gain(p.u)	a1,a2	Additional control signal gain
T	Voltage regulator time constant(sec.)	tm	Measurement time constant(sec.)
Tb	Thyristor phase control time constant(sec.)	td	Thyristor phase control delay(sec.)
t1,t2	Voltage regulator time constant(sec.)	tbmax,tbmin	Maximum,minimum susceptance limit(p.u)

1. INTRODUCTION

Electrical power systems are being more and more complicated every year and proportionally their analysis will also become more difficult. So, there is an intense need to use more efficient methods for power system analysis. One of the most important topics in power system is the inspection of the transient stability when power system being subjected to a contingency. Transient stability is the ability of power system to keep its synchronism when a large disturbance, like three phase short circuit, occurs in the system. Several factors like the initial condition of the power system, type, severity and location of the fault affect the transient stability. The maximum duration that one fault can remain in the power system without causing instability is the critical clearing time (CCT) of that fault. Improvements in transient stability performance of power systems have been achieved traditionally through uses of high-speed fault-clearing, high initial-response exciters, series capacitors, facts controller and other stability measures [1]-[3]. With the development of modern power systems, there is a tendency of increased complexity of stability problems and an increasing concern about consequences of instability. The need for introducing new methods to improve stability has been widely recognized. The model developed so far for transient stability analysis has assumed balanced three phase operation even during the fault period [2]. Although three-phase fault are in most cases the most onerous, there are occasions when unsymmetrical fault conditions need to be analyzed [3].

In this paper improvement of transient stability analysis of 9-bus multi machine system by using the coordinated effect of power system stabilizer(PSS),static var compensator(or SVC) and by increasing the inertia of the machine. In this analysis we create a three phase fault on specified bus and then investigation is to analyse the behaviour of the synchronous machine. For this work we used the licensed packaged of ETAP software.

The paper is organised as follows: section 2 gives a brief introduction of power system stabilizer (or PSS) and static var compensator (or SVC).A 9-bus multi machine system or test system is described In section 3. The computer simulation results for system under study are presented and discussed in Section 4 and in Section 5 conclusions are given.

2. MODEL SYSTEM

The test system that has been considered here is the 9-Bus Multi-Machine System as shown below in Fig.(a).which consisted 9-bus, three generators, four cables,five transformer and two loads one is static load of 100 MVA and another is an induction motor of 25 MW. Gen-1,Gen-2 and Gen-3 rated of 85 MW,127.5 MW and 170 MW respectively.All other input parameters of generators are shown below in Table-1,2 and 3. The IEEE type of DC1 exciter, with continuously acting voltage regulators are installed with all generators. The exciter is self exicted,.When self-excited, Ke is selected so that initially Vr =0, representing operator action of tracking the voltage regulator by periodically trimming the shunt field rheostat set point. Input data of exicter is shown in Table-4. And IEEE type of PSS1A is connected with all generators.The parameters of power system stabilizer is shown in Table-5. SVC 1 is connected in shunt at the bus-9 of Gen-3.

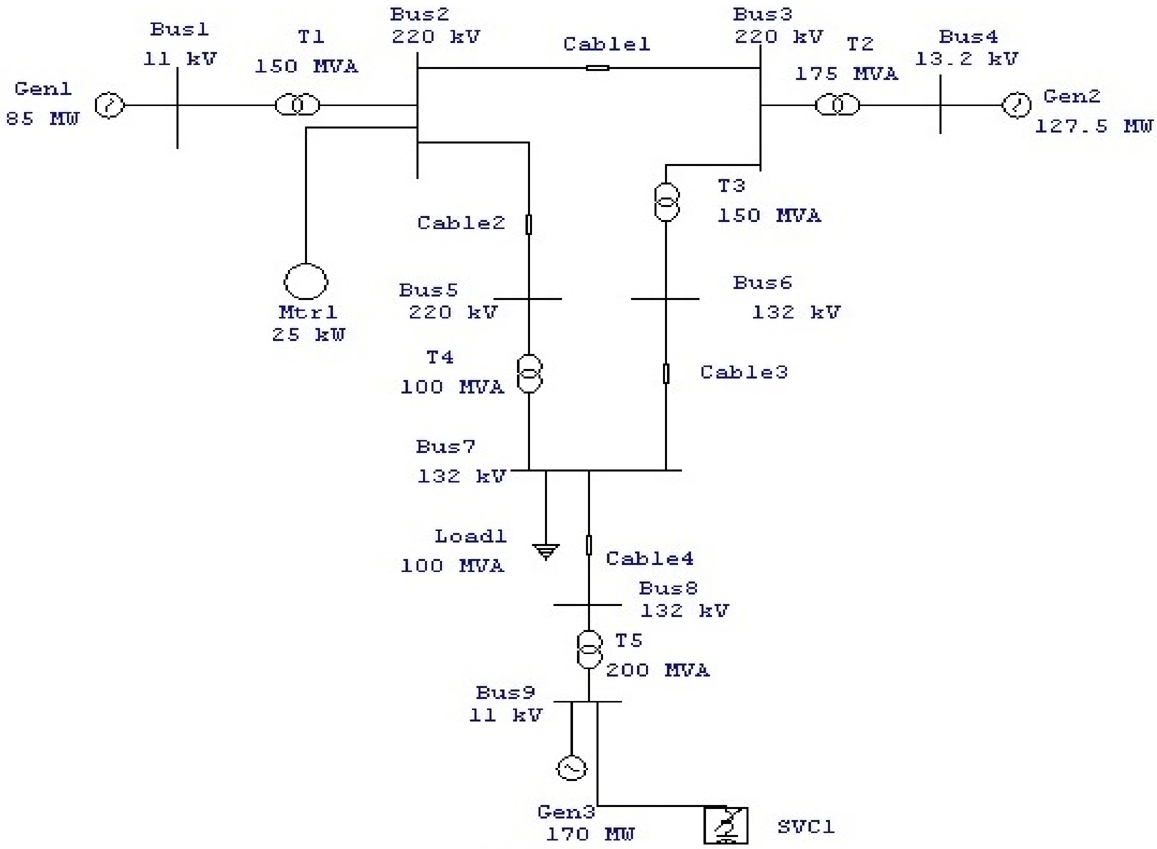


Fig.(a) Test system

Table-1: SYNCHRONOUS MACHINE PARAMETERS

Machine			Rating		Positive sequence impedence(%)								Zero seq. Z(%)		
ID	TYPE	MODEL	MVA	KV	R_a	X_d"	X_d'	X_d	X_q"	X_q'	X_q	X_1	X/R	R_0	X_0
Gen1	Generator	Subtransient, Round-Rotor	100	11	1	19	28	155	19	65	155	15	7	1	7
Gen2	Generator	Subtransient, Round-Rotor	150	13.2	1	19	28	155	19	65	155	15	7	1	7
Gen3	Generator	Subtransient, Round-Rotor	200	11	1	19	28	155	19	65	155	15	7	1	7

Table-2: DYNAMIC PARAMETERS OF SYNCHRONOUS MACHINE

Machine	Connected bus	Time cons.(sec.)				H(Sec.),,D(MW pu/Hz)&Saturation					Grounding	
ID	ID	T_{d0}"	T_{d0}'	T_{q0}"	T_{q0}'	H	%D	S100	S120	Sbreak	Conn.	Type
Gen1	Bus1	0.03	6.5	0.03	1.25	12	0	1.7	1.18	0.8	WYE	SOLID
Gen2	Bus4	0.03	6.5	0.03	1.25	12	0	1.7	1.18	0.8	WYE	SOLID
Gen3	Bus9	0.03	6.5	0.03	1.25	12	0	1.7	1.18	0.8	WYE	SOLID

Table-3: MECHANICAL PARAMETERS OF SYNCHRONOUS MACHINE

Machine		Generator/Motor			Coupling			Prime Mover/Load			Equivalent Total		
ID	TYPE	WR^2	RPM	H	WR^2	RPM	H	WR^2	RPM	H	WR^2	RPM	H
Gen1	Gen.	32406	1500	4	32406	1500	4	32406	1500	4	97217.99	1500	12
Gen2	Gen.	48609	1500	4	48609	1500	4	48609	1500	4	145826.98	1500	12
Gen3	Gen.	64811	1500	4	64811	1500	4	64811	1500	4	194432.98	1500	12

Table-4: EXCITER INPUT DATA

Type: DC1

Machine ID	Control Bus ID	KA Efd_{max}	KE	KF	TA	TB	TC	TE	TF	TR	VR_{max}	VR_{min}	SE_{max}	SE.75
Gen1	Bus1	46 2.63	0.05	0.1	0.06	0	0	046	1	0.005	1	-0.9	0.33	0.1
Gen2	Bus4	46 2.63	0.05	0.1	0.06	0	0	0.46	1	0.005	1	-0.9	0.33	0.1
Gen3	Bus9	46 2.63	0.05	0.1	0.06	0	0	0.46	1	0.005	1	-0.9	0.33	0.1

Table-5: POWER SYSTEM STABILIZER (PSS) INPUT DATA

Type: PSS1A

Generator ID	VSI	KS	VSTMax	VSTMin	VTMin	TDR	A1	A2	T1	T2	T3	T4	T5	T6
Gen1	SPEED	3.15	0.9	-0.9	0	0.2	0	0	0.76	0.1	0.76	0.1	1	0.1
Gen2	SPEED	3.15	0.9	-0.9	0	0.2	0	0	0.76	0.1	0.76	0.1	1	0.1
Gen3	SPEED	3.15	0.9	-0.9	0	0.2	0	0	0.76	0.1	0.76	0.1	1	0.1

3. IMPLEMENTATION OF SVC AND PSS

SVCs are part of the Flexible AC transmission system device family, regulating voltage and stabilising the system. The term "static" refers to the fact that the SVC has no moving parts (other than circuit breakers and disconnects, which do not move under normal SVC operation). The SVC is an automated impedance matching device, designed to bring the system closer to unity power factor. If the power system's reactive load is capacitive (leading), the SVC will use reactors (usually in the form of Thyristor-Controlled Reactors) to consume VARs from the system, lowering the system voltage. Under inductive (lagging) conditions, the capacitor banks are automatically switched in, thus providing a higher system voltage. They also may be placed near high and rapidly varying loads, such as arc furnaces, where they can smooth flicker voltage. It is known that the SVCs with an auxiliary injection of a suitable signal can considerably improve the dynamic stability performance of a power system . It is observed that SVC controls can significantly influence nonlinear system behavior especially under high-stress operating conditions and increased SVC gains.By rapidly controlling the voltage and reactive power ,an SVC can contribute to the enhancement of the power system dynamic performanance.Normallly , voltage regulation is the primary mode of control , and this improves voltage stability and transient stability. However , the contribution of an SVC to the damping of the system oscillation resulting from voltage regulation alone is usually small; supplementary control is necessary to achieve significant damping.[2]

A commonly used topology of a svc shown in fig.(b).Comprises a parallel combination of TCR and fixced capacitor.it is basically a shunt connected static var generator/absorber.whose output is adjusted to exchange capacitive or inductive current so as to maintain or control specific parameters of electrical power system,typically bus voltage.

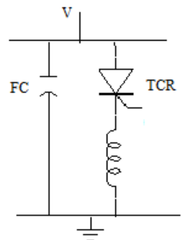


Fig.(b) SVC

The reactive power injection of a SVC connected to bus k is given by

$$Q_k = V_k^2 B_{SVC}$$

$B_{svc}=B_c-B_L$; the symbol B_c and B_L are the respective susceptance of the fixced capacitor and TCR.it is also important to note that a svc does not exchange real power with the system.

The small signal dynamic model of a SVC is shown in fig.(c).ΔB_{svc} is defined as ΔB_c-ΔB_L.the differential equation from this block diagram can easily be defined as

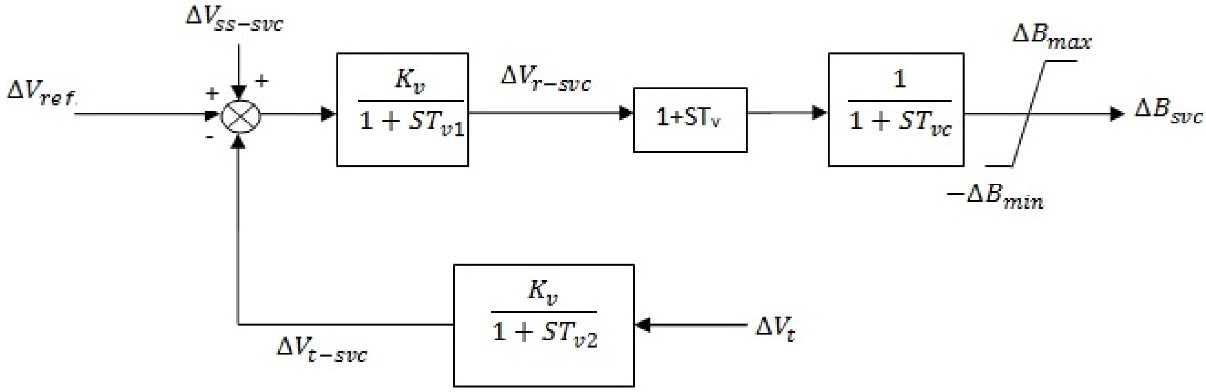


Fig.(c) SVC Dynamic model

$$\frac{d}{dt}\Delta B_{svc} = \frac{1}{T_{svc}}\left\{-\Delta B_{svc} + \left(1-\frac{T_{v1}}{T_{v2}}\right)\Delta V_{r-svc} - \frac{K_v T_{v1}}{T_{v2}}\Delta V_{t-svc}\right\} + \frac{K_v T_{v1}}{T_{v2}T_{svc}}\{\Delta V_{ss-svc} + \Delta V_{ref.}\}$$
$$\frac{d}{dt}\Delta V_{r-sv} = \frac{1}{T_{v2}}\{-\Delta V_{r-svc} - K_v\Delta V_{t-svc} + K_v V_{ref.} + K_v V_{ss-svc}\}$$
$$\frac{d}{dt}\Delta V_{t-svc} = \frac{1}{T_m}\{\Delta V_t - \Delta V_{t-svc}\}$$

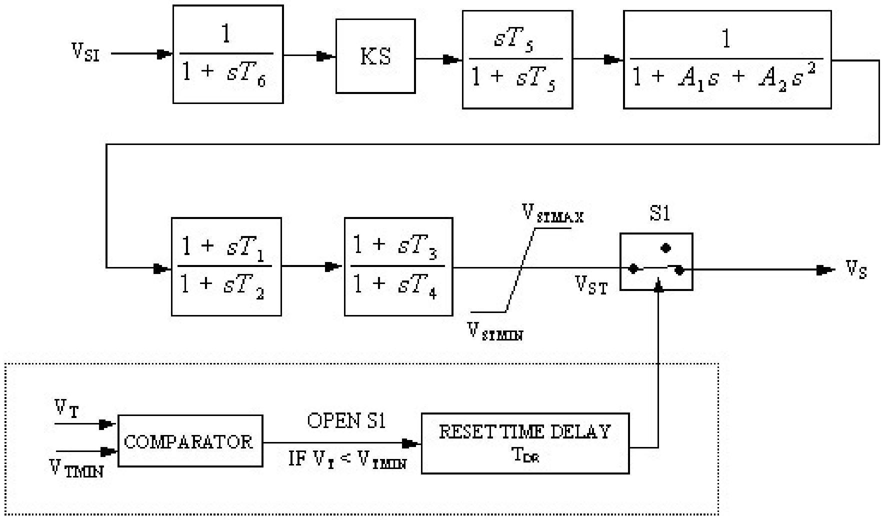
K_v,T_{v1},T_{v2} are the gain and time constant of voltage controller respectively.T_{svc} is the time constant associated with SVC response.T_m is the voltage sensing circuit time constant.

The effectiveness of an SVC in enhancing system stability depends on location of the SVC.To determine a suitable location for SVC ,where the voltage swing are gretest without the SVC is on bus-9 in given test system fig.(a).Svc control model which has been used is shown below in fig.(c).

An SVC comprising a fixed capacitor and a thyristor-controlled reactor is considered for enhancement of the system stability .the rating of the SVC is assumed to be 150 Mvar capacitive and 150 Mvar inductive .The voltage regulator gain is set at 10 to provide a 10% slope in the control range.

Power system stabilizer

The basic of a power system stabilizer (PSS) is to add damping to the generator oscillation by using auxiliary stabilizing signal(s).To provide damping, the stabilizer must produce a component of electrical torque in phase with the rotor speed variation. This is achieved by modulating the generator excitation so as to develop a component of electrical torque in phase with rotor speed deviation. Shaft speed, integral of power and terminal frequency are among the commonly used input signals to PSS.[4].PSS based on shaft speed signal has been used successfully since the mid-1960s.a technique developed to derive a stabilizing signal from measurement of shaft speed of a system. Among the important consideration in the design of equipment for the measurement of speed deviation is the minimization of noise caused by shaft run out and other causes.[3]-[4] the allowable level of noise is dependent on its frequency. For noise frequency below 5Hz, the level must be less than 0.02%, since significant changes in terminal voltage can be produced by low-frequency changes in the field voltage. The application of shaft speed stabilizer to thermal unit requires a careful consideration of the effects on torsional oscillation. The stabilizer, while damping the rotor oscillation, can cause instability of the torsional modes. One approach successfully used to circumvent the problem is to sense the speed at a location on the shaft near the nodes of the critical torsional modes [5]-[6].In addition ,an electronic filter is used in stabilizing path to attenuate the torsional components.The power system stabilizer(PSS1A) model which has been used with the generators is shown below in fig.(d).



Discontinuous Excitation Controller

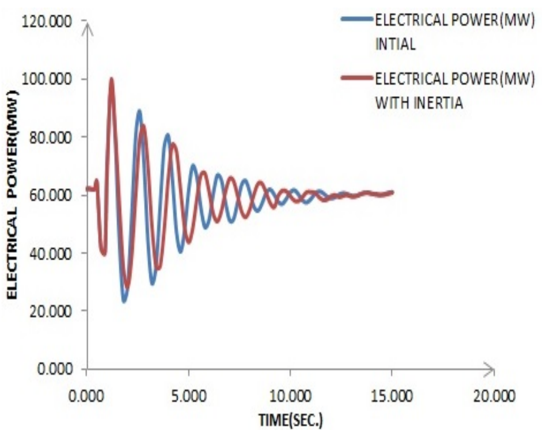
Fig.(d) IEEE type PSS1A

4. SIMULATION RESULT AND DISCUSSION

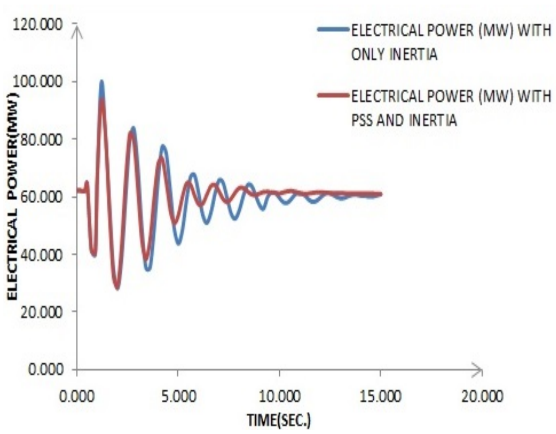
The Etap Transient Stability Analysis is designed to investigate the system dynamic response disturbance. The program models dynamic characteristics of a power system, implements the user-defined events and action, solves the system network equation and machine differential equation interactively to find out system and machine response in time domain.

In this paper we discuss the transient stability performance with PSS,SVC and by increasing inertia of synchronous machine.The transient stability improvement is not only sufficient by using one method. So here we use these three combined method for improving stability. Here we use ACCELERATED GAUSS-SEIDEL for initial load flow calculation. In which maximum number of iteration is 2000 and Solution Precision for the Initial LF is 0.000001 And Time Increment for Integration Steps (Δt) is 0.0100 and acceleration factor for the initial load flow is 1.45.Intial inertia of the installed machine was 4 MW-Sec/MVA and after increasing its inertia is 7 MW-Sec/MVA.Inertia of the machine is not so much increased. Because after increasing inertia of the machine rotor will be havier.so that it is kept always within limit as considering its reliability and economy. Here used PSS with given data as in table-5 with test system Fig(a). The electromechanical oscillation for generator electrical power is reduced as well as the steady state power is also enhanced as seen in fig-(e).oscillation in terminal current and field current is also reduced and the magnitude of field current is also reduced as seen in Fig(g) &Fig.(h).Field voltage of Gen-1 is initially oscillated but after some time it is constant and within limit as shown in fig.(f).if only inertia of generator is increased then field voltage was does not change.

The different plot for Gen-1. When a three phase fault on bus-3 at 0.5 sec and cleared at 1 sec are shown below in fig.



(1)



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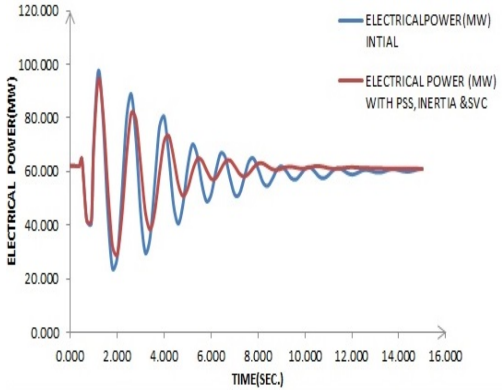
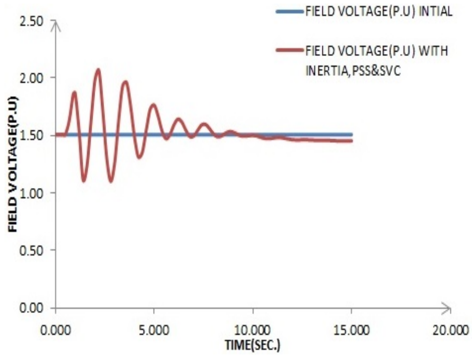


(3)

Fig(e) Electrical power of Gen-1 (1)only inertia is increased (2) implementation of pss and inertia (3) implementation of inertia ,pss &svc



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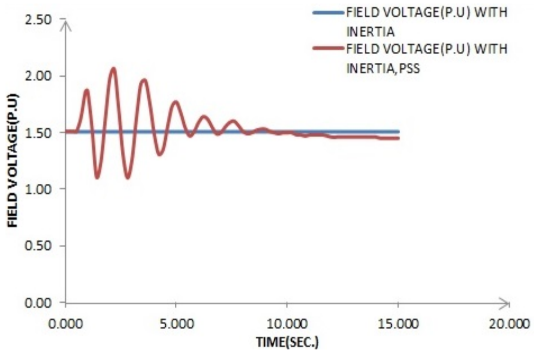
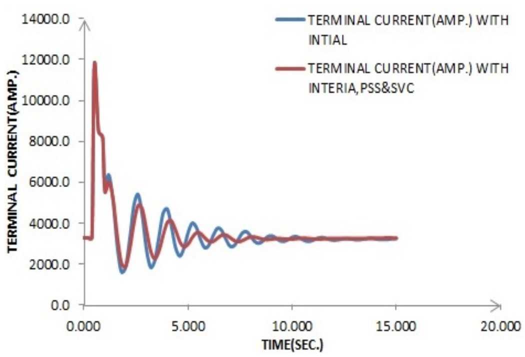
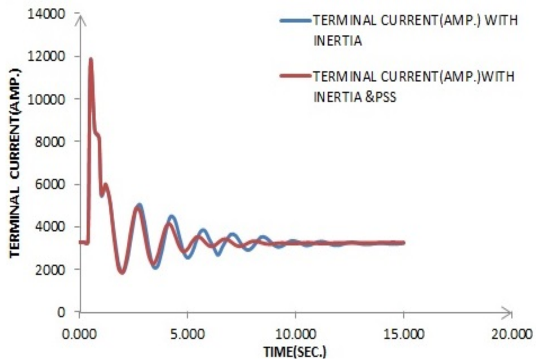


(2)

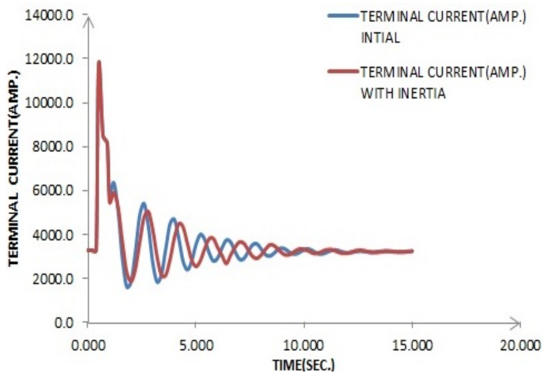
Fig(f)Field voltage of Gen-1 (1)implementation of inertia&pss (2)implementation of inertia,pss and svc.



(1)

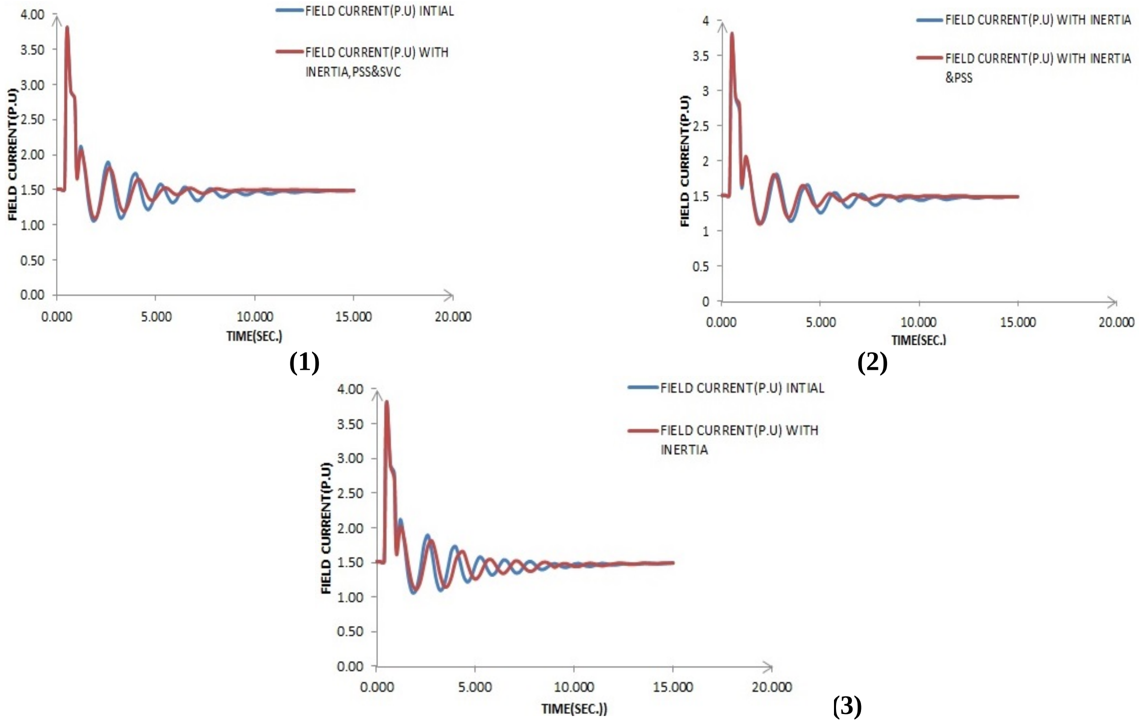


(2)



(3)

Fig(g) terminal current of Gen-1 (1)only inertia is increased (2) implementation of inertia &svc (3) implementation of inertia,pss&svc.



Fig(h)Field current of Gen-1 (1)only inertia is increased (2) implementation of inertia and pss (3) implementation of inertia ,pss &svc.

5. CONCLUSION

In this paper a new optimal control approach for improvement of transient stability.Here Transient stability Performances of the multi machine system by using coordinated effect of PSS, SVC and by increasing inertia of machine and conventional method has been compared. And we see that better response in terms of electromechanical oscillation has been achieved in case of with PSS and SVC.The proposed method also has the advantage of considering the permissible system conditions. In general, analytical analysis and simulation results using E-TAP software show that the proposed and good flexibility for transient stability improvement.

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