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Modelling and Simulation of SSSC and UPFC with Symmetrical Faults

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***Abstract:* - Increasing power demands leads to the condition were transmission are heavily loaded, thus power system stability become concern. This paper studies the effect of UPFC on power system stability. For heavy fault condition, the machines in a stable power system initially oscillate and then settle at the stable equilibrium point where the transient energy is zero. This paper utilizes the rate of dissipation of transient energy as a measure of system oscillation damping. This concept is used to determine the additional damping provided by power system stabilizer and facts device SSSC and UPFC. This technique is then studied with help of MATLAB Stimulant for various condition with help of single machine infinite bus system(SMIB).**

***Keywords*—power system oscillation, power system stabilizer, SSSC (Static series synchronous compensator), UPFC (Unified power flow controller) , SMIB (Single machine infinite bus),MATLAB Simulink**

I. INTRODUCTION

Recently, large interconnected power systems are operating to their stability limits for reliable and economical operation. As a result , power demand has increased to a great extent while the expansion of power generation and transmission has been rigorously limited due to limited resources and environmental constraint .Thus , some transmission lines are heavily loaded and system stability become one of the reason for power loss and areas of generation are found to be prone to electromechanical oscillation. However, low frequency oscillation with the frequencies in the range of 0.1 to 2 Hz is one of the direct results of the large interconnected power system. If this oscillation is not damped they make the interconnected system susceptible to danger of instability. These oscillations may come up to the overall rated capacity of a transmission line due to their superimposed effect on steady state line flow. For overcoming this situation power system become interconnected and complicated, that is why areas of generation are found to be prone to electromechanical oscillation.

The key factor of having sustained or growing oscillations is the deficiency of adequate system damping. Power system stabilizer is possibly the first measure that has been used to improve damping. In last few decades flexible ac transmission systems (FACTS) devices have been increasingly used in power systems to improve both the steady state and dynamic performances of the systems

Conventionally, power system stabilizer (PSS) has been employed as the first choice to lessen these problems. However, performance of PSS can get affected by network structure, load variation etc. Hence installations of FACTS devices have been suggested in this paper to achieve appreciable damping of system oscillations. This has initiated a new and more versatile approach to control the power system in a desired way [4]. FACTS controllers provide a set of interesting improvements including power flow control, reactive power compensation, voltage regulation, damping of oscillations [5]-[12].

A number of Flexible AC Transmission System (FACTS) controllers based on the rapid development of power electronics technology have been proposed in recent years for better utilization of existing transmission facilities. FACTS devices have shown very promising results when used to improve power system steady-state performance. They have been very promising candidates for utilization in power system damping enhancement. The first generation thyristor-controlled FACTS devices, such as static var compensator (SVC) and thyristor-controlled series capacitor (TCSC) have satisfactorily been used in power systems for dynamic reactive compensation. The above FACTS devices require fully rated capacitor or reactor bank to supply or absorb reactive power. However, this requirement can be avoided by employing self-commutated voltage-sourced switching converters to realize static synchronous s voltage Sources at fundamental frequency .The FACTS devices that belong to this category synchronous series compensator (SSSC) and unified power flow controller (UPFC) which are second generation facts devices.

Dynamic control of generator output power is the main point in subduing electromechanical oscillation or improving damping of a power system .The damping of a generator can be enhanced by growing its output power when the angle δ increases or speed $\omega > 0$ and reducing the power when the angle decreases or $\omega < 0$. Thus, the speed ω can be reflected as asuitable control signal for improving damping of generator by variable its output power.

After studying various paper , it is dispels the impression that there are several ways which are used for enhancement of oscillation in power system .In this paper study of facts device UPFC is done with help of SMIB system. This paper also include the mathematical modeling of SMIB system with and without facts device respectively.

II. POWER SYSTEM STABILIZER

The reaction of AVR in front of the station voltage oscillate is to force field current changes in generator. This is so called negative damping may be eradicated by presentingadditional control loop, known as power system stabilizer .The basic function of PSS is to spread the stability limits by moderating the generator excitation to provide damping for the rotor oscillation of synchronous machines. The PSS can improve the damping of power system, rises the static stability and improve the transmission proficiency .The PSS output is additional to the variance between reference and actual value of the terminal voltage .Normalinput signal for the PSS are the rotor speed deviation,the accelerating power,active power output or the system frequency as revealed in fig .1

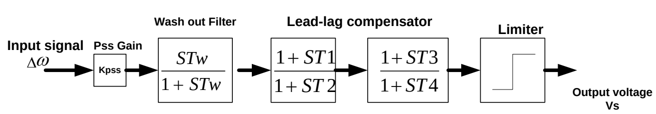

Fig 1: Block diagram of PSS

The block diagram is used in portrayed in fig.1. The PSS assembly contain a washout block $(\frac{STw}{1+STw})$, used to decrease the over response of the damping during severe events. Also the washout block, serves as high–pass filter,with constant that permits the signal related with oscillation in rotor speed to pass unaffected, but also does not allow the steady state alteration to adapt the terminal voltages. For native mode operation, a washout time constant T_W of 1 s to 2s is acceptable. Since the PSS must create a constituent of electrical torque in phase with speed deviation, phase lead block circuits ate used to recompense for lag between the PSS output and the action control, the electrical torque. The number of lead lag blocks rest on the specific system and the tuning of PSS. The PSS gain $K_{PSS}$is a significant as the damping provided by the OSS increases in proportion into an increase in the gain up to a definite value, after which the damping begins to decline. In order to limit the value of generator terminal voltage variation during transient condition, limits are forced on the PSS output.

III. STATIC SYNCHRONOUS SERIES COMPENSATOR(SSSC)

Static synchronous series compensator(SSSC) is a series FACTS device which inserts a controlled voltage into the system in quadrature with line current but controlled freely of the line current, so as to control impedance which is a function of reactive power.The simple diagram of SSSC is shown in figure2.The SSSC is capable of internally generating a controllable compensating voltage over an identical capacitive and inductive range independently of the magnitude of the line current. The series impedance of the line primarily limits AC power transmission over long distances. The SSSC has the inherent ability to interface with an external dc power supply to provide compensation for the line resistance by the injection of the real power, as well as for the line reactance by the injection of reactive power.

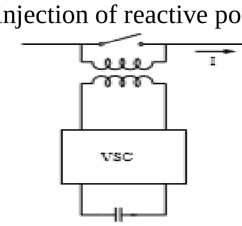

Fig.2 Single line diagram with SSSC

The main control objective of the SSSC is to directly contorl the current, and indirectly the power, flowing through the line by controlling the reactive powerexchange between the SSSC and the AC system. The main advantage of this controller over a TCSC is that it does not significantly affect the impedance of the transmission system and, therefore, there is no danger of having resonance problem.

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IV. UNIFIED POWER FLOW CONTROLLER(UPFC)

The UPFC is a device which can control simultaneously al the three parameters of line power flow. It is the combination of two old devices STATCOM and SSSC. These two device are two voltage source inverters (VSI) connected respectively in shunt with the treansmission line through a shunt transformer and in series with the transmission line through a series transformer connected to each other by a common dc link including a stoage capacitor.The shunt inverter is used for voltage regulation at the point of connection injecting an opportune reactive power flow into the line and to balance the real power flow exchanged between te series inverter and the transmission line. The series inverter can be used to control the real and reactive line power flow inserting an opportune voltage with contollable magnitude phase in series with the transmission line. The basic configuration of upfc, which is installed \between the sending-end Vs and the receiving-end VR as shown in fig below. The UPFC consists of a combination of a series device and a shunt device, the dc terminals of which are connected to a common dc link capacitor

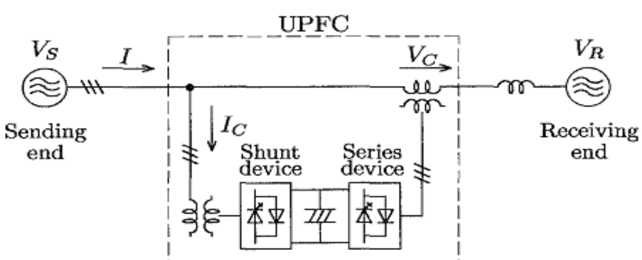

Fig.3 Single line diagram with UPFC

The shunt inverter is operating in such a way to inject a controllable current Ic into the transmission line. This current consist of two components with respect to the line voltage:

1. the real or direct component id
2. reactive or quadrature component iq

The direct component is automatically determined by the requirement to balance the real power of the series inverter. The quadrature component, instead, can be independently set to any desired reference level (inductive or capacitive) within the capability of the inverter, to absorb or generate respectively reactive power from the line. So, two control modes are possible:

1)VAR control mode : the reference input is an inductive or capacitive var request.
2)Automatic Voltage Control mode: the goal is to maintain the transmission line voltage at the connection point to a reference value.

V. MATHEMATICAL MODELLING

A .Generator Modelling:

One of the important factor of SMIB is synchronous generator,thus the modelling of generator is explained below,

Stator winding eqation:
$v_q = -rs_{iq} - xd_{0id} + E_{q0}$
$v_d = -rs_{id} + xq_{0iq} + E_{d0}$
wherers is the stator winding resistance
xd0 is the d−axis transient resistance
xq0 is the q−axis transient resistance
Eq0 is the q−axis transient voltage
Ed0 is the d−axis transient voltage

Rotor winding eqation:
$T_{do}\ dE_{q0}dt + E_{q0} = E_f - (xd - xd0)id$
$T_{qo0}dEdt + E_{d0} = (x_q - x_{q0})iq$
where
T_{do0} is the d−axis open circuit transient time constant
T_{qo0} is the q−axis open circuit transient time constant
$E_f$is the field voltage

Torque equation:
$T_{el} = E_{q0}iq + E_{d0}id + (x_{q0} - x_{d0})id\ iq$

Rotor eqation:
$2Hd\omega\ dt = T_{mech} - Tel - T_{damp}$
$T_{damp} = D\Delta w$
where
T_{mech} is the mechanical torque, which is constant in this model
T_{el} is the electrical torque
T_{damp} is the damping torque
D is the damping coincident.

B. SMIB system with PSS:

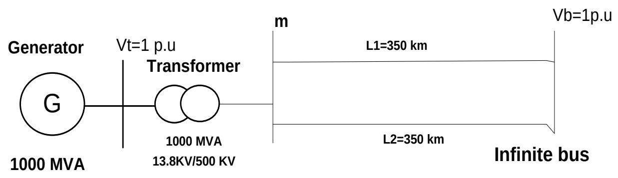

Fig.4 Single line diagram of SIMB system

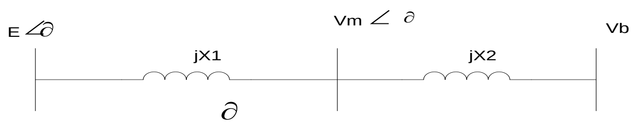

Fig.5 Equivalent diagram of SIMB system

Consider the simple machine infinite bus (SMIB) as presented in the fig 2. It comprise of a generator attached to an infinite bus through a step–up transformer and a double circuit transmission line. Vt andVb are magnitude of machine internal voltage and infinite busa respectively. The system equivalent circuit diagram is given in fig.3.X_1characterizes transformer xt plus machine sub transient $\acute{x}d$and X_2represent reactance X_{L1} line 1 in parallel to reactance X_{L2} of line 2. The magnitude of the machine internal voltage and infinite bus voltage is characterized by E and V correspondingly.

The dynamics of the machine in conventional model can be considered by the following differential equation,

$$\frac{d\delta}{dt} = \omega \quad (1)$$

$$\frac{d\omega}{dt} = \frac{1}{M}(Pm - Pe - D\omega) \quad (2)$$

Here, δ, ω, M, Pm and D arethe angle,speed, moment of inertia, input mechanical power and damping co-efficient, correspondingly of the machine. The electrical output power Pe of machine in the fig.3 can be written as,

$$Pe = Pmax \sin \delta \quad (3)$$

Where $Pmax = \frac{EV}{X1+X2}$

The transient energy E of the system can be expressed as,

$$E(\delta,\omega)\frac{1}{2}M\omega^2 + [-Pm(\delta - \delta s) - Pmax(\cos\delta - \cos\delta s] \quad (4)$$

Hereδsis the machine angle at the post fault stable symmetrypoint.Note that most of the works on the TEF method are based on the basic machine model . The method may not be very used when very urbane machine model and all associated controls are deliberated2. The first term on the right hand side of (4) depends upon ω and is called the kinetic energy (KE)and the rest of the terms dependson δ is called the potential energy (PE).The time derivative of the energy function is written as ,

$$\dot{E}(\delta,\omega) = \frac{dE}{dt} = \frac{\partial E}{\partial \omega}\left(\frac{d\omega}{dt}\right) + \frac{\partial E}{\partial \delta}\left(\frac{d\delta}{dt}\right)$$
$$= M\omega\left(\frac{d\omega}{dt}\right) + (-Pm + Pmax\sin\delta)\frac{d\delta}{dt} \quad (5)$$

Using(1)and (2), (5) can be written as

$$-\dot{E}(\delta,\omega) = (D\omega^2 + Pe\omega - Pmax\,\omega\sin\delta) \quad (6)$$

Note that $-\dot{E}$ can be considerd as rate of dissipation of transient energy. Inthe absence of a FACTS device, Pe is govern by (3) and for such case $-\dot{E}$of (6) becomes,

$$-\dot{E}(\delta,\omega) = D\omega^2 \quad (7)$$

Thus, without any FACTS device, the rate of dissipation of transient energy rest on the damping coefficient D. The detached of this study is to increasethe rate of dissipation of transient energy by appropriately modulating machine output power Pe with the help of FACTS devices and which is defined. The transient energy at the SEP is zero and thus the rate of dissipation of transient energy can be deliberated as anamount of system damping. In this study additional, SSSC and UPFC are to increase the rate of dissipation of transient energy and hence to expand damping. The extra damping delivered by these devices in the simple system of fig.2 is methodicallyresulting in further work on this area.

C. SMIB system with SSSC:

A SSSC is a VSC-based series facts device that injects a voltage in series with the transmission line voltage. Consider that a SSSC is placed near bus m in the SMIB system as shown in fig.5. The equivalent circuit of the system is shown in fig 6. where the SSSC is represented by a series voltage sources

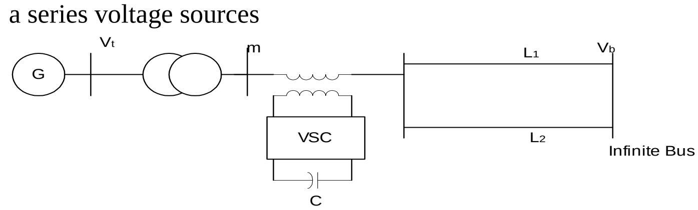

Fig.6Single line diagram of SIMB system with SSSC

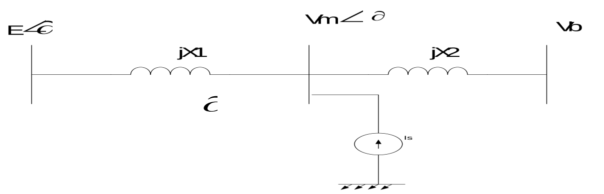

Fig.7 Equivalent diagram of SIMB system with SSSC

Note that Vs is always kept in quadrature with the line current so that SSSC can exchange only ractive power with the system. Thus,

$$Vs = Vse^{j(\theta \pm \frac{\pi}{2})} \quad (8)$$

Here, θ is the angle of line current and is given by,

$$\theta = \tan^{-1}(\frac{V-E\ \acute{c}os\,\delta}{E\ \sin\delta}) \quad (9)$$

With the SSSC,the machine power Pe can be written as,

$$Pe = Pmax + f_2(\delta)Vs \quad (10)$$

Where,

$$\text{f2}(\delta) = \frac{Pmax\ \sin\delta}{\sqrt{E^2+V^2-2EV\cos\delta}} \quad (11)$$

Note that $f_2(\delta)$ is positive when δ oscillates in between zero and Π. It may be mentioned here that Vs in eqaution (9) is positive or negative when SSSC is is operate in capacitive or inductive mode.

Thus, Pe of equation (9) can be modulated by properly controlling the value of Vs. When is used to control signal Vs can be expressed as

,

$$Vs = k2\omega; -Vs^{max} \leq Vs \leq Vs^{max} \quad (12)$$

Here,k2 is apositivegain and its depend on the maximum volatge rating (Vs^{max}) of the SSSC.using equation (10) and (11), $-\dot{E}$of equation (6) can be written as,

$$-\dot{E}(\delta,\omega) = [D + k2f2(\delta)]\omega^2 \quad (13)$$

D. SMIB system wth UPFC:

A unified power flow controller (UPFC) is the most favorable device in the FACTS concept. It has capability to adjust the three control parameters, the bus voltage, transmission line reactance and phase angle between two buses , either simultaneously or self-sufficiently. So it is the arrangement of the propeties of Static synchronous compensator (STATCOM) and static synchronous series compensator (SSSC). UPFC contains two voltage source converter coupled through a mutual link as shown in fig 8. The series converter exchanges both real and reactive power within the transmission line by alteringthe magnitude and phase angle of the injected voltage produced by SSSC. The simple function of the shunt converter is to hoard the real power demanded by the series converter through the common dc link.It can also generate or absorb manageable reactive power. UPFC was represented by corresponding circuit with a shunt curretnt source and a series voltage source as shown in fig.9

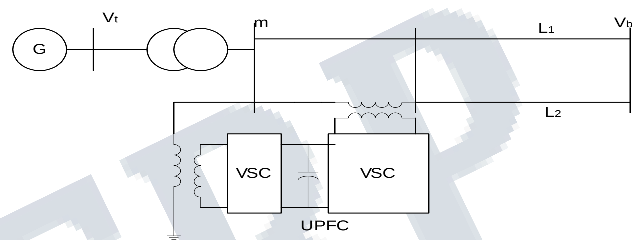

Fig.8 Single line diagram of SMIB system with UPFC

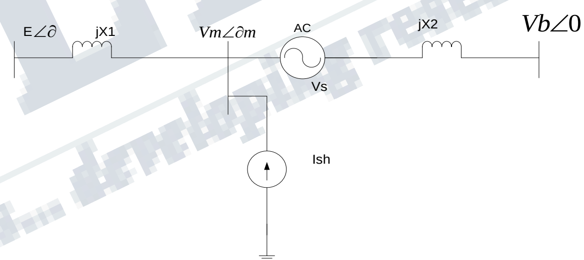

Fig.9 Equivalent diagram of SIMB system with UPFC

Note that Vs is always kept in quadrature with the line current so that VSC can exchange only ractive power with the system. Thus,

$$Vs = Vse^{j(\theta \pm \frac{\pi}{2})} \quad (14)$$

Here, θ is the angle of line current and is given by,

$$\theta = \tan^{-1}(\frac{V - E\ \acute{c}os\,\delta}{E\ \sin\delta})$$

A shunt reactive current source **I**s is given by,

$$Is = Is\ e^{i(\delta m \mp \frac{\pi}{2})} \quad (15)$$

Where,

$$\delta m = \tan^{-1}(\frac{EX_2\ \sin\delta}{VX_1 + EX_2\ \cos\delta})$$

With the UPFC,the machine power Pe can be written as,

$$Pe = Pmax + f_1(\delta)Is + f_2(\delta)Vs \quad (16)$$

Where,

$$f_1(\delta) = \frac{EX_2}{X_1 + X_2}\sin(\delta - \delta_m)$$

$$f_2(\delta) = \frac{Pmax\ \sin\delta}{\sqrt{E^2 + V^2 - 2EV\cos\delta}}$$

VI. SIMULATION RESULT

The single line diagram of SMIB which is shown above in fig.2 is modeled and simulate in MATLAB Simulink. The run time for the system is 10 sec. The symmetrical fault is applied at bus m. The time where the fault is applied is 2sec and it is cleared at time 3 sec for analysis of system. The system is studied for four different case which are as follow:

A. Without Fault and with PSS.

In this case, system is simulating without any symmetrical fault at bus m. Although PSS is introduced in the system.Now system is simulate for the run time of 10 sec. Thus we get the following result. fig.8 the rotor speed of machine and fig.9analyses load angle of the machine.

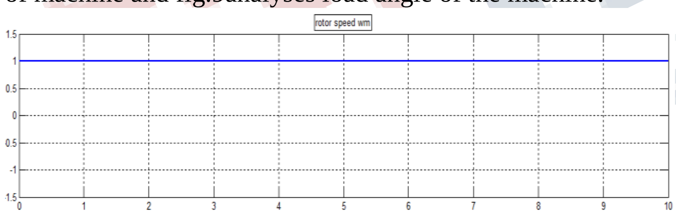

Fig.8 Rotor speed of machinefor run time of 10 sec

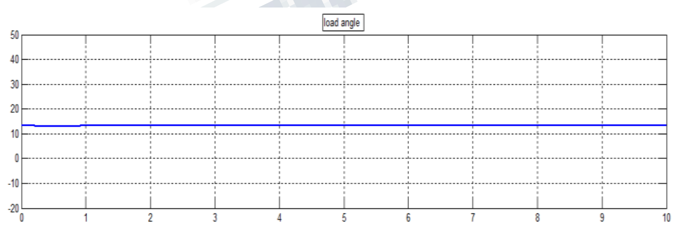

Fig.9Load angle for run time of 10sec

B. With fault and PSS.

In this case, system is simulating with symmetrical fault at bus m. PSS is also introduced in the system. Now system is simulate for the run time of 10 sec. Thus we get the following result. Fig.10 the rotor speed of machine and fig.11analyses rotor angle of the machine

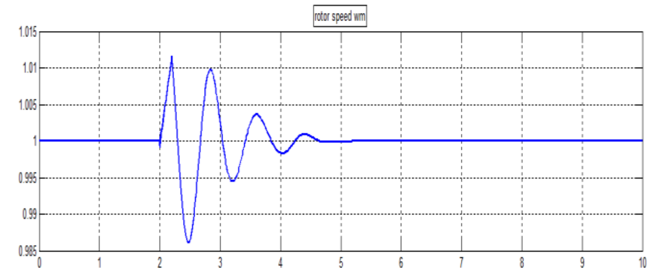

Fig.10 Rotor Speed Of Machine For A Threefault At 2 Sec At Run Time Of 10sec

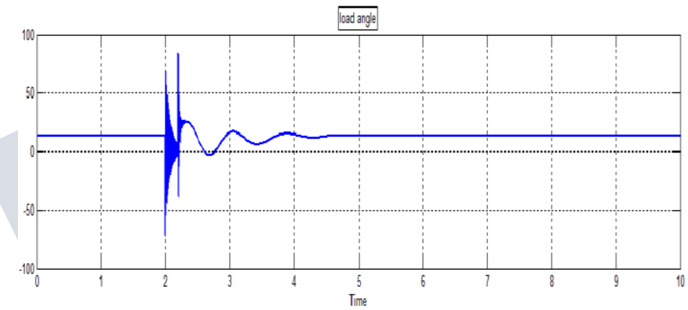

Fig.11 Load Angle Of Machine For A Three Fault At 2 Sec Run Time Of 10 Sec

C. With Facts Device SSSC.

In this case, system is simulate with symmetrical fault at bus m. Although sssc is introduced in the system. Now system is simulate for the run time of 10 sec. Thus weget the following result.fig.16 the rotor speed of machine and fig.18 analyzes load angle of the machine.

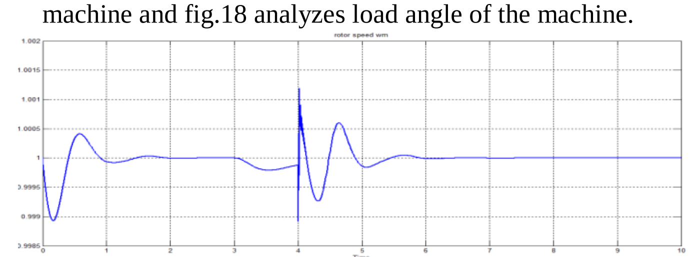

Fig.12 Rotor Speed Of Machine For A Three Fault At 4 Sec At Run Time Of 10sec

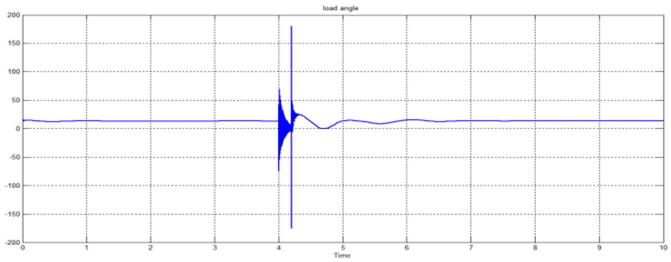

Fig.13 Load Angle Of Machine For A Three Fault At 4 Sec Run Time Of 10 Sec

D. With Facts Device UPFC.

In this case, system is simulate with symmetrical fault at bus m. Although upfc is introduced in the system. Now system is simulate for the run time of 10 sec. Thus we get the following result.fig.14 the rotor speed of machine and fig.15 analyzes load angle of the machine.

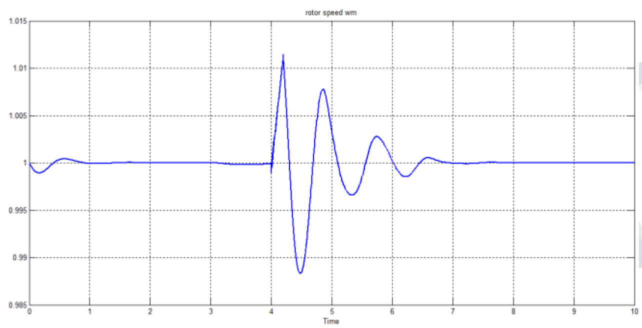

Fig.14 Rotor Speed Of Machinefor Three Phase Fault At 4sec With Upfc Forrun Time Of 10 Sec

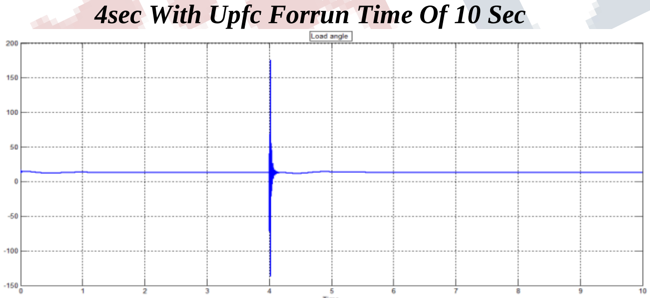

Fig.15 Load Angle For Three Phase Fault At 4sec With Upfc Forrun Time Of 10 Sec

VII. CONCLUSION

The result obtained from simulation shows that electromechanical oscillation are not present in the system when it is not applied to the fault, so system is completely stable without any fault. Further when symmetrical fault is applied at receiving end there is sustained low frequency oscillation. Now this low frequency oscillation is suppressed using PSS but not completely removed. Thus, for removing this sustained oscillation the two facts devices are used. The result shows that with SSSC the low frequency oscillation are suppressed but not completely removed and also damping is improved. And time required to damped oscillation is also decreased than that require with PSS. For removing these oscillations completely this is than studied with UPFC.The result shows that the oscillation is completely removed and within time. So it is concluded that UPFC is better than any other Facts device in removing the sustained oscillation and in time.

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