MITIGATION OF OSCILLATIONS IN POWER SYSTEM BY USING UPFC AND PSS

M.Kishore Kumar[1], M.Sankaraiah[2], Dr.S.Suresh Reddy[3]
[1]Student,Electrical & Electronics Engineering, N.B.K.R.I.ST, Andhrapradesh, India
[2]Assistant Professor,Electrical & Electronics Engineering, N.B.K.R.I.ST, Andhrapradesh, India,
[3]Professor & HOD,Electrical & Electronics Engineering,N.B.K.R.I.ST,Andhrapradesh,India

ABSTRACT

Now a days electrical power consumption has been increased and increasing drastically. So it must be supplied to all the consumers with high reliability and quality. Since the load is unpredicted but only estimated the generation must be equal to load all the times. But due to variations in load there is effect on the power system whether the load is switched on or off suddenly which causes low frequency oscillations in the entire system. Low frequency electromechanical oscillations are inevitable characteristics of power systems and they greatly affect the transmission line transfer capability and power system stability. Power system stabilizers (PSS) along with FACTS devices can help in damping these low frequency oscillations. The objective of this paper is to design an advanced PSS and UPFC damping controller using Swing equation. This paper presents a control scheme, comprehensive analysis and result obtained for the dynamic control of power transmission, damping of oscillations with Unified Power Flow Controller (UPFC) on the basis of theory and computer simulations through MATLAB software. In this paper UPFC is not designed but its controller is designed and the effect of UPFC on the system under the fault condition, disturbances is being verified

Index Terms: UPFC damping controller, PSS, Low frequency oscillations. FACTS.

. INTRODUCTION:

The Power transfer in an integrated power system is constrained by transient stability, voltage stability and small signal stability. These constraints limit a full utilization of available transmission corridors. These constraints limit a full utilization of available transmission corridors. Flexible ac transmission system (FACTS) is the technology that provides the needed corrections of the transmission functionality in order to fully utilize the existing transmission facilities and hence, minimizing the gap between the stability limit and thermal limit.

A unified power flow controller (UPFC) is a multi-functional FACTS controller with the primary function of Power flow control plus possible secondary duties of voltage support, transient stability improvement and oscillation damping i.e. a UPFC can control power, line impedance and phase angle which can be used for power system stabilizing control.

In view of the main objectives of the research work presented in the paper are:

- To present a systematic approach for designing UPFC based damping controllers.
- To examine the relative effectiveness of modulating alternative PSS & UPFC control parameters
- To investigate the performance of the alternative damping controllers, following wide variations in loading conditions and system parameters in order to select the most effective damping controller.

2. UNIFIED POWER FLOW CONTROLLER:

A Unified Power Flow Controller (or UPFC) is an electrical device for providing fast-sensation on high-voltage electricity transmission networks. It uses a pair of three-phase controllable bridges to produce current that is injected into a transmission line using a series transformer. The controller can control active and reactive power flows in a transmission line. The UPFC uses solid state devices, which provide functional flexibility, generally not attainable by conventional thyristor controlled systems. The UPFC is a combination of a static synchronous compensator (STATCOM) and a static synchronous series compensator (SSSC) coupled via a common DC voltage link. The UPFC concept was described in 1995 by L. Gyugyi of Westinghouse. [1] The UPFC allows a secondary but important function such as stability control to suppress power system oscillations improving the transient stability of power system compensation without an external electric energy source.

The UPFC, by means of angularly unconstrained series voltage injection, is able to control, concurrently or selectively, the transmission line voltage, impedance and angle or alternatively, the real and reactive power flow in the
line. The UPFC may also provide independently controllable
Shunt reactive compensation. Viewing the operation of the UPFC from the standpoint of conventional

power transmission based on reactive shunt compensation, series compensation and phase shifting, the UPFC can fulfill all these functions and thereby meet multiple control objectives by adding the injected voltage VBt with appropriate amplitude and phase angle, to the terminal voltage V_0.

The Unified Power Flow Controller (UPFC) is the most versatile of the FACTS controllers envisaged so far. It not only performs the function of STATCOM, TCSC, and the phase angle regulator but also provides additional flexibility by combining some of the functions of above controllers. The main function of UPFC is to control the flow of real and reactive power by injection of a voltage in series with transmission line. Both the magnitude and the phase angle of the voltage can be varied independently. Real and reactive power flow control can allow for power flow in prescribed routes; loading of transmission lines closer to their thermal limits and can be utilized for improving transient and small signal stability of the power system. The schematic of the UPFC is shown in Figure1.

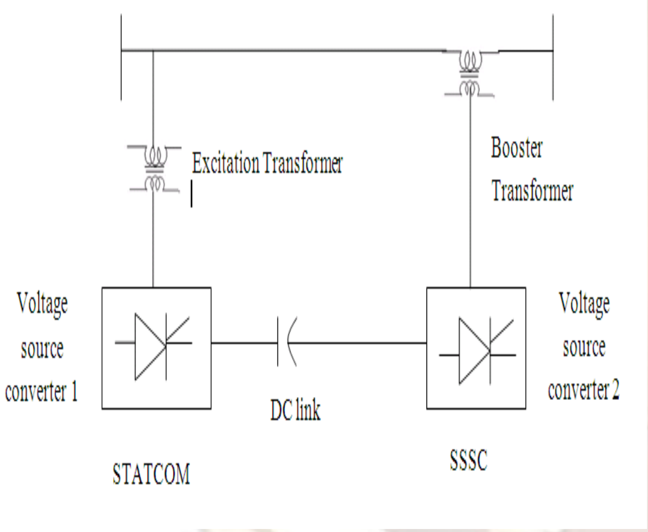


Fig-1: Schematic diagram of UPFC

3. BASIC OPERATING PRINCIPLE:

The basic components of the UPFC are two voltage source inverters sharing a common dc storage capacitor, and connected to the power system through coupling transformers. One VSI is connected to in shunt to the transmission system via a shunt transformer, while the other one is connected in series through a series transformer [1].

The series inverter is controlled to inject a symmetrical three phase voltage system (V_{se}), of controllable magnitude and phase angle in series with the line to control active and reactive power flows on the transmission line. So, this inverter will exchange active and reactive power with the line. The reactive power is electronically provided by the series inverter, and the active power is transmitted to the dc terminals. The shunt inverter is operated in such a way as to demand this dc terminal power (positive or negative) from the line keeping the voltage across the storage capacitor V_{dc} constant. So, the net real power absorbed from the line by the UPFC is equal only to the losses of the inverters and their transformers. The remaining capacity of the shunt inverter can be used to exchange reactive power with the line so to provide a voltage regulation at the connection point.

The two VSI's can work independently of each other by separating the dc side. So in that case, the shunt inverter is operating as a STATCOM that generates or absorbs reactive power to regulate the voltage magnitude at the connection point. Instead, the series inverter is operating as SSSC that generates or absorbs reactive power to regulate the current flow, and hence the power low on the transmission line. The UPFC has many possible operating modes. A basic UPFC functional scheme is shown in Figure 2

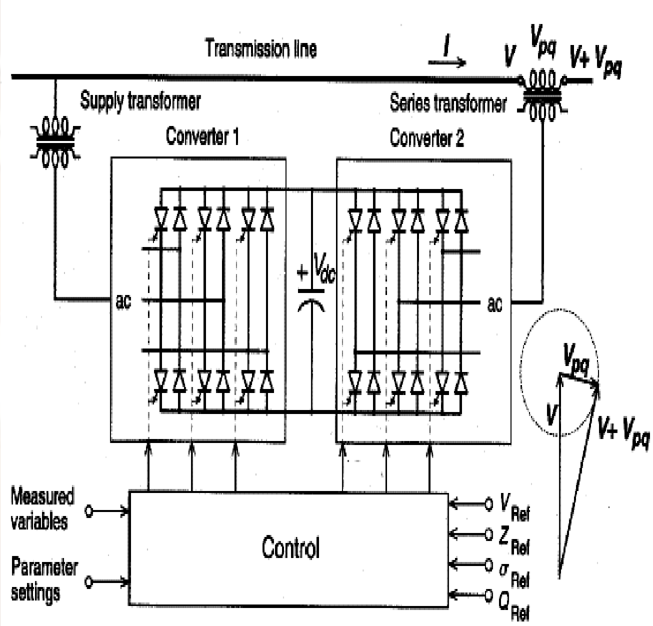


Fig-2: Implementation of UPFC by two back-to-back voltage sourced converter

In the presently used practical implementation, the UPFC consists of two voltage-sourced converters, as illustrated in Figure. These back-to-back converters, labeled "Converter I" and "Converter 2" in the figure, are operated from a common dc link provided by a dc storage capacitor. As indicated before, this arrangement functions as an idea! AC-to-AC power converter in which the real power can freely flow in either direction between the terminals of the two converters, and each converter can independently generate {or absorb) reactive power at its own ac output terminal. Converter 2 provides the main function of the UPFC by injecting a voltage $\mathbf{V}_w$ with controllable magnitude $\mathbf{V}_M$ and phase angle **ρ** in series with the line via an insertion transformer. This injected voltage acts essentially as a synchronous ac voltage source.

The transmission line current flows through this voltage source resulting in reactive and real power exchange between it and the ac system. The reactive power exchanged at the ac terminal (i.e., at the terminal of the series insertion transformer) is generated internally by the converter. The real power exchanged at the ac terminal is converted into dc Power which appears at the dc link as a positive or negative Real power demand.

4. DESIGN OF DAMPING CONTROLLERS:

4.1. Power System Stabilizer:

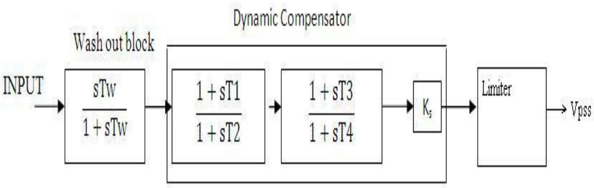


Fig-3. Power system Stabilizer

The block diagram of a Power system stabilizer used as damping controller in industries is shown in above Figure 3. Power System Stabilizer consists of Washout block, Dynamic compensator block and limiter.

The basic function of a Power system stabilizer is to provide sufficient damping to the generator rotor oscillations by controlling its excitation using auxiliary stabilizing signal(s). To provide damping the stabilizer must produce a component of electrical torque in phase with the rotor speed deviations.

4.1.a.Wash out block: serves as a high-pass filter, with the time constant T_W high enough to allow signals associated with the oscillations in $\boldsymbol{\omega}_r$ to pass unchanged. Without it the steady state changes in the speed would modify the terminal voltage. It allows the PSS to respond only to changes in the speed.T_W may be in the range of 1 to 20seconds.

4.1.b.The Dynamic compensator: It is used in industries have two lead lag stages and it is shown in the above Fig3. Where Ks is the amount of damping introduced by the PSS. Ideally, the gain should be set at a value corresponding to maximum damping however it is often limited by other considerations. Time constants T1 to T4 are chosen to provide a phase lead for the input signal in the range of frequencies that are interest.

4.1.c.Limiter: It is designed to pass the swing mode frequency signal while allowing from any variation in this frequency from system conditions. It rejects frequencies associated with non-power swing modes, such as sub synchronous torsional oscillations and modes relating to noise signals that override the auxiliary control signals. In some cases, this noise may be within the bandwidth of the power swing frequencies.

4.2. UPFC Damping Controller:

For designing we are using swing equation. By using swing equation a block is designed which results the output as Active power command. The output of this controller is P_{ref} which is compared and fed as input to the UPFC. The controller is designed primarily from dominant swing mode frequency. The operating point signifying a heavy power transfer function scenario is chosen and a specific magnitude of the system damping is selected for this scenario. A maximum level of interaction with sub synchronous modes is ensured and noise amplification beyond an acceptably small limit is not permitted. The efficiency of the PSDC controller must be established for both forward and reverse power flow in the tie-line. The below Figure 4 shows the schematic diagram of UPFC damping controller.

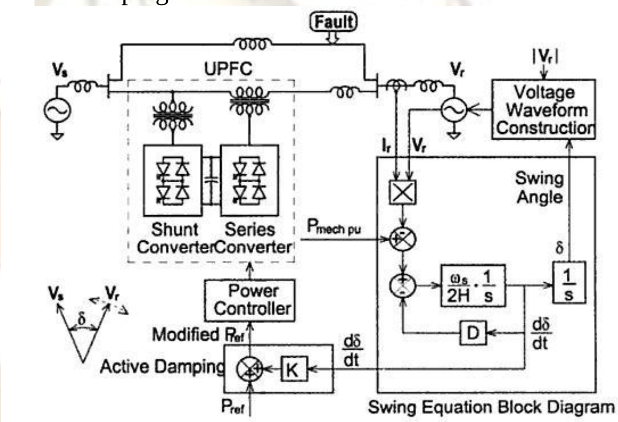


Fig-4: Block diagram showing the "swing bus" & control algorithm for power oscillation damping

According to swing equation,

$$M\frac{d^2\delta}{dt^2} = Pm - Pe \text{ ---- (1)}$$

Where M=Inertia constant
Pm=Mechanical power
Pe=Electrical power

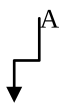
Providing active damping where the rate of change of the differential phase angle between the sending-end and receiving-end buses $(\frac{d\delta}{dt})$ is sensed and fed into the real power command, P_{ref}, for the UPFC with the correct polarity and an appropriate gain can control the power flow through the line which helps in generating source to relieve from sudden loads and reduces system oscillations[2]. A tentative value of controller gain can be obtained by performing stability simulations for the worst system configuration in the absences of PSDC and be chosen as that which can cause the FACTS device reactive power to transverse its entire controllable range for this peak variation in the auxiliary control signal. To initiate a power oscillation in this simple system model, a fault was applied for duration of several cycles through impedance to ground at the V_r bus as shown in Fig 4 simulating a distant fault condition. The waveforms for the above circuit are given in chapter 5. But here it is 2-bus system and the actual network used is 11-bus system. The initial conditions for all the cases are identical, with the mechanical power request for generator V_r programmed to produce 1.0p.u. Power flows from V_s to V_r. Line impedances are such that with zero compensation (V_{pq}=0), the UPFC is then operated to obtain 1.0 p.u. real power flow on its line, so that no power is transferred through the parallel line.

Where ωs [7] is usually in the range of 300Hz to 500Hz here we have to select this one as 0.1 to 2 Hz as low frequency oscillations, torsional oscillatory modes 5-55Hz, etc.

4.2.a Operation under line faults :

The current of the compensated line flows through the series converter of the UPFC. Depending on the line impedance of the line and the location of the system fault, the line current during faults may reach a magnitude which would far exceed the converter rating. Under this condition the UPFC would typically assume a bypass operating mode. In this mode the injected voltage would be reduced to zero and the line current, depending on its magnitude, would be bypassed through either the converter valves, electronically reconfigured for terminal shorting, or through a separate high current thyristor valve. For the contingency of delayed fault clearing, a mechanical bypass breaker would also be normally employed[2].

Resulting waveforms for this case are given in section VI. When the UPFC senses the over current on faulted phase A, it immediately activates the electronic bypass to protect the series converter. During the fault, the shunt converter may, if desired, remain operational to supply reactive compensation. However the gross voltage unbalance caused by the fault may cause distortion on the compensating currents. These currents shows normal fault clearing conditions, where the fault current is conducted by the electronic bypass switch. Should the fault clearing be delayed beyond the thermal capacity of the electronic switch, a mechanical bypass would be initiated. If the series transformer is mechanically bypassed, a specific reinsertion sequence for the UPFC would be required



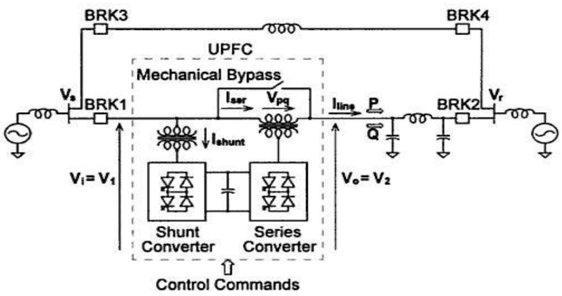


Fig-5: Simplified Schematic of Power system installed with UPFC during Fault conditions

5. SYSTEM INVESTIGATED:

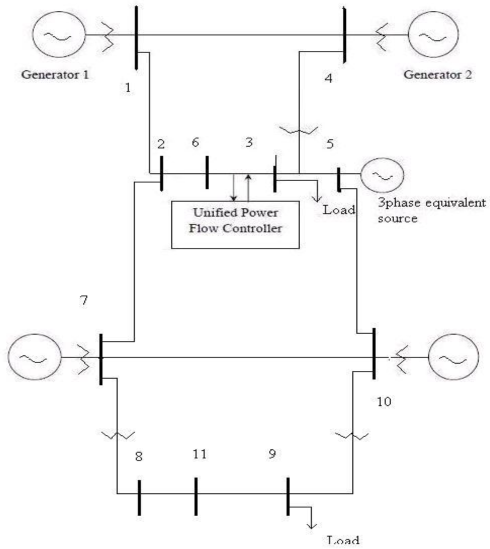


Fig-6: UPFC installed in a multi machine system having 11-bus system

In this present work at first it is taken a Multi machine system where there are four synchronous generators and one equivalent source feeding two loads which are connected to bus bar 3 and 9. Generator 1 is connected to bus1 and generator 2 is connected to bus 4 where as the UPFC is not connected in the first instant. At that time the system performance during various disturbances is studied and after that UPFC is placed between bus 3 and bus6. Simulations are carried out on the system using MATLAB/Simulink.

6. SYSTEM MODEL:

In a 500 kV/230 kV transmission system. Which is connected in a loop configuration, consists essentially of Eleven buses (B1 to B11) interconnected through transmission lines (L1, L2, L3, L4 and L5) and six 500 kV/230 kV transformer banks Tr1 to Tr6. Four power plants located on the 230-kV system generate a total of 4000 MW which is transmitted to a 500- kV 15000-MVA equivalent and to a 200-MW load connected at bus B3 and 800-MW load connected between bus9 and bus11. The plant models include a speed regulator, an excitation system as well as a power system stabilizer (PSS). In normal operation, most of the 1000-MW generation capacity of power plant #2 is exported to the 200MW connected between buses B4 and B5 and 800Mw between B9 and B11

The equipments ratings are as follows:

- Four Generators of 13. 8 KV, 1000 MVA, rotor type:
- Salient pole each with mechanical input is 0.5 P.U.
- Two Transformers connected in Delta / Star fashion along the generator side, and in main network Star / star fashion with 230 KV / 500 KV respectively.
- Line L1, L2, L3, L4, L5 each of 100 KM.
- Three phase VI measurement blocks B1 to B11 of base voltage of 230 KV, and base power of 100 MVA respectively.
- Three phase voltage source in series with R-L branch having phase to phase rms voltage of 500 KV and X/R ratio of 10.
- Three phase parallel RLC load of voltage 500 KV and power of 200 MW at B3 and 500MW at B11 and B9.
- The four dynamic generators are connected to two transformers which in turn connected to bus bar. Three line of 100 KM each is connected in the transmission network.

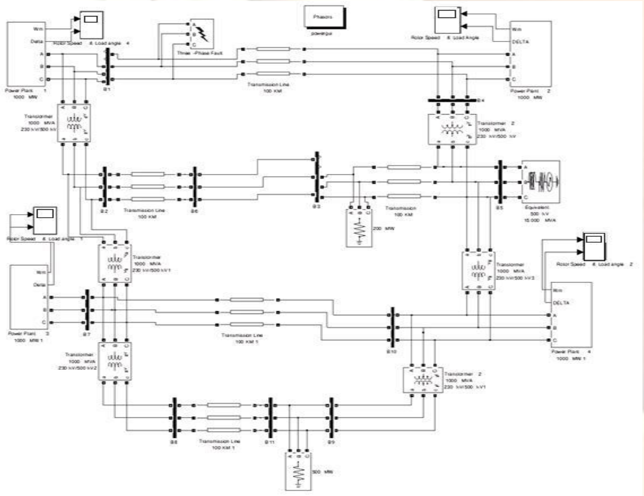


Fig-7: Multimachine system without UPFC

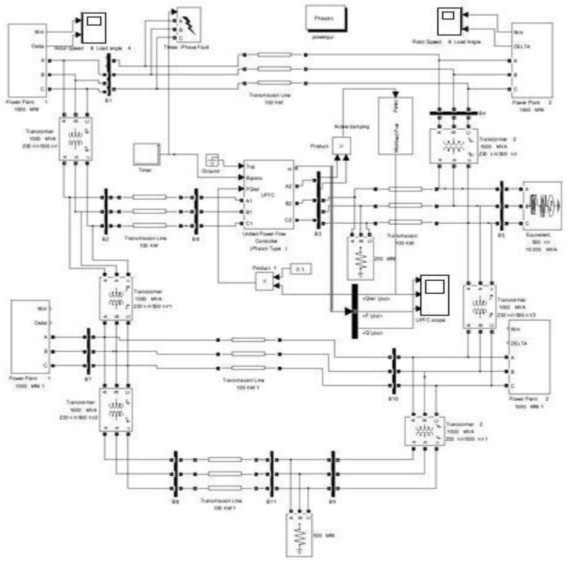


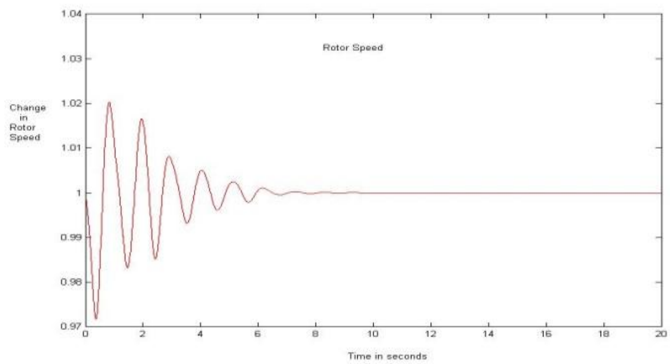
Fig-8: Multimachine system installed with UPFC

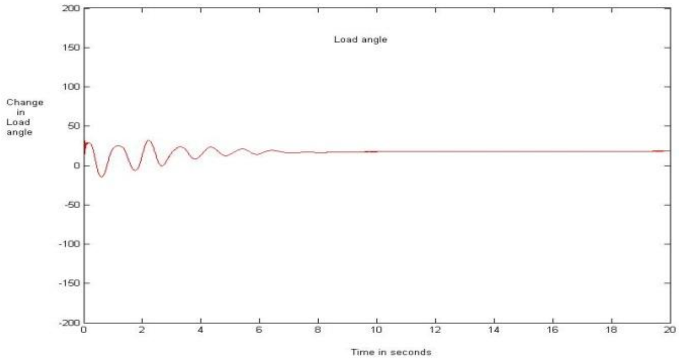
7. SIMULATION AND RESULTS:

The Multimachine is shown in above Fig 6 has no damping controllers such as UPFC and PSS. In Fig 7 UPFC and PSS are installed and a fault is created. The system is tested under various conditions such as oscillations and oscillations during faults, mitigation of oscillations due to faults and mitigation of oscillations during starting conditions etc. Here the fault is initiated at t=14 sec and it is cleared at t=14.1 sec.

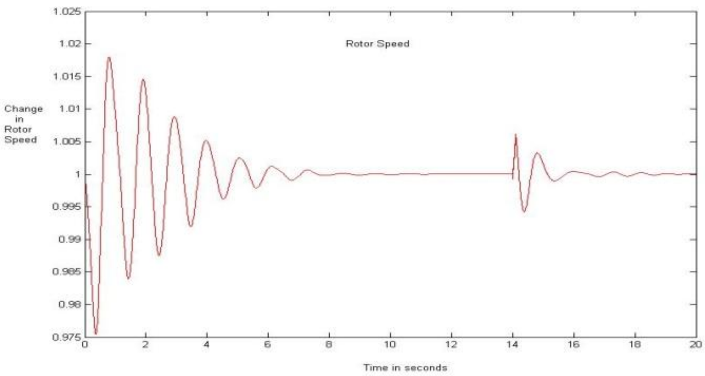
The various test conditions are:

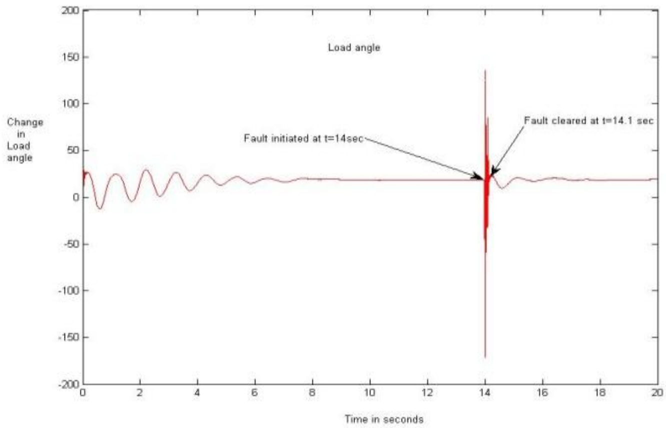
1. Simulation results of Multimachine system without PSS, UPFC, no Fault applied with respect to Rotor Speed (ω_m) and Load angle (Delta).



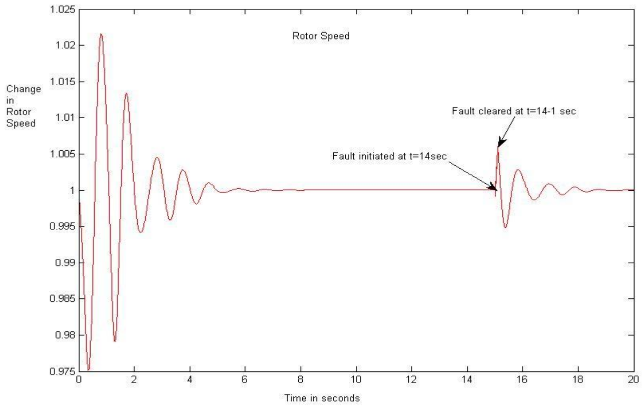


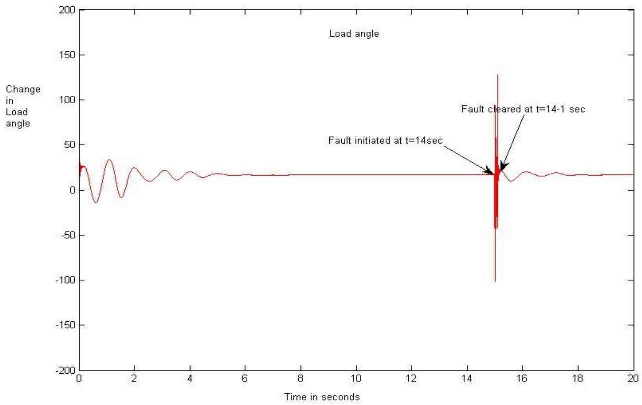
2. Simulation results of Multimachine system without PSS, UPFC and Fault applied with respect to Rotor Speed ($\boldsymbol{\omega}_m$) and Load angle (Delta)



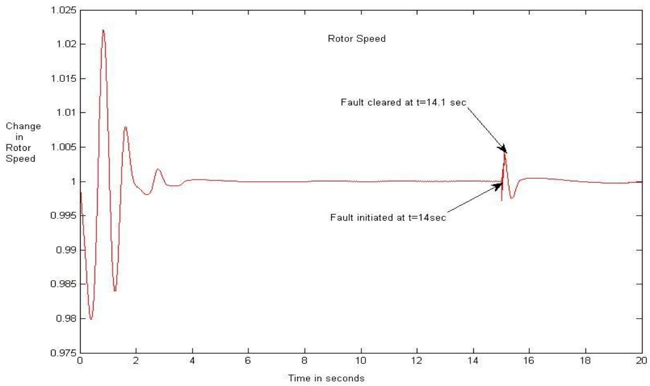


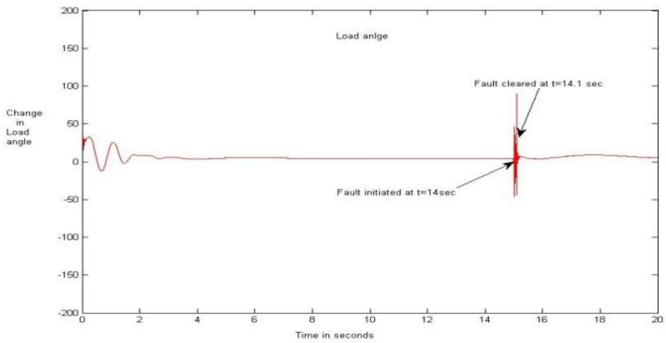
3. Simulation results of Multimachine system without PSS, with UPFC and Fault applied with respect to Rotor Speed ($\boldsymbol{\omega}_m$) and Load angle (Delta)



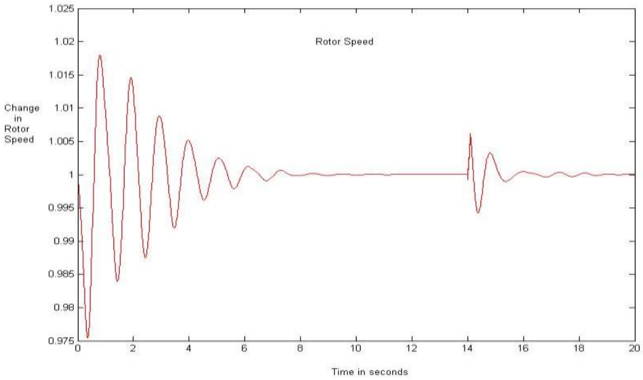


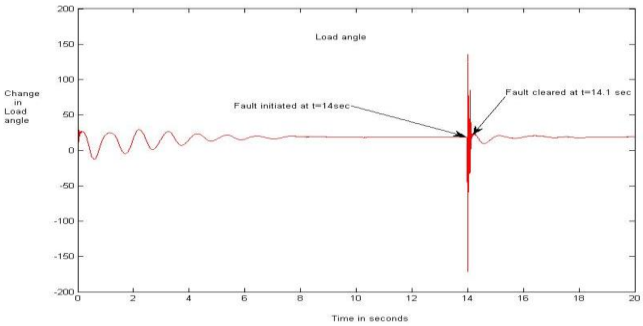
4. Simulation results of Multimachine system with PSS, with UPFC and Fault applied with respect to Rotor Speed ($\boldsymbol{\omega}_m$) and Load angle (Delta)

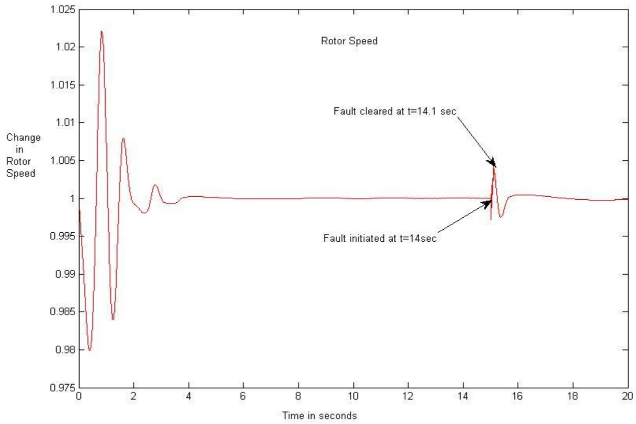


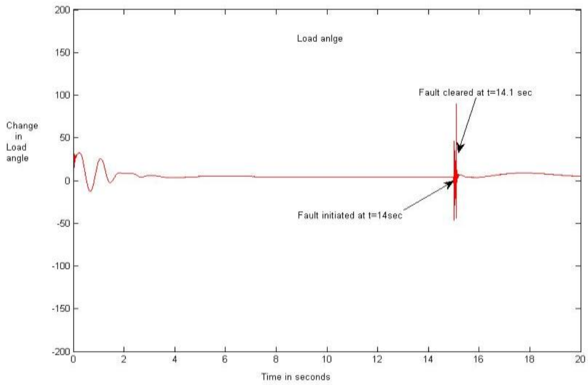


5. Comparison of above results without damping controllers and with damping controllers.









8. CONCLUSION:

A systematic approach for designing UPFC based controllers for damping power system oscillations has been presented. The Combination of Power System Stabilizer and UPFC not only reduces the system oscillation but also reduces the oscillations present in the real & Reactive power & phase voltage i.e. it maintains the constant power flow after the occurrence of the fault

This paper focuses on PSS and UPFC damping controller design and their contributions in damping the system oscillations during adverse conditions. Here during the simulation studies the position of UPFC is kept constant. The simulation studies revealed that oscillations present after occurrence of fault are greatly reduced after PSS and UPFC combination.

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BIOGRAPHIES:

	**M.Kishore kumar** is now pursuing his Master of Technology with specialization as Computer Aided Power Systems in NBKR Institute of Science & Technology, affiliated to Vikrama Simhapuri University, Nellore, Andhrapradesh, India. His current work includes Power system stability and FACTS device application.
	Sri **M.Sankaraiah** is Assistant Professor with the Department of Electrical & Electronics Engineering in NBKR Institute of Science & Technology, Nellore, Andhrapradesh, India. He has passed M.tech from NIT Calicut, with specialization in Power Systems. He has attended conferences on FACTS devices and its applications.
	Sri **Dr. S. Suresh Reddy** Professor & HOD of Electrical & Electronics Engineering in NBKR Institute of Science & Technology , Nellore, AndhraPradesh and has completed his Ph.D from J.N.T.University. He has presented five papers on Various FACTS devices, Load flows. He has teaching experience of more than 8 years.

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