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COMPARISON BETWEEN STATCOM-POD AND PSS FOR SMALL SIGNAL STABILITY ENHANCEMENT

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ABSTRACT: *The growth of the modern power system with the continuous change in power demand and supply has led to an increasing complexity in the study of power systems analysis, and in particular, to the aspects of transient stability and small-signal stability. The enhancement of power system stability using PSS (power system stabilizer) which is used to improve low frequency oscillations as a type of the rotor angle stability and STATCOM-POD (Static Synchronous Compensator with power oscillation damper) which is an effective FACTS (Flexible AC Transmission System) device capable of controlling the active and reactive power flows in a transmission line by controlling appropriately parameters also improve low frequency oscillations due to POD controller with STATCOM. In this Paper comparison between PSS and STATCOM-POD performance for power system stability enhancement of the 14-bus test system network is investigated. The comparison is based on investigation of the eigenvalues of the linearized power system model in the framework of dynamic hopf- bifurcation theory.*

KEYWORDS: Stability, PSS, STATCOM, POD, HOPF-Bifurcations, Eigenvalues.

INTRODUCTION

In recent years, the power system is continuously expanding in size and growing complexity all over the world. During their operation power systems undergo a large number of disturbances, some of them occurring continually, such as modifications in load demands, while others are less common but nonetheless can potentially be very dangerous, such As faults and structural changes like tripping of circuit breaker. From a practical viewpoint such disturbances are usually classified as either small or large, respectively, depending on the effects they have on system behavior. The inter-area modes are associated with the swinging of many machines in one part of the System against machines in other parts [1].

They are observed especially when two or more net Groups in the power system. These so-called Inter-area oscillations are slow damped oscillations with quite low frequencies. The power system Stability is largely a problem of insufficient damping of these oscillations. The problem is termed small-signal stability or oscillatory stability, respectively [2]. When undammed inter-area power oscillations emerge, their amplitude can increase over several minutes and loss of synchronism may appear in such cases and partial or complete collapse of the power system may follow [3].A contemporary solution to this problem is the addition of power system stabilizers to the automatic voltage regulators (AVR) on the generators in the power system. Power system stabilizers are designed to enhance the damping of power system oscillations in order to extend power transfer limits of system and maintain the reliable operation of the power system. As a supplementary control to provide extra damping for synchronous generators, power system stabilizer (PSS) has been widely used in the electric power industry [4-6].

In such cases, other effective solution such as the use of recently developed power electronic devices in the transmission system, such as the STATCOM, is being considered which solid-state voltage source converter which is tied to a transmission line. A STATCOM injects an almost sinusoidal current, of variable magnitude, at the point of connection. This injected current is almost in quadrature with the line voltage, thereby emulating an inductive or a capacitive reactance at the point of connection with the transmission line [7].This FACTS device has been proved to have additional benefits for increasing system damping with power oscillation damper (POD), other than its primary function, i.e. power flow control. Many researchers have investigated inter-area mode oscillations. A representative sample of these is [8], [9].

Nevertheless, FACTS devices such as STATCOM-POD were not considered in these studies.. However, the damping effects of the PSS and STATCOM-POD were analyzed by using a reduced order model of the generators as well as by considering only static load characteristics. In this paper, the contributions of the STATCOM-POD to the enhancement of power system inter-area modes oscillation damping are investigated and compared to PSS by considering a detailed two-axis generator model with a static using small signal stability analysis tool and Hopf –Bifurcations analysis in PSAT which is computational tool under Matlab program for effective simulation and monitoring with the (FACTS) device in the network system operation.
This paper is organized as follows:

Section 2 briefly describes the small-signal analysis tools used in this study as well as gives a general description of the system used for analysis.
Section 3 presents the simulation results and discussion. Conclusions are made in Section 4.

Modeling of Power System and small signal stability

Power systems are modeled by a set of differential and algebraic equations (DAE), i.e.

$$\dot{X} = f(x, y, \lambda, p) \qquad (1)$$
$$0 = g(x, y, \lambda\ p)$$

Where $x \in \Re^n$ is a vector of state variables associated with the dynamic states of generators, loads, and other system controllers; $y \in \Re^M$ is a vector of algebraic variables associated with steady-state variables resulting from neglecting fast dynamics (e.g. most load voltage phasor magnitudes and angles); $\lambda \in \Re^L$ is a set of uncontrollable parameters, such as variations in active and reactive power of loads, stands for a a set of parameters that slowly change in time, so that the system moves from one equilibrium point to another until reaching the collapse point; and $p \in \Re^K$ is a set of controllable parameters such as tap and automatic voltage regulator (AVR) settings, controller Reference voltages and shunt and series compensation levels. The system model can be reduced by the term

$$\dot{X} = f(x, h(x, \lambda), \lambda, p) = S(x, \lambda, p) \qquad (2)$$

A saddle node bifurcation of the system (2) occurs when the Jacobin $D_X S(x, \lambda, p)$ is singular at equilibrium point (x_0, λ_0, p_0) where two solutions of the system, stable and unstable, merge and then disappear as the parameter λ , i.e. system load changes. At the bifurcation point (x_0, λ_0, p_0) , the Jacobin $D_X S(x, \lambda, p)$ has a simple and unique zero Eigenvalues with normalized right eigenvector V and left eigenvector W [5].

$$D_X S(x_0, \lambda_0, p_0)\, V = 0 \qquad (3)$$
$$W^T D_X S(x_0, \lambda_0, p_0)\, V = 0^T \qquad (4) \qquad W^T \frac{\partial S}{\partial \lambda} at\ (x_0, \lambda_0, p_0) \neq 0 \qquad (5)$$
$$W^T [D_X^2 S(x_0, \lambda_0, p_0)\, V]\, V \neq 0 \qquad (6)$$

The above equations guarantee quadratic behavior near bifurcation point and are used to determine the voltage collapse point [10]. The eigenvectors at the bifurcation point provide information on the areas prone to voltage collapse and the control strategies to most effectively prevent this problem. For a given set of controllable parameters P, voltage collapse studies usually concentrate on determining the collapse or bifurcation point (x_0, y_0 ,λ_0,p_0) where λ typically corresponds to the maximum loading level or loadability margin in P.U., %, MW or MVA depending on how the load variation are defined. Based on bifurcation theory, Two known basic tools based on bifurcation theory are direct and continuation methods and are used to compute the voltage collapse point.

For small-signal stability analysis, we assume the system parameter variation is slow enough so that the model can be linearized around some equilibrium point as,

$$\Delta \dot{x} = A\Delta x \qquad (7)$$

where

$$A = J_1 - J_2 J_4^{-1} J_3 \qquad (8)$$

is the system state matrix, provided det$J_4 \neq 0$. J_1, J_2, J_3 and J_4 are Jacobian matrices of f and g related to dynamic state and algebraic variables, respectively.

The bifurcation theory can be used to predict how the system becomes unstable as parameters vary. In this approach stability analysis is performed by computing the eigenvalues of the system state matrix as certain parameters are allowed to vary slowly and continuously. The loss of local stability of an operating point is associated with an eigenvalue transition from one complex half-plane to the other. This instability may be due to real mode instability (null-eigenvalue) or complex mode instability (one pair of pure imaginary eigenvalues) [11]

Power system oscillations are associated with a pair of complex Eigen values of equlibria crossing the imaginary axis of the complex plane, from the left half plane to the right half plane, when the system undergoes sudden changes as shown in figure 1. If this particular dynamic problem is studied using gradual changes it can be viewed as Hopf bifurcation problem. Thus by predicting these types of bifurcations well in advance, a possible dynamic instability problem may be avoided [12] .In this paper, this approach is used for the analysis of small signal stability.

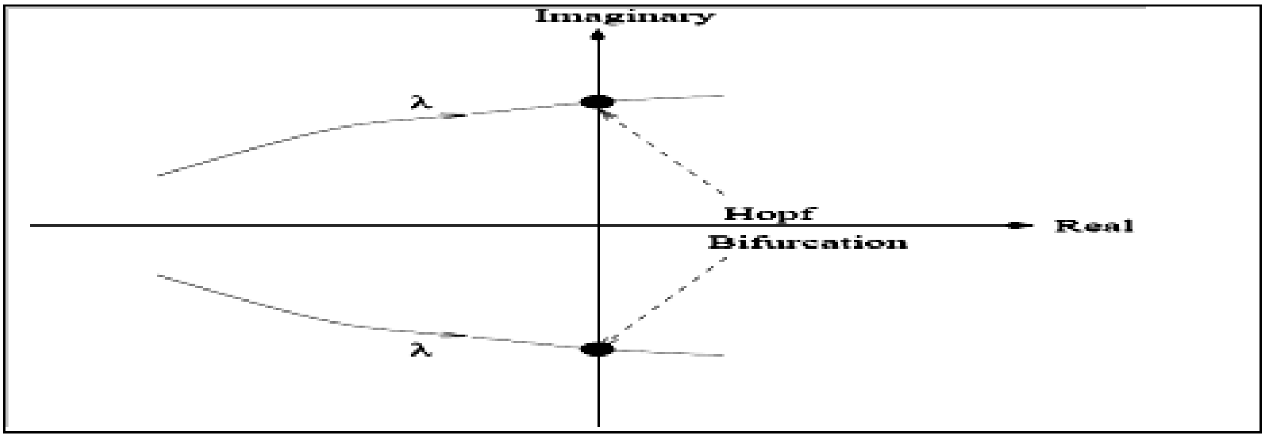

Fig.1 Hopf Bifurcation theory

Modeling of Power System Stabilizer (PSS)

Power system stabilizer (PSS), is used to damp out the low frequency oscillation. (Pss) input signals are the rotor speed ω, the active power p_g and the bus voltage magnitude v_g of the generator to which the (PSS) is connected through the automatic voltage regulator. The output signal of any (PSS) is a voltage signal,v_s. A common structure for (PSS) is reported in Figure 2. Different parameters of (PSS) are stabilizer gaink_{pss}, washout time constant t_w, first, second third and forth stabilizer time constant t_1, t_2, t_3, t_4 respectively. The first stage PSS gain K is an important factor as the damping provided by the PSS increases in proportion to an increase in the gain up to a certain critical gain value, after which the damping begins to decrease. The second stage is usually a high-pass filter often called wash-out filter, which provides zero output in steady state conditions. One or more, most commonly two, lead/lag filters are employed to provide sufficient phase compensation between rotor speed deviation and the output torque. [13-18]

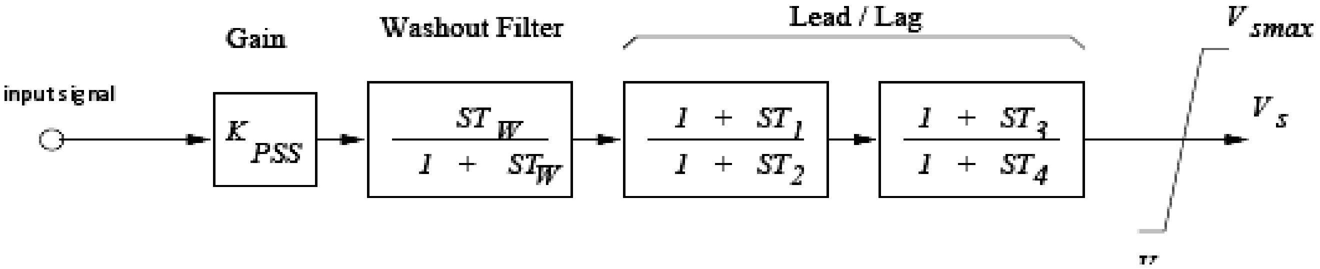

Fig.2 The block diagram of Power System Stabilizer

4 - Modeling of Static synchronous Compensator (STATCOM) with power oscillation damper (POD)

The STATCOM is a shunt device of the FACTS family and it improves transient stability on power grids. The STATCOM consists of a coupling transformer,a voltage-sourced inverter, a control system and a dc capacitor. The STATCOM used to regulate voltage at its terminals by controlling the amount of reactive power injected into or absorbed from the power system. The VSC uses forced-commutated power electronic devices (GTOs, IGBTs or IGCTs) to synthesize a voltage V_2 from a DC voltage source. The principle of operation of the STATCOM is explained on the figure 3 below showing the active and reactive power transfer between a source V_1 and a source V_2. In this figure, V_1 represents the system voltage to be controlled and V_2 is the voltage generated by the VSC.

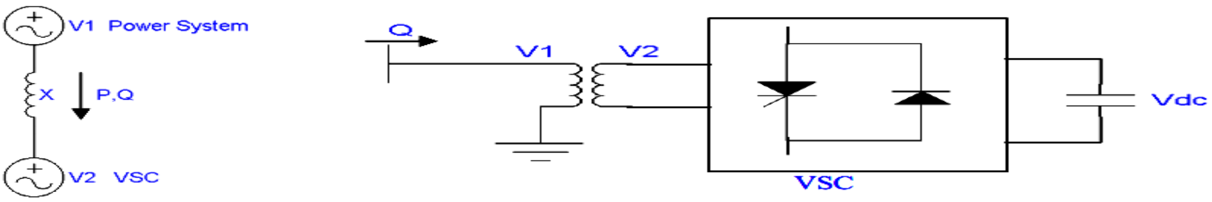

Fig 3. Operating Principle of the STATCOM

For purely reactive power flow the three phase voltages of the STATCOM must be maintained in phase with the system voltages. The variation of reactive power is performed by means of a VSC connected through a coupling transformer. The VSC uses forced commutated power electronics devices (GTO's or IGBT's) to synthesize the voltage from a dc voltage source. A capacitor connected on the DC side of the VSC acts as a dc voltage source [13, 14].

a Power Oscillation Damper (POD). This model has been initially implemented by [19].and an important contribution was given also by [20]. The output signal of the POD can be used with STATCOM.
The implemented STATCOM-POD model is a current injection model which is based on. The dynamic model is shown in Fig.4 the differential equation and the reactive power injected at the STATCOM node are given, respectively, by [21]:

$$I_{sh}= (k_r(V_{ref}+V_s^{POD}-V)- I_{sh})/T_r$$
$$Q= I_{sh}.V \qquad (9)$$

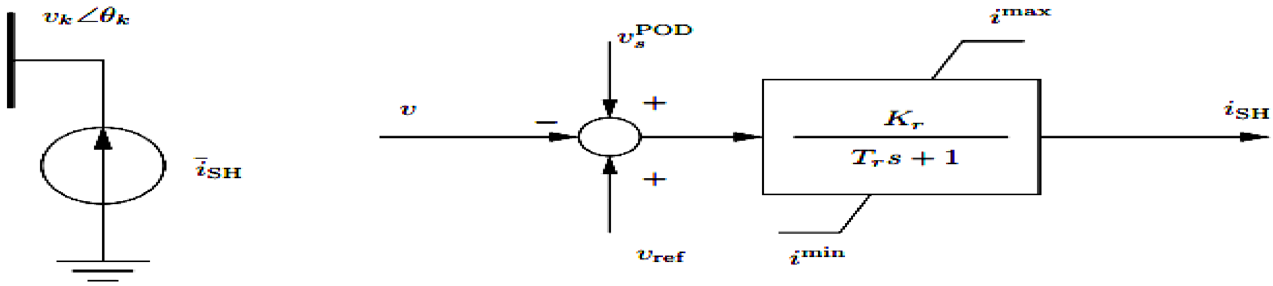

Fig.4 STATCOM circuit and control block diagram

The regulator has a non-windup limiter, thus the current i_{SH} is locked if one of its limits is reached and the first derivative is set to zero.

Test System

The IEEE14- bus test system is used for the objective of these studies. Fig.5 show the IEEE 14 bus test system used. It consists of 14 buses, 20 branches, three transformers, and five synchronous machines. The generators are molded as standard PV buses with both P and Q limits, loads are represented as constant PQ loads. Power system analysis toolbox software (PSAT), which has many features including power flow and continuation power flow, is used [22].

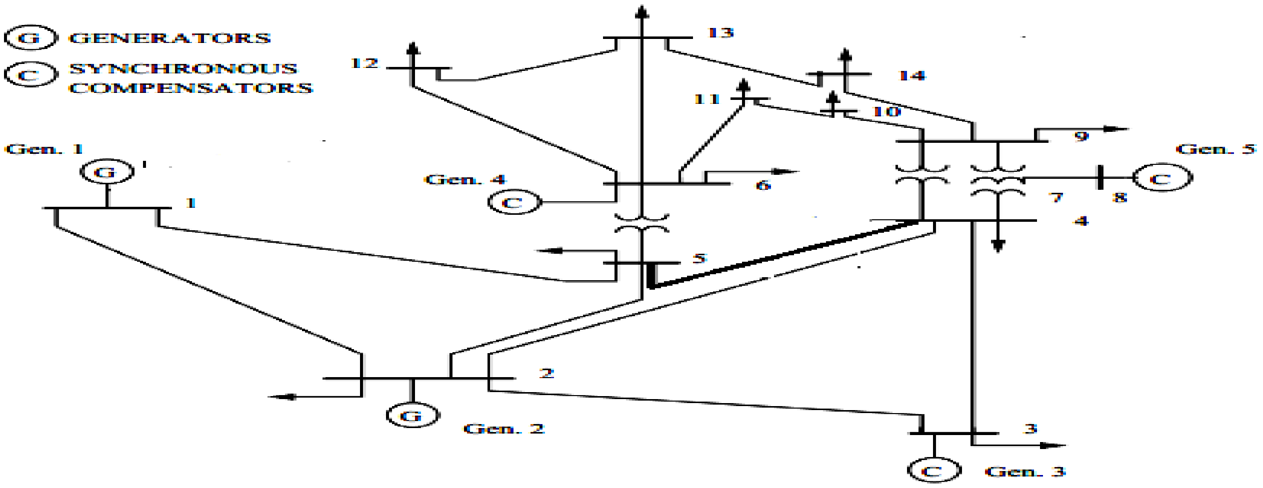

Fig.5 IEEE 14-bus test system

SIMULATION RESULTS

This simulation presents results associated with stability problems of the test system with the inclusion of some controllers. For small perturbation, one can determine the available Static Margin (SM), which is the maximum loading level beyond which steady state solutions cannot be obtained for the system. This is accomplished by obtaining full P-V curves for normal and line outages conditions. On these curves, Dynamic Margins (DM), which are typically the loading levels at which the system presents oscillatory instabilities associated with Hopf bifurcations, are also depicted.

Simulation with PSS

The PSS controller model used in this case is shown in Fig2. The gain and various time constants of the PSS based on the rating of the machine and A complete set of data for the PSS controller parameters are selected from [22]. The best placement of the PSS controller is generator no.1 [23]. Table 1 illustrates the DM and SM associated with P-V curves for normal operating and for two considerable two lines outage. To study the behavior of the test system under large disturbance the time domain simulation and small signal stability analysis by eigenvalue method were performed for the system at operating point λ=1.2 . Thus, Figure 6 shows the eigenvaluesfor the system at the selected operating point, whereas Figure7 and Figure8 show the corresponding time domain simulations. These results confirm that the PSS can’t remova the Hopf bifurcation and the oscillation damping.

Table. 1: Dynamic and Static Loading Margins for Test System with PSS

System with PSS	**Normal operating**	**Line outage 2-3**	**Line outage 4-2**
SM	1.7086	1.2603	1.5472
DM	1.1218	0.8670	1.0188

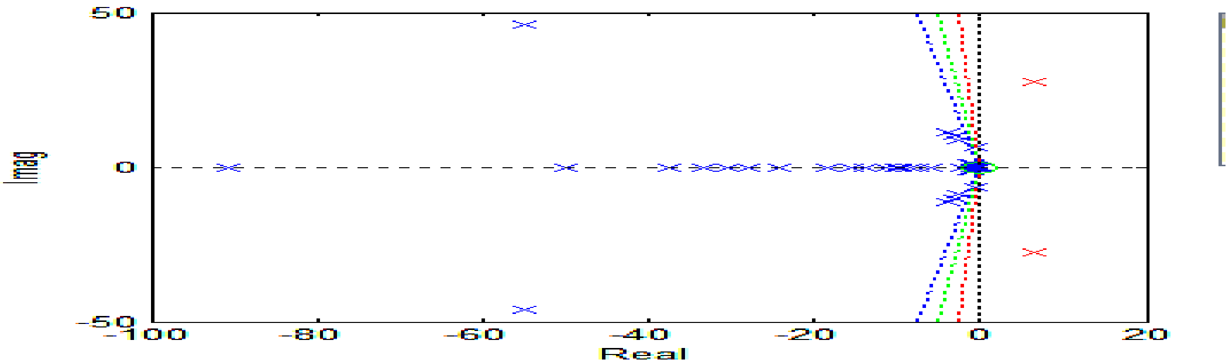

Fig.6 eigenvalues with PSS at bus 1 for in the IEEE 14-bus test system at λ=1.2

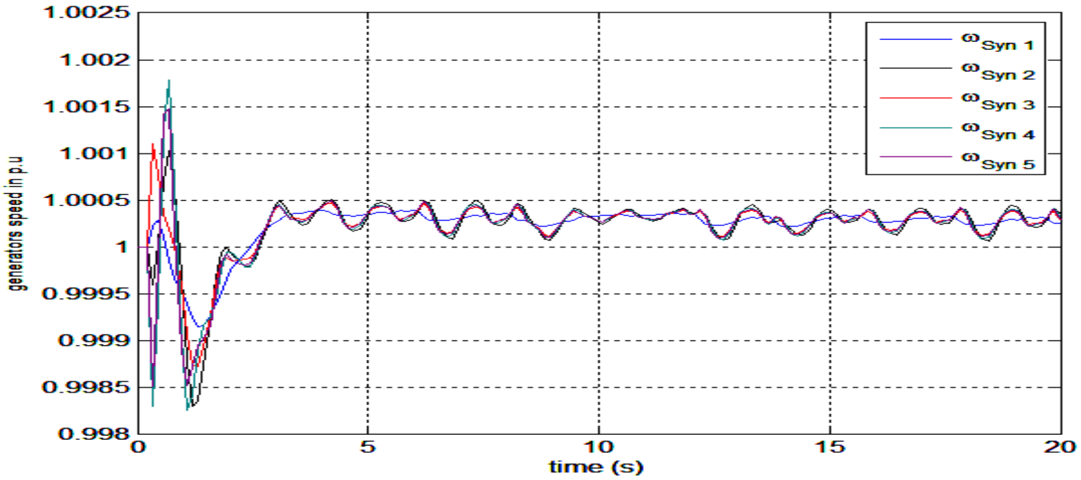

Fig .7 Generator speed oscillation with PSS at bus 1 for the IEEE 14-bus test system λ=1.2

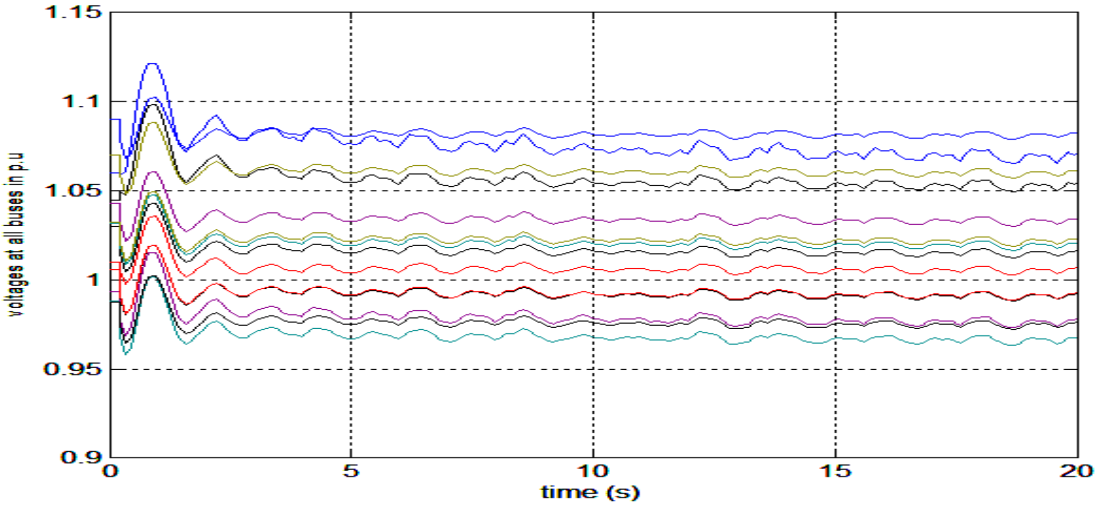

Fig .8 voltages at all buses with PSS at bus 1 for the IEEE 14-bus test system at λ=1.2

Simulation with STATCOM-POD

The STATCOM-POD controller model used in this case is shown in Fig3. The gain and various time constants of the PSS based on the rating of the machine and A complete set of data for the STATCOM-POD controller parameters are selected from [22]. The best placement of the STATCOM-POD controller at bus 9 according to [24].Table 2 illustrates the DM and SM associated with P-V curves for normal operating and for two considerable two lines outage. To study the behavior of the test system under large disturbance the time domain simulation and small signal stability analysis by eigenvalue method were performed for the system at operating point λ=1.2 . Thus, Figure 9 shows the eigenvalues for the system at the selected operating point, whereas Figure10 and Figure11 show the corresponding time domain simulations. These results confirm the removal of the Hopf bifurcation and the oscillation damping introduced by the STATCOM-POD.

Table.2: Dynamic and Static Loading Margins for Test System with STATCOM-POD.

System with STATCOM-POD	**Normal operating**	**Line outage 2-3**	**Line outage 4-2**
SM	1.9752	1.3610	1.7786
DM	1.4011	1.1501	1.1132

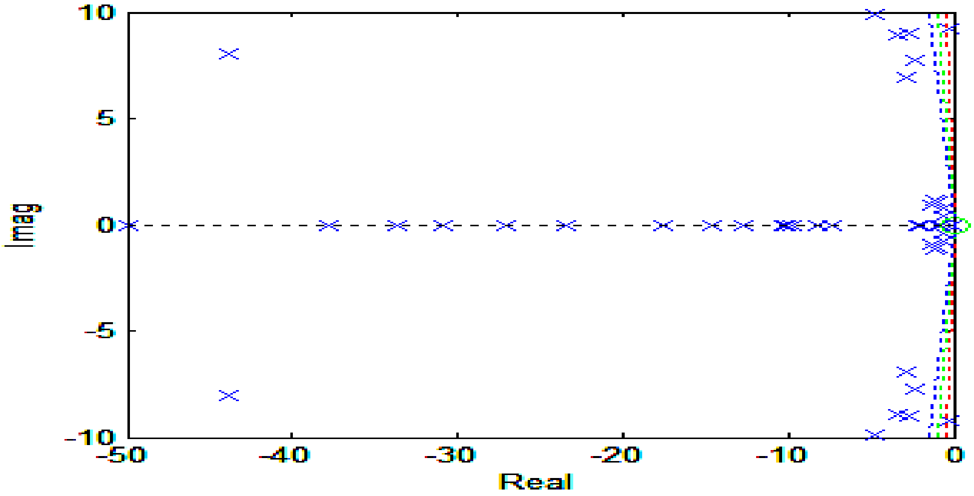

Fig.9 eigenvalues with STATCOM-POD at bus 9 for the IEEE 14-bus test system at λ=1.2

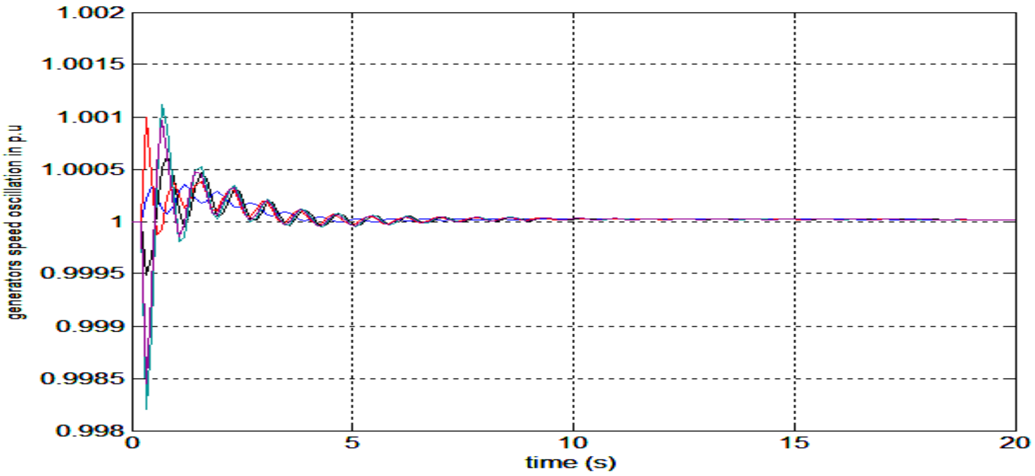

Fig .10 Generator speed oscillation with STATCOM-POD at bus 9 for the IEEE 14-bus test system λ=1.2

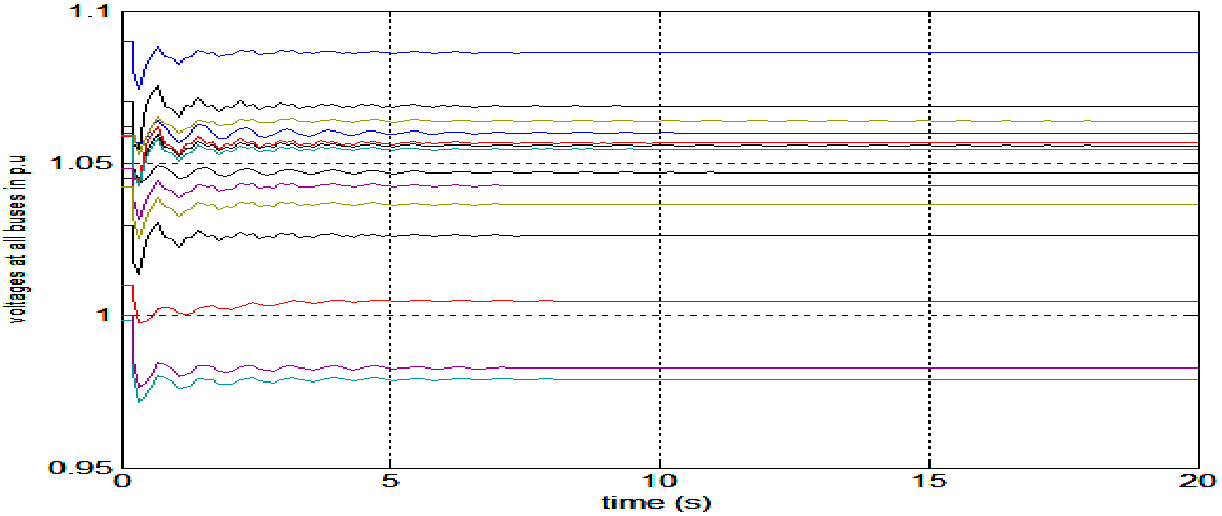

Fig .11 voltages at all buses with STATCOM-POD at bus 9 for the IEEE 14-bus test system at λ=1.2

CONCLUSIONS

This paper has compared the effects of STATCOM-POD with PSS controller for damping of inter-area mode oscillations. The studies were conducted using eigenvalues analysis and bifurcation theory with time domain simulation. It was shown that STATCOM-POD have a great impact on the damping of the inter-area mode oscillations in addition to increasing the static and dynamic loading point more than the PSS controller for the same loading condition . where the inclusion of the STATCOM-POD in the test system regardless of the load model used (static or dynamic), the simulations results presented show that oscillatory instability, that is to say, Hopf bifurcation, does not occurs, since the damping effect of STATCOM-POD is an increasing function of the system loading. In all cases, the studies revealed that this bifurcation occurs for the same value of bifurcation parameter. Clearly, results shows that the effect of the STATCOM-POD controller compared to PSS on the dynamic performance of the test system.

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