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Design of Adaptive Power Oscillation Damping controller by STATCOM with Energy Storage

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Abstract

This paper describes an approach to design adaptive power oscillation damping controller of an energy storage type a static synchronous compensator is advanced FACT device, which controls both active and reactive power at PCC in the power system. To maintain power system stability damping of low frequency power oscillations are essential, which are measured by using a signal estimation technique based on modified recursive least square algorithm. During the disturbances the proposed method productive by increasing the damping of the system at the different frequencies, system parameter uncertainties and various connection points of static synchronous compensator. i.e.,STATCOM. Paper discuss anatomy of an influence of active and reactive power injection of power system, which will carried out using two machine model and damping controller design. This controlling method optimizes performance of active and reactive power injection at different connection points of STATCOM with energy storage will be derived using simplified model. The result of the study show that, the proposed control strategy provides effective power oscillation damping regardless of the connection point of the device and the system variables uncertainties will be verified through power system simulation.

INDEX TERMS - Energy Storage, FACTS, Low frequency oscillations, STATCOM, E-STATCOM, RLS-algorithm

1.INTRODUCTION

In recent years, the electric power system has grown in size and complexities with more number of inter connections to mitigate the increase in the electric power demand. So, the construction of new long distance, large power transmission lines are difficult due to economical, social and environmental problems.

On the basis of the above back ground many FACT technologies have been developed. Furthermore, as a typical FACT devices, static synchronous compensator(STATCOM) has been developed and put in operation at distribution level to mitigate power quality and maintain voltage, power oscillation damping at transmission level by reactive power control[1]-[2].With recent advances in energy storage technology by equipping the STATCOM with an energy storage system connected to dc link of the converter has now become feasible for steady state voltage control and elimination of power system disturbances[5]. Wind energy and other distributed generation will provide a smooth easy way for more energy storage into power system and auxiliary stability enhancement function is possible from the energy sources [6]. Due to the interaction among the system components the low frequency electro mechanical oscillations appear in a power system. These oscillations usually in the range of 0.2Hz to 2.5Hz. In this regard, FACT controllers both shunt and series configuration have been widely used to improve the system stability means damping of those low frequency oscillations [1]. In the particular case of shunt connected FACTS controllers (SVC &STATCOM), First swing stability and power oscillation damping can be provided by changing the voltage at the point of common coupling(PCC)using reactive power injection; But one drawback of the shunt controllers for this kind of applications is that PCC voltage must be regulated within the specific limits(typically between ±10% of the rated voltage) and this reduces the amount of damping provided by the compensator.

Active power injection used temporarily during transient and this injected active power affects the PCC voltage angle without varying the voltage magnitude significantly. In the past, power system stabilizers are recognized as an efficient and economical method to damp out oscillations. Where cascade of wash out and lead-lag filter links are used to generate the control input signals. This type of control is effective only at the point where the design of filter links is optimized and also is speed response is limited by the frequency of electromechanical oscillations. In recent years, as new solutions FACTS controllers with energy storage are used for power system stability enhancement has been discussed in [4]-[6]. This control strategy optimizes the injection of active and reactive power to provide uniform damping at various locations in the power system. This is achieved using modified recursive least square algorithm as described in [9],[10] will be used to estimate required control signals from locally measured signals. Finally, effectiveness of proposed control method will be validated via simulation and better controlling achieved through fuzzy controller.

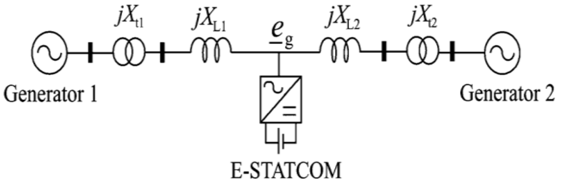

Fig.1.Simplified two-machine system with E-STATCOM

II. MODELLING OF SYSTEM FOR CONTROLLER DESIGN

A Simplified two-machine system with E-STATCOM is used to study the impact of the E-STATCOM on the power system dynamics. This two-machine system approximates an aggregate model of two area power system, where each area represented by a synchronous generators. Synchronous generators are modeled as voltage sources of constant magnitude (V_{g1}, V_{g2}) and with their corresponding rotor angles (δ_{g1}, δ_{g2}) behind a transient reactance (X_{d1}^{I}, X_{d2}^{I}). The transmission system contains two transformers and they are represented by their equivalent leakage reactances (X_{t1}, X_{t2}) and transmission line is represented with equivalent reactance ($X_{L=}X_{L1} + X_{L2}$)as shown in fig.3. For simple analysis losses in the transmission system are neglected. Initially overall damping in the system is zero when mechanical damping in the generators is neglected. For analysis purpose, the electrical connection point of the converter along transmission line is represented by the parameter 'a' is expressed as

$$a = X_1/X_1 + X_2$$

Here $$X_1 = X_{d1}^{I} + X_{t1} + X_{L1} \quad (1)$$

$$X_2 = X_{d2}^{I} + X_{t2} + X_{L2}$$

The control strategy of E-STATCOM consists of two control loops. They are Outer control loop and Inner control loop. The outer control loop which can be POD controller ac voltage or ac voltage or dc-link voltage. It will sets the reference current for the inner current controller. The measured signal (Y_m) depends on the type of outer control loop. The control algorithm is executed in dq-reference frame. Where PLL (phased locked loop)[7]is used to trace the voltage angle θ_g from the grid voltage vector e_g. Synchronizing the PLL with the grid voltage vector e_g , The injected currents of d-q components (i_f^d, i_f^q) control the injected active and reactive power respectively. The superscript'*'denotes the corresponding reference signal. The outer control loop is assumed as POD controller and details description is presented in section 3. Initially, we assume that the injected active and reactive powers in the steady state are zero. In the designing of cascade controller, the speed of outer control loop is typically selected to be much slower than the inner control loop to guarantee the stability. That is the current controller should be considered as infinitely fast when designing the outer control loop. Therefore, E-STATCOM can be modeled as a controlled ideal current source, as represented in the equivalent circuit in fig.3.

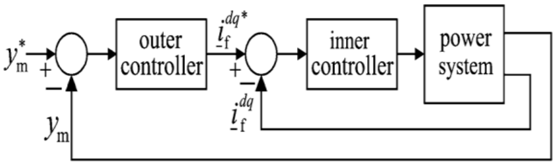

Fig.2.Block diagram for the control of E-STATCOM

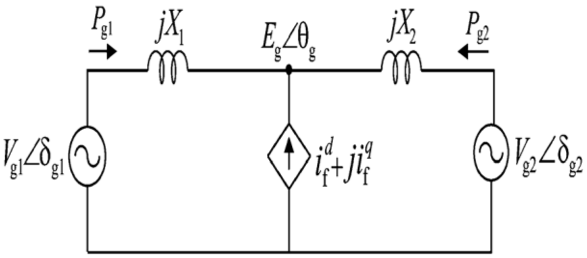

Fig.3.Equivqlent circuit for the two machine system with E-STATCOM

The level of power oscillation damping provided by the converter depends on injected current i_f.The i_f modulate the active power output from the generators. The change in active and reactive power output from the generators due to injected active and reactive power from the E-STATCOM, for the system in fig.3. is calculated as

$$\Delta P_{g1,p} = -\Gamma p P_{inj}$$

$$\Delta P_{g2,p} = -(1 - \Gamma p) P_{inj}$$

$$\Delta P_{g1,Q} = [\frac{V_{g1}V_{g2}\sin(\delta_{g10} - \delta_{20}) a(1-a)}{E_{g0}^2}] Q_{inj}$$

$$\Delta P_{g2,Q} = -[\frac{V_{g1}V_{g2}\sin(\delta_{g10}-\delta_{20})a(1-a)}{E_{g0}^2}]Q_{inj} \qquad (2)$$

Here $\Delta P_{g1,p}, \Delta P_{g2,p}$ are change in the active power from corresponding generators due to injected active power (P_{inj}) and $\Delta P_{g1,Q}$, $\Delta P_{g2,Q}$ are the change in active power from corresponding generators due to injected reactive power(Q_{inj}).

$$\Gamma p = \frac{[(1-a)V_{g1}]^2+a(1-a)V_{g1}V_{g2}\,cos(\delta_{g10}-\delta_{g20})]}{E_{g0}^2} \qquad (3)$$

$$P_{inj} = E_{g0}i_f^d$$

$$Q_{inj} = -E_{g0}i_f^q$$

E_{g0} is the initial steady state PCC voltage magnitude. $\delta_{g10}, \delta_{g20}$are the generator rotor angles corresponding to the operating point.

III. DESIGN OF POD CONTROLLER

The derivation of POD controller from locally measured signals as shown in this section.

A. Derivation of control input signals

Considering fig.1.the active power output from the each generator is change in proportion to the change in its speed to provide damping [3].From the above equations, the change in active power output from the generators depends on the location of converter 'a', as well as on the amount of injected active and reactive power .From equation (2)the effect of the reactive power injection depends on the magnitude and direction of transmitted power from the generators. Using equivalent system in fig.3.a control input signals are derived that contains the information on the speed variation of the generators. When the E-STATCOM is not injecting any current, the variations in the locally measured signals $\theta_g$and P_{tran} at different connection points of E-STATCOM using the dynamic rotor angles is given by

$$\theta_g = \delta_{g2} + \tan^{-1}[\ \frac{(1-a)V_{g1}\sin(\delta_1-\delta_2)}{(1-a)V_{g1}\cos(\delta_{g1}-\delta_{g2})+aV_{g2}}] \qquad (4)$$

$$P_{tran} = \frac{V_{g1}V_{g2}\sin(\delta_{g1}-\delta_{g2})}{X_1+X_2}$$

θ_g is the PCC voltage phase, P_{tran} is the transmitted active power.Required control input signals can be derived from the PCC voltage phase and transmitted active power is given by

$$\frac{d\theta_g}{dt} = \Gamma p\omega_{g0}\Delta\omega_{g1} + (1-\Gamma p)\,\omega_{g0}\omega_{g2} \qquad (5)$$

$$\frac{dP_{tran}}{dt} = \left\{\frac{V_{g1}V_{g2}\cos(\delta_{g10}-\delta_{g20})}{X_1+X_2}\right\}\omega_{g0}[\Delta\omega_{g1} - \Delta\omega_{g2}] \qquad (6)$$

Where ω_{g0} is the nominal system frequency and $\Delta\omega_{g1}, \Delta\omega_{g2}$ are the speed variation of the generators in p.u.

The electromechanical dynamics for each generator [i=1,2]is given by[3]

$$2H_{gi}\frac{d\Delta\omega_{gi}}{dt} = \Delta T_{mi} - \Delta T_{gi} - K_{Dmi}\Delta\omega_{gi} \qquad (7)$$

Where H_{gi} , $\Delta T_{mi,}\Delta\omega_{gi}$, ΔT_{gi} and K_{Dmi} indicate inertia constant, change in input torque, speed variation, change in output torque and mechanical damping constant for the i^{th} generator respectively.

The control input signals $\frac{d\Theta g}{dt}$,$\frac{dPtran}{dt}$ are depends on the speed variation of the generators and the moreover $\frac{d\Theta g}{dt}$ depends on the location of the E-STATCOM, through the parameter Γp. So, for two-machine system damping is related to the variation of the speed difference between two generators $\Delta\omega_{g12} = \Delta\omega_{g1} - \Delta\omega_{g2}$.From(2) and(3) It is clear that the change in the output power from the generators due to injected active power is maximum when compensator is connected at the generator terminals $(\text{i.e.}, \text{a} = 0\ \&a = 1)$.Consider inertia constant of the two generators is equal, no damping is provided by the injection of active power at the electrical mid pint of the line (i.e., $\text{a} = 0.5$, for $\text{Hg1} = \text{Hg2}$) as the power output of two generators is same, The net impact is zero. At this point $\frac{d\Theta g}{dt}$ is zero[see(5)].This means that the derivative of PCC voltage phase scales the speed variation of the two generators depending on the location of the E-STATCOM and its magnitude changes in proportion to the level of damping provide by the active power injection. Therefore, $\frac{d\Theta g}{dt}$ is an appropriate control input signal. From (2), it can be understood that at the electrical id point of the line $(\text{i.e.}, \text{a} = 0.5)$ the change in the output power from the generators due to injected reactive power is maximum and minimum at the generator terminals $(\text{i.e.}, \text{a} = 0\ \&a = 1)$. As the change in the output powers of generators are same magnitude and opposite sign,a signal that varies linearly with speed variation between the two generators, $\Delta\omega_{g12}$ is an appropriate control input signal to control the reactive power injection. $\Delta\omega_{g12}$ is obtained from $\frac{dPtran}{dt}$.

B. Evaluation of control input signals

Effective power oscillation damping for different power system operating points and E-STATCOM locations required accurate, fast and adaptive estimation of the critical power oscillation frequency component. This achieved by using modified RLS algorithm. In previous section described that, the derivative of PCC voltage phase and transmitted power should be estimated for controlling the active and reactive power injection respectively. The main aim of algorithm is estimate the signal components that contains only the low frequency electromechanical oscillation in the measured signal $\theta_g$and P_{tran}. By selecting the PLL bandwidth much higher the frequency of electromechanical oscillations, $\frac{d\Theta g}{\mathrm{dt}}$ obtained from the change in the frequency estmation of the PLL. Therefore, low frequency electromechanical oscillation component directly obtained from the frequency estimation of the PLL. On the other hand, $\frac{dP_{tran}}{dt}$ is estimated by extracting the low frequency electromechanical oscillation component from the measured signal P_{tran} , and then applying a phase shift of $\Pi/2$.

Control input signals $\frac{d\Theta g}{\mathrm{dt}} = \omega_{g,osc}$ and $\frac{dP_{tran,osc}}{dt}$, which contain only a particular frequency oscillation component. To set up POD controller the reference injected active and reactive current components (i_f^{d*} and i_f^{q*}) from E-STATCOM can be calculated. K_p and K_Q represent proportional controller gains for the active and reactive current components respectively. To describe the estimation algorithm an input signal y is considered as either ω_g orP_{tran} as shown in fig.4. Behind a power system disturbance,y will consists of an average value that varies slowly and number of low frequency oscillatory components depends on the number of modes that are excited by the disturbance.

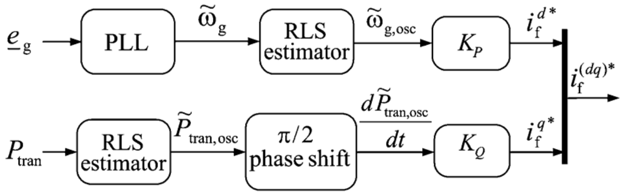

Fig.4.Block diagram for the POD controller

For simple analysis, let us assume that there exits a single oscillatory component in the input signal. So, the input signal consists of average component Y_{avg} and the oscillating component Yosc, that canbe expressed in terms of amplitude Y_{ph},frequency ω_{osc} and phase(ϕ) as

$$y(t) = Y_{avg}(t) + Y_{ph}(t)\cos(\omega_{osc}t + \varphi(t)) \qquad (8)$$

y (t) can be expressed in d-q reference frame by including the oscillation angle$\theta_{osc}(t)$ =ω_{osc}t . So,(8)can be rewritten as

$$y(t) = Y_{avg}(t) + Y_{ph,d}(t)\cos\big(\theta_{osc}(t)\big) - Y_{ph,q}\sin(\theta_{osc}(t)) \quad (9)$$

Where $Y_{ph,d}$ and $Y_{ph,q}$ are phase voltage in d-q frame is expressed as

$$Y_{ph,d}(t) = Y_{ph}(t)\cos\big(\theta_{osc}(t)\big)$$

$$Y_{ph,q}(t) = Y_{ph}(t)\sin\big(\theta_{osc}(t)\big)$$

The estimated state vector is derived using the RLS algorithm in discrete time [9],[10] using an observational matrix Φ and measured input signal Y (t)

$$\hat{h}(k) = \hat{h}(k-1) + G(k)[y(k) - \Phi(k)\hat{h}(k-1)$$
$$\hat{h}(k) = [\,\hat{Y}_{avg}(k) \quad \hat{Y}_{ph,d}(k) \quad \hat{Y}_{ph,q}(k)]^T \qquad (10)$$

$\Phi(k)$ is Observational matrix

$$\Phi(k) = [1 \;\; \cos\big(\theta_{osc}(t)\big) \;\; \text{-}\sin\big(\theta_{osc}(t)\big)] \qquad (11)$$

Where $G(k)$= Gain matrix

$$G(k) = R(k-1)\phi^T(k)[\lambda + \Phi(k)R(k-1)\phi^T(k)] \quad (12)$$

Where $R(k)$ is the Covariance matrix.

$$R(k) = \{[I - G(k)\phi(k)]R(k-1)\} \div \lambda \qquad (13)$$

I is identity matrix

Where λ is the forgetting factor for the RLS algorithm such that 0<λ≤1.Steady state band width of the RLS algorithm is α_{RLS}

$\alpha_{RLS=(1-\lambda)/\,T_s}$

Where $T_s$is sampling time

$$\mathcal{E}(k) = y(k) - \Phi(k)\hat{h}(k-1) \tag{14}$$

$\mathcal{E}(k)$ is estimation error

Alternation In The Conventional RLS Algorithm

The choice of α_{RLS} is tradeoff between a good selectivity for the estimator and its speed response [9],[10]. A high value of forgetting factor results in low estimation speed with good frequency selectivity. Decreasing the value of λ means increasing the estimation speed and the frequency selectivity of the algorithm reduces. Due to this reason, the conventional RLS algorithm must be modified in order to obtained fast estimation without comprising its steady state selectivity. This is achieved with the use of variable forgetting factor[10]. Durnig the steady state bandwidth of the RLS algorithm is determined by the steady state forgetting factor. If any rapid change is detected in the input means if the estimation error magnitude $|\mathcal{E}(k)|$ exceeds predefined threshold value,λ value will be modified to a smaller transient forgetting factor λ_{tr} and then using a high passfilter with time constant T_{hp}, λ will be slowly increased back to its steady state value λ_{ss}.

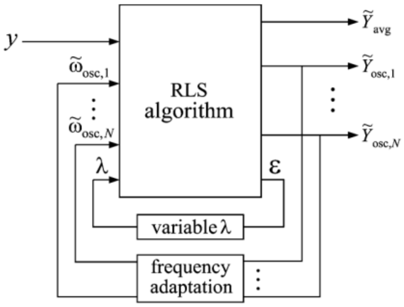

Fig.5.Block diagram for the modified RLS estimator for multiple oscillation mode

The performance of estimation method depends on not only λ,it also depends on oscillating frequency ω_{osc} and it depends on the system parameters and its operation conditions. If the frequency of the input changes, estimator will give rise to a phase and magnitude error in the estimated quantities.A frequency adaption mechanism[10]is implemented to trace the true oscillation frequency of the input from the estimated oscillatory component Y_{osc} .

Modification For Multi Oscillation Mode

The control method has been derived in the above section under the assumption of single oscillatory frequency component in the input signal. In this section describes the how the proposed algorithm can be extended to multi area system with multiple oscillation modes. Assuming that input signal y contains N oscillatory components,(8) must be modified as

$$y(t) = y_{avg}(t) + \sum_{i=1}^{N} Y_{osc,i} \tag{15}$$

$$y(t) = y_{avg}(t) + \sum_{i=1}^{N} Y_{ph,i}(t)\cos[\omega_{osc,i}t + \varphi_i\,(t)]$$

The i^{th} oscillation mode $Y_{osc,i}$ (i=1,2…….,N)is expressed in terms of its amplitude($Y_{ph,i}$) ,frequency ($\omega_{osc,i}$) and phase(φ_i). The POD controller in fig.4.could be modified accordingly to control every mode independently. The phase shift applied for calculation of the reference currents depends on the examine system and need to calculated for each oscillatory mode[8].

IV.SYSTEM STABILITY ANALYSIS

In this section mathematical model of the system in fig.3. is developed to examine the performance of the POD controller using active and reactive power injection. Using the expressions 5&6, the injected currents of controller as

$$i_f^d \approx k_p\omega_{g0}[\Gamma_p\Delta\omega_{g1} + (1-\Gamma_p)\Delta\omega_{g2} \tag{16}$$

$$i_f^q \approx k_Q\omega_{g0}\left\{\frac{V_{g1}V_{g2}cos(\delta_{g10}-\delta_{g20})}{X_1+X_2}\right\}(\Delta\omega_{g1} - \Delta\omega_{g2}) \tag{17}$$

Linearization of the small signal dynamic model of two machine system with E-STATCOM in p.u is developed as

$$\frac{d}{dt}\begin{bmatrix}\Delta\omega_{g1}\\ \Delta\delta_{g12}\\ \Delta\omega_{g2}\end{bmatrix} = \begin{bmatrix}\beta_{11} & \beta_{12} & \beta_{13}\\ \omega_{g0} & 0 & -\omega_{g0}\\ \beta_{31} & \beta_{32} & \beta_{33}\end{bmatrix}\begin{bmatrix}\Delta\omega_{g1}\\ \Delta\delta_{g12}\\ \Delta\omega_{g2}\end{bmatrix} + \begin{bmatrix}\frac{1}{2H_{g1}} & 0\\ 0 & 0\\ 1 & \frac{1}{2H_{g2}}\end{bmatrix}\begin{bmatrix}\Delta T_{m1}\\ \Delta T_{m2}\end{bmatrix}$$

$\Delta\delta_{g12}$ represents rotor angle difference between the two generators. Let us assume initial steady state speed of the generators is set to ω_{g0} and no mechanical damping is provided. The constants are

$$\beta_{11} = \frac{\omega_{g0}(K_p E_{g0}\Gamma_p^2 + K_Q \Gamma_Q)}{2H_{g1}}$$

$$\beta_{12} = -\frac{V_{g1}V_{g2}\cos(\delta_{g10}-\delta_{g20})}{2H_{g1}(X_1+X_2)}$$

$$\beta_{13} = \frac{\omega_{g0}(K_p E_{g0}\Gamma_p(1-\Gamma_p) - K_Q\Gamma_Q)}{2H_{g1}}$$

$$\beta_{31} = \frac{\omega_{g0}(K_p E_{g0}\Gamma_p(1-\Gamma_p) - K_Q\Gamma_Q)}{2H_{g2}} \qquad (18)$$

$$\beta_{32} = \frac{V_{g1}V_{g2}\cos(\delta_{g10}-\delta_{g20})}{2H_{g2}(X_1+X_2)}$$

$$\beta_{33} = \frac{\omega_{g0}\left(K_p E_{g0}(1-\Gamma_p)^2 + K_Q\Gamma_Q\right)}{2H_{g2}}$$

$$\Gamma_Q = \frac{[V_{g1}V_{g2}]^2 \sin\left(2\left(\delta_{g10}-\delta_{g20}\right)\right) a(1-a)}{2E_{g0}(X_1+X_2)} \qquad (19)$$

The terms β_{12} and β_{32} indicate the synchronizing torque coefficients. β_{11} and β_{33} represent the damping torque coefficient provided by the E-STATCOM with respect to the change in speed of respective generators.The terms β_{11} and β_{33} should be negative for providing positive damping. For this sign of k_p also negative and sign of k_Q depends on sign of Γ_Q. Γ_Q is positive when power transmitted from generator1 to generator2. Then sign of k_Q is negative and vice versa. $\beta_{13}$and β_{31} represent the cross coupling terms between two generator speed variations.

In the case of active power injection only ($k_Q = 0$),The cross coupling terms $\beta_{13}$and β_{31} reduce the damping with respect to the speed variation of the generators will be opposite at the oscillatory frequency. At the electrical mid point of the line, the damping due to P_{inj} is zero. Therefore, the active power injected by the E-STATCOM at the electrical mid point of the line is set to zero by the control algorithm. When moving towards the generator terminals, Γ_p increases and cross coupling terms decreases. It enhances the damping which is provided by the active power injection. With the reactive power injection only ($k_p = 0$), cross coupling terms provide positive damping and maximum damping is provided at the electrical mid point of the line. Where magnitude of Γ_Q is maximum.

V.SIMULATION RESULTS

The implemented system is rated 20/230kV, 900 MVA, total series reactance of 1.665 p.u. P_{tran} =400 MW and inertia constants $H_{g1} = H_{g2} = H_{g3} = H_{g4} = 6.5s$.Leakage reactance of transformers 0.15 p.u. and transient impedance of generators 0.3 p.u. By creating a three phase fault at transmission line and E-STATCOM is connected at various points and simulation results were carried out by using simulink/MATLAB software. The simulation results for both PI and Fuzzy controller are discussed in this section.

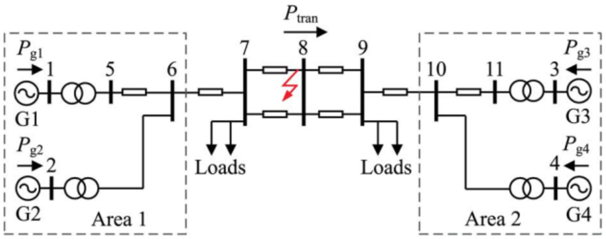

Fig. 6. Simplified two area four machine power system

In this system each area consists of two generators, rated ass 900 MVA connected to a transmission system through a step up transformers, buses. The load 200MW is connected at bus7 and bus9. Three phase fault is created on transmission between bus7 and bus8. The simulation results of measured transmitted active power output without E-STATCOM and POD controller as shown below.

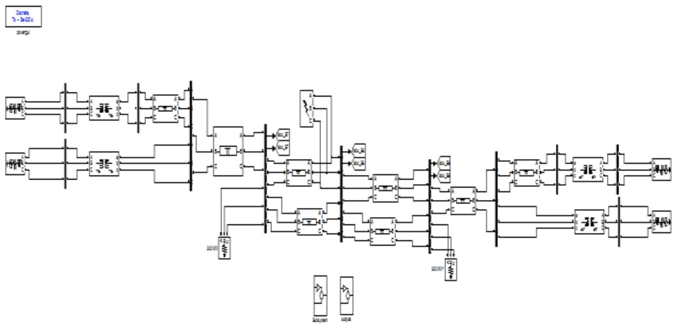

Fig.7.Simulation block diagram for the system without POD controller

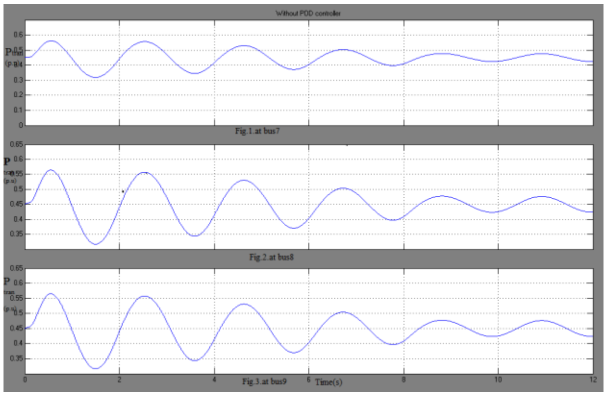

Fig.8. Simulation results for the two-area four machine system without POD controller

In the above figure,fig1. fig2 and fig3 indicates the low frequency power oscillations at bus7,bus8 and bus9 respectively.

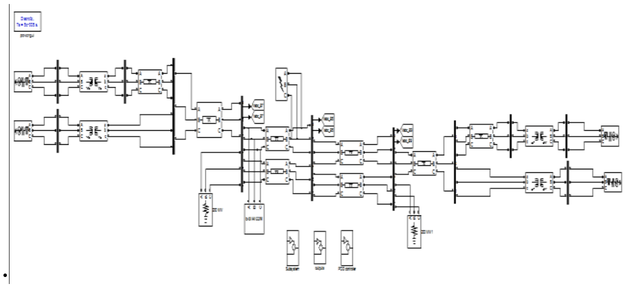

Fig.9. Simulation Block Diagram for the System With POD Controller and E-STATCOM is connected at Bus7

The above simulink block diagram represents, E-STATCOM connected to the implemented system with POD controller at bus7.The corresponding simulation results i.e.,Measured transmitted active power output follwed by three phase fault withE-STATCOM conneted at bus7.

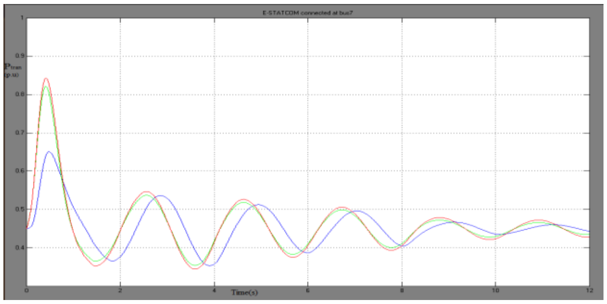

Fig.10.E-STATCOM connected at bus7 with PI controller

In fig.10.red and blue color lines indicate the POD by P_{inj} and Q_{inj} respectively and green color line represents the POD by both P_{inj} and Q_{inj}.

Similarly when E-STATCOM connected at bus 8 and bus 9 with POD controller and their corresponding simulation results are shown below figures.

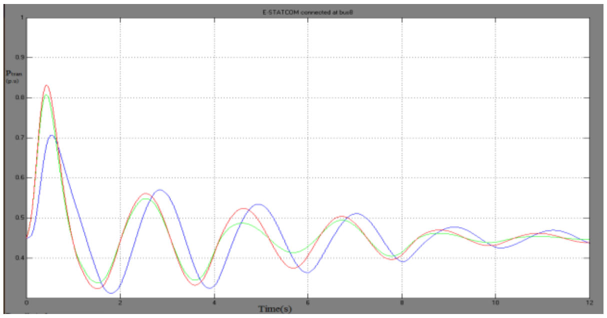

Fig.11. E-STATCOM connected at bus8 with PI controller

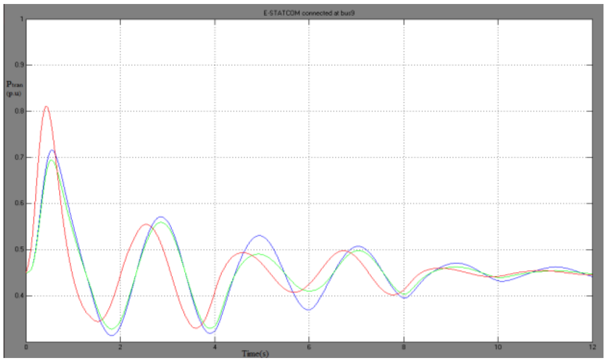

Fig.12. E-STATCOM connected at bus9 with PI controller

Fuzzy logic controller (FLC) is very simple shown in fig.7 and it consists of fuzzification block (done by transferring input (crisp)sets into fuzzy sets),inference system(rules are framed) and defuzzifica-tion block(toprovidespecificoutputs).

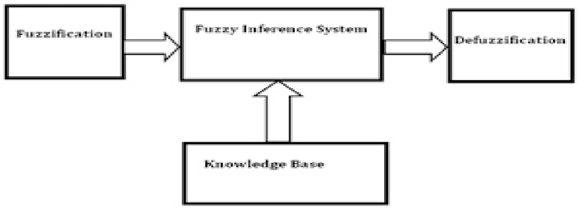

Fig.13. Fuzzy logic diagram

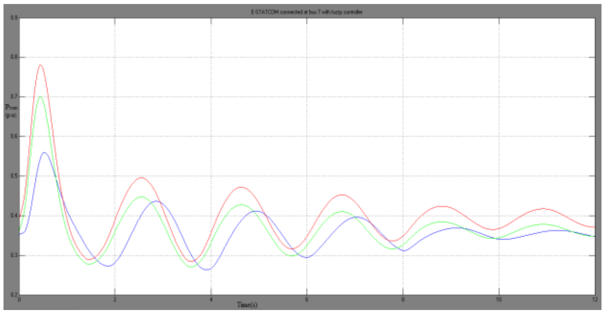

Fig.14.E-STATCOM connected at bus7 withfuzzy controller

Above figure indicates the measured transmitted active power output following a three phase fault by E-STATCOM connected at bus 7 with fuzzy controller. Red and blue color lines indicate the POD by P_{inj} and Q_{inj} respectively and green color line represents the POD with fuzzy controller by both P_{inj} and Q_{inj}. Similarly when E-STATCOM connected at bus 8 and bus 9 with fuzzy controller and their corresponding simulation results are shown below figures.

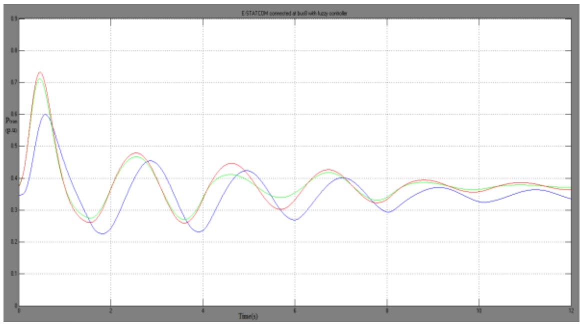

Fig.15.E-STATCOM connected at bus8 with fuzzy controller

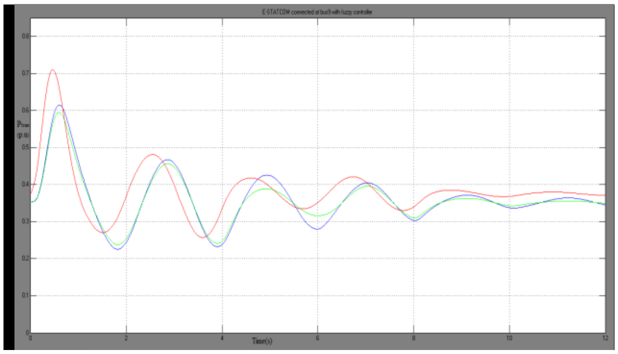

Fig.16.E-STATCOM connected at bus9 with fuzzy controller

VI. CONCLUSION

With the POD controller structure the performance of the E-STATCOM following the fault at three different locations, This low oscillation frequency highlights the importance of the adopted estimation method, since the classical approaches based on filters would require low bandwidth, resulting in a reduction in the estimation speed. The small-signal analysis for two-machine system, when moving closer to the generator units, a better damping is achieved by active power injection. With respect to reactive power injection, maximum damping action is provided when the E-STATCOM is connected close to the electrical midpoint of the line and the level of damping decreases when moving away from it. Because of a good choice of signals for controlling both active and reactive power injection, effective power oscillation damping is provided by the E-STATCOM irrespective of its location in the line. Instead of PI controller, the fuzzy logic controller then the performance of the system increases, Transients decreases and the stability of the system increases and also to improve the power quality.

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