Wide Area Fuzzy Statcom Controller for Angular Stability Improvement

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***Abstract*—**This paper presents a fuzzy based supplementary controller for STATCOM for improving the angular stability of a multi-area power system. The controller provides a supplementary voltage signal in addition to the usual line bus controller for damping low-frequency interarea oscillation present in the system. The Mamdani based fuzzy controller forms the core of the supplementary controller. The selection of the wide area signal as stabilizing input is made according to participation factor based on the modal analysis. The proposed controller effectively damps interarea oscillations over wide operating range thus improving the angular stability of the system. The effectiveness of the proposed controller is tested on two area multimachine system.

***Keywords**-STATCOM, fuzzy controller, angular stability, interarea oscillation,*

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I. INTRODUCTION

The power system has become more complex due to intruding renewable sources, deregulation of power and more stressed transmission lines. Under such situations events in one area have significant impact on other area. Thus the need to regulate the power flow, the voltage profile and proper synchronization of all the machines present within the power system arises. Oscillations, local or interarea, may set in if the operating conditions of the power system are changed. Change in operating conditions affects the damping characteristic of the system [1]. To damp the oscillations in the power network each machine in the system is equipped with automatic voltage regulators (AVR) and power system stabilizers (PSS). But the limitation of using the PSS is that they are designed by classical control technique around a nominal operating point and the power system continually experience changes in operating conditions. In recent times FACTS based supplementary controllers are effectively used to damp these low frequency oscillations. These supplementary controllers work along with the local PSS [2-8]. Such controller uses local inputs and is good only to damp the local oscillations. The presence of interarea modes of oscillations which are controllable in one area and observable in the other are not damped by the local controller. For damping use of robust control scheme over wide operating range can be found in literature. Recently a lot of research is carried out defining a controller with inputs as the global signals for damping interarea oscillations [9-18]. The wide area signals are used to provide control actions mostly to the generator excitation system or to supplement the local PSS. Application of fuzzy logic in enhancing stability using wide area signals is also reported in literature [19-21]. The conventional method which use only one model which is either analytically derived or is approximated is capable of addressing the local problems or they are defined for operating condition. Moreover with the growing complexity and the size of the power network the modeling and design of the controller becomes difficult and the model cannot address to global problems such as variation in the generation pattern, change in load etc. For this fuzzy model can be used as they have the advantage of combining the characteristics of sub models defined for different operating conditions into one as per the defined rule base to make the system adapt to the different operating points. In this paper a systematic procedure is forwarded for the selection of the available wide area signals as input to the auxiliary controller of the STACOM which is installed with the primary objective of improving the voltage profile of the weak area to damp the identified interarea low frequency oscillations. The selection of the global signal is based on modal analysis and identification of mode shape. Secondly a fuzzy control scheme is presented to make the identified auxiliary controller to stabilize the system to multiple operating points.

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II. STATCOM STRUCTURE

Wherever STATCOM is a voltage source converter (VSC) coupled to the transmission line through a coupling transformer which converts the dc link voltage into a three phase output voltage at fundamental frequency. A capacitor is used to maintain a constant dc link voltage for the converter operation The voltage at the point of common coupling (PCC) is maintained by controlling the magnitude and phase of the VSC output voltage.. The control strategy uses two PI controllers, PIv and PIDC, are for regulating the line voltage at the point of common coupling (PCC) and the dc link voltage inside the device. The deviations in the line voltage ΔV and the dc link voltage ΔVdc are passed through these two decoupled PI controllers in order to determine the inverter modulation index ma and the phase shift α, respectively which is fed to the PWM switching module to generate the firing pulses for the VSC for generating three phase voltage to provide independent reactive power support. The complete decoupled scheme is shown in fig. 1.

The nonlinear STATCOM equation of the VSC based STATCOM described in d-q reference frame [11] are given by

$$v_d = Ri_d + L\frac{di_d}{dt} - \omega Li_q + v_{in} \tag{1}$$

$$v_q = Ri_q + L\frac{di_q}{dt} + \omega L i_q + v_{in} \quad (2)$$

$$C\frac{dV_{dc}}{dt} = \frac{3}{2}\left(S_d i_d + S_q i_q\right) \quad (3)$$

where i_d and i_q are injected STATCOM currents, C is the equivalent capacitance of the dc bus capacitors, V_{dc} is the voltage across the DC capacitor, R and L represent the coupling transformer resistance and inductance, ω: synchronous angular speed of the network voltage at the fundamental system frequency f.

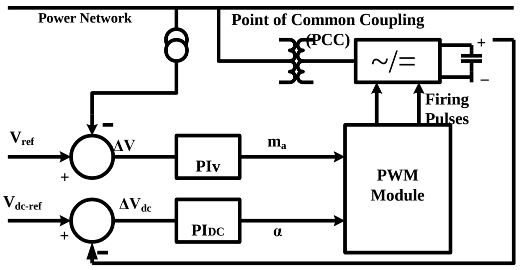

Figure 1. STATCOM decoupled control scheme

The power flow equation is given by

$$P = \frac{3}{2}(v_d i_d + v_q i_q) \quad (4)$$

$$Q = \frac{3}{2}(v_d i_d - v_q i_q) \quad (5)$$

The modulation index and phase injection voltage angle is given as

$$m_a = \sqrt{v_d^2 + v_q^2} \quad (6)$$

$$\alpha = \tan^{-1}\left(\frac{v_d}{v_q}\right) \quad (7)$$

The output of the STATCOM is given by

$$Ea = m_a V_{dc}\cos(\omega t + \alpha) \quad (8)$$

III. MODAL ANALYSIS AND MODE SHAPE IDENTIFICATION

A simplified linearized method, dependent on the operating condition of the power system, is applied for introducing auxiliary signals to the STATCOM controller for improving the transient and dynamic behaviors of the power system, by controlling the network parameters in its neighborhood. The state space representation of the power system can be expressed as

$$\Delta\dot{x}(t) = A\Delta x(t) + B\Delta u(t) \quad (9)$$
$$\Delta y(t) = C\Delta x(t) + D\Delta u(t)$$

where $\Delta x(t)$ and $\Delta y(t)$ are the state and output vector of dimension n and m respectively, A is the state matrix of dimension $n \times n$. For any given eigenvalue λ_i of the state matrix A, assume Φi and Ψ_i to be the left and the right eigenvectors respectively. Φi is an n column vector and Ψi is a n row vector which satisfies the criterion

$$A\phi_i = \lambda_i \phi_i \quad (10)$$

$$\varphi_i A = \lambda_i \varphi_i \quad (11)$$

For obtaining the system mode the concept of similarity transform is used. Considering matrix z with n variable such that the variable zi representing transformed variables of Δxi then

$$\Delta x(t) = \phi z(t) \quad (12)$$

The above equation gives the mode shape. The activity of the state variable xk in the ith mode is given by the element Φki of the right eigenvector Φi. The participation factor has been used as an index for the selection of the stabilization signal. The participation factor helps to relate the participation of the respective state variable to the selected mode or in other words it relates the left and the right eigenvectors for identifying the relationship between the states and the modes. For any given eigenvalue λi the participation factor p, for the kth element is defined as

$$p_{ki} = \phi_{ki}\psi_{ik} \quad (13)$$

This is actually same to eigenvalue sensitivity of eigenvalue λi to the diagonal element of state matrix A where Pki is also defined as

$$p_{ki} = \frac{\partial\lambda_i}{\partial a_{kk}} \quad (14)$$

In this paper, the measurement-based participation factors are used to select the generators that participate in system mode of interarea oscillation. Many variables can be used as potential feedback signal but in this paper only the rotor angle variations are taken to be the potential feedback signals for the potential auxiliary controller.

IV. SYSTEM DESCRIPTION

The two area system involving four machines, eleven bus systems is considered shown in fig. 2. Each area has two generators equipped with automatic voltage regulators, static exciters and locally tuned PSS. The two areas are connected with tie lines between buses 7-8 and 8-9. Form the power flow studies carried out using PSAT it is found that reactive support is required at the tie line bus and reactive power support in form of STATCOM is applied at bus 8. The flow of power takes place from area one to area two.

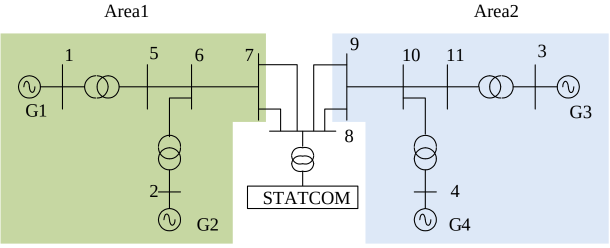

Figure 2. Two area 4 bus 11 machine system

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V. FUZZY BASED SUPPLEMENATRY CONTROLLER

The fuzzy controller is implemented in order to enhance the angular stability of the selected power system under different operating conditions. Since in general the conventional controller is based on the linearized model for a selected operating point it has indifferent behavior for other operating points or conditions. The fuzzy controller is an expert system which has the capability to emulate the conventional control characteristics. It is based on if-then rules. By defining the rule base on the basis of the expert knowledge of the linearized sub models for different operating conditions it can easily govern the system to attain stability under different operating points. The output of the obtained non linear control is used as the stabilization signal for the STATCOM to damp the present interarea low frequency oscillation. To develop a fuzzy model the system model is linearized at different operating conditions are selected. The active power flow in the tie line form area 1 to area 2 is increased to 3pu, 4pu and 4.5

VI. WIDE AREA FUZZY INTERAREA OSCILLATION DAMPING CONTROLLER

This section explains the implementation of the fuzzy based STATCOM control scheme for the damping of the interarea low frequency oscillation damping. The selection of input signal to the fuzzy based supplementary controller is a key issue. Out of available many measured signals such as bus parameters of line voltage, current, power, generator based signals viz. rotor angle and frequency the rotor speed deviation has been selected as input to the controller and because of the presence of four generators in the system the selection of signal becomes of outmost importance the selection is based on the participation of the selected input variable i.e. on the given mode of oscillation of the selected power system. Owing to the configuration of the selected power network there are two modes of oscillation one is the local mode of oscillation for which local tuned PSS are present and the other is the interarea mode of oscillation experienced in the tie line which is affected either or the power is transferred from one area to another. The critical modes of oscillations are shown in table 1.

TABLE I. MODES OF OSCILLATION OF TEST SYSTEM

System mode	Frequency (Hz)	Participation factor			
		$\omega 1$	$\omega 2$	$\omega 3$	$\omega 4$
−0.052± 4.021i	0.64	0.967	0.937	0.988	0.923
−0.529± 6.295i	1.002	0.968	0.949	0.999	0.924

The mode-I represents the critical mode of interarea oscillation. The participation of generator 1 from area 1 and generator 3 in area 2 represents the speed variable with highest participation in this critical mode oscillating at the frequency of 0.64 Hz. and hence they are selected as potential input the Fuzzy controller. Based on if then rules extracted from the linearized sub models the proposed control surface of the fuzzy controller is shown in fig. 3 below.

The output of the fuzzy controller is the change in the Iqref current of the STATCOM controller which generates new voltage reference for which accordingly the active and reactive power flow is maintained with the prime objective of controlling the voltage profile. The tie line power is varied over three operating points thus the speed variations are taken as the input and hence the nonlinear model is fuzzified over these operating points.

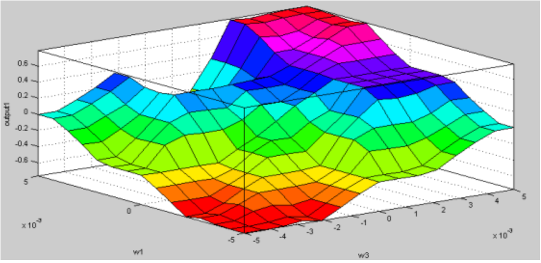

Figure 3. Control surface of auxilary controller

VII. RESULTS AND VALIDATION

The performance of the proposed STATCOM fuzzy auxiliary controller has been evaluated under the condition of three phase fault and variation of load. The performance of the proposed controller is compared with the system with STATCOM. During the simulation results shown below each generator is equipped with local tuned PSS controller.

A. Case I: Applied Three Phase Fault at Bus 8

The performance of the proposed fuzzy controller is discussed with the application of three phase fault at bus 8 which connects the area 1 and area 2. The fault is applied for a period of 120ms Fig. 4(a) and (b) shows the frequency deviation of tie line 7–9 power flow and the zoomed version of the frequency oscillation with STATCOM based Fuzzy auxiliary controller (SFAC). The active power oscillations are shown in the fig. 5. With the application of fuzzy controller the system becomes stable.

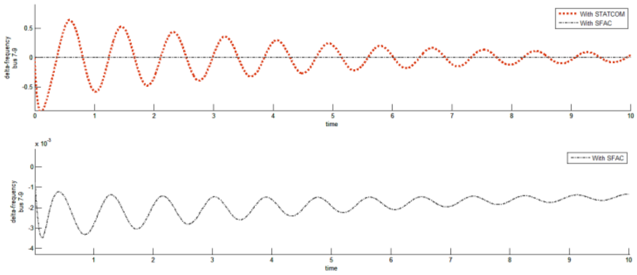

Figure 4. (a) Tie lie 7-9 frequency variation under three phase fault (b) enlarged version of frequency deviation using SFAC

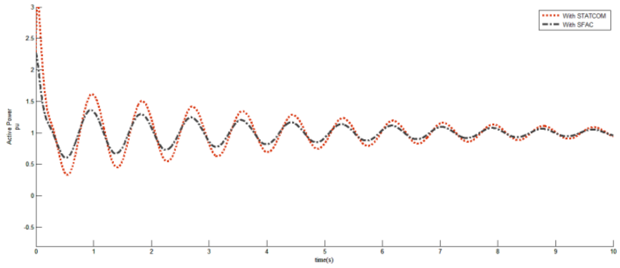

Figure 5. Tie line active power oscillation under three phase fault

B. Case I1: Application of Load at Bus 7 and 9

The impedance based load at bus 7 and 9 are up by the performance of the proposed fuzzy controller is discussed the load at bus 7 is decreased to 400 W form 970 W. The system with STATCOM becomes unstable but the application of SFAC the system becomes stable and shows improved performance (Fig. 6 and Fig 7)

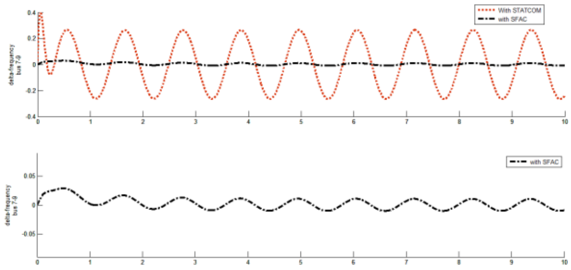

Figure 6. (a) Tie line 7-9 frequency variation under load variation (b) enlarged view of frequency devaition usinf SFAC

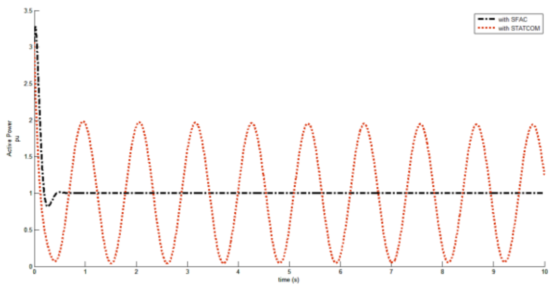

Figure 7. Tie line active power oscillation under load vairation

VIII. CONCLUSION

A wide area fuzzy STATCOM controller is proposed in this paper. The performance of the proposed controller is tested on two area system. . The proposed Fuzzy based controller for the STATCOM effectively damps the present interarea low frequency oscillation over a wide range of operating conditions. The input signals for the fuzzy controller from the wide area measured signal are selected on the basis of participation factor. The inclusion of the proposed controller for the STATCOM effectively enhances the angular stability of the multimachine network

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