A Fuzzy Logic Based Controller for Damping Transient Oscillation of Flexible AC Transmission System

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Abstract: In this research paper, an efficient power controller is introduced which consists of series and shunt converters both have inherited characteristics of manipulating reactive power flow in an electronics based Unified Power Flow Controller (UPFC) in a multimachine power system and filter out the transient contaminations. The proposed structure provides an overall variable proportional and integral gain which reduces transient oscillations locally as well as globally of synchronous generators in multi-machine power systems. The compensation performance and capacity are examined in term of stability check at the instant of disturbances such as load shedding, faults, sudden switching etc. A fuzzy logic-based controller is constructed to adjust the reference signal for the system based on sliding surface and its derivative hence provides far better performance in steady state as well as dynamic operation that quickly dies out the system oscillations comparing it with conventional PI controller. Simulation and experimental results of few case studies validate the satisfactory operation of this model.

Keywords: Damping, Fuzzy, Stability, Transient, Unified.

I. Introduction

Flexible AC Transmission Systems (FACTS) using sophisticated power electronics techniques are employed to solve the problems associated with ever-growing size of power blocks to be transferred over long distance between generating units and stationed loads. Major engineering issues to be addressed namely stability and reliability of voltage at post-faults. The dynamic stability enhancement can be then realized and therefore modeled and designed when small and large disturbances are introduced. Small disturbances are taken care by rather build-in regulators such as PSS and AVR. In the event of large disturbance e.g. sudden loss of feeder, heavy loading, the operating point of the system will vary that linear controllers may not be appropriate in maintaining stability. Conventional controllers such P or PI are in-adequate for large perturbation and have poor damping properties that may vary considerably. To ensure good regulation and fast response quality dynamic structure namely variable structure fuzzy logic controller using 3 linguistic variables E, DE and V (error, change of error and output) is introduced in place of the proportional term of the conventional PI controller in a multi-machine power system.

FACTS devices are fast emerging technologies that provide a comprehensive functionality for an efficient power system operation; this include: enhancement of power system stability, control active and reactive power flow in a transmission line, increase transmission capacity, reduces transmission congestions and has a continues compensating ability. Perhaps the compensation factor makes this package attractive to search and explore improvements of system stability through enormous case studies and simulation studies because it involves a constant exchange of real and reactive flow into the line. Voltage source converters of this research are considered as voltage generator along with current injection model that are widely applied for load flow control and voltage stability studies at the event of unplanned disturbances. The voltage source converters of the UPFC are the conventional ones which as PI regulators [1-6], their chief disadvantage is that when the operating points of the multi-machine power system change drastically then PI malfunctions in term of greater damping contaminations for local and global mode oscillations of the multi-machine power system. Fuzzy logic based controllers [7] is studied here. The Fuzzy logic has successfully been adopted in series voltage source converter of UPFC [8-12]. This research paper, a proposed a variable structure fuzzy logic controller in place of the proportional term of the conventional PI controller for the UPFC to provide a superior damping characteristics under large disturbances is designed in a multi-machine power system [13-15]. The model is evaluated and verified through case studies and simulations tests.

II. System Model

The series converter injects a controlled voltage source between buses of Fig. 1 thereby controls real and reactive power flow in the line. Shunt converter controls the bus voltage and generate or absorbs necessary reactive power for the three-machine power system shown in Fig. 1 which is considered as our model for a check transient stability the generators are represented by 3rd order Parks equations. Simple AVRs (automatic voltage regulators) are connected to each generator and a conventional PSS (power system stabilizer) is used in machine-2 to damp the small oscillations in local mode.

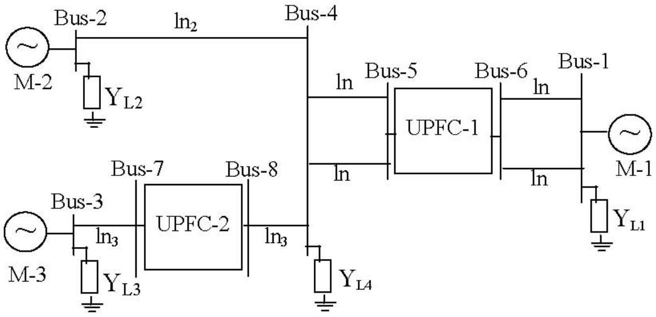


Fig. 1: Multi-Machine Power System

III. Design of Fuzzy Variable Structure Controller

Since power systems are non-linear in nature, a non-linear control will be most suitable for power oscillation damping and power flow control. Fuzzy controllers are deigned for series convereter control only, they replace the conventional proportional integral, which is considered the most widely used in industry due to its simple control structure, easy to design and inexpesive cost. Because of the fact that PI type controller cannot yield a good damping arrestor if a controlled object is highly non-linear and uncertain. To take care if the non-linearity the proportional term is replaced by an incremental fuzzy logic controller and the integral term remains as it is. This construct a fuzzy logic proportional plus conventional integral controller (Fuzzy-P controller) [9].

The control signal of a conventional PI controller can easily be computed by combining the proportional and integral terms as

$$u(t) = K_p.e(t) + K_i \int_0^t \mathrm{e(t)}\ .\mathrm{dt} \qquad (1)$$

Where K_p and K_i are the controller parameters. It is discretised and incremental form is e

Where e(k) is the error at the kth sampling instant and T is the sampling time.

$$\Delta u(k) = u(k) - u(k-1) = K_p\left[e(k) - e(k-1)\right] + K_i Te(k) \qquad (2)$$

The PI controller can be designed by simply adjusting only two controller parameters: K_p and K_i. ance is acceptable in many applications. This hyprid controller (PI-FuzzyP) uses an incremental fuzzy controller based on the property of siding surface in place of the proportional term while the integral term is unchanged. The controller output in this case is:

$$K_p.\Delta uf(k) + K_i T.e(k)$$

where K_p and K_i are indentical to the conventional PI controller in (8) and Δu_f(k) is the output of the incremental fuzzy logic controller.

Sliding surface σ is considered instead of the error in order to drive the system to the initial position after the fault or disturbance in the presence of uncertainties and unmodeled system dynamics. The integral controller is however, retained to provide zero-steady state error to the system oscillations. The active (V_{ci}) and reactive (V_{ci}) component of the series voltage source are controlled by reactive and active power deviations, respectively. The active and reactive power devaitions are fuzzified using two input fuzzy sets P (positive) and N (negative). The membership functions used for the positive and negative sets are given by:

$$\mu_P(\sigma) = \begin{cases} 0 & \sigma < -L_1 \\ \dfrac{x_i + L_1}{2L_1} & -L_1 \le \sigma \le L_1 \\ 1 & \sigma > L_1 \end{cases} \qquad (3)$$

$$\mu_N(\sigma) = \begin{cases} 1 & -\sigma > -L_1 \\ \dfrac{-x_i + L_1}{2L_1} & -L_1 \le \sigma \le L_1 \\ 0 & \sigma > L_1 \end{cases} \qquad (4)$$

where σ (k) denotes the input to the fuzzy controller at the kth sampling instant and is:

$$\begin{aligned} &\sigma(k) = \dot{e}(k) + \lambda\, e(k) \\ &\dot{e}(k) = [e(k) - e(k-1)]/T \\ &\textit{and} \\ &\sigma^{\bullet}(k) = [\sigma(k) - \sigma(k-1)]/T \end{aligned} \qquad (5)$$

and the error

$e(k) = P_{\text{ref}}$ - P or Q_{ref} -Q at the kth instant

Similar expression holds for the fuzzification of σ in terms of Positive and Negative fuzzy sets; L_2 is the maximum value of σ. The fuzzy controller uses four simplified rules [13] given by:

R_1: If $\sigma(k)$ is P and $\dot{\sigma}(k)$ is P then $\Delta u_f(k)$ is NB

R_2: If $\sigma(k)$ is P and $\dot{\sigma}(k)$ is N then $\Delta u_f(k)$ is NS

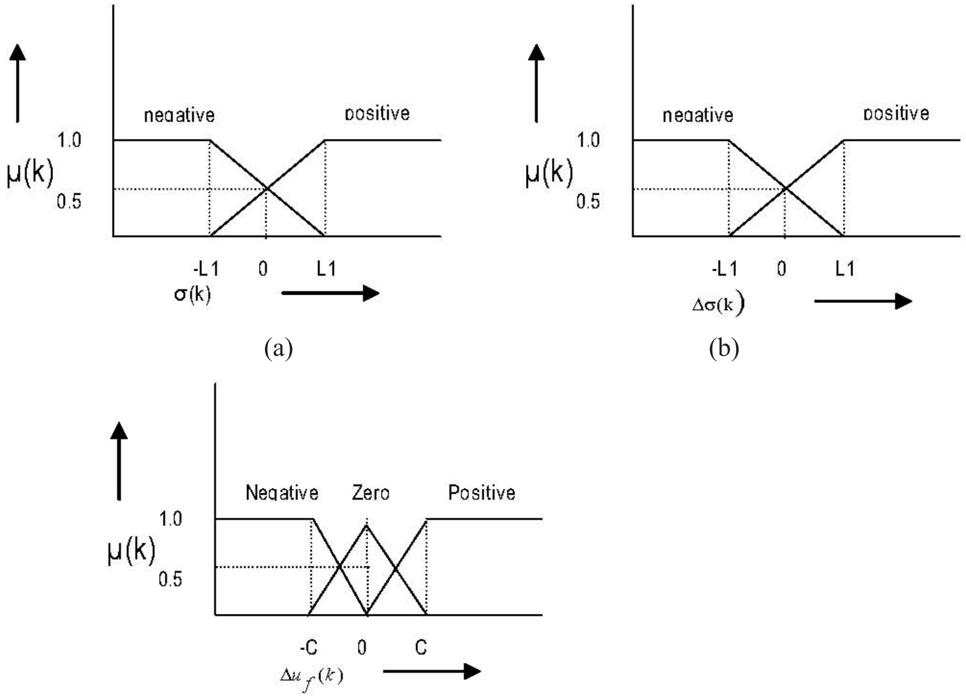
R_3: If $\sigma(k)$ is N amd $\dot{\sigma}(k)$ is P then $\Delta u_f(k)$ is PS

R_4: If $\sigma(k)$ is N and $\dot{\sigma}(k)$ is N then $\Delta u_f(k)$ is PB

In the above rule base P, and N correspond to positive, negative fuzzy sets for the input. The membership functions for σ(k), $\dot{\sigma}(k)$ and $\Delta u_f(k)$ are shown in Fig. 2a, Fig. 2b and Fig. 2c, respectively. The values of L_1 and L_2 are chosen on the basis of the maximum value of real or reactive power error and its derivative. Using Zadeh's rules for AND operation and general defuzzifier, the output $\Delta u_f(k)$ of the fuzzy controller is

$$\Delta u_f(k) = \frac{\sum_{j=1}^{4} (\mu_j)^{\gamma} c_j(k)}{\sum_{j=1}^{4} (\mu_j)^{\gamma}} \tag{6}$$

Where $c_j(k)$ corresponds to the value of control output for which the membership values in the output sets are equal to unity. However, for $\mu = 1$ we get the centroid defuzzifier. The value $\dot{e}(k)$ is taken as the difference e(k)-e(k-1) for implementing the control.



(a) (b) (c)

Fig. 2: (a) Membership Function of σ (b) Membership Function of Δσ (c) Membership Function of Change of Control Δu_f

In case the PI regulator is used in controlling V_{cp} and V_{cr}, the equations are:

$$V_{cp} = (K_{pp}.\Delta Q + K_{ip}\int \Delta Q),\ V_{cr} = (K_{pr}.\Delta P + K_{ir}\int \Delta P) \tag{7}$$
$$\text{where} \quad \Delta P = (P_{\text{ref}} - P), \Delta Q = (Q_{\text{ref}} - Q)$$

The proportional and integral parameters of the conventional PI controller are tuned. K_{pp} and K_{ip} are tuned by taking Δ P as the error and the error Δ Q tunes K_{pr} and K_{ir}.

IV. Computer Simulation Results

To examine the suitability of this proposed controller and to show that the performance of the hybrid fuzzy controller in damping the global mode (difference in speed machine-2 and machine-1) and local mode (difference in speed of machine-2 and machine-3) is better, case study is tested on a multi-machine power system (Fig. 1) subjected to a variety of transients disturbances such as faults at different locations, sudden change in local loads, change in mechanical power input, etc. Taking machine M-1 as the reference and loading of the machines in p.u. as $P_1 = 4.4120$, $Q_1 = 1.9634$, $P_2 = 1.3$, $Q_2 = 0.1$, $P_3 = 1.3$, $Q_3 = 0.15$, the response of the network to different disturbances are presented, to establsih the superiority of Fuzzy-P controller over the conventional PI controller. The system data is provided in Appendix-III. A modulating signal based on the algebric sum of difference in speed between th machines M-1, M-2 and M-3 is used to damp the power system oscillations.

V. Conclusion

The paper presents a new Fuzzy variable structure controller for the UPFC in a multi-machine power system to damp the electromechanical oscillations in the system subjected to transient disturbances. The incremental fuzzy controller adapts the proportional gain of the conventional PI controller in an incremental fashion depending on a sliding surface derived from active and reactive power errors and their rate of change. The integral gain, however, comprises the conventional fixed component and a variable component obtained from the fuzzy variable structure control scheme. This controller is found to be robust and provides significant transient stability performance improvements over a wide range of operating conditions. Both inter-area and local modes of power system oscillations are damped much faster using this new controller instead of the conventional PI controller.

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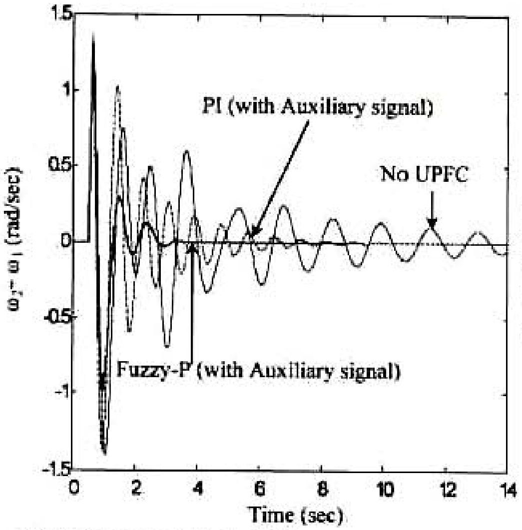

Fig.7. Inter-area mode oscillations

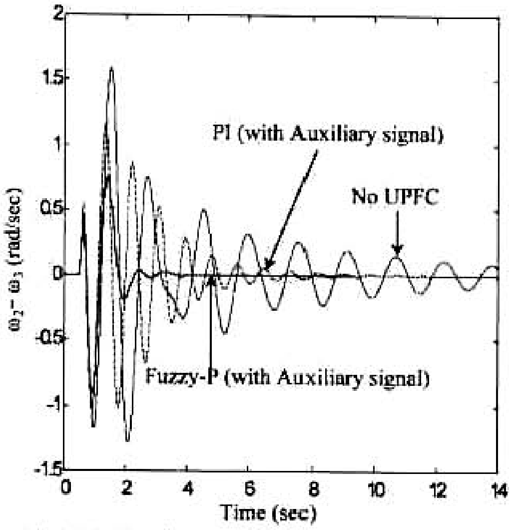

Fig.8. Local-mode oscillations

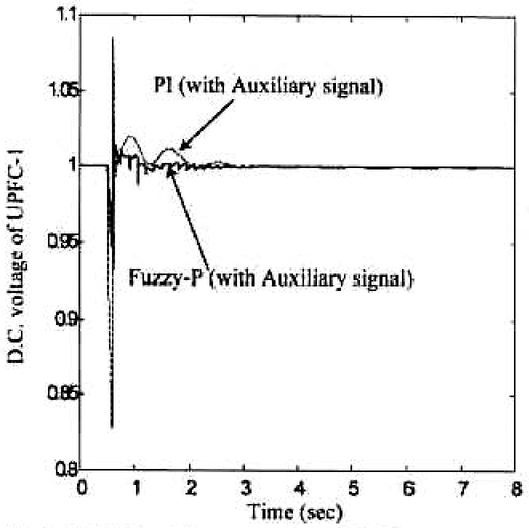

Fig.9. D.C. link voltage excursion of UPFC-1

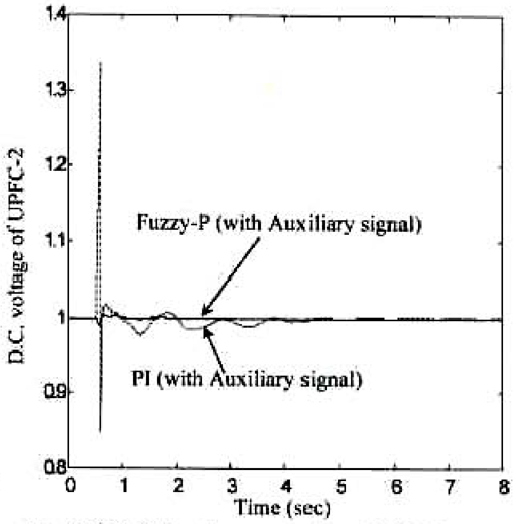

Fig.10. D.C. link voltage excursion of UPFC-2

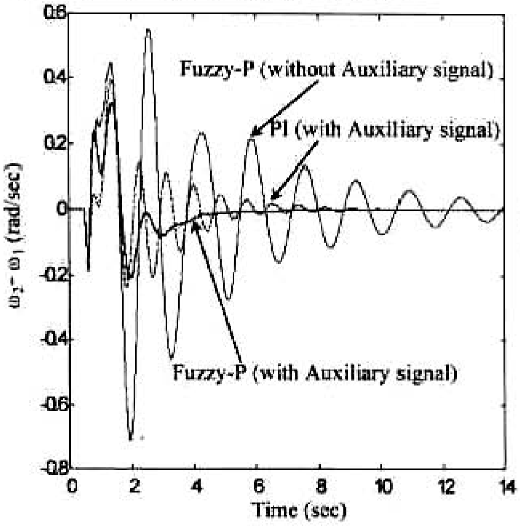

Fig.11. Inter-area mode oscillations

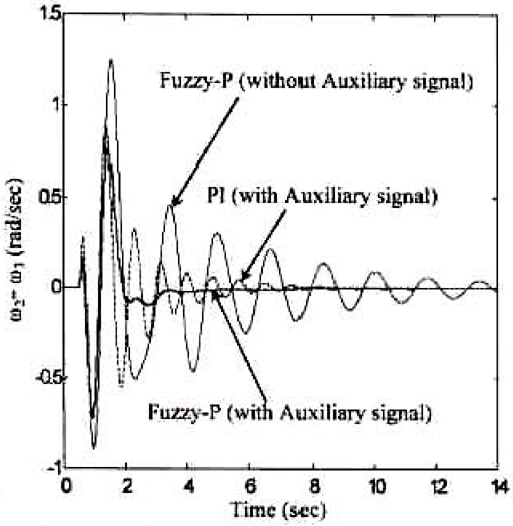

Fig.12. Local-mode oscillations