

# Development of a Fuzzy Control Scheme with UPFC's For Damping of oscillations in multi machine integrated power systems

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**ABSTRACT** – In this paper damping of oscillations in multi machine power systems when a three phase to ground fault occurs at each generator bus are developed using a fuzzy logic technique. Simple fuzzy logic controller using mamdani type inference system is used. The fuzzy controller is to control the Unified power flow control (UPFC).power oscillation damping (POD) is used to damp the oscillations. Digital simulations of a multi-machine power system subjected to a wide variety of disturbances are validating the efficiency of the power system.

**Keywords** – FACTS (UPFC), Fuzzy Logic, Coordination, Fuzzy Coordination Controller, Damping, Stability, Power System Oscillations, Power oscillation damping (POD)

## 1. INTRODUCTION

FACTS technology opens up new opportunities for controlling power and enhancing the usable capacity of present as well as new and upgraded lines. The FACTS technology is not a single high power controller, but rather a collection of Controllers. In general facts controller are of four types

1. Series Controllers.
2. Shunt controllers.
3. Combined series-series controllers.
4. Combined series-shunt Controllers.

Here we use combined series shunt controller. This could be a combination of Series and Shunt Controllers. In this UPFC (Unified power flow control) is the most powerful FACTS device. Here line impedance, terminal voltages, and voltage angle can be controlled by UPFC. UPFC is a combination of STATCOM and SSSC. These two are voltage source converters. The well designed FACTS controllers increases Transients and dynamic stability and also damps the electro mechanical oscillations. Fuzzy coordination controller is used. Fuzzy logic Controllers are Rule based controllers in which a set of rules represents a control decision mechanism to adjust the effect of certain cases coming from power system. Fuzzy Logic may be viewed as a methodology for computing with words rather

than numbers. Although words are inherently less precise than numbers, their use is closer to human intuition. This

Paper introduces the model of the system first and then control scheme followed by design.

## 2. SYSTEM MODEL

### Power system model

A Three machine, nine bus interconnected power system is shown in Fig 1. There are two UPFCs in the power system between Bus2, Bus3 and Bus6, Bus7 respectively.

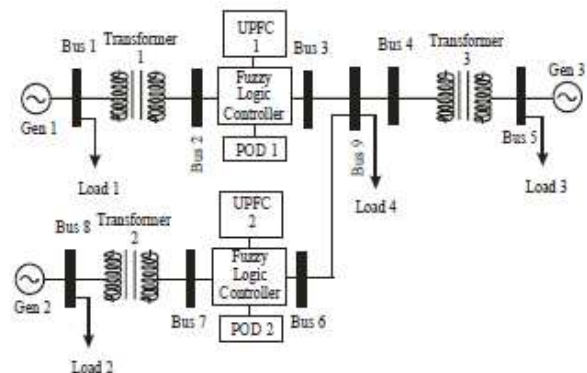


Fig. 1 3-machine, 9-bus interconnected power system model with 4-loads & 2 POD-UPFC & the fuzzy controller

The UPFC is a generalized synchronous voltage source (SVS), represented at the fundamental frequency by voltage phasor with controllable magnitude and angle in series with the transmission line UPFC consists of two voltage source converters. In the parallel branch of UPFC the active power is controlled by the phase angle of the converter output voltage. In the series branch of UPFC the active and reactive power flows in the transmission line are influenced by the amplitude as well as the phase angle of the series injected voltage. Therefore, the active power controller can significantly affects the reactive power flow and vice versa.

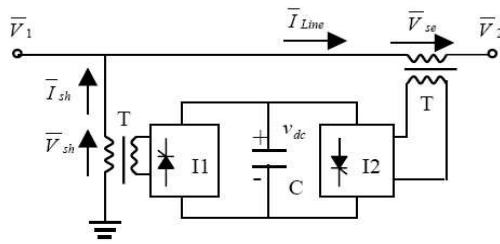


Fig. 2 UPFC Scheme

It is connected to the system through two coupling transformers. The two converters are operated from a common DC link provided by a dc storage capacitor. The UPFC has several operating modes. Shunt converter control and series converter control. Two controls modes are possible for the shunt control:

- 1) VAR control mode: the reference input is an Inductive or capacitive VAR request.
- 2) Automatic voltage control mode: the goal is to maintain the transmission line voltage at the connection point to a reference value.

By the control of series voltage, UPFC can be operated in four different ways:

- 1) Direct voltage injection mode: the reference inputs are directly the magnitude and phase angle of the series voltage.
- 2) Phase angle shifter emulation mode: the reference input is phase displacement between the sending end voltage and the receiving end voltage.
- 3) Line impedance emulation mode: the reference input is an impedance value to insert in series with the line impedance.
- 4) Automatic power flow control mode: the reference inputs are values of P and Q to maintain on the transmission line despite system changes.

### 3. CONTROL SCHEME

Under a large disturbance, line impedance emulation mode will be used to improve first swing stability. For damping of the subsequent swings, as suggested before, UPFC will be operated in the direct voltage injection mode.

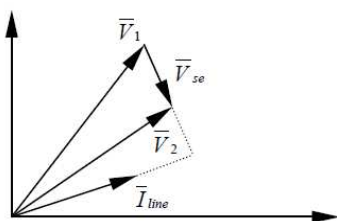


Fig. 3. Series compensation mode

In this mode, the UPFC output is the series compensation voltage  $V_{se}$ . This voltage is perpendicular to the line current

$I_{line}$  and the phase angle of  $I_{line}$  is ahead of  $V_{se}$ . By the control of the magnitude of  $V_{se}$ , the series compensation damping control can be achieved.

### 3.1 POD Controller

Commonly the POD controllers involve a transfer function consisting of an amplification link, a washout link and two lead-lag links. In this paper the active power of the transmission line is used as input signal.

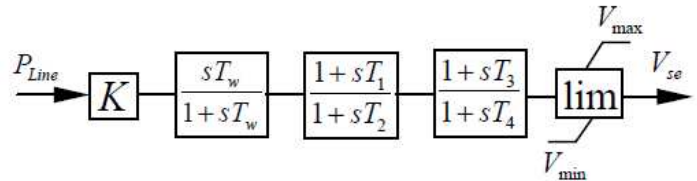


Fig. 4. UPFC POD controller

The UPFC POD controller works effectively in single machine system. In order to improve the dynamic performance of a multi-machine system, the behavior of the controllers must be coordinated. Otherwise the power system will be deteriorated.

### 4. FUZZY LOGIC COORDINATED CONTROLLER DESIGN

Most of the FACTS POD controllers belong to the PI (proportional integral) type and work effectively in single machine system especially, after the parameter optimization, the damping of power system oscillations is perfectly achieved. However the performance of the above mentioned POD controllers deteriorates in multi-machine system

In this paper the fuzzy logic controller is to coordinate the parameters of FACTS controllers.

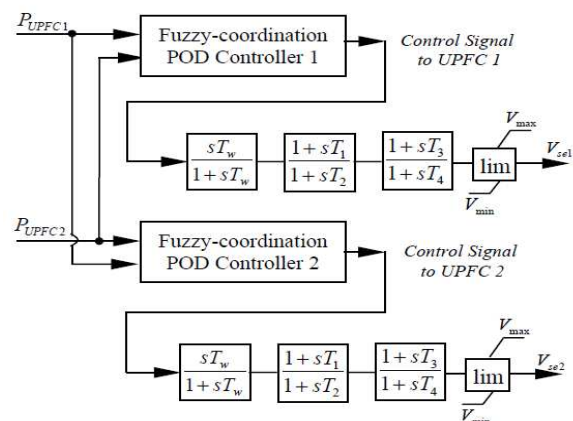


Fig. 5. Fuzzy coordinated-POD-UPFC controller

Where the inputs  $P_{upfc1}$  and  $P_{upfc2}$  are the active power flow through the UPFC1 and UPFC2. The output signals are command signals adjusted to the UPFC controllers 1 and 2. In this way, the conventional POD controllers are tuned by using fuzzy-coordination controllers. The fuzzy coordination controller involves Fuzzification, Inference and defuzzification unit. Our basic structure of the fuzzy logic coordination controller to damp out the oscillations in the power system consists of 3 important parts, fuzzification, knowledge base – decision making logic (inference system) and the defuzzification.

**4.1 Fuzzification:**

Fuzzification is a process whereby the input variables are mapped onto fuzzy variables (linguistic variables). Each fuzzified variable has a certain membership function. The inputs are fuzzified using three fuzzy sets: B (big), M (medium) and S (small)

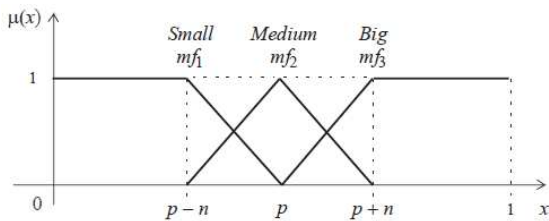


Fig.6 .Membership Function

The membership function of the small set is

$$\mu_{small}(x) = \begin{cases} 1 & x < (p-n) \\ -x + \frac{p}{N} & (p-n) \leq x \leq p \\ 0 & x > p \end{cases} \quad (1)$$

Where x, namely  $P_{UPFC1}$  or  $P_{UPFC2}$ , is the input to the fuzzy controller. Similarly the big set membership function is:

$$\mu_{Big}(x) = \begin{cases} 0 & x < p \\ \frac{x-p}{N} & p \leq x \leq (p+N) \\ 1 & x > (p+N) \end{cases} \quad (2)$$

And the medium set membership function is:

$$\mu_{Big}(x) = \begin{cases} 0 & x < (p-N) \\ \frac{x+N-p}{N} & (p-N) \leq x \leq p \\ \frac{-x+N+p}{N} & p \leq x \leq (p+N) \\ 1 & x > (p+N) \end{cases} \quad (3)$$

**4.2 Inference**

Control decisions are made based on the fuzzified variables. Inference involves rules for determining output decisions. Due to the input variables having three fuzzified variables, the fuzzy-coordination controller has nine rules for each UPFC controller. The rules can be obtained from the system operation and the knowledge of the operator. To determine the degree of memberships for output variables, the Min-Max inference is applied. Both of the two UPFC controllers use the same inference system. Only the input of them are exchanged

$P_{UPFC1} \backslash P_{UPFC2}$	S	M	B
S	B	M	S
M	B	M	S
B	M	S	S

TABLE I Inference system

**4.3 Defuzzification:**

The output variables of the inference system are linguistic variables. They must be converted to numerical output. The fuzzy-coordination controller uses centroid method. The output of the fuzzy-coordination controller is

$$u = \frac{\sum_{i=1}^9 \mu_c(u_i) \cdot u_i}{\sum_{i=1}^9 \mu_c(u_i)} \quad (4)$$

Where  $u$  corresponds to the value of control output for which the membership values in the output sets are equal to unity.

**5. SIMULINK MODEL**

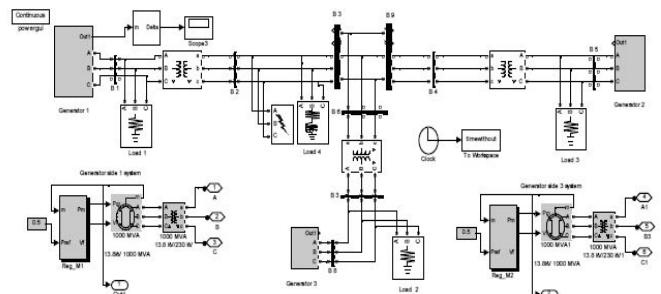


Fig. 7 Model of a 3-machine, 9-bus system without Fuzzy based UPFC-POD (without controller)

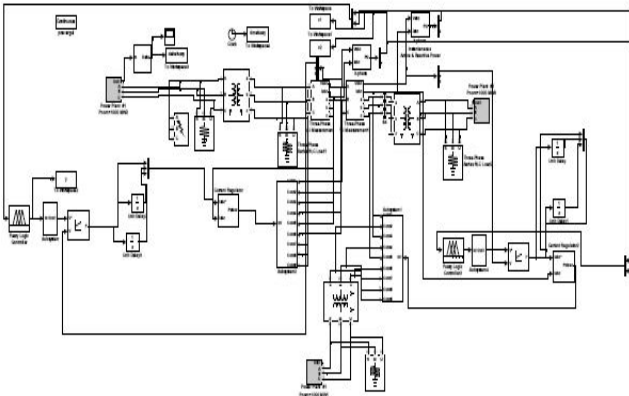


Fig. 8 Model of a 3-machine, 9-bus system with Fuzzy-POD-UPFC (with controller)

### 6. SIMULATION RESULTS

The results are between power angle (degrees) vs. time (seconds) are shown in figures 9, 10 & 11 without controller when fault occurs at generator 1, 2 & 3 respectively.

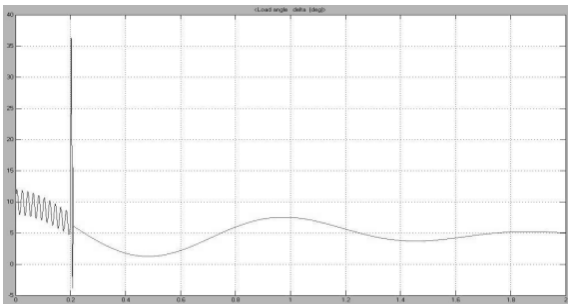


Fig. 9. Simulation result of power angle v/s time (Without UPFC) for model 1, fault at generator 1

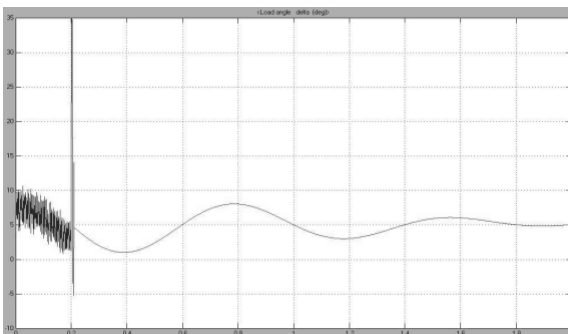


Fig. 10. Simulation result of power angle v/s time (Without UPFC) for model 2, fault at generator 2

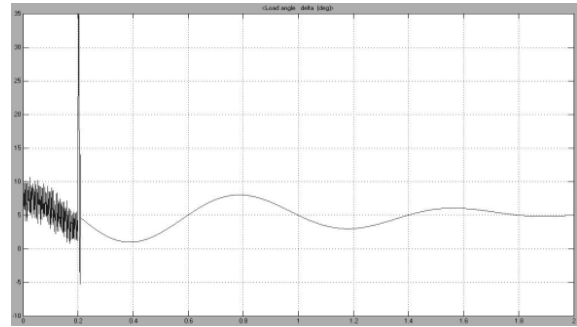


Fig. 11. Simulation result of power angle v/s time (Without UPFC) for model 3, fault at generator 3

The results in figures 12, 13 & 14 shows the results between power angle (degree) vs. time (seconds) with UPFC and fuzzy controller when fault occurs at generator 1, 2 & 3 respectively

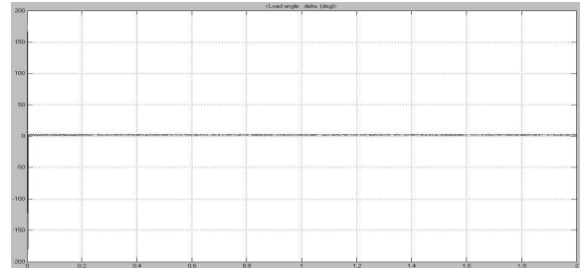


Fig. 12. Simulation result of power angle v/s time (With UPFC & fuzzy control), fault at generator 1 for model 1

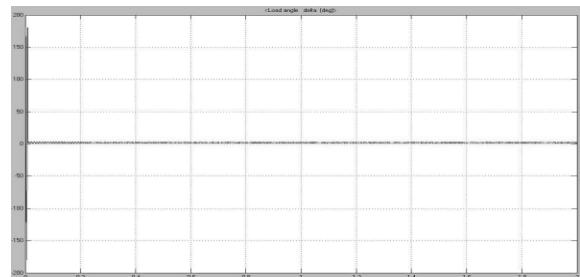


Fig. 13. Simulation result of power angle v/s time (With UPFC & fuzzy control), fault at generator 2 for model 2

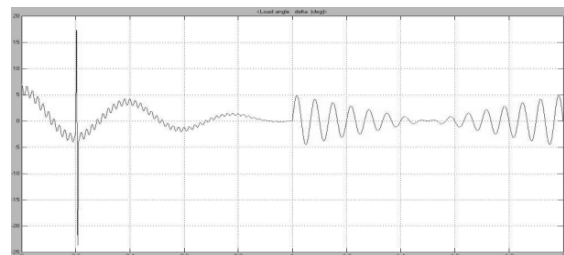


Fig. 14. Simulation result of power angle v/s time (With UPFC & fuzzy control), fault at generator 3 for model 3

## 7. CONCLUSION

This paper presented the hybrid fuzzy coordination controller in multi machine power system to damp the oscillations. The Amplification signals are modified and pure signals without any oscillations or disturbances are occurred from FUZZY-POD-UPFC controller. The performance of the proposed method is simulated over a wide range of operating conditions and disturbances and its robustness is proved and settling will be less. The results are obtained in power angle curves for each generator fault in multi machine system with controller and without controllers. The developed control strategy is not only simple, reliable, and may be easy to implement in real time applications.

## 10. REFERENCES

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