Research Paper ENGINEERING

# Implementation of PSS and UPFC for Power System Stability Enhancement Using PI and Fuzzy Controllers

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**ABSTRACT**

In electric power systems, enlarged communication often lead to the situations where the structure no longer remains in secure operating region. The flexible Ac transmission system (FACTS) controllers can take part in an important role in the power system security enhancement. However, due to high capital investment, it is necessary to locate these controllers optimally in the power system. This paper presents an application of fuzzy control to determine the control signal of Unified Power Flow Controller (UPFC) for improvement of power system stability. UPFC is a combined shunt-series type FACTS device which is used in power system primarily for the purpose of voltage and reactive power control. A fuzzy logic based supplementary controller for Unified Power Flow Controller (UPFC) is developed which is used for damping the rotor angle oscillations and to improve the transient stability of the power system. Generator speed and the electrical power are chosen as input signals for the fuzzy logic controller (FLC). A Standard 3-phase, six bus system is taken as test system to evaluate the FACTS device Unified Power Flow Controller (UPFC) performance for proposed controllers PI and fuzzy with Power System Stabilizer in multi machine system.

**KEYWORDS** Fuzzy Logic Control, PI Controller, Power System Stabilizer, Unified Power Flow Controller

## INTRODUCTION

Flexible ac Transmission Systems (FACTS) devices have emerged in power system because of the development of power electronics components for high voltage and power. The FACTS devices provide higher controllability in power systems by means of power electronic devices. Several FACTS equipment's have been already introduced for various applications worldwide, and new types of FACTS are in the stage of being introduced in practice. FACTS technology provides a better ability to varying operational conditions and improves the usage of existing installations. The flexible AC transmission system is akin to high voltage DC and related thyristor developments, designed to overcome the limitations of the present mechanically controlled AC power transmission systems. By using reliable and high-speed power electronic controllers, the technology offers five opportunities for increased efficiency of utilities.

1) Greater control of power so that it flows on the prescribed transmission routes.
2) Secure loading of transmission lines to levels nearer their thermal limits.
3) Greater ability to transfer between controlled areas.
4) Prevention of cascading outages.
5) Damping of power system oscillation.

The increased interest in these devices is essentially due to two reasons. Firstly, the recent development in high power electronics has made these devices cost effective and secondly, increased loading of power systems, combined with deregulation of power industry, motivates the use of power flow control as a very cost effective means of dispatching specified power transactions. Several emerging issues in competitive power market, namely, as congestion management, enhancement of security and available transfer capability of the system, transmission pricing, etc. have been restricting the free and fair trade of electricity in the open power market.

FACTS devices can play a major role in these issues. Moreover, it is important to ascertain the location for placement of these devices because of their considerable costs. The insertion of such devices in electrical systems seems to be a promising strategy to reduce the power flows in heavily loaded lines resulting in increased system loadability, low system loss, improved stability of the network and reduced cost of production. The FACTS devices can be categories as shunt, series, series series and combine shunt-series controllers [1-3] namely, static VAR compensator (SVC), thyristor controlled series capacitor (TCSC), thyristor controlled phase angle regulator (TCPAR), static compensator (STATCOM), static synchronous series compensator (SSSC), unified power flow controller (UPFC), generalized unified power flow controller (GUPFC) and interline power flow controller (IPFC) etc.

Static Var compensator (SVC) improves the system performances by controlling the magnitude of voltage. Thyristor controlled phase angle regulator (TCPAR) controls the phase angle of voltage, while thyristor controlled series compensator (TCSC) changes the effective impedance of transmission line to the system performance. The unified power flow controller (UPFC) offers to combine all three functions in one device [4,5]. The control of system parameters can be carried out concurrently or sequentially with transfer from one type control (phase shift) to another one (series compensation) in real time. The other devices of FACTS controller family are static compensator (STATCOM), static synchronous series compensator (SSSC), generalized unified power flow controller (GUPFC) and interline power flow controller (IPFC) etc. [6-8].

## UNIFIED POWER FLOW CONTROLLER

The UPFC can provide simultaneous control of all basic power system parameters (transmission voltage, impedance and phase angle). The controller can fulfill functions of reactive shunt compensation, series compensation and phase shifting, meeting multiple control objectives.

The voltage at the bus i is taken as reference (all other angles are taken with respect to the bus angle)

$$V_i = |V| \angle 0^\circ$$

And voltage up to UPFC is $V_i' = V_i + V_{se}$. The voltage sources, $V_{se}$ and $V_{sh}$, are controllable in both magnitude and phase angles. The values of $\gamma$ and r are defined within the limits as

$$0 \le r \le r\max$$

$$0 \le \gamma \le 2$$

$V_{se}$ is defined in terms of reference bus voltage (i.e) ,Vi.

$$V_{se} = r^{*} V_i * e^{\wedge}(j\gamma)$$

For finding the power fed by the UPFC we go for superposition theorem. First considering the series voltage source and then the shunt one.

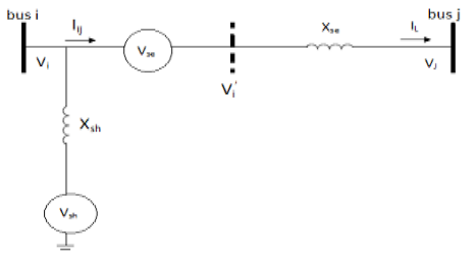



**Figure 1: Two voltage source model of UPFC**

By considering the series source the circuit is as below the steady-state UPFC mathematical model is developed by replacing $V_{se}$ by a current source using duality principle. Which is connected in parallel with the transmission line, where $b_{se} = 1/X_{se}$.

$$I_{se} = -j * b_{se} * V_{se}$$

The convention for flow of current is if the current leaves the node it is negative and if it enters the node it is positive.

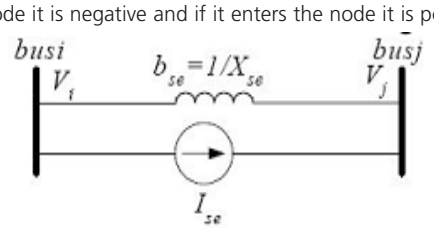



**Figure 2: Replacement of voltage source by current source**

As the power is equal to the product of voltage and current conjugate

$$P + jQ = V_{j^*}(I')$$

$$S_{is} = V_i(-I_{se})'$$

$$S_{js} = V_j(I)$$

The injected powers $S_{is}$, $S_{js}$ can be simplified according to following operations

$$S_{se} = V_i(j_{bse} \quad r \quad V_i e^{\wedge}(j\gamma))'$$

From eulers identity

$$e^{\wedge}(j\gamma) = \cos\gamma + j\sin\gamma$$

$$S_{is} = V_i(e^{\wedge}(-j(\gamma+90) \times b_{se} r V_i')$$

So

$$S_{is} = -rb_{se}V_i^2[\cos(-\gamma-90) + j\sin(-\gamma-90)$$

As

$$\cos(-\gamma-90) = -\sin\gamma \quad \sin(-\gamma-90) = -\cos\gamma$$

$$S_{is} = -rb_{se}V_i^2 \sin\gamma - jb_{se}rV_i^2\cos\gamma$$

Since

$$S_{is} = P_{is} + jQ_{is}$$

Comparing above equations,

$$P_{is} = -rb_{se}V_i^2 \sin\gamma$$

$$Q_{is} = -rb_{se}V_i^2 \cos\gamma$$

The voltage $V_j = V_j\angle\theta_j$ and $V_i = V_i\angle\theta_i$

$$S_{js} = V_j(I_{se})'$$

$$S_{js} = V_j\angle\theta_j(-j \quad r \quad V_i\angle\theta_j e^{\wedge}(j\gamma))$$

$$S_{js} = V_i \quad V_j \quad b_{se} \quad r\sin(\theta_i - \theta_j + \gamma) + jIV_j b_{se} r\cos(\theta_i - \theta_j + \gamma)$$

And

$$S_{js} = P_{js} + Q_{js}$$

Comparing above equations we get

$$P_{js} = V_i \quad V_j \quad b_{se} \quad r\sin(\theta_i - \theta_j + \gamma)$$

$$Q_{js} = V_i \quad V_j \quad b_{se} \quad r\cos(\theta_i - \theta_j + \gamma)$$

Consider the shunt source, in UPFC, the shunt branch is used mainly to provide both the real power, $P_{se}$, which is injected to the system through the series branch, and the total losses within the UPFC. The total switching losses of the two converters is estimated to be about 2% of power transferred ,for Thyristor based PWM converters, if losses are included in real power injection of shunt connected voltage source at bus I , $P_{sh}$ is equal to 1.02 times the injected series real power through the series connected voltage source to the system.

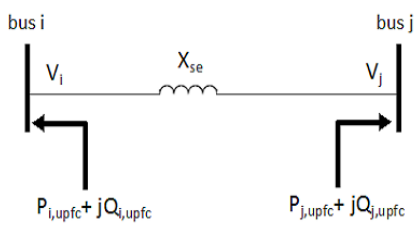
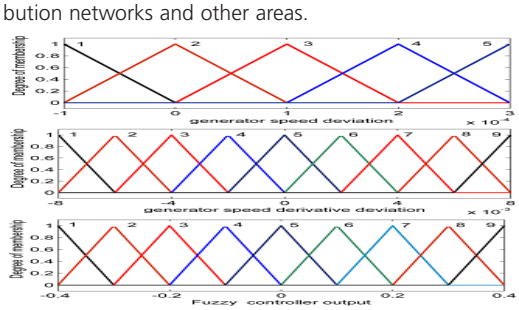


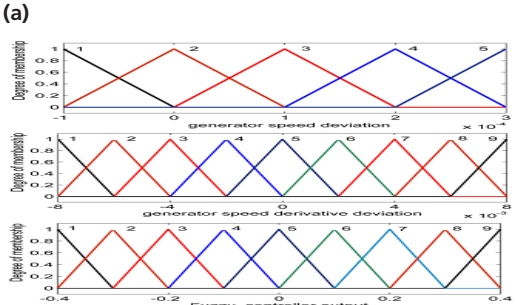

**Figure 3: Steady state mathematical model**

## FUZZY LOGIC CONTROL

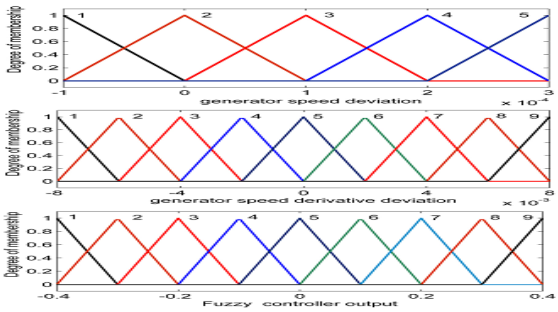
In 1965, Zadeh proposed fuzzy logic, and it has been effectively utilized in many field of knowledge to solve control and optimization problems [9]. The FLC is a good means to control the parameters when there is not any direct or exact relation between the input and the output of a system, and we only have some linguistic relations in the If-Then form [10]. The use of fuzzy logic has received increased attention in recent years because of its usefulness in reducing the need for complex mathematical models in problem solving [11]. In the power system area, it has been used in stability studies, load frequency control, unit commitment, reactive compensation in distribution networks and other areas.




**(a)**

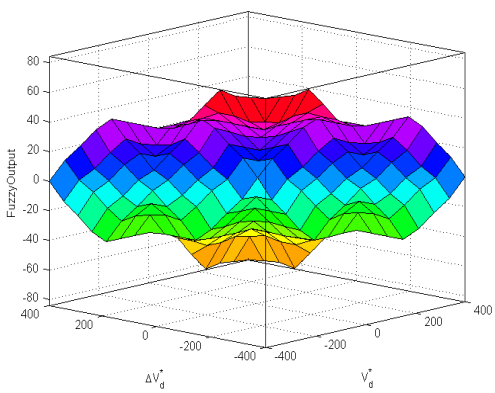


**(b)**

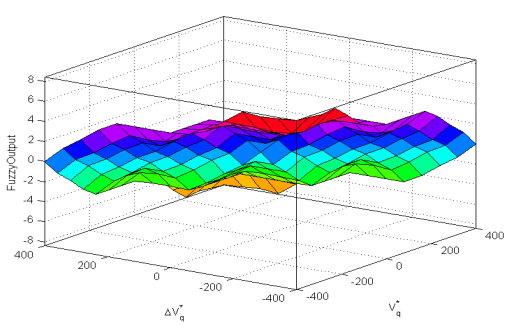



**(c)**

**Figure 4: Membership functions of inputs and output.**




**(a) D-axis fuzzy output**




**(b) D-axis fuzzy output**

**Figure. 5. Decision surface of proposed FLC**

A fuzzy control system is made from different blocks such as the numeral quantity converter to fuzzy quantities (fuzzifier interface) block, the fuzzy logical decision maker section, the knowledge base section, and the defuzzier interface block. The following steps are involved in designing a fuzzy PSS controller [12]:

1. Choose the inputs to the FLC. As shown in Figure. 3, only two inputs, the generator speed deviation ($\Delta\omega$) and the generator speed derivative deviation ($\Delta\hat{\omega}$), have been employed in this study. The symbol Uc has been synonymously used to represent the output or decision variable of the FLC.
2. Choose membership functions to represent the inputs in fuzzy set notation. Triangular functions are chosen in this study. Fuzzy representations of the generator speed change, acceleration, and output variable have been illustrated in Figure. 4.
3. A set of decision rules relating the inputs to the output are compiled and stored in the memory in the form of a "decision surface". The decision surface is provided in Figure. 5.

**SIMULATION RESULTS**

In this study, the performance of the combined controllers for the stabilization of a synchronous generator is evaluated by computer simulation studies. A Standard 3-phase, six bus system shown in Figure.6 is taken as test system to evaluate the FACTS device (UPFC) performance for proposed controllers PI and FUZZY with PSS stabilizer in multi machine system. To evaluate the system a LG Fault was established/ implemented between the BUS 1 and BUS 4 at a duration of 0.4 to 0.5 sec and 1.4 to 1.5 sec. Corresponding Voltage and current waveforms for at each with UPFC controlled by PI and FUZZY is shown below Figures.7-20. Form the wave form it's clear that the voltage magnitude of during fault as well as normal condition FUZZY employed UPFC has superior performance over PI controller, comparison of voltage magnitude also shown table 1. Figures.13 and 20 show the angle deviation is lesser than that of PI UPFC and fuzzy UPFC, It's also clearly seen that the performance of PSS also improved in fuzzy controller than PI controller.

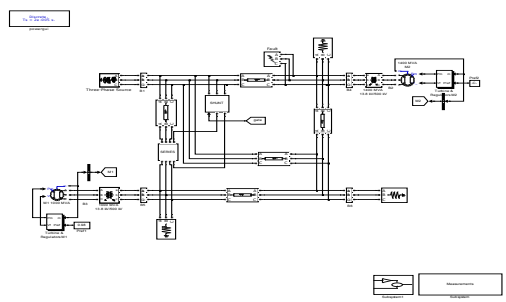


**Figure 6: Simulink of a 2-machine, six-bus system with PI-fuzzy controller based UPFC**

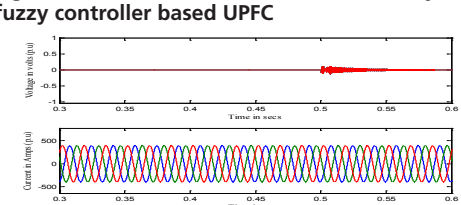



**Fig.7. Voltage and current waveforms of Bus 1 with UPFC controlled by PI controller**

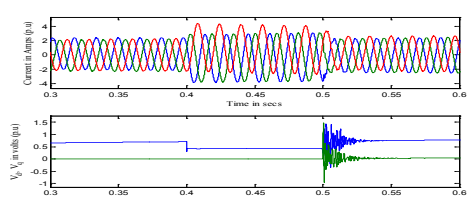



**Fig.8. Voltage and current waveforms of Bus 2 with UPFC controlled by PI controller**

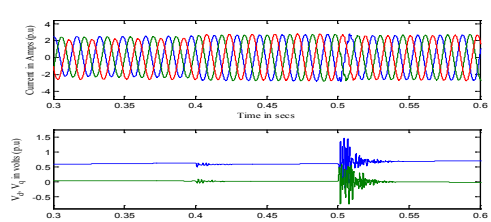



**Fig.9. Voltage and current waveforms of Bus 3 with UPFC controlled by PI controller**

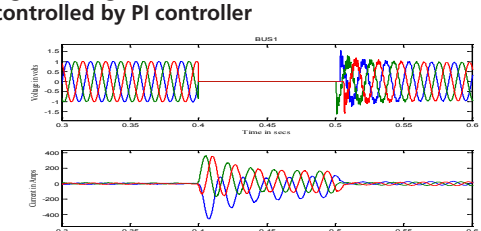



**Fig.10. Voltage and current waveforms of Bus 4 with UPFC**

**controlled by PI controller**

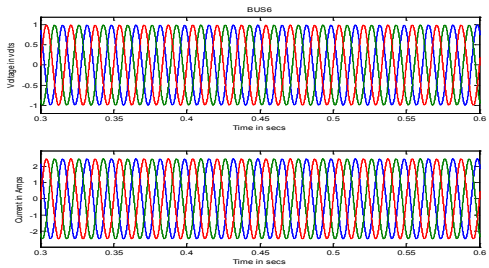



**Fig.11. Voltage and current waveforms of Bus 5 with UPFC controlled by PI controller**

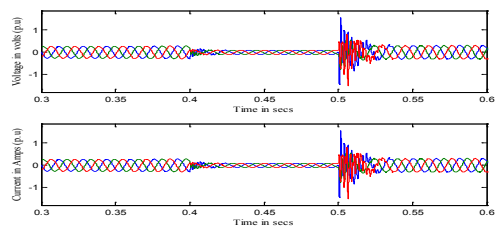



**Fig.12. Voltage and current waveforms of Bus 6 with UPFC controlled by PI controller**

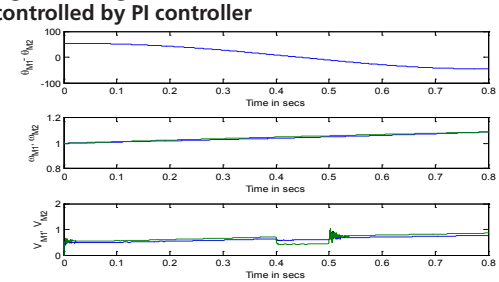



**Fig.13. Simulation waveform of Machine1&2 (Angle Difference, Speed & Voltage) with PI controller**

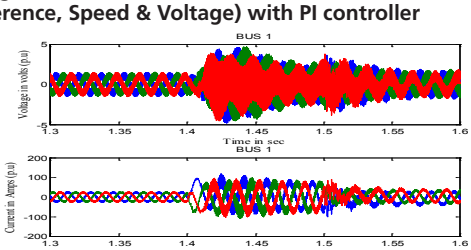



**Fig.14. Voltage and current waveforms of Bus 1 with UPFC controlled by fuzzy controller**

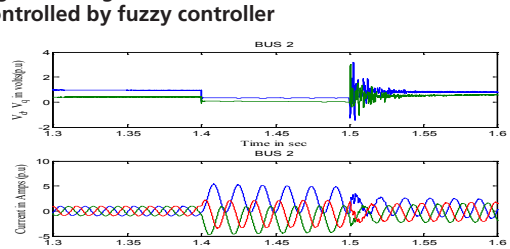



**Fig.15. Voltage and current waveforms of Bus 2 with UPFC controlled by fuzzy controller**

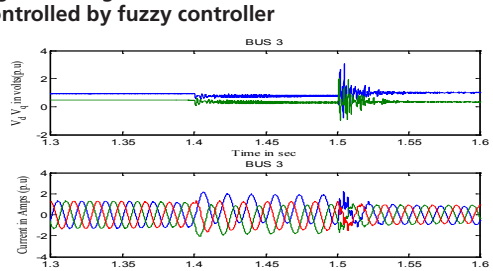



**Fig.16. Voltage and current waveforms of Bus 3 with UPFC controlled by fuzzy controller**

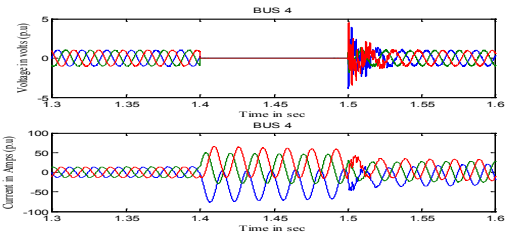



**Fig.17. Voltage and current waveforms of Bus 4 with UPFC controlled by fuzzy controller**

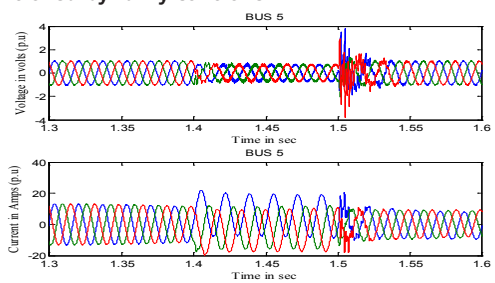



**Fig.18. Voltage and current waveforms of Bus 5 with UPFC controlled by fuzzy controller**

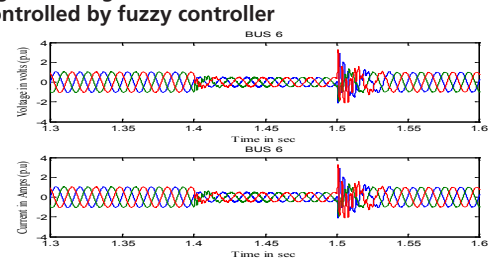



**Fig.19. Voltage and current waveforms of Bus 6 with UPFC controlled by fuzzy controller**

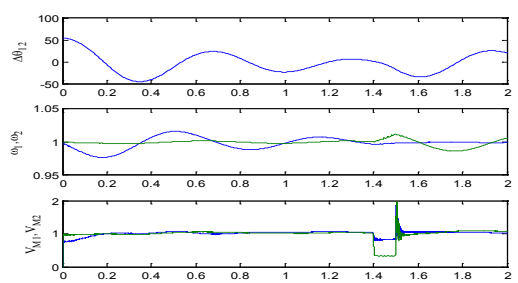


**Fig.20. Simulation waveform of Machine1&2 (Angle Difference, Speed & Voltage) with fuzzy controller**

**TABLE – 1 VOLTAGE MAGNITUTE OF 6 BUS SYSTEM**

| Bus | PI-UPFC Voltage in p.u | Fuzzy-UPFC Voltage in p.u |
|---|---|---|
| Bus 1 | 0 | 1 |
| Bus 2 | 0.51 | 0.85 |
| Bus 3 | 0.6 | 0.84 |
| Bus 4 | 0 | 0 |
| Bus 5 | 1 | 1 |
| Bus 6 | 0.1 | 0.52 |

## CONCLUSIONS

In this paper a combined design of a UPFC and a power system stabilizer is used to power system stability enhancement. A fuzzy logic controller and PI controller has designed for the PSS employed to search for the UPFC controller parameters

in a two machine, six bus test system. The optimal design of the controllers has been implemented on a proposed system and discussed. The system performance characteristics demonstrate that the combined design of the UPFC and PSS controllers is superior to the uncombined design of the controllers.

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