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Implementation of UPFC, UPFC Along with PI and Fuzzy Based Controllers in Three Area Interconnected Power Systems for Load Frequency Control

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ABSTRACT- In this paper, the author intends to present the application of Unified Power Factor Controllers (UPFC) to control the frequency of three area interdependent and interconnected reheat and hydro systems by controlling the frequency of the system under disturbance due to load variations. Efficacy of the PID controllers to regulate the system dynamics has already been analyzed. By the use of fuzzy logic controllers, the system dynamics is further enhanced and the furtherance in the results is ascertained. This paper also demonstrates the superiority of Fuzzy Logic Controller (FLC) in connection with PID controllers and the UPFC. This paper also discusses the mathematical model of the system.

KEYWORDS- Static Synchronous Series Compensator (SSSC), Static Synchronous Compensator (STATCOM), Load Frequency Control (LFC), PID Controller, Fuzzy Logic Controller.

I. INTRODUCTION

There is an undesirable variation of frequency of a power system due to the inequality between generated values and changing load. The Load Frequency Control (LFC) is employed for the purpose of nullifying the difference between generation and load such that the change in frequency is minimized [1][2]. The modern power systems employ thermal and hydro units as the predominant units of power production. They also serve as base load units in a power system [3]. Hydro power plants exhibit non-minimum phase characteristics and these characteristics differentiate them from the thermal units. For the purpose of investigation in this paper, three interconnected units like hydro and two reheat-thermal are considered. The disturbances like load changes often lead to the inter area oscillations system which consequently produce changes in frequency. The oscillations can be damped out using Flexible Ac Transmission Devices (FACTS). Hence, the LFC's in association with the FACTS devices turns amusing. Different FACTS devices [4, 5, 6, 7].By improving the stability of power systems Unified Power Flow Controller (UPFC) find their purpose in modern power systems. The imbalance between generation and demand results in the variation of frequency of power system. In our system, for damping out the oscillations caused due to load variation, a Unified Power Flow Controller (UPFC) is used. The system response is further tested with the combination of UPFC with PID controller. PID is favoured on account of its desirable qualities like simplicity, reliability, low cost of manufacturing and implementation as well as it's straight forward usage. PID controllers have always maintained their place as the best option for LFC. While considering the advantages of the PID controllers it is necessary to consider the major shortcomings of PID controller i.e., the proportional and derivative components which cause sudden overshoots and sharp spikes. In order to address the disadvantages of PID controller we can use Fuzzy Logic Controller (FLC) clubbed with UPFC for the sharp spikes of frequency deviation and the settling time to be reduced.

II. DETAILS OF SYSTEM UNDER INVESTIGATION

Three area hydro and thermal-reheat system are considered interconnected for the purpose of investigation. Given below is the figure below for the representation of transfer functions of various elements of the power system. Ref [8, 9] provides the details as well as the parameters of system under investigation. PID and Fuzzy controllers are employed separately as auxiliary controllers with the UPFC (a FACTS device constituting of SSSC and STATCOM together) as shown in Fig. 1. The pursuance of UPFC with different controllers is observed. A step load perturbation is used to evaluate the system performance. The step load perturbation considered for making the studies realistic.

A. Generator Modelling

Generator model is given in Fig. 2. The term Generation Rate Constraint (GRC) is defined as the specified maximum rate at which the generation of power in a power system can change. The GRC has certain effects on a power system. When the GRC is changed the effects like increment of settling time and overshoots are the evidence of changes in the response of the power system. At the moment, we are looking at for thermal units having 3% per minute of GRC. [10]. The synchronous machine's swing equation is given by

$$\frac{d^2\Delta\delta}{dt^2} = \Delta P_m - \Delta P_e$$

For an infinitesimal speed change, we have

$$\frac{\mathrm{d}\Delta\frac{\omega}{\omega_s}}{dt} = \frac{1}{2H}(\Delta P_m - \Delta P_e)$$

In per unit, we have

$$\frac{d\Delta\omega}{dt} = \frac{1}{2H}(\Delta P_m - \Delta P_e)$$

Laplace transform of equation (3) is

$$\Delta\omega\,(s) = \frac{1}{2Hs}[\Delta P_m(s) - \Delta P_e(s)]$$

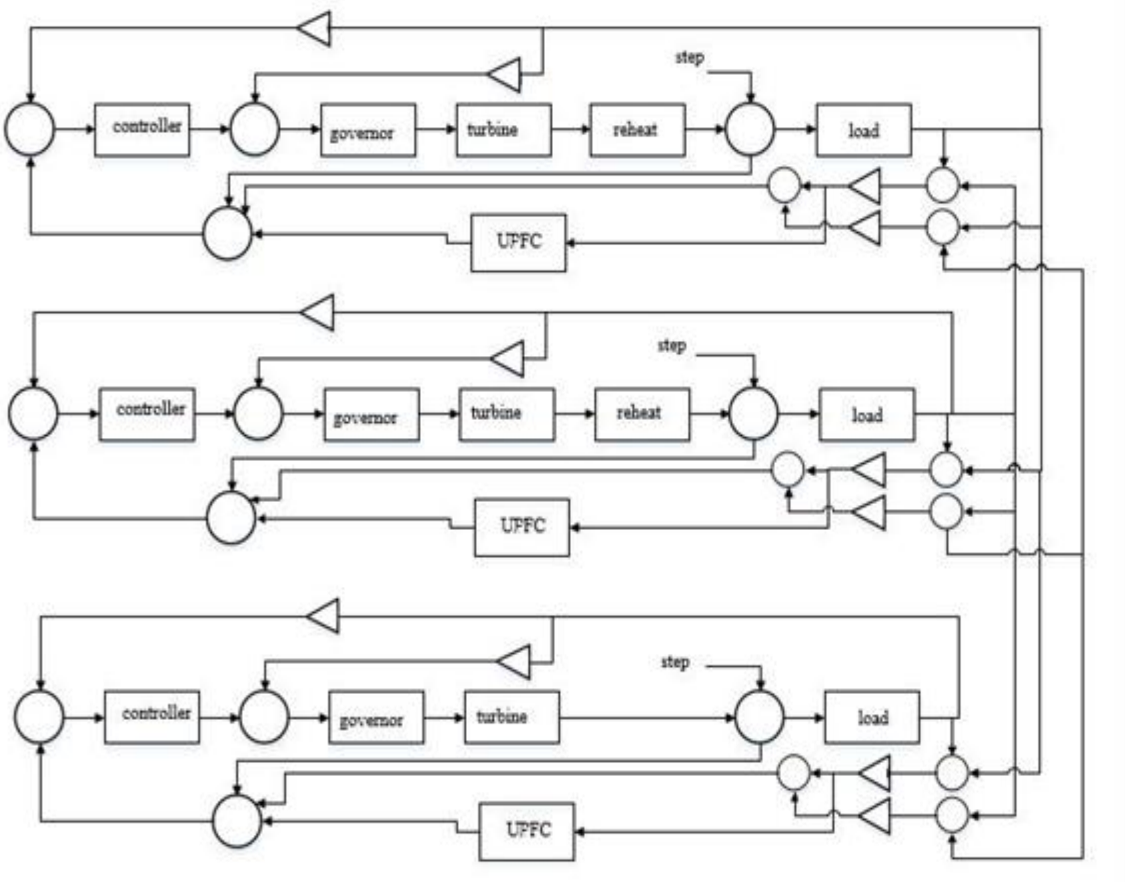

Figure.1: A Three area power system represented by its lock diagram

A block diagram representation of the same is as follows.

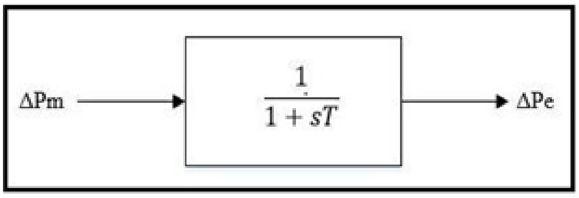

Figure. 2: Model of the Generator

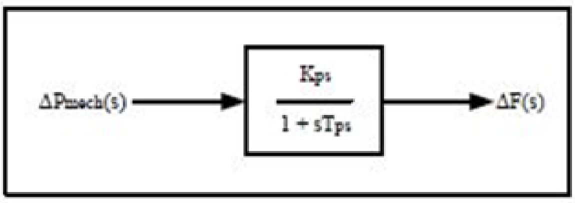

Figure. 3: Load model

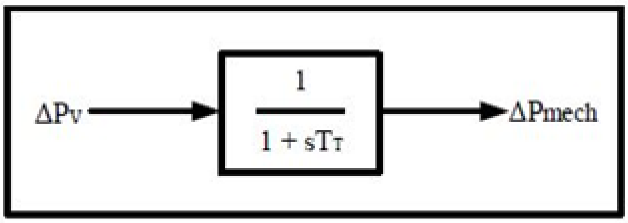

Figure. 4: Turbine model

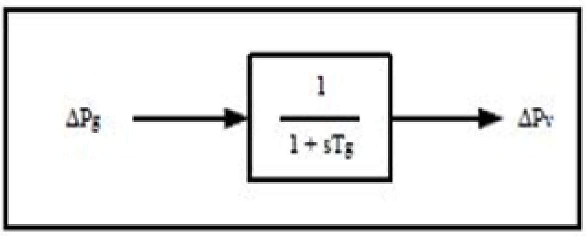

Figure. 5: Model of the Governor

B. Modelling of The Load

Loads encountered in an electrical power system are either frequency independent resistive loads or inductive loads that are sensitive to the frequency changes. Speed-load characteristics determine the sensitivity of inductive load. Mathematical relation to show the same is:

$$\Delta P_e = \Delta P_L + D\Delta\omega W$$

Here, the percentage ratio of change in load to change in frequency is represented by the value of D. ΔP_L represents the frequency independent $D\Delta\omega$ is the frequency dependent load as shown in Fig. 3.

C. Modelling of the Prime Mover

From literature, we know that hydraulic turbines are the prime mover for waterfalls and steam turbines are the prime movers for gas and nuclear powerplants. While modelling the turbine we need to uphold the relation that changing mechanical power ΔP_m) is directly proportional to the change in steam valve ΔP_V).

A non-reheat turbine has only one time constant. The modelled transfer function is represented by:

$$G_T(s) = \frac{\Delta P_m(s)}{\Delta P_V(s)} = \frac{1}{1 + T_T(s)}$$

D. Modelling of the Governor

The equation representing the governor model and as shown in Fig. 5 is.

$$\Delta P_V(s) = \frac{1}{1 + Tg}\Delta P_g(s)$$

III. FUZZY LOGIC CONTROLLER

Fuzzy logic controllers find tremendous applications in modern power system. The principle for the working of FLC's is the knowledge acquisition process. Each fuzzy set is linked to a membership function. And we use fuzzy IF-THEN rule to achieve the purpose of controlling the process of fuzzy systems. PID controller generates an error which is used by FLC's for optimization in order to produce the membership function's horizontal range. The frequency deviation produced by changing load has to be in permissible limits. That is the foundation for LFC.

Table 1: Rule Base

ACE'/ DACE'	NB'	NS'	ZZ'	PS'	PB'
NB'	S'	S'	M'	M'	B'
NS'	S'	M'	M'	B'	VB'
ZZ'	M'	M'	B'	VB'	VB'
PS'	M'	B'	VB'	VB'	VVB'
PB'	B'	VB'	VB'	VVB'	VVB'

Fuzzification: The process of conversion of real-valued variable into fuzzy variable.

Rule base: The elemental and essential rule applied in the rule base is the IF-THEN rule, which is composed of a collection of rules. Combination of these fuzzy rules gives rise to the rule base. Membership functions are required for carrying out this information.

De-Fuzzification: In order to control the process real and meaningful values of the interpreted information are needed. After passing through the rule base the information is still not clear and needs to be converted to usable form. All of this is achieved by the process called De-Fuzzification. De-Fuzzification involves the conversion of a fuzzy variable to real valued variable called crisp value. The representation of de-Fuzzification is given by the block diagram below. By changing the rule base, the controlling action of the FLC can be altered. [11]-[16].

The governor generates the dΔ decide t￼￼fs). It is fed as the input to FLC. There are five variables (NB', NS', ZZ', PS' and PB') which are used to form the rule base and the membership functions. This method is valid for the inputs and two output system and the same is represented the rule-base table and in the diagram.

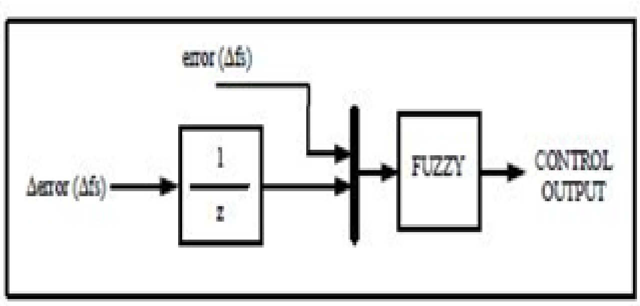

Figure. 6: Fuzzy controller

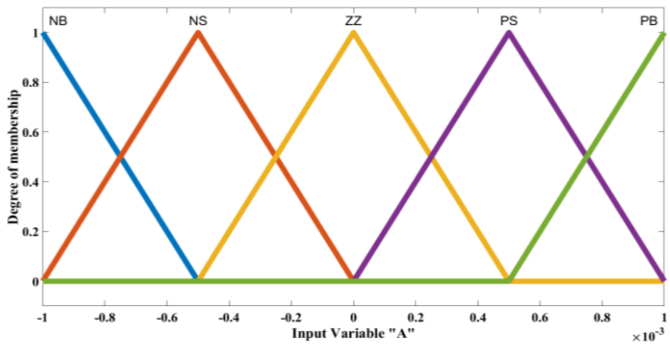

Figure. 7: Input variable ACE

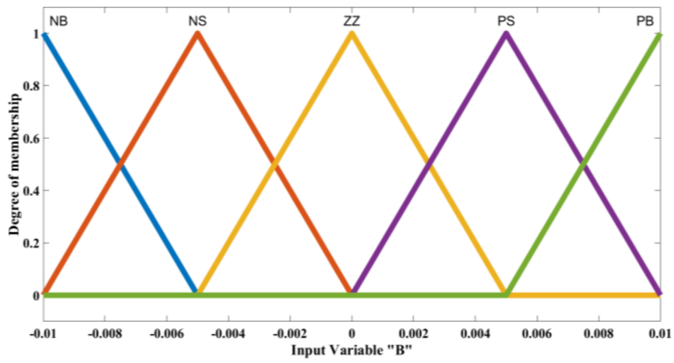

Figure. 8: Input variable DACE

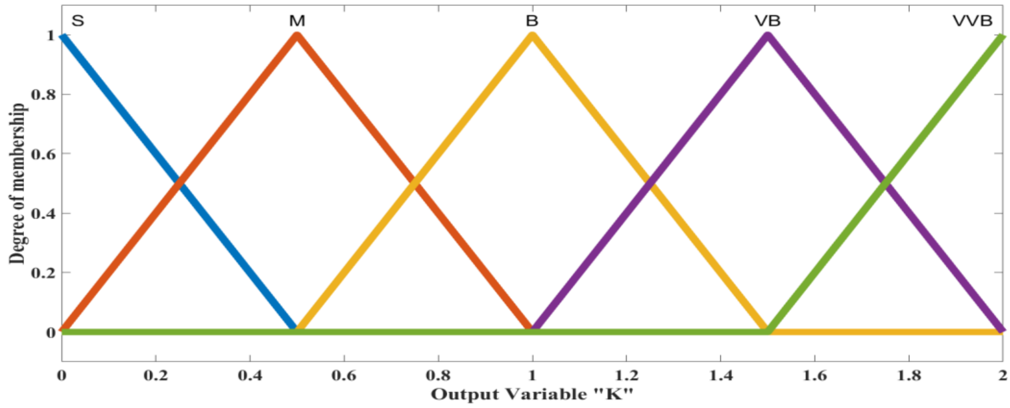

Figure. 9: Output variable K

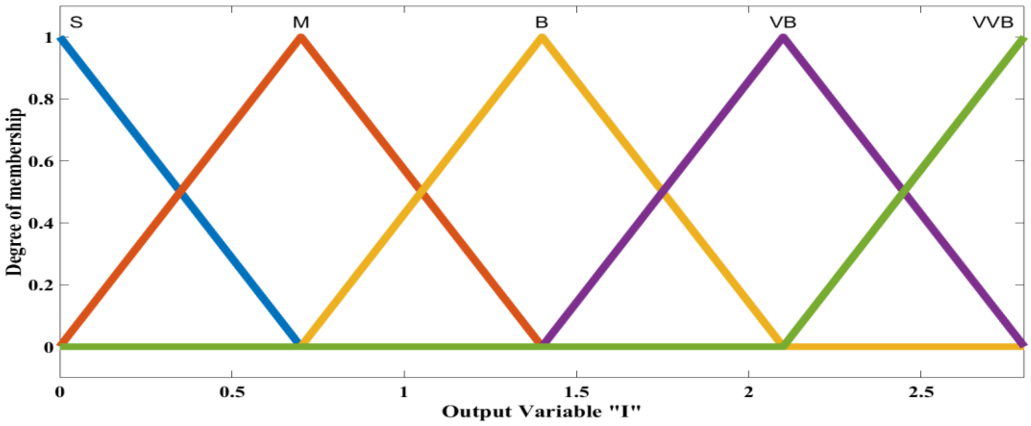

Figure. 10: Output variable I

IV. SIMULATIONS AND RESULTS

A step variation of load in the system has been used to simulate the three-area power system. The system oscillates around a new frequency with initially high spikes and large overshoot. By implementing UPFC the oscillations are eliminated with the reduction in the transient spikes. However, a PID controller is also used to boost the system's response but the high spikes still persist. The system regains its steady state at its nominal frequency with some time delay. Further the system is tested for fuzzy controller instead of PID controller to improve the response further. With the incorporation of fuzzy controller, we see that the system attains steady state earlier than with the PID controller at the nominal frequency i.e., the settling time of the system is reduced along with the reduction in the high spikes. Thus, using fuzzy controller, the system response is better than UPFC and PID.

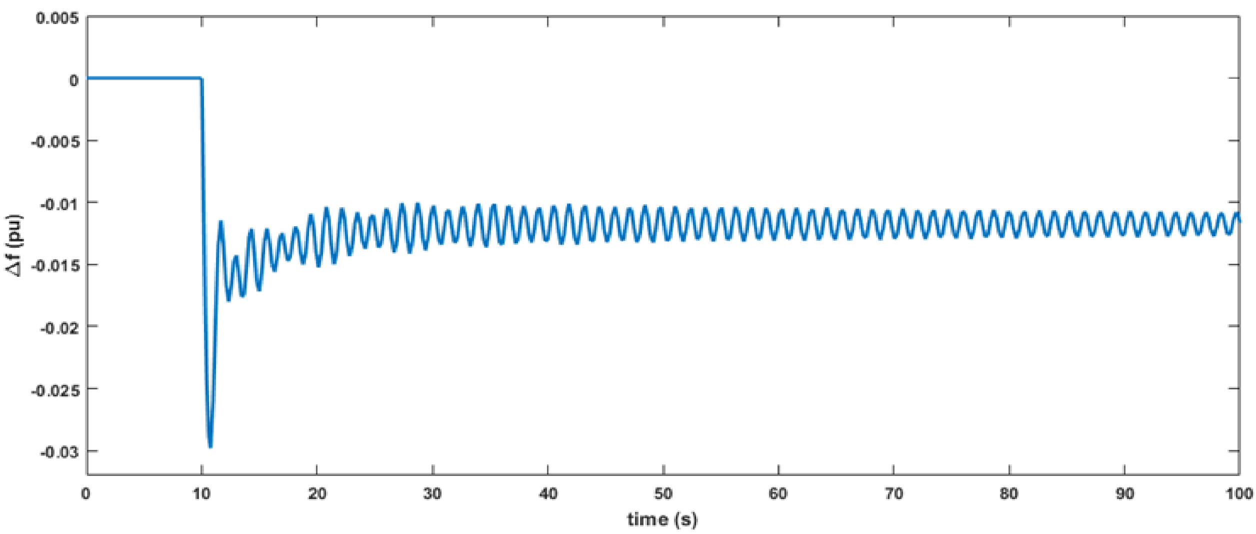

Figure. 11: Uncompensated

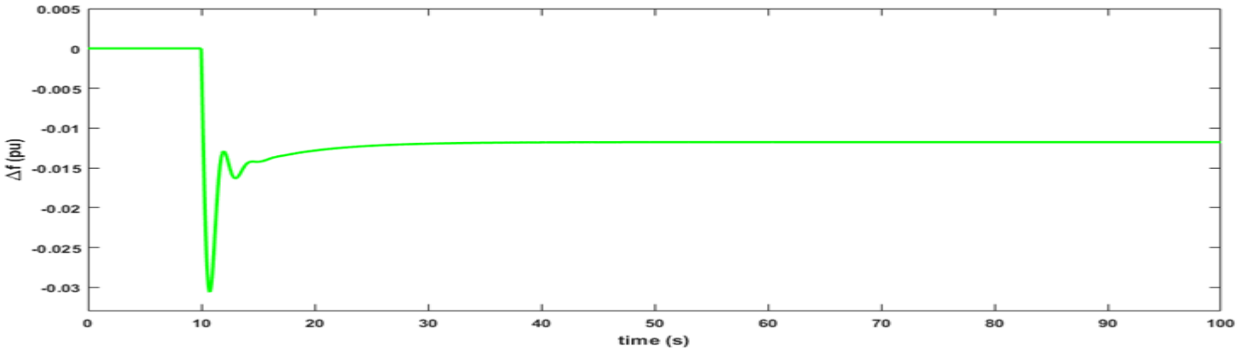

Figure. 12: With UPFC

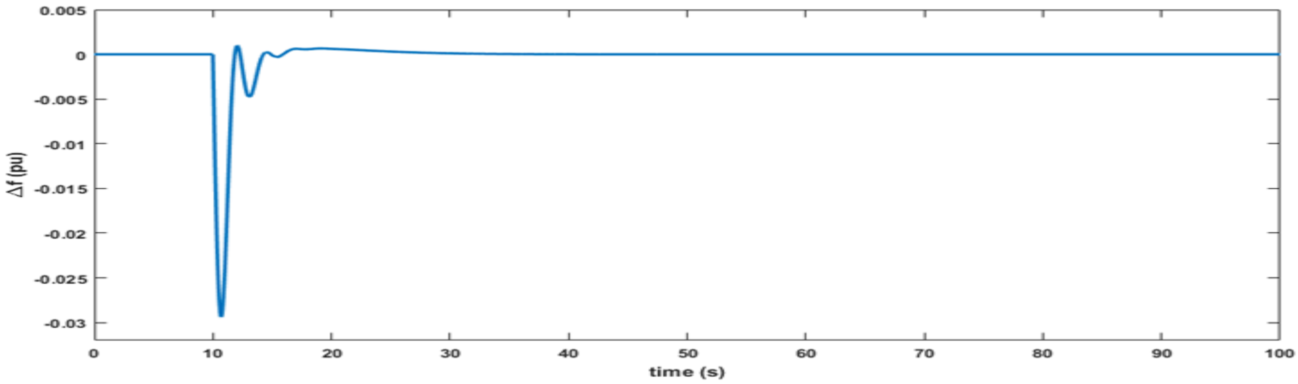

Figure. 13: With UPFC and PI

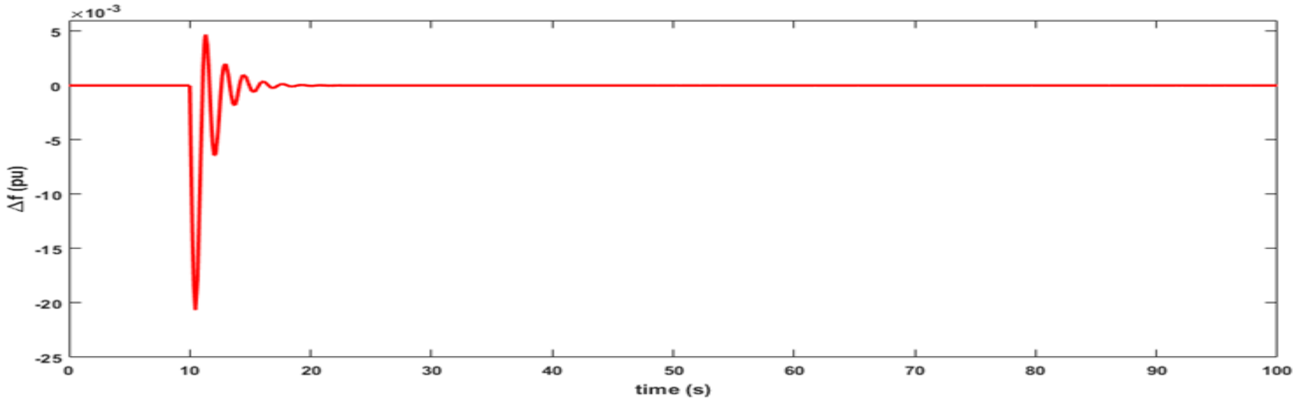

Figure. 14: With UPFC and fuzzy

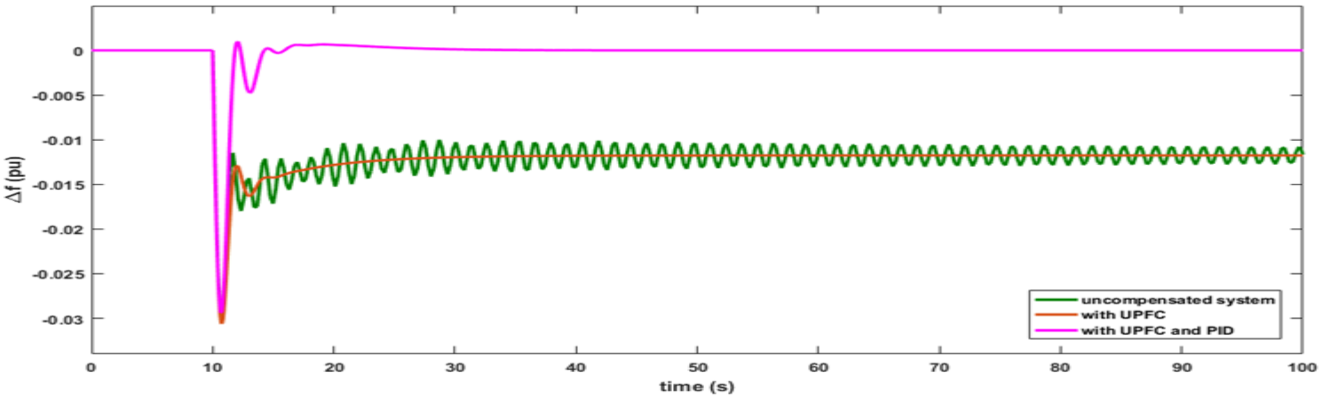

Figure. 15: Comparison 1

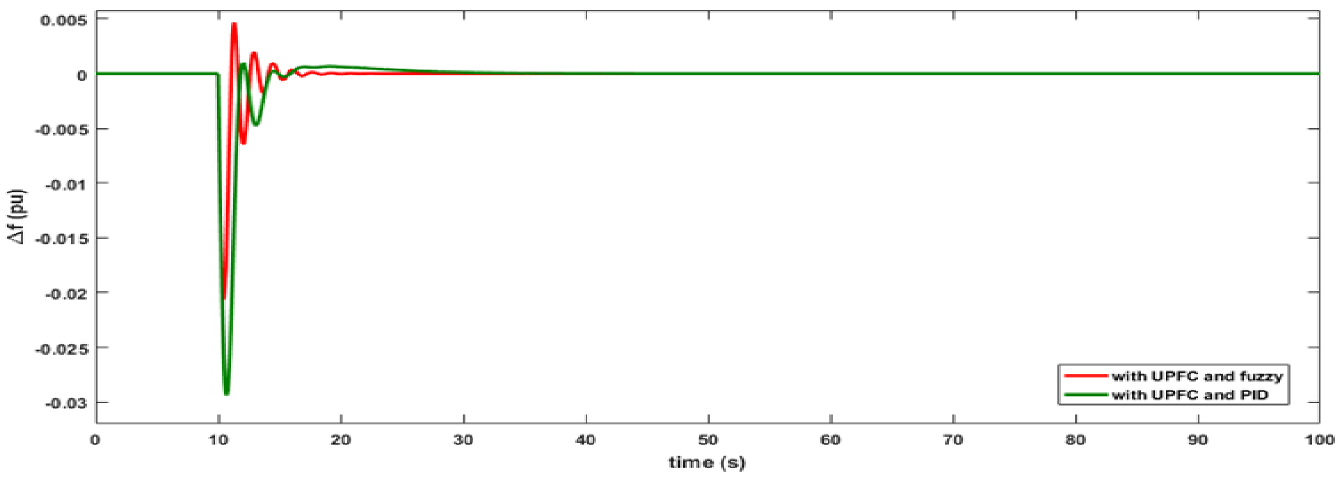

Figure. 16: Comparison 2

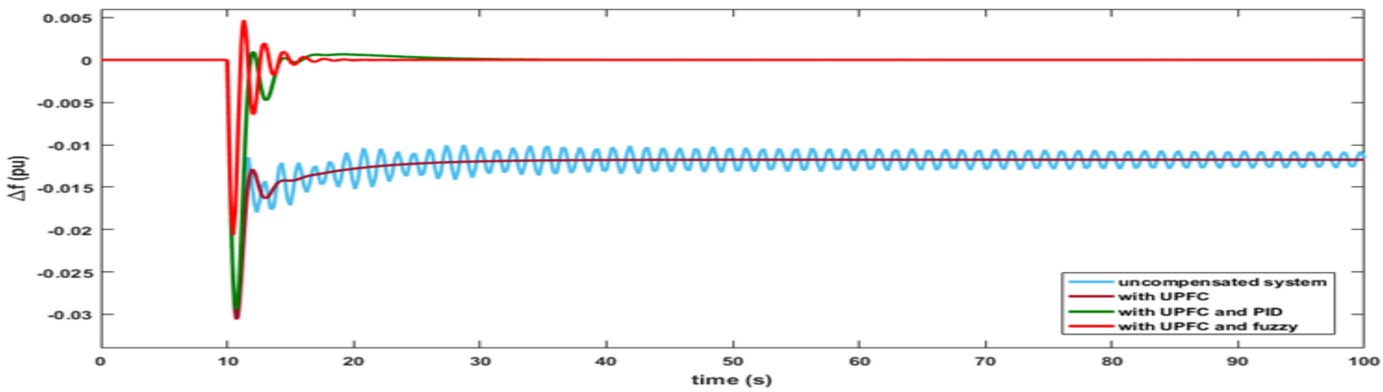

Figure. 17: Comparison 3

V. CONCLUSION

With the implementation of the UPFC in the system we can eliminate the oscillations due to load change, but the system steady state is achieved at frequency different from the nominal frequency. For eliminating the steady state error PID controller is employed in the system. The system regains the steady state at its nominal frequency after some time (settling time). The system is subjected to high spikes and large over shoots due to the PID controller used. To reduce the high peaks in the transient period and the overshoot a Fuzzy Logic Controller is used. It is observed that the fuzzy controller used reduces the settling time as well. Thus, fuzzy controller gives the finest results in reference to transient response as compared to the UPFC alone and as compared to the UPFC and PID controller together in the system.

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