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Grid Stability Improvement in Deregulated Environment Using HVDC and Fuzzy Controller

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Abstract- In this paper, two equal areas is considered. This paper deals with the results of dynamic performance of frequency control and tie line. A fuzzy logic controller is proposed for two area power system interconnected via parallel HVAC/HVDC transmission link which is also referred as asynchronous tie lines. The linear model of HVAC/HVDC link is developed and the system responses to sudden load change are studied. For obtaining least deviations we have formed a deregulated system of Wind Turbine Generator for both system and tie line separately. Then these systems are applied to our original systems and tie lines. The deviations have decreased appreciably.

Keywords:- Automatic generation control (AGC) Deregulated environment, Fuzzy logic controller, Generation rate constraint, Area control error, HVDC Link

I. INTRODUCTION

The Grid Stability is a technical requirement for the proper operation of an interconnected power system and it is the prerequisite for a stable electricity grid and guarantees secure supply at a frequency of 50 Hz [1]. As far as production is concerned, this is relatively simple: the production of electrical energy is largely foreseeable, apart from the new renewable energies [2]. An interconnected power system consists of interconnected control areas. A worldwide trend in the development of power systems is to build interconnections with the goal to achieve economical benefits. Automatic Generation Control (AGC) is used to maintain the schedule system frequency. With the advancement of systems analysis techniques such as optimal control theory, their application to power system problems was inevitable. In particular, there are three significant reasons to search for better control strategies for the AGC problem. First, the continuing growth of this nation has been and will continue to be achieved at the expense of an enormous consumption of electrical energy, thus causing a demand for more efficient use of generation facilities. Second, careful usage of generating facilities reduces the ecological impact through reduction in fuel consumption and discharge problems [4]. Finally, the trend is toward larger units, which increases the problems of system stability. Thus, better control strategies are required in improving stability margins and overall power system reliability. Controlling the frequency has always been a major subject in electrical power system operation and is becoming much more significant recently with increasing size, changing structure and complexity in interconnected power systems. Next importance is given to the use of High Voltage DC transmission (HVDC) link in the system rather than High Voltage Alternating Current (HVAC) transmission only. HVDC is a foreseen technology due to huge growth of this transmission system and due to its economic, environmental and performance advantages over the other alternatives [1]. Therefore it is proposed to have a dc link in parallel with HVAC link interconnecting control areas to get an improved system dynamic performance. These studies are carried out considering the nominal system parameters. Intelligent controllers are designed using proportional-plus-integral control strategy and implemented on the system under consideration in the wake of 1% step load perturbation in the interconnected area. The conventional control method does not give required solutions due to complex and multivariable power systems. Therefore next step is taken to improve the reliability and robustness of the system using Fuzzy Controllers [10]. Fuzzy Controllers are advantageous in solving wide range of control problems including AGC of interconnected power system. Fuzzy logic based controller can be implemented to analyze the load frequency control of two area interconnected power system with HVAC and HVDC parallel link taking parameter uncertainties into account. In the system working under deregulated environment, a Wind Turbine Generator (WTG) or other locally generating plants can be simulated using in the to carry out all the proposed operations and to control the frequency of the system using AGC and Integral Controller with the Fuzzy Controller. The power system is modelled and simulated using MATLAB simulink environment. Then the frequency deviation has been studied and presented with fuzzy controller, HVDC and WTG [3].

II. TWO AREA POWER SYSTEM

The two area power system model identified in the present study has the following configuration;
(i) It is a two area interconnected power system consisting of identical single stage turbines.
(ii) The two areas are interconnected via HVAC tie line in parallel with HVDC link. The single line diagram of the model under consideration for two areas is presented in Figure 1.The transmission links are considered as long transmission lines specifically of length greater than break even distance length of HVAC and HVDC transmission lines [5].

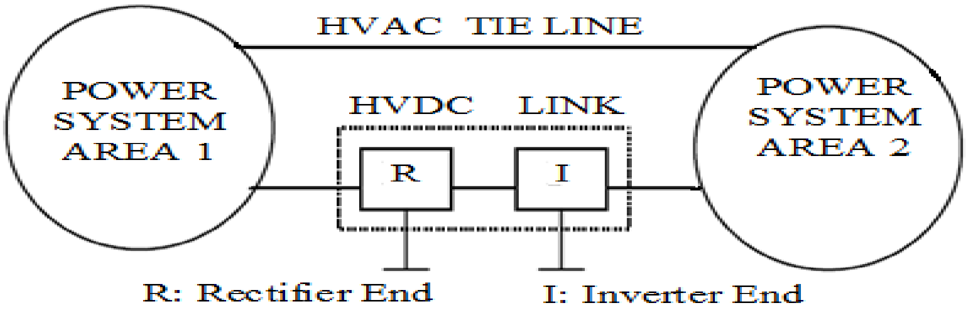


Figure1: Single line diagram of two area power system with parallel HVAC/HVDC links

III. FUZZY LOGIC CONTROLLER

Because of inherent characteristics of the changing loads, complexity and multi-variable conditions of the power system, conventional control methods may not give satisfactory solutions. Artificial intelligence based gain scheduling is an alternative technique commonly used in designing controllers for non-linear systems. Fuzzy system transforms a human knowledge into mathematical formula. Therefore, fuzzy set theory based approach has emerged as a complement tool to mathematical approaches for solving power system problems. Fuzzy set theory and fuzzy logic establish the rules of a nonlinear mapping [6]. Nowadays fuzzy logic is used in almost all sectors of industry and science. One of them is automatic generation control. The main goal of AGC in interconnected power systems is to protect the balance between production and consumption. The fuzzy logic controller designed for the system analysis is shown in Figure 2.

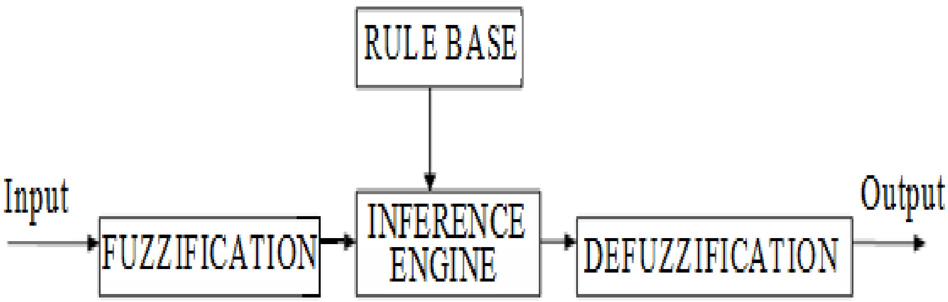


Figure2: Components of fuzzy controller

The fuzzy logic controller is comprised of four main components: the fuzzification, the inference engine, the rule base, and the defuzzification, as shown in Figure 4. The fuzzifier transforms the numeric/crisp value into fuzzy sets; therefore this operation is called fuzzification. The main component of the fuzzy logic controller is the inference engine, which performs all logic manipulations in a fuzzy logic controller. The rule base consists of membership functions and control rules. Lastly, the results of the inference process is an output represented by a fuzzy set, however, the output of the fuzzy logic controller should be a numeric/crisp value. Therefore, fuzzy set is transformed into a numeric value by using the defuzzifier. This operation is called defuzzification. For the proposed study, Mamdani [7] fuzzy inference engine is selected and the centroid method is used in defuzzification process.

LN: large negative, MN: medium negative, SN: small negative, Z: zero, SP: small positive, MP: medium positive and LP: large positive

Table 1.Rules for the fuzzy logic controller

		A	C'	E				
		LN	MN	SN	Z	SP	MP	LP
A	LN	LP	LP	LP	MP	MP	SP	Z
C	MN	LP	MP	MP	MP	SP	Z	SN
E	SN	LP	MP	SP	SP	Z	SN	MN
	Z	MP	MP	SP	Z	SN	MN	MN
	SP	MP	SP	Z	SN	SN	MN	LN
	MP	SP	Z	SN	MN	MN	MN	LN
	LP	Z	SN	MN	MN	LN	LN	LN

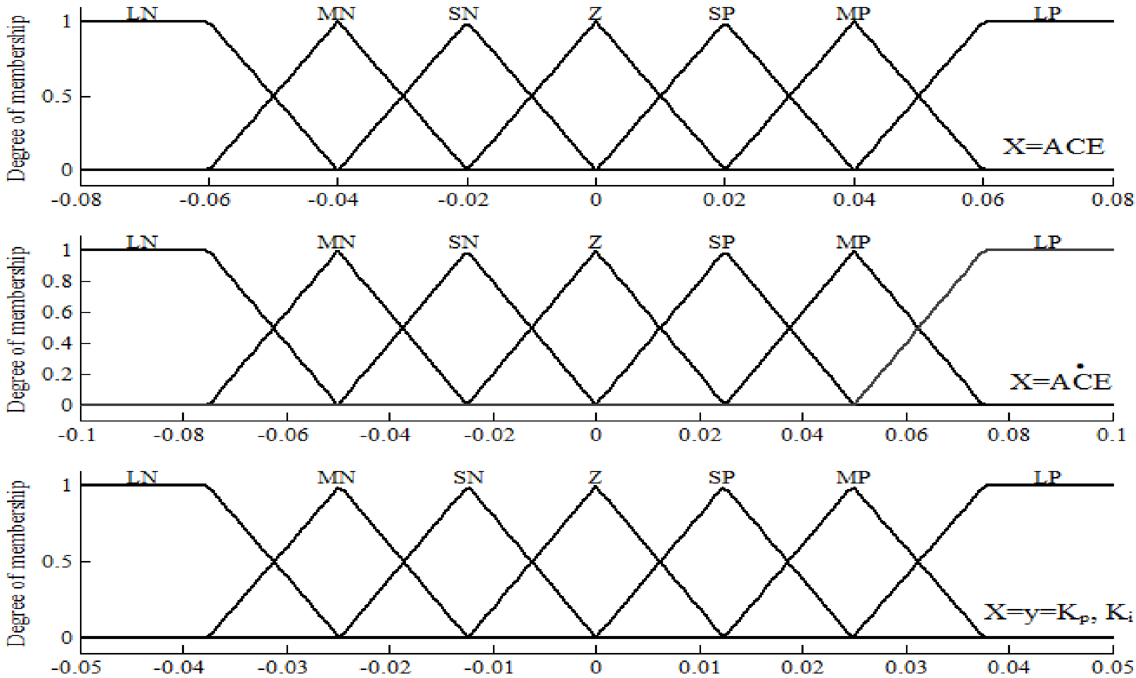


Figure 3.Membership functions used in study

Fuzzy logic shows experience and preference through membership functions which have different shapes depending on the experience of system experts [8]. These rules are obtained based on experiments of the process step response, error signal, and its time derivative. The membership functions of the fuzzy logic pi controller presented in Figure 3 consist of three memberships functions (two-inputs and one-output). Each membership function has seven memberships comprising two trapezoidal and five triangular memberships. Seven numbers of rules have been taken in inference mechanism. Therefore, 49 control rules are used for this study. The range of X is selected from simulation results. All memberships are selected to describe the linguistic variables. These functions have different shapes depending on system experts' experience. For the determination of the control rules, it can be more complicated than membership functions, which depend on the designer experiences and actual physical system. The control rules are build from the if-then statement (i.e. if input 1 and input 2 then output 1). Table 1 taken from [12], indicates the appropriate rule base used in the study. Let us consider the fourth row and fifth column in Table 1 e.g. if ACE is Z and AĊE is SP then *y* is SN.

IV. WIND TURBINE GENERATOR AS DEREGULATED SYSTEM

The dynamic modelling of wind power generators (WTG), in order to estimate their impact on the power system dynamic behaviour, is a matter of high interest. The 'Wind Power Model' contains the following basic formula to calculate the turbine mechanical power. The two transfer functions are used here for low pass filter and for high wind speed. In the upper part the wind speed is low-pass filtered. This time constant depends on the average wind speed, but is assumed constant for this simplified model. The lower part is used for maintaining high speed of wind and then both are added as shown in figure4.

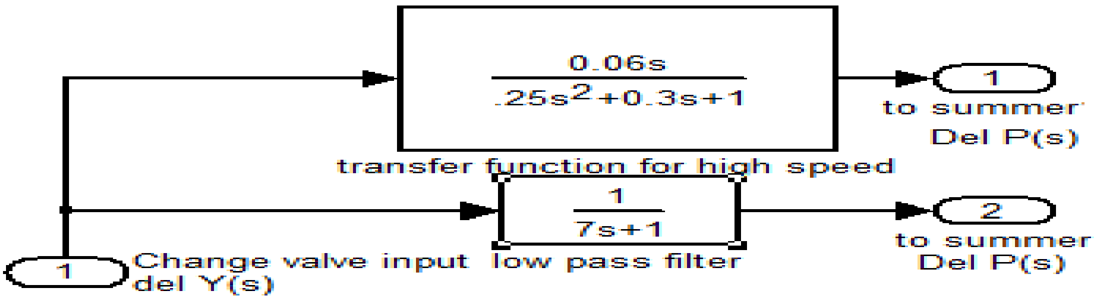


Figure 4.Wind turbine generator used as deregulated system

V. WTG AS LINEAR FUNCTION IN TIE LINE

The output of wind turbine generator depends on the wind speed at that instant. The wind turbine system contains several nonlinearities. When a wind turbine uses its pitch controller to counteract utility grid frequency oscillations, its output power varies between maximum, or rated power, and zero power. In general, a necessary condition for a linear system can be determined in terms of an excitation $x(t)$ and a response $y(t)$. Suppose that the system at rest is subjected to an excitation $x1(t)$ and the result is a response $y1(t)$. Also suppose that when subjected to an excitation $y1(t)$ the result is a corresponding response $y2(t)$. For a linear system it is necessary that the excitation $x1(t) + x2(t)$ results in a response $y1(t)+ y2(t)$. This is usually called the principle of superposition. Thus the wind turbine can be simplified to a first order system. The transfer function of the WTG and generator is represented by a first-order lag [11] as

Gt(s) = 1/(1+sWt)

Gg(s) = 1/(1+sWg)

The transfer function of two area interconnected system using HVDC and fuzzy controller is shown in figure 5.

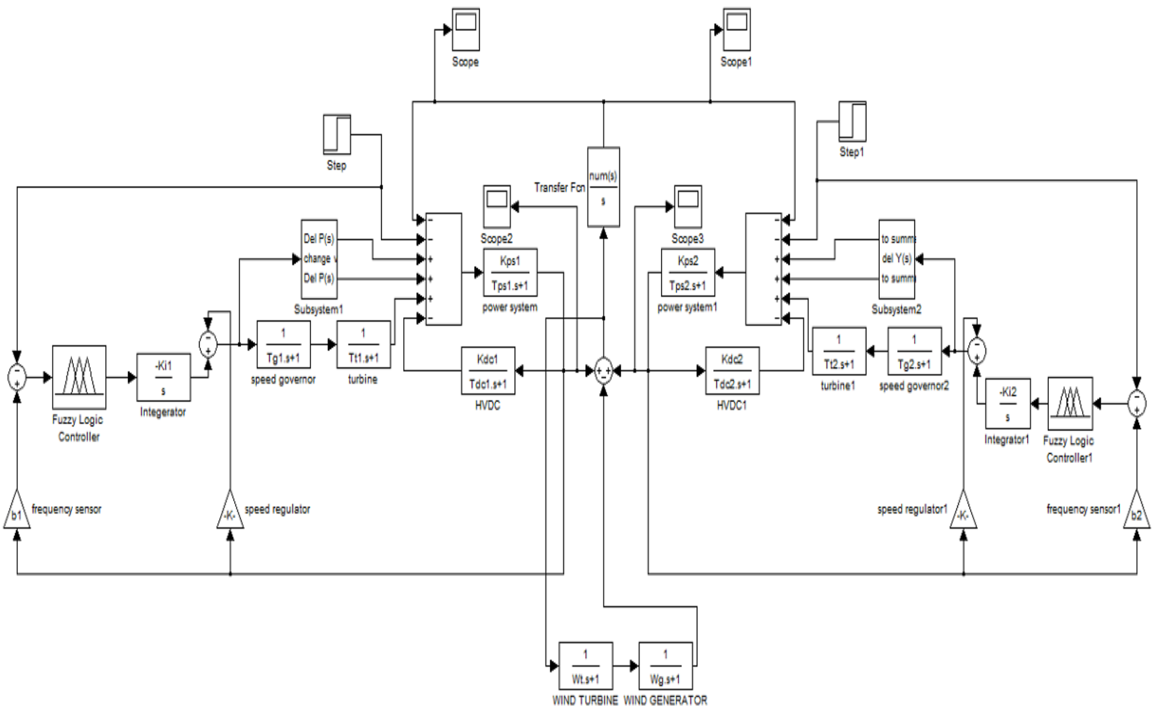
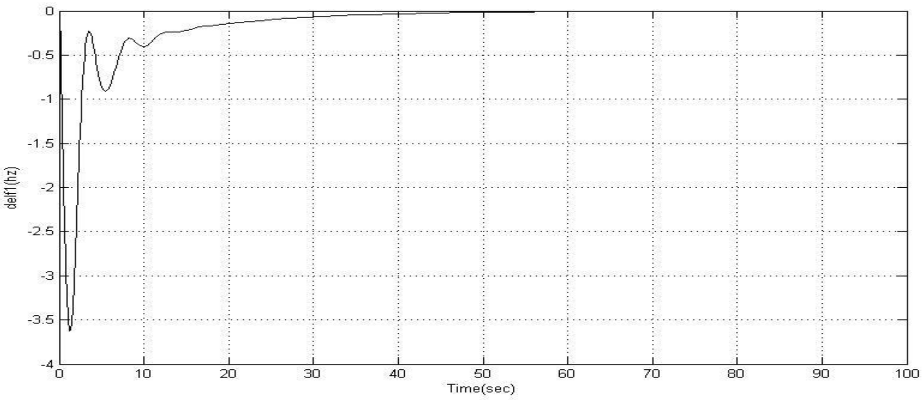


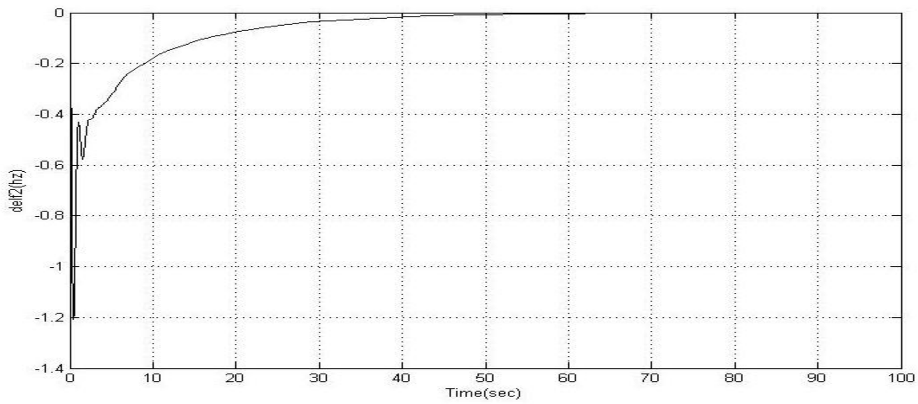
Figure5- Two area interconnected system using HVDC and Fuzzy controller

V. SIMULATION RESULTS

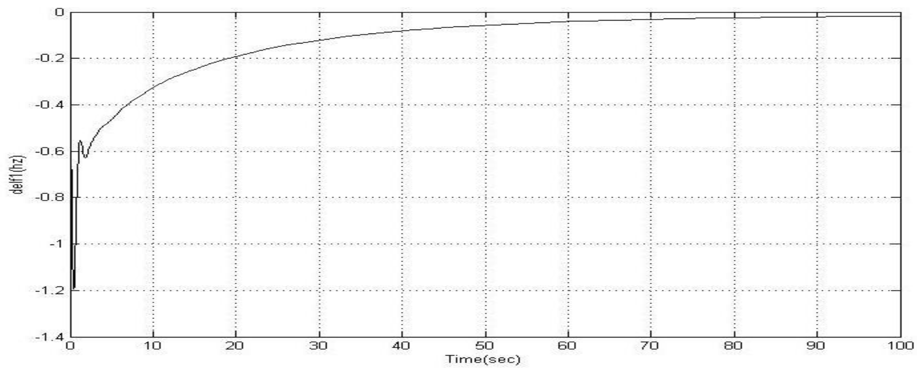
In this paper, a fuzzy logic based proportional integral (pi) controller has been designed and applied to analyze the effect of HVDC link on the AGC of two area interconnected power system. The implementation worked with Matlab-Simulink software. The response plots for variables like frequency deviations in area 1 to area 2 and tie line power deviations for power system model with and without HVDC link and wind turbine system, in the wake of load disturbance of 1% in area 1 are obtained with the implementation of Fuzzy logic controller to analyze the system dynamic performance. Figure 6 shows the frequency deviation responses and Figure 7 shows some tie line power deviation responses .The simulation results of frequency deviations and tie line power deviation with fuzzy controller advocates, the HVDC link's suitability for AGC schemes.



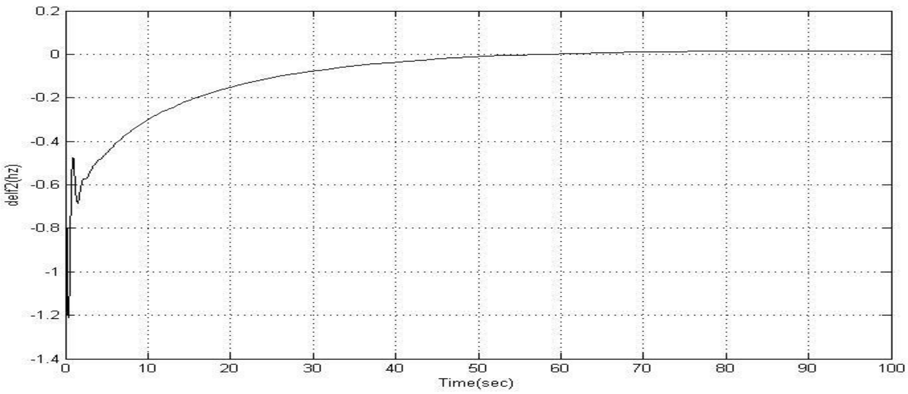
(I) ΔF1(s) vs. time(s) of the power Subsystem1 model with Fuzzy Conroller only



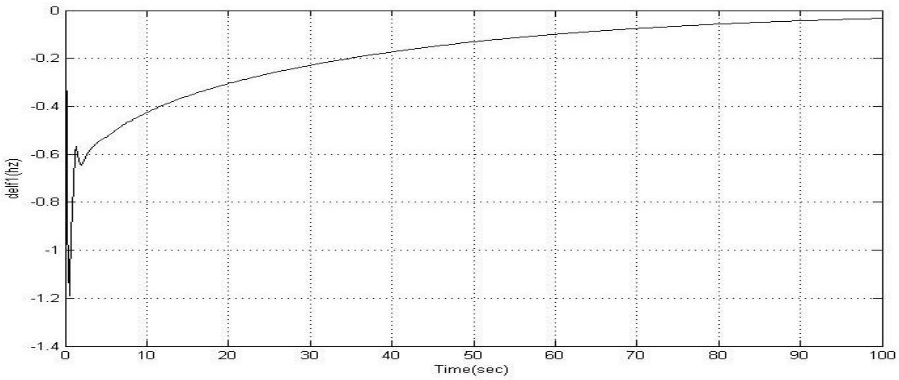
(ii) ΔF2(s) vs. time(s) of the power Subsystem2 model with Fuzzy Controller only



(iii) ΔF1(s) vs. time(s) of the power Subsystem1 model with Fuzzy Controller and HVDC link

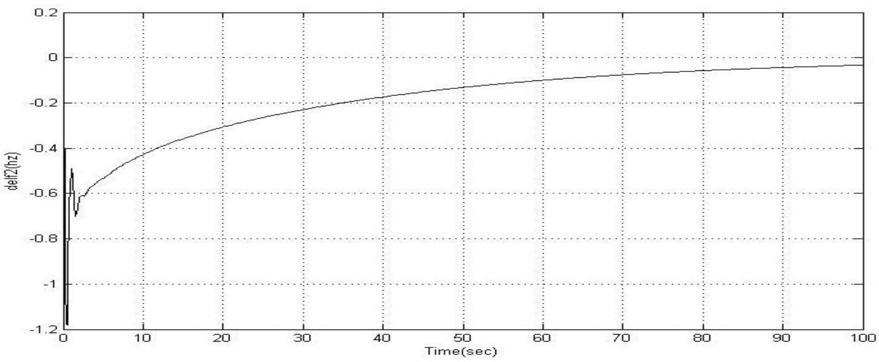


(iv) ΔF2(s) vs. time(s) of the power Subsystem2 model with Fuzzy Controller And HVDC

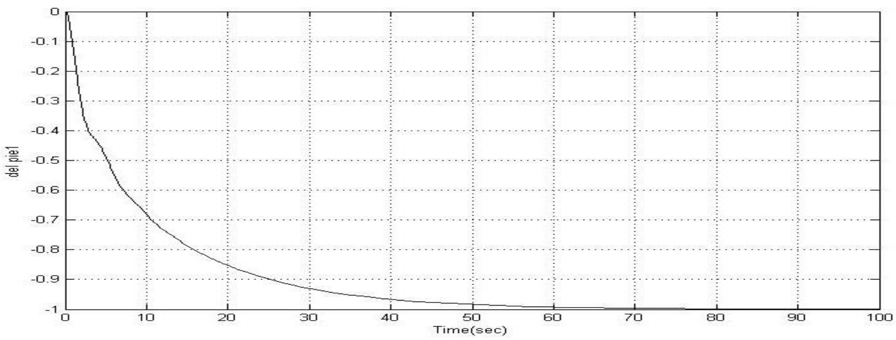


(v) ΔF1(s) vs. time(s) of the power Subsystem1 model with Fuzzy Controller, HVDC and WTG

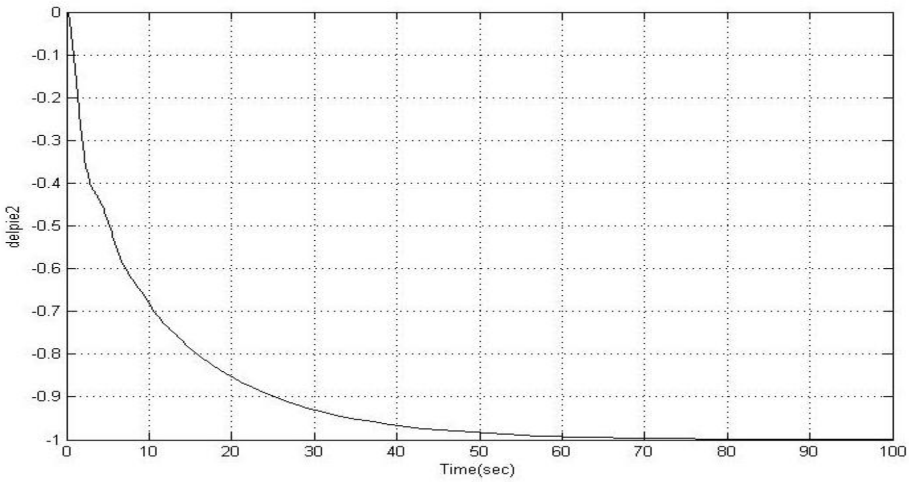
Figure6- Frequency Comparison



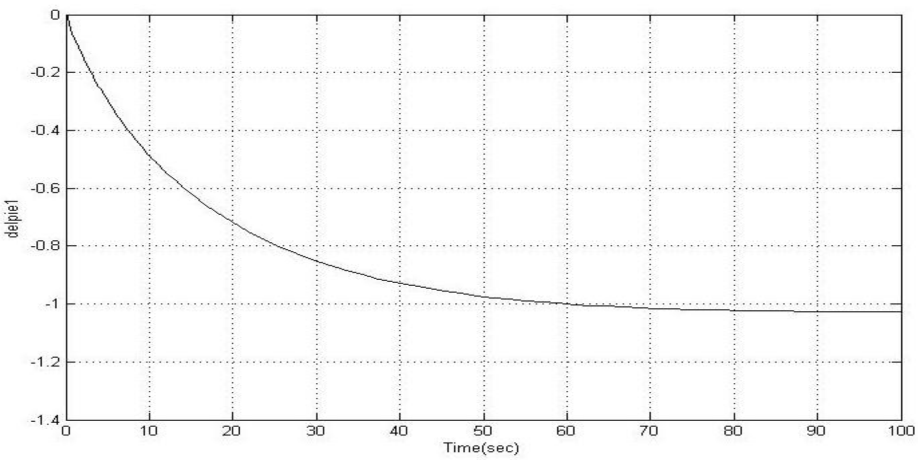
(vi) ΔF1(s) vs. time(s) of the power Subsystem2 model with Fuzzy Controller, HVDC and WTG



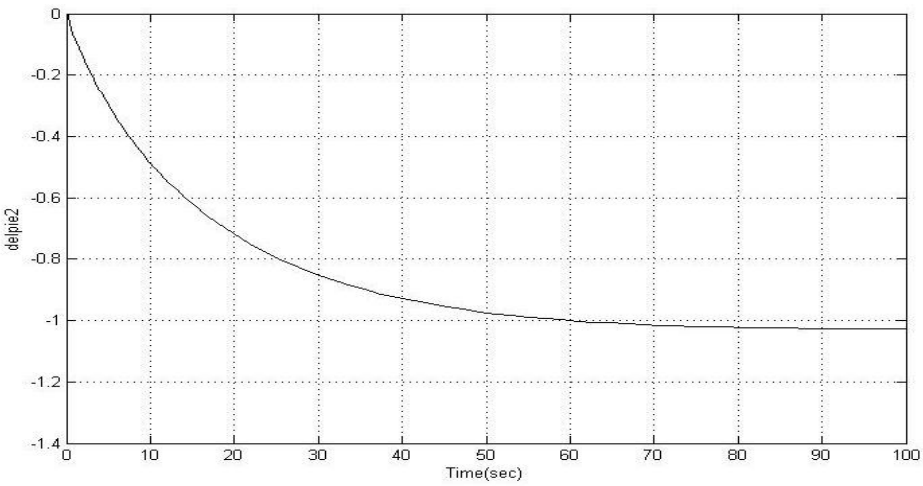
(i) Tie Line Power Deviation of area 1 With Fuzzy Controller only



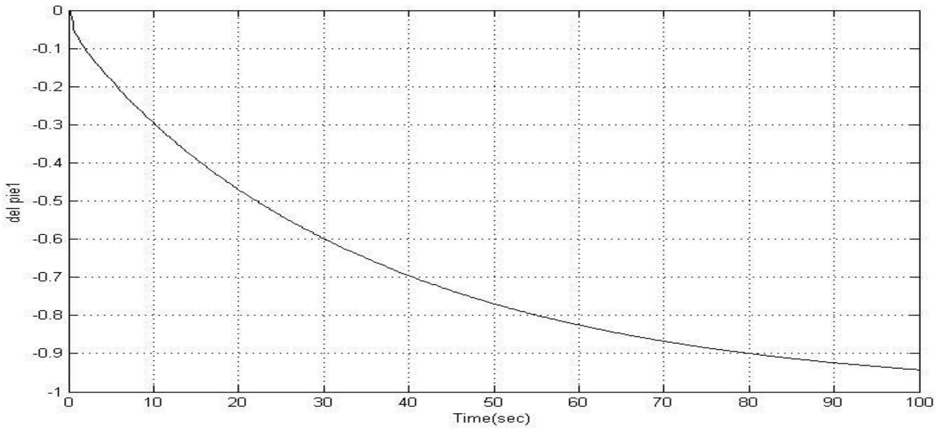
(ii) Tie Line Power Deviation of area 2 With Fuzzy Controller only



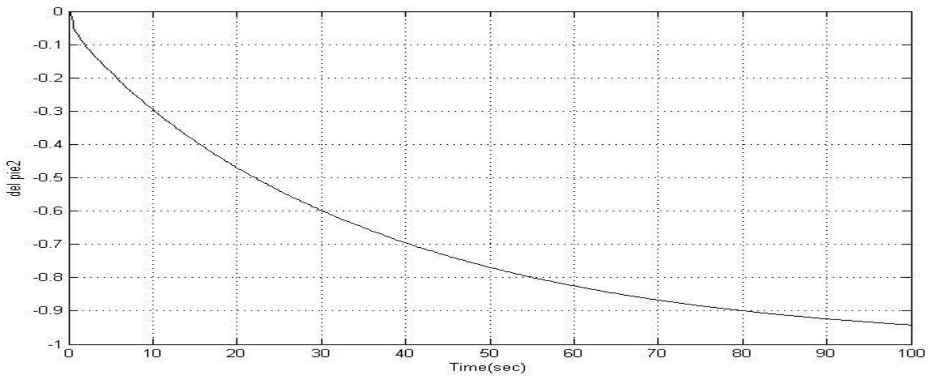
(iii) Tie Line Power Deviation of area1 With Fuzzy Controller and HVDC



(iv) Tie Line Power Deviation of Area2 with Fuzzy Controller and HVDC



(v) Tie Line Power Deviation of area 1 with Fuzzy Controller, HVDC and WTG



(vi) Tie Line Power Deviation of area2 with Fuzzy Controller, HVDC and WTG

Figure7. Tie Line deviation

VI. CONCLUSION

In this paper, a new power system model is proposed to improve the dynamic performance of interconnected two area power system by the use of HVDC link in parallel with existing HVAC link. The system dynamic performance in the wake of load disturbance in either area of interconnected power system has been investigated comprehensively. A fuzzy logic control strategy is designed and its feasibility is studied by varying system parameters. It has been observed that responses of the system with parallel HVDC link and WTG are better in terms of dynamic parameters such as peak overshoot and settling time. Simulation results presented justify the incorporation of HVDC transmission link to supply consumers reliable and quality power.

APPENDIX

Nominal parameters of the two area system investigated:

Ki1=Ki2=0.09
Tg1=0.08
Tg2=0.04
Tt1=0.5
Tt2=0.3
Tdc1=Tdc2=0.2
Kps1=100
Kps2=120
Wt=1.5
Wg=0.5
Num(s) =0.05
B1=B2=0.42
K=0.33

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