Grid Stability of Interconnected System with Fuzzy-logic controller & HVDC in Deregulated Environment

Mukta, Balwinder Singh Surjan

Abstract This paper investigates the effects of integral controller, fuzzy controller,HVDC on an interconnected two area power system in a deregulated environment. The system is simulated using Matlab-Simulink along with controllers. The frequency deviation responses are studied using Matlab-simulink. Robustness of the controller is thus checked and we get a new proposed system with better results i.e. lesser deviation for reliable and quality power supply.

Index Terms— Frequency Control, Interconnected Power System, Integral Controller, Fuzzy logic Controller,HVDC, Deregulated Environment, Wind Turbine Generator

I. INTRODUCTION

Frequency Control 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. An interconnected power system consists of interconnected control areas. When load changes or abnormal conditions occur like outages of generation and varying system parameters, mismatches in frequency can be caused. These mismatches can be corrected by controlling the frequency. Automatic Generation Control is used to maintain the schedule system frequency [1][2-4].. Next importance is given to the use of High Voltage DC transmission (HVDC) [1] 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. 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. Practically system parameters vary considerably with changing operating conditions. Intelligent controllers can be employed to solve this problem. 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 [5-6]. 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[7-9].

The power system is modelled and simulated using MATLAB simulink environment. Then the frequency deviation has been studied and presented with and without integral controller, fuzzy controller, HVDC and WTG.

II. SYSTEM MODELLING: SINGLE AREA POWER SYSTEM

A single area power system is used as the basic system comprising of power system block representing the generation transmission, prime-mover and its control. The load variation has been simulated as step change. The transfer function model has been built using MATLAB simulink [10]. The system component blocks used in transfer function model are simplified from the differential equations of the system [2-4]. The whole functions are used in s domain only.

The different transfer functions used are speed governor, turbine and power system function.

$$\text{Speed Governor Transfer Function} = \frac{1}{1+sT_{sg}} \tag{1}$$

$$\text{Turbine Transfer Function} = \frac{1}{1+sT_t} \tag{2}$$

$$\text{Power System Transfer Function} = \frac{K_P}{1+sT_P} \tag{3}$$

$$\text{Speed Regulation} = \frac{1}{R} \tag{4}$$

With integral action, the controller output is proportional to the amount of time the error is present. Integral action eliminates offset [7].

$$X_I = -\,k_I\,\Sigma(Er\ dt) \tag{5}$$

Where

X_I = output integrating controller
k_I = integrating gain or action factor of the controller
dt = time sample

The integral controller produces an output proportional with the summarized deviation between the set point and measured value and integrating gain or action factor. Integral controllers tend to respond slowly at first, but over a long period of time they tend to eliminate errors. The integral controller eliminates the steady-state error.

The frequency deviation ΔF is studied using MATLAB simulink as shown in Fig.1.

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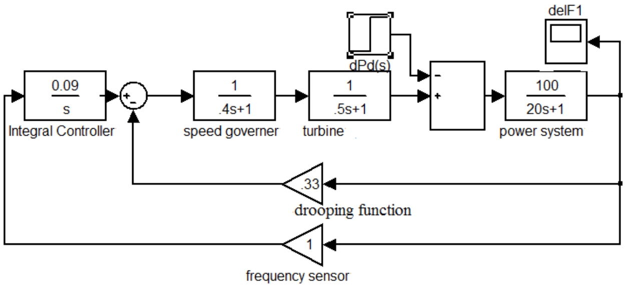

Fig. 1 Single Area Power System using Integral control

III. INTERCONNECTED POWER SYSTEM

Electricity grid interconnections have played a key role in the history of electric power systems. As power systems expanded out from their urban cores, interconnections among neighbouring systems became increasingly common. Groups of utilities began to form power pools, allowing them to trade electricity and share capacity reserves. The large synchronous alternating current (AC) power grids of all the interconnected systems maintain the same precise electrical frequency [1][11]. The Interconnection shown in our model is shown in Fig. 2 with each subsystem consisting of single phase system shown in Fig.1.

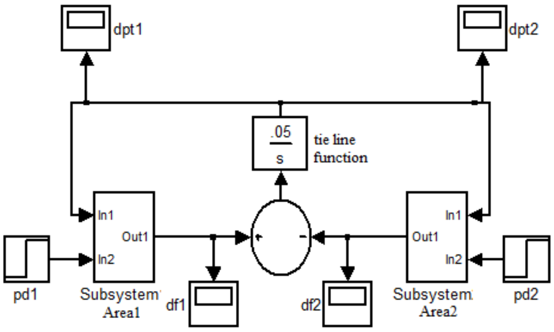

Fig. 2 Interconnected Two Area Power System

IV. WIND TURBINE GENERATOR DEREGULATED SYSTEM

By investigating the dynamic behaviour of wind power generators, more insight is obtained concerning the ability of a wind farm to provide frequency control. It is independent on any other power system and it is working as a deregulated system here. A WTG is designed using the system parameters given [8]. The two transfer functions are used here for low pass filter and for high wind speed. This time constant depends on the average wind speed, but is assumed constant for this simplified model.

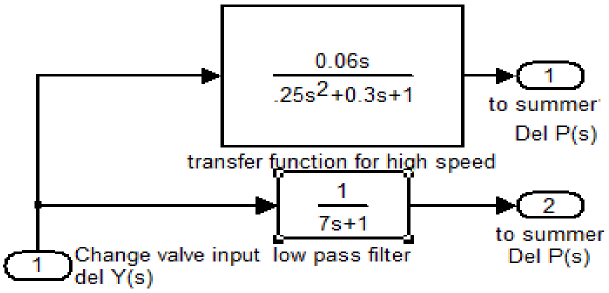

Fig. 3 Transfer Function of WTG

Now the system model is combined with WTG as shown in Fig. 5 then scope is used for response ΔF(s) Vs t(s). Then it is implemented to two area interconnected system.

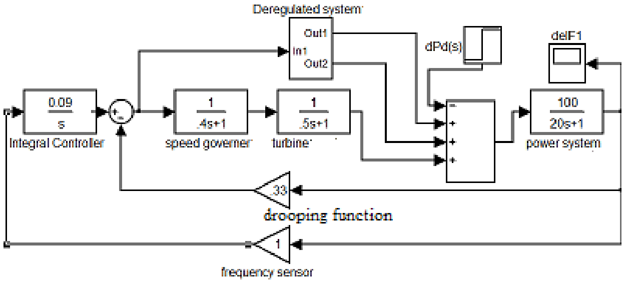

Fig. 4 Single Area Power System with WTG & Integral Controller

V. FUZZY CONTROLLER

The inherent characteristics of the changing loads, complexity and multi-variable conditions of the power system limits the conventional control methods giving 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 control is based on a logical system called fuzzy logic which is much closer in spirit to human thinking and natural language than classical logical systems. Nowadays fuzzy logic is used in almost all sectors of industry and science. One of them is AGC. The fuzzy logic controller designed for the system analysis is shown in Fig 6[1].

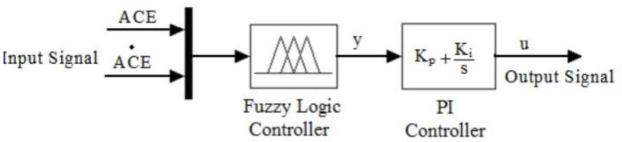

Fig. 5 Fuzzy Logic Controller

The fuzzy logic controller is comprised of four main components [1]: the fuzzification, the inference engine, the rule base, and the defuzzification. The various components are present for the detailed study of the system. 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.

The control signal is given by[6]

$$u(t) = -(K_p y + K_i \int y \, dt) \tag{6}$$

K_p and K_i are the proportional and the integral gains respectively and taken equal to one. For the proposed study, Mamdani fuzzy inference engine is selected and the centroid method is used in defuzzification process.

Table I. Rules for the fuzzy logic controller [1]

		$A\dot{C}E$						
		LN	MN	SN	Z	SP	MP	LP
ACE	LN	LP	LP	LP	MP	MP	SP	Z
	MN	LP	MP	MP	MP	SP	Z	SN
	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

LN: large negative,

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

Fuzzy logic shows experience and preference through membership functions which have different shapes. These rules are obtained based on experiments of the process step response, error signal, and its time derivative [1]. The membership functions of the fuzzy logic pi controller presented in Fig.7 consist of three memberships functions (two-inputs and one-output) [1]. Each membership function has seven memberships comprising two trapezoidal and five triangular memberships.

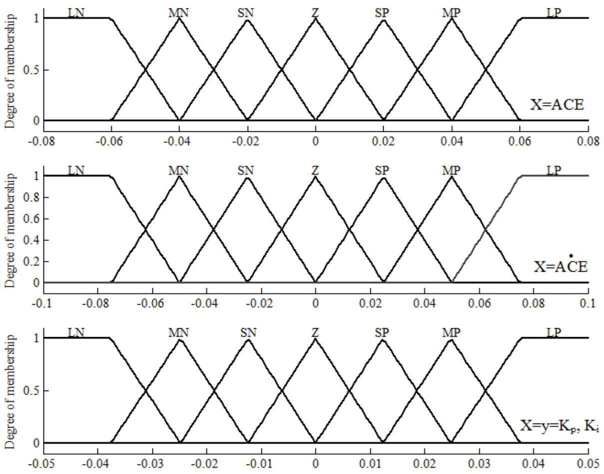

Fig. 6 Membership functions used in the study

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. 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 built from the if-then statement (i.e. if input 1 and input 2 then output 1). Table I taken from [1], 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 $A\dot{C}E$ is SP then y is SN.

The System is now modelled with Fuzzy Controller as shown in Fig. 8, 9. Then implemented to two area interconnected system.

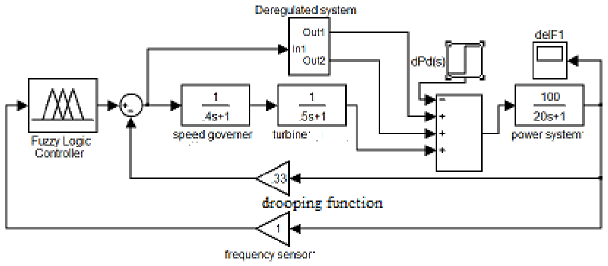

Fig. 7 Single Area Power System with Fuzzy Controller and WTG

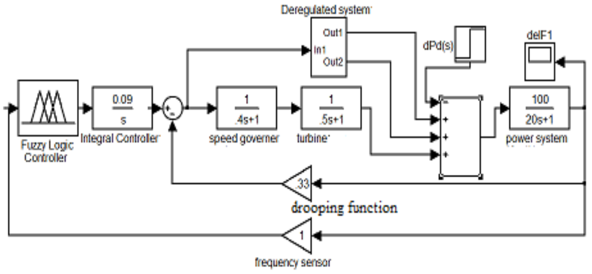

Fig. 8 Single Area Power System with Fuzzy Controller, Integral Controller and WTG

VI. HIGH VOLTAGE DC TRANSMISSION

One of the great engineering achievements of the last century has been the evolution of large synchronous alternating current (AC) power grids, in which all the interconnected systems maintain the same precise electrical frequency. The use of HVDC interconnections is also rapidly expanding as a result of technical progress over the last two decades. HVDC permits the asynchronous interconnection of networks that operate at different frequencies, or are otherwise incompatible, allowing them to exchange power without requiring the tight coordination of a synchronous network. HVDC has other advantages as well, especially for transmitting large amounts of power over very long distances. A two area interconnected system is presented in the Fig.10 connected via HVAC tie line in parallel with HVDC link [1][12].

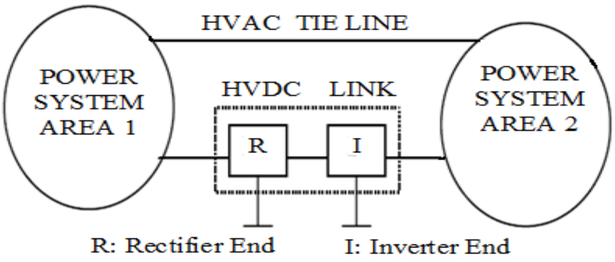

Fig. 9 Single line diagram of two area power system with parallel HVAC/HVDC links

The linearized model of a two-area interconnected system including the dynamic of power modulation controller of HVDC link is shown through equation [12]. It should be noted that the power modulation output of HVDC link (ΔP_{DC}), acting positively on an area, reacts negatively on another area in an interconnected system.

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ΔP_{DC}, therefore, flows into both areas with different sign (+, -), simultaneously. The time constant T_{DC} of proportional controller is set appropriately at 0.05 sec in the simulation study [12]. The matrix used for stimulation study is [12]

$$S : \begin{bmatrix} \Delta \dot{f}_1 \\ \Delta \dot{P}_{AC} \\ \Delta \dot{f}_2 \end{bmatrix} = \begin{bmatrix} -D_1/M_1 & -1/M_1 & 0 \\ 2\pi T_{12} & 0 & -2\pi T_{12} \\ 0 & A_{12}/M_2 & -D_2/M_2 \end{bmatrix} \begin{bmatrix} \Delta f_1 \\ \Delta P_{AC} \\ \Delta f_2 \end{bmatrix} + \begin{bmatrix} -1/M_1 \\ 0 \\ A_{12}/M_2 \end{bmatrix} \Delta P_{DC} \tag{7}$$

where S is the system matrix [12-13]. The variables and parameters are defined as follows:Δf_1, Δf_2 are frequency deviations of areas 1 and 2 respectively. ΔP_{AC} is an AC tie line power deviation between areas 1 and 2. ΔP_{DC} is a power modulation by HVDC link. ΔP_{12} is the total tie line power deviations (ΔP_{AC} + ΔP_{DC}). M_1, M_2 are inertia constants of areas 1 and 2. D_1, D_2 are damping coefficients of areas 1 and 2. A_{12} is an area capacity ratio between areas 1 and 2. Then system decoupled into two systems and for one system values are expressed in terms of matrix as[13]

$$\begin{bmatrix} \Delta \dot{f}_1 \\ \Delta \dot{P}_{AC} \end{bmatrix} = \begin{bmatrix} -D_1/M_1 & -1/M_1 \\ 2\pi T_{12} & 0 \end{bmatrix} \begin{bmatrix} \Delta f_1 \\ \Delta P_{AC} \end{bmatrix} + \begin{bmatrix} -1/M_1 \\ 0 \end{bmatrix} \Delta P_{DC} \tag{8}$$

By eigen value assignment method, the feedback control scheme of ΔPDC can be expressed as [13].

$$\Delta f_1 = -k_{\Delta f_1} \Delta f_1 - k_{\Delta P_{AC}} \Delta P_{AC} \tag{9}$$

The values of constants are taken from reference [1] and [13]. The HVDC system block is designed in MATLAB using the values of gain and time constant and is inserted in the subsystems as shown in Fig.11.

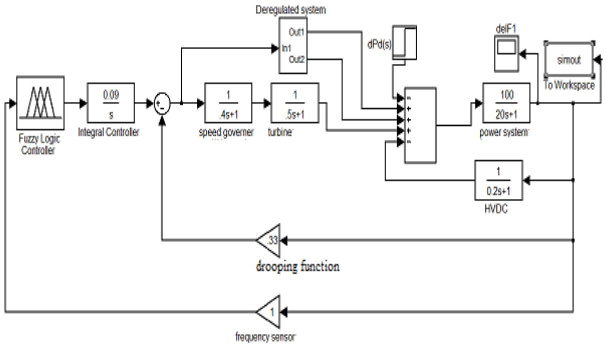

Fig.10 Subsystem block with HVDC, Integral Controller, Fuzzy Controller and WTG

VII. SYSTEM DATA [4, 13]

Two area and wind turbine generator data used for the system study in this paper has been given in Table II and III :

Table II Parameters of Subsystems1

Parameters of Area 1&2		
K_{P1} K_{P2}	Power System Gain	100
T_{P1} T_{P2}	Power System Time Constant	20
$K_{sg1}K_{sg2}$	Governor Gain	1
T_{sg1} T_{sg2}	Governor Time Constant	0.4
K_{t1} K_{t2}	Turbine Gain	1
T_{t1} T_{t2}	Turbine Time Constant	0.5
R_1R_2	Speed regulation Droop	3
B_1 B_2	Frequency Sensor Gain	0.425
K_{i1} K_{i2}	Integral Controller Gain	0.09
K_{dc1} K_{dc2}	HVDC System Gain	1
T_{dc1} T_{dc2}	HVDC Time Constant	0.2

Table III Parameters of Wind Turbine Generators [3]

Parameter	
T_{low1}, T_{low2}	7.0 sec
T_{O1}, T_{O2}	0.5 sec
D_1 D_2	0.3
K_{high1}, K_{high2}	0.006

VIII. SIMULATION RESULTS

In this paper, a deregulated WTG has been used along with integral, fuzzy logic controller and HVDC link to control the load frequency of the power system. The implementation worked with Matlab-Simulink software with simulation time 50 sec. The values of system parameters as explained above are used for all simulations to facilitate a comparative study.

The frequency deviation plot vs. time for subsystems model is studied. First case is without any controller,HVDC and WTG. Then these are used one by one and simultaneously to obtain frequency deviation plot with 1% disturbance in load. The simulation results show that the settling time, steady state error and peak overshoot is reduced using WTG , integral and fuzzy controller alone and the different combination of these show even better results as shown in Figs.

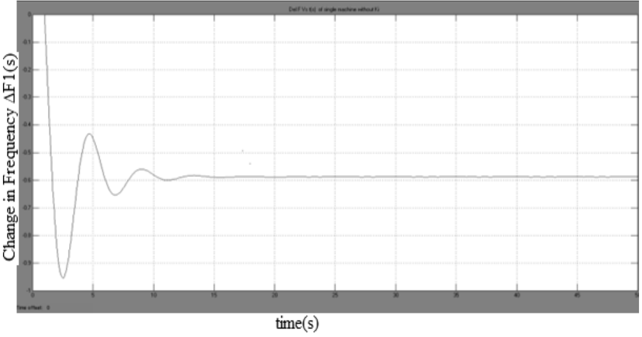

Fig.11: ΔF1(s) vs. time(s) of subsystem1

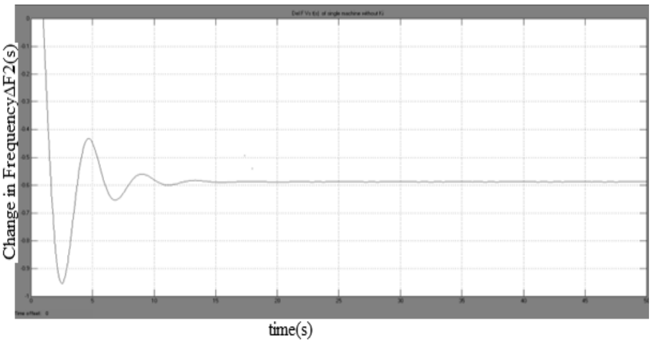

Fig.12: ΔF2(s) vs. time(s) of subsystem2

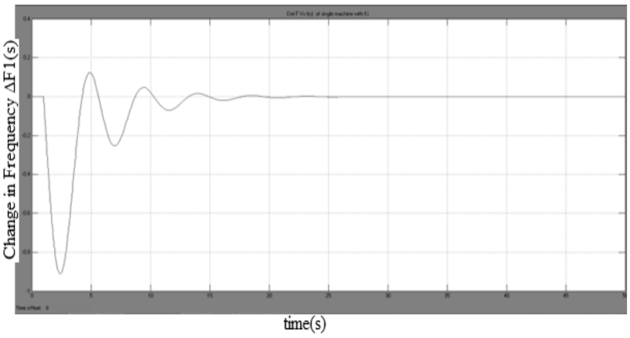

Fig.13 ΔF1(s) vs. time(s) of the subsystem1 model with integral controller

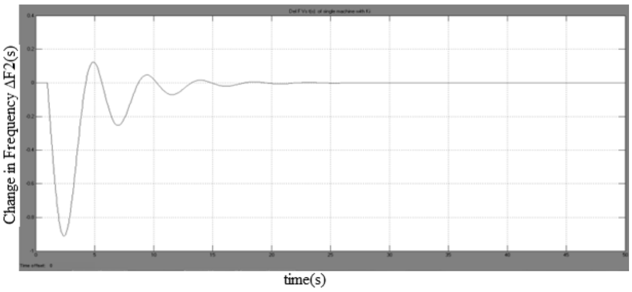

Fig.14 ΔF2(s) vs. time(s) of the subsystem2 model with integral controller

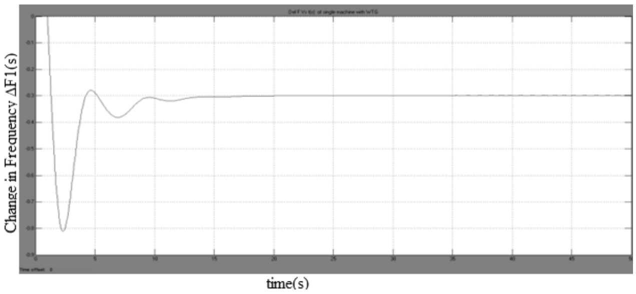

Fig.15 ΔF1(s) vs. time(s) of the subsystem1 model with WTG

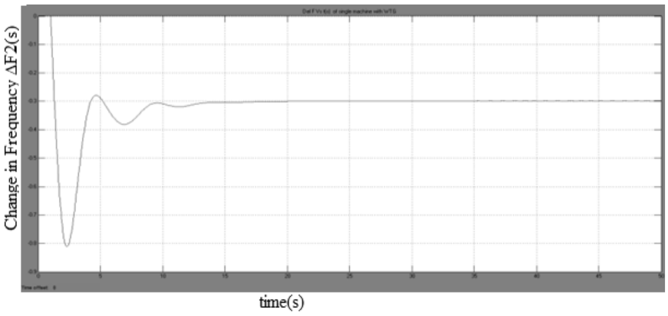

Fig.16 ΔF2(s) vs. time(s) of the subsystem2 model with WTG

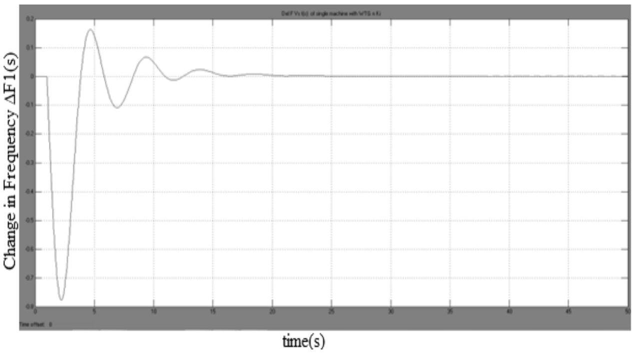

Fig.17 ΔF1(s) vs. time(s) of subsystem1 model with integral controller &WTG

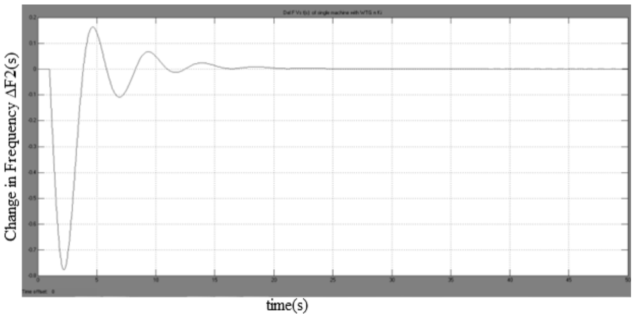

Fig.18 ΔF2(s) vs. time(s) of subsystem2 model with integral controller &WTG

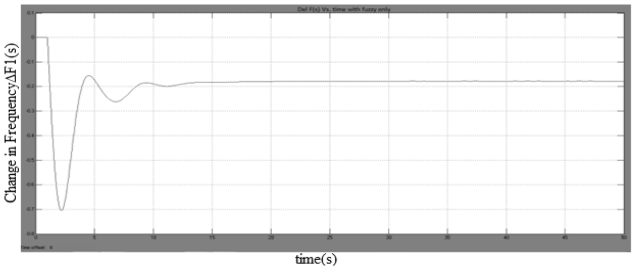

Fig.19 ΔF1(s) vs. time(s) of the power subsystem1 model with Fuzzy only

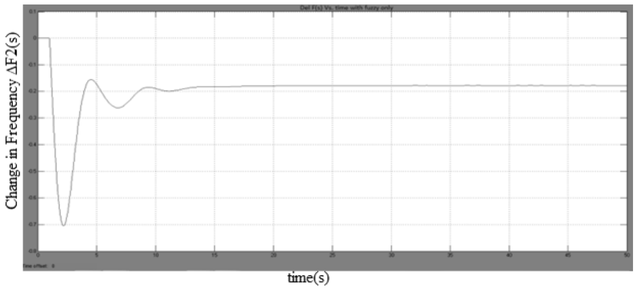

Fig.20 ΔF2(s) vs. time(s) of the power subsystem2 model with Fuzzy only

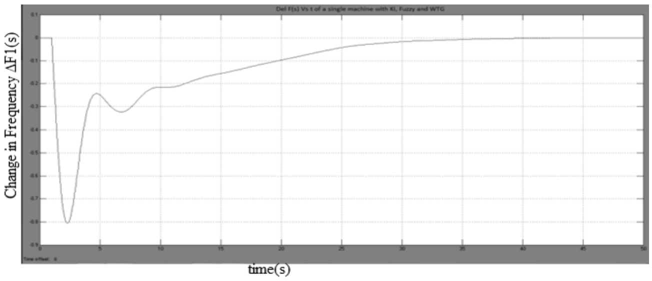

Fig.21 ΔF1(s) vs time(s) of subsystem1 model with integral controller and Fuzzy controller

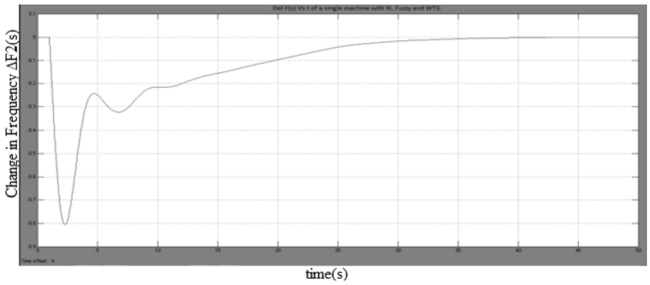

Fig.22 ΔF2(s) vs time(s) of subsystem 2 model with integral controller and Fuzzy controller

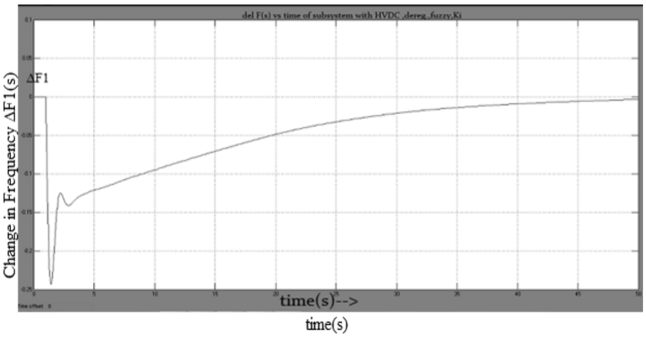

Fig.23 ΔF1(s) vs time(s) of subsystem 2 model with integral controller and Fuzzy controller and HVDC

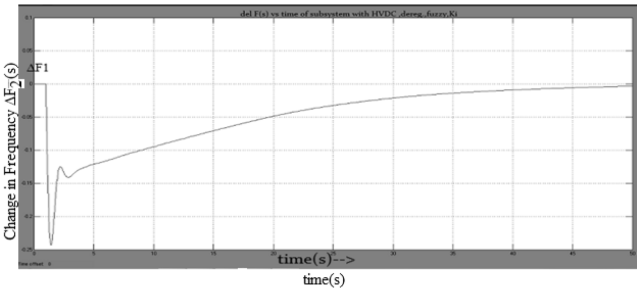

Fig.24 ΔF2(s) vs time(s) of subsystem 2 model with integral controller and Fuzzy controller and HVDC

IX. CONCLUSIONS

The system with the Fuzzy controller and HVDC proposed to improve the dynamic performance of the interconnected two area power system in deregulated environment has been studied. Fuzzy controller, WTG and HVDC have been coordinated for feasibility study by implementing it to the interconnected two area system, which can be employed for multi-area problems. It has been observed that responses of frequency deviation with Fuzzy Controller and WTG are better in terms of steady state error, settling time, transients. Simulation results presented justify the use of Fuzzy Controller in deregulated environment for the supply of reliable and quality power

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