Load Frequency Control of a Wind Integrated Power System using Conventional PID & Fuzzy PID Controller

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***Abstract -** In this area of energy crisis, renewable energy is the most promising solution to man's ever-increasing energy needs. But the power production by these sources cannot be controlled unlike in thermal plants. As a result, standalone operation of renewable energy is not reliable. Hence grid connection of these along with conventional plant is preferred due to the improved performance in response to dynamic load. It is observed that the fluctuations in frequency caused due to the load variations are low with increase in penetration of renewable sources. Load frequency control (LFC) including PID and FPID controllers are proposed in order to supress frequency deviation for a power system including wind, thermal and hydro plants owing to load and generating power fluctuations caused by the penetration of renewable sources. A system of four area, with each area consisting a wind, a hydro and two thermal plants is modelled giving step load perturbation (SLP) 1% in all areas using MATLAB /SIMULINK. Furthermore, a HVDC link is also connected parallel to AC line to improve dynamic response. From the simulation results it is observed that, system including renewable sources gives better dynamic response with FPID controller compared to a conventional sources system.*

Keywords: Load Frequency Control (LFC), Proportional-Integral-Derivative(PID) Controller, Fuzzy-PID (FPID) Controller, Membership Function, Tie line Power deviation

1. INTRODUCTION

A modern power system is complex and sophisticated with multi area and diverse source of power generation. The control of electric energy with nominal system frequency and tie line power interchange within prescribed limits are very much important. The load frequency control play important role in power pool by maintaining scheduled system frequency and scheduled tie line power in normal operation and during small perturbation.

In a four-area system if any change of power occur in one area, is met by the increase in generating power in other three areas that are interconnected with that system. A multi area system consists of two or more single area systems, connected through a power called tie line. Among all the four areas, each control area can be represented by an equivalent generator, turbine and governor system. The area control error as the controlled output of LFC is driven to zero in order to make the frequency and the tie line power deviations of control areas to zeros [1]. The environmental drive to promote green energy invites new renewable sources of power generation and their corresponding participation factor are more important for the study of LFC.

There is an evolution of intelligent techniques in recent years. Almost all new algorithms report better results than the previous ones in different engineering fields. Some algorithms give a better solution for some particular problems than others do. The intelligent controllers such as Particle Swarm Optimization based PID controller [1], Differential Evolution Algorithm based PID controller [2], Differential Evolution Particle Swarm Optimization based PID controller [3], Firefly optimized PID [4], Teaching Learning Based Optimization (TLBO) optimized PID [5].

The growth in size and complexity of electric power system due to nonlinear load characteristics and variable operating points has necessitated the use of fuzzy based methods to address satisfactorily the performance under small perturbations. A jaya algorithm optimized fuzzy pi controller [6], Adaptive Neuro Fuzzy Interface System controller containing SMES-TCPS [7], a Firefly algorithm (FA) optimized fuzzy PID controller [8], Fuzzy gain scheduled PI controller [9].

It has been observed in literature survey that most of the researchers adopt thermal-thermal or thermal hydro systems in LFC studies. The bulk power transmission through HVDC lines connected with AC lines possesses many advantages like fast controllability of HVDC lines through convertor control, ability to reduce the transient stability problem of AC lines and other economical and technical operation of power system.

The authors have proposed a FPID controller for load frequency control of the present scenario of a realistic power system with four areas having multi sources of power generation including renewable generation source. Moreover, the proposed FPID controller is easily implemented. The main investigations of the present work:

To propose an FPID controller for the load frequency control of realistic power system including renewable energy source.

(i) To compare the dynamic performance of FPID controller for multi area power system with PID controller between control areas with 1% step load perturbation in all areas.

(ii)To compare the dynamic performance of power system including renewable source with conventional power system.

This paper is organised in five sections; the 1st section is the introduction part which is explained above. In section 2nd system investigation is done. Section 3rd describes control methodology for stabilization of frequency power systems. Section 4th is devoted to the simulation models and simulation results. Conclusion is derived in section 5th.

2. SYSTEM INVESTIGATION

In real practice the system of a single generator that feeds a large and complex area has rarely occurred. Several generators connected in parallel may be at a single location or at a different location to meet the load demand of such a large area. Large load areas are divided into several small areas and load demand is met accordingly by interconnected power systems. The aim of the control system now is to regulate the tie line power of the system at same instants as per intra area power contracts.

The two identical area power system interconnected by parallel AC-DC tie lines [10-13] which comprises more practical combination of generating units such as reheat thermal, hydro and gas units in each area. In the present study four equal areas of power system, one area having thermal, hydro and wind power plants participating in LFC is simulated by the proposed FPID controller using MATLAB Simulink. A dc link is also connected in the power system to improve the dynamic response of the system. For, the sake of simplicity only one area is shown in simulink model. Furthermore, the generators in each area may or may not participate in the LFC task and the participation rates are not same for all participating generators. The summation of participation factor of all participating generators is equal to unity in each control area. The nominal parameters of the power system are given in Appendix.

3. CONTROL METHODOLOGY

3.1 PID Controller

PID controller is a closed loop feedback mechanism widely used in industrial control systems. The PID controller involves three separate parameters, namely proportional, integral and derivative gain values. The proportional parameter action determines the reaction based on the current error the integral action determines the reaction based on the sum of recent errors and derivative action determines the reaction based on the rate at which the error has been changing, and the weighted sum of these three actions is used to adjust the process via the final control element.

The transfer Function of a PID controller has the following form:

$$G_c(s) = K_p + \frac{K_i}{s} + K_d s$$

Where K_p, K_i, and K_d are the proportional, integral, and derivative gains, respectively.

The objective of any controller of load frequency is to produce a controlling signal which keeps the frequency of given system constant and power exchange between control areas at predetermined values. The area control error (ACE) is input to the PID controller.[14] The ACE signal includes the data about frequency error and tie line power error for the related control area. In this control, ACE_1 , ACE_2, ACE_3 and ACE_4 are made linear combination of frequency and tie line power error[15]. They may be represented for areas,

$$ACE_1 = \Delta P_{12} + B_1 \Delta F_1$$

$$ACE_2 = \Delta P_{23} + B_2 \Delta F_2$$

$$ACE_3 = \Delta P_{34} + B_3 \Delta F_3$$

$$ACE_4 = \Delta P_{41} + B_4 \Delta F_4$$

3.2 FPID Controller

Fuzzy gain scheduling is a procedure normally used for making controllers for power system's dynamic output varies nonlinearly with the operating parameters of the system. It is generally applied when the variation between the system dynamics and operating parameters are given, and for which a linear time-invariant model is not enough [16]. Nowadays, gain scheduling is performed according to the step frequency deviation response of the model for various values of the integral gain. A large value of integral gain reduces the maximum overshoot value of the system frequency but the value of integral gain yield higher maximum frequency deviation in the starting but then delivers effective damping after few cycles, this shows the importance of a variable integral gain, hence large values of integral gain are planned at the beginning and then varied gradually based on the system frequency variations. Here we use this methodology to control the performance parameters of the FPID controller according to the change of the new area control error (ACE) and the change in the area control error ΔACE[17].

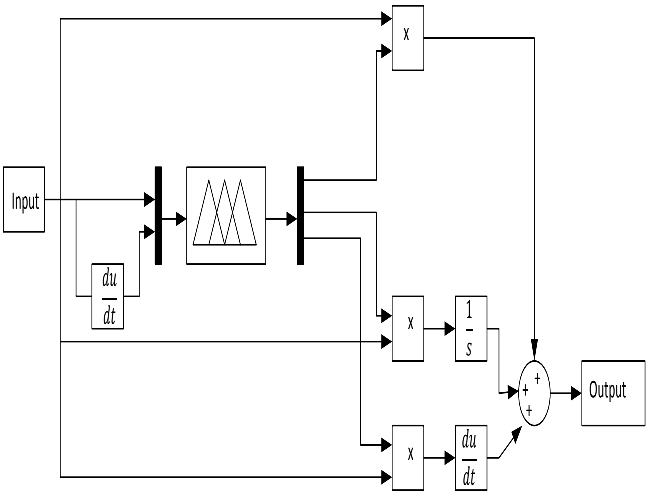
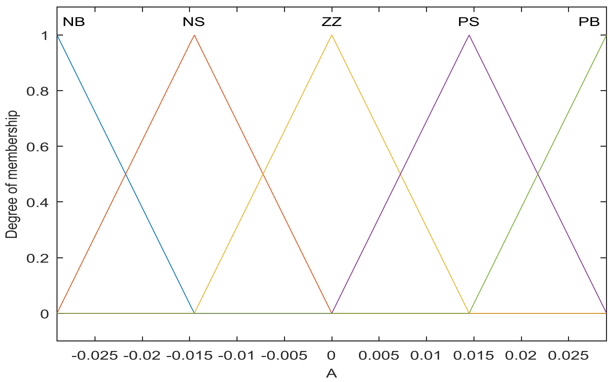
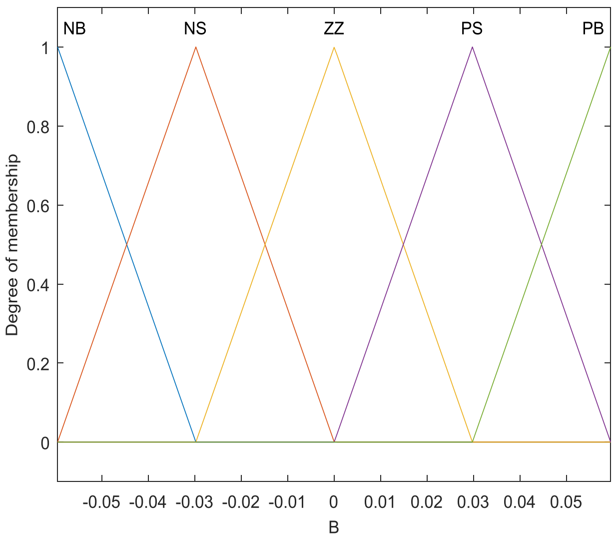


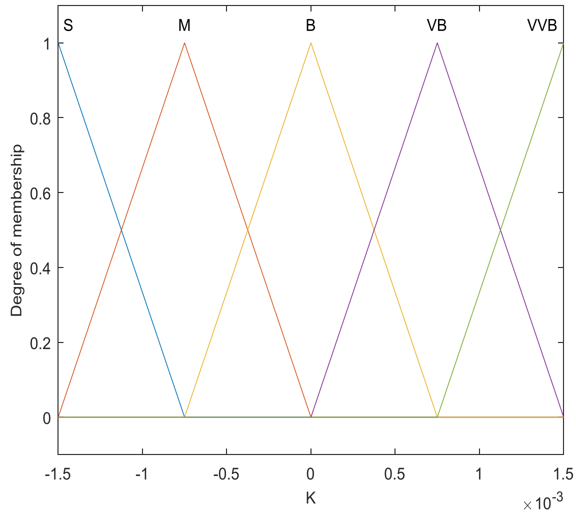
Fig 1 Fuzzy-PID Logic Controller



(a)



(b)



(c)

Fig.2 Member Function of FPID controller of a) ACE, b) ΔACE c) K_p, K_i, K_d

Fuzzy input to the inference system depends on fuzzifier input gains which process the ACE and its differential signal. In this paper fuzzy tuned PID controller is implemented. This Fuzzy logic controller having two inputs and three outputs. Each input consist five membership functions i.e. Negative Small (NS), Positive Small (PS), Zero (ZZ), Negative Big (NB), Positive Big (PB). Each output also consist five membership functions i.e. Small (S), Medium (M), Large (L), Very Big (VB),Very Very Big (VVB)with nominal range values defined by ACE. To drive these membership functions, twenty five IF-Then rules are created using Table I.

Table I Fuzzy logic rules for FPID controller

ACE/ΔACE	NB	NS	ZZ	PS	PB
NB	S	S	M	M	L
NS	S	M	M	L	VB
ZZ	M	M	L	VB	VB
PS	M	L	VB	VB	VVB
PB	L	VB	VB	VVB	VVB

4. SIMULATION MODEL AND RESULTS

4.1 Simulation Model

Analysis of different types of controllers have been implemented on different power system models. Once the tuning of the controllers is done than we have to give a unit step function to over Simulink model of the power system to check the simulation result for both PID and FPID controller with MATLAB/SIMULINK . This design is implemented in MATLAB/SIMULINK to examine the performance of PID and FPID controller. A two input three output fuzzy controller is designed and the membership functions and fuzzy ruled are determined. The step function given to four area power system model is simulated by using MATLAB.

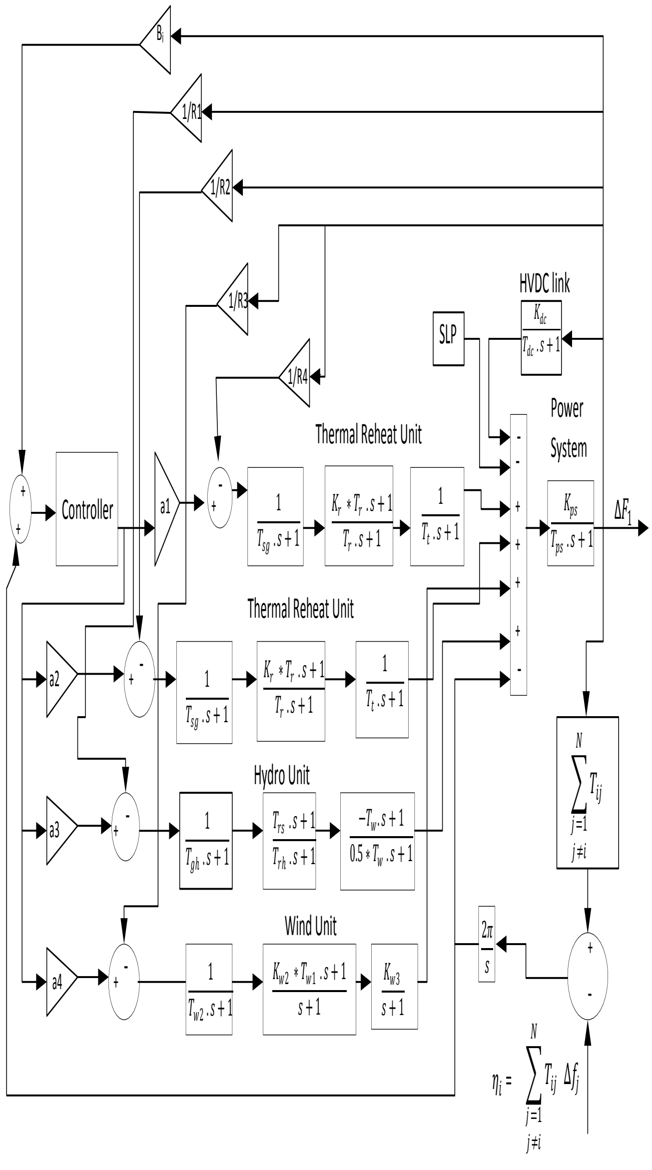


Fig 3 Simulink model of Four area multisource single unit

4.2 Simulation Results

The model of the system under study has been developed in MATLAB/Simulink environment. The following simulations were performed on all areas with conventional PID and FPID controller with 1% SLP in all areas.

(a) Frequency Responses

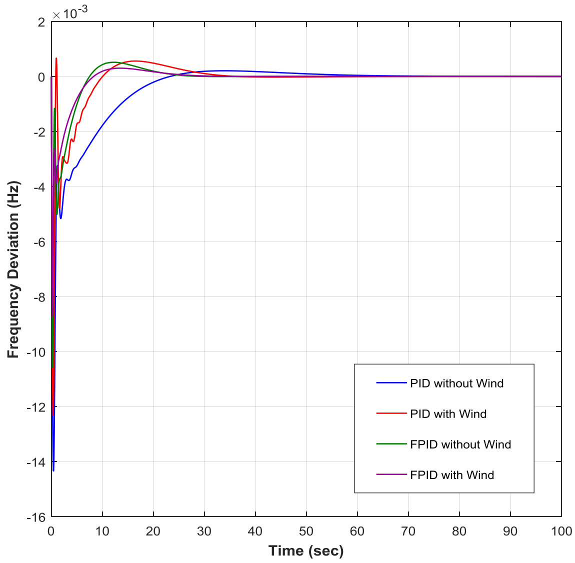


Fig. 4 Frequency deviation of area 1

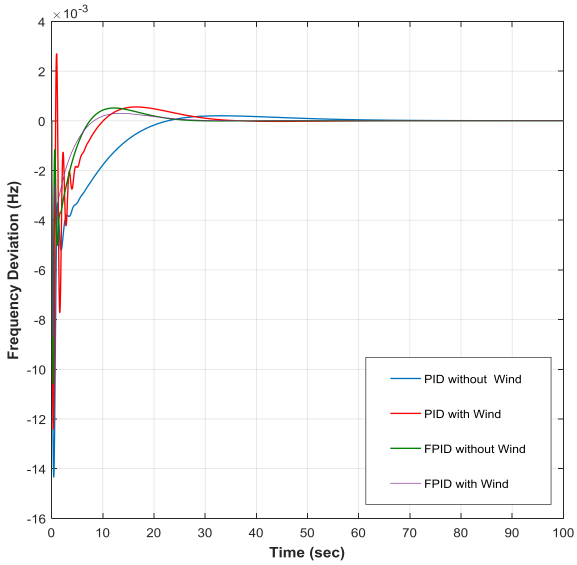


Fig. 5 Frequency deviation of Area 2

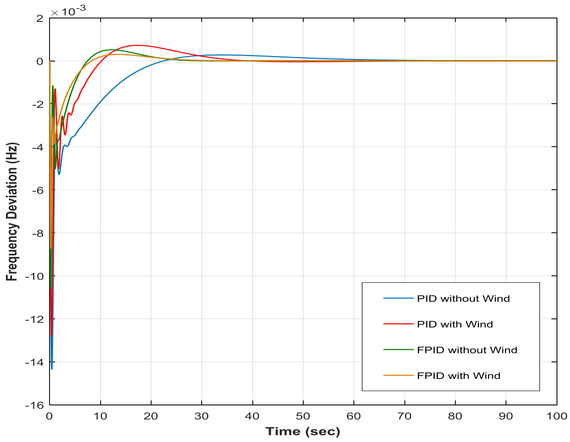


Fig. 6 Frequency Deviation of Area 3

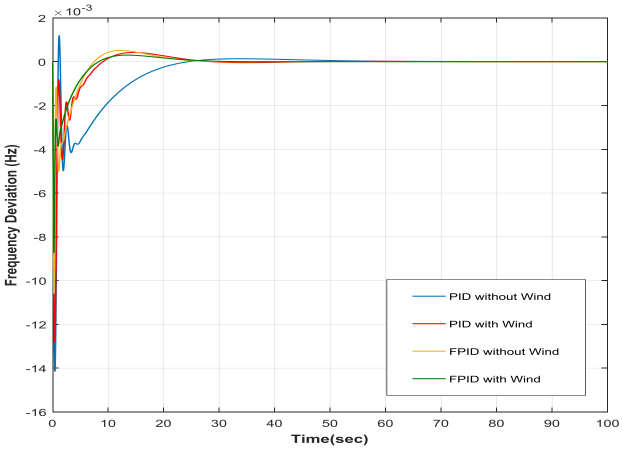


Fig. 7 Frequency Deviation of Area 4

(b) Tie Line Power Deviations

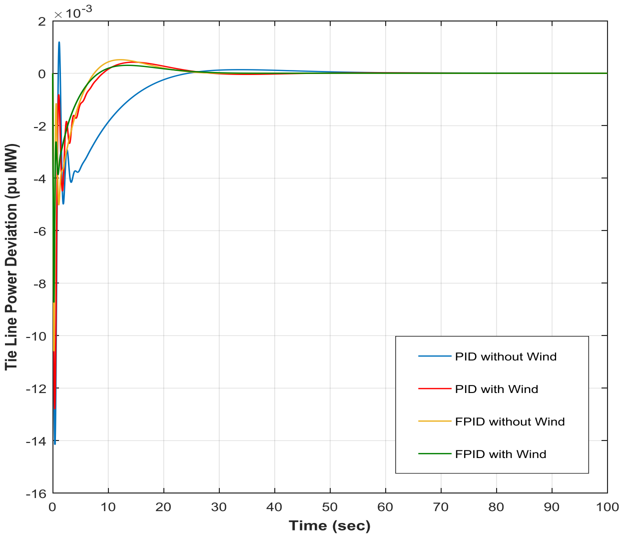


Fig. 8 Tie Line Power Deviation of Area 1-2

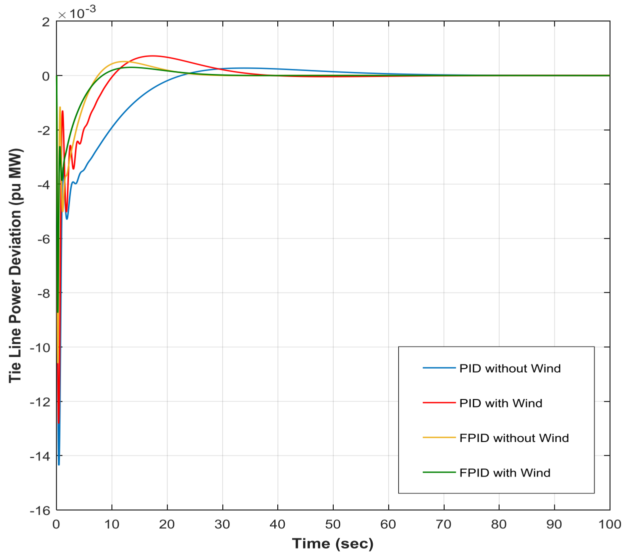


Fig. 9 Tie Line Power Deviation of Area 2-3

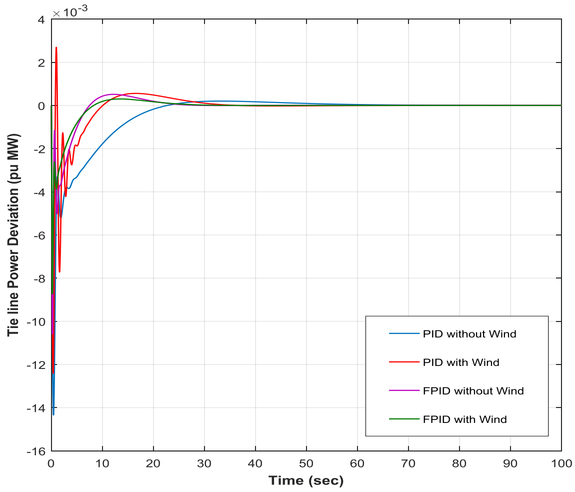


Fig. 10 Tie Line Power Deviation of Area 3-4

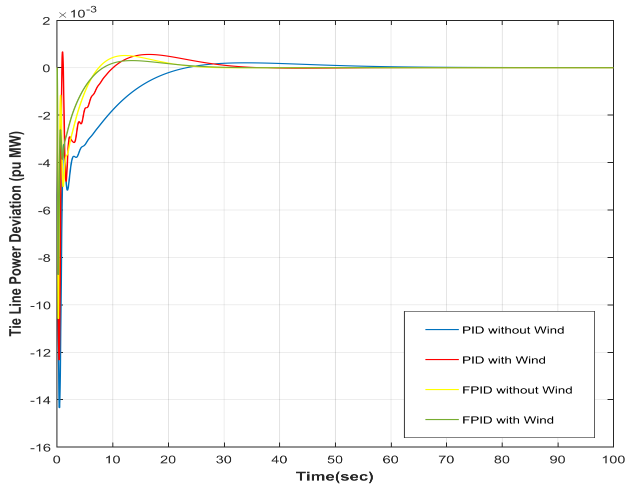


Fig. 11 Tie Line Power Deviation of Area 4-1

(C) Comparative Analysis

Table 1- Frequency Response of area 1

Parameters	PID without Wind	PID with Wind	FPID without Wind	FPID with Wind
Settling Time (sec)	55	35	30	22
Peak Undershoot (Hz)	-0.0142	-0.0122	-0.0104	-0.0085

Table-2 Frequency Response of area 2

Parameters	PID without Wind	PID with Wind	FPID without Wind	FPID with Wind
Settling Time (sec)	55	36	28	24
Peak Undershoot (Hz)	-0.0142	-0.0121	-0.0104	-0.0085

Table 3- Frequency Response of area 3

Parameters	PID without Wind	PID with Wind	FPID without Wind	FPID with Wind
Settling Time (sec)	60	38	30	28
Peak Undershoot (Hz)	-0.0143	-0.0129	-0.0106	-0.0087

Table 4-Frequency Response of area 4

Parameters	PID without Wind	PID with Wind	FPID without Wind	FPID with Wind
Settling Time (sec)	50	28	27	26
Peak Undershoot (Hz)	-0.0140	-0.0126	-0.0106	-0.0087

Table 5- Tie Line Power Deviation of area 1-2

Parameters	PID without Wind	PID with Wind	FPID without Wind	FPID with Wind
Settling Time (sec)	48	30	29	28
Peak Undershoot (Hz)	-0.0140	-0.0127	-0.0104	-0.0088

Table 6- Tie Line Power Deviation of area 2-3

Parameters	PID without Wind	PID with Wind	FPID without Wind	FPID with Wind
Settling Time (sec)	54	30	29	27
Peak Undershoot (Hz)	-0.0142	-0.0127	-0.0105	-0.0086

Table 7- Tie Line Power Deviation of area 3-4

Parameters	PID without Wind	PID with Wind	FPID without Wind	FPID with Wind
Settling Time (sec)	55	28	27	26
Peak Undershoot (Hz)	-0.0143	-0.0122	-0.0107	-0.0087

Table 8- Tie Line Power Deviation of area 4-1

Parameters	PID without Wind	PID with Wind	FPID without Wind	FPID with Wind
Settling Time (sec)	54	30	29	28
Peak Undershoot (Hz)	-0.0143	-0.0122	-0.0104	-0.0088

5. CONCLUSION

Load frequency control becomes more important, when a large amount of renewable power supplies like wind power generation are introduced. In this paper, load frequency control with considerable penetration of renewable has been analysed in the presence of Thermal, Hydro and Wind Systems with PID and FPID controllers. It is observed that frequency deviation is low when wind system is introduced in actual power system, and it is within the tolerable limits for fixed load variations. When FPID controller is compared to PID controller, FPID controller gives steady state error zero in less time than the other one.

APPENDIX

Parameters	**Description**	**Value**	**Unit**
B_1, B_2, B_3, B_4	Tie line frequency bias in areas 1,2,3 &4	0.425	pu MW/Hz
R_1, R_2, R_3, R_4	Regulations of governors in areas 1, 2,3 &4.	2.4	Hz/pu MW
T_{sg}	Speed governor time constant	0.08	sec
T_t	Steam turbine time constant	0.3	sec
T_r	Steam turbine reheat time constant	10.2	sec
K_r	Steam turbine reheat constant	0.3	Thermal unit
T_w	Nominal starting time of water in penstock	1.1	sec
T_{rs}	Hydro turbine speed governor reset time	5	sec
T_{rh}	Hydro turbine speed governor transient droop time constant	28.75	sec
T_{gh}	Hydro turbine speed governor main servo time constant	0.2	sec
T_{w1}, T_{w2}	Time constant of hydraulic pitch actuator of wind turbine	0.6, 0.041	sec
K_{w2}	Hydraulic pitch actuator constant	1.25	-
K_{w3}	Pitch constant of wind turbine	1.3	-
K_{dc}	Gain of HVDC system	1	-
T_{dc}	Time constant of HVDC system	0.2	sec
K_{ps}	Power system constants in areas 1,2,3 &4	120	Hz/ pu MW
T_{ps}	Power system time constants in areas 1,2,3 &4	20	sec
ΔF	Change in frequency	-	Hz
ΔP_D	Change in load	0.01	pu
a1,a2,a3,a4	Participation Factor	0.4,0.4, 0.2,0.2	-

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