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LOAD FREQUENCY CONTROL OF INTERCONNECTED POWER SYSTEM GRID INVOLVING WIND AND HYDROPOWER PLANT AND COMPARATIVE ANALYSIS

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Abstract— Power demand is expanding day by day. The greatest test is to give continuous and top-notch power to clients in factor conditions particularly when we interconnect the two areas utilizing power tie-line. To achieve this, the two boundaries should consistently be checked for each condition, these boundaries are Load Distribution and Load Frequency Control (LFC).The primary work of the load frequency control is to regulate the power output of the generator within a specified area with respect to change in system frequency and tie-line power, such as to maintain the scheduled system frequency and power interchange with other areas in a prescribed limit [1][2]. In this paper, the study of LFC system for two areas consisting of Hydropower Plant and Wind Power Plant are carried out. The fuzzy gain scheduled proportional-integral (FGSPI) and fuzzy gain scheduled proportional integral derivative (FGSPID) controllers are designed for load frequency control (LFC) of a two-area interconnected power system. The proposed FGSPI and FGSPID controllers are compared against conventional proportional-integral (PI) controllers and Proportional integral derivation (PID) controllers concerning settling times and peak overshoots of the tie-line power and frequency deviations as performance indices. Comparative analysis indicates that the proposed intelligent controller gives better performance than conventional controllers. Simulations have been performed using Simulink toolbox in MATLAB.

Keywords— load frequency control, wind power plant, hydropower plant, two area network, area control error, PI, PID, fuzzy gain scheduling

I. INTRODUCTION

The objective of the load frequency control (LFC) is to maintain the scheduled frequency and scheduled tie-line power in a normal mode of operation, during the small perturbation in operating conditions. The input mechanical power is used to control the frequency of the generators and the change in the frequency and tie-line power are sensed, which is a measure of the change in rotor angle. A well-designed power system should be able to provide acceptable levels of power quality by keeping the frequency and voltage magnitude within tolerable limits [3]. The enormous interconnected power systems are made out of control areas that represent different units of generators. The different areas are interconnected through tie-lines. The tie-lines are utilized for exchanging the power between the consecutive two areas and provides inter-area support in case of abnormal conditions of the power system.

number of conventional controllers like Proportional(P), Integral(I), Proportional Integral (PI) and Proportional Integral Derivatives (PID) are utilized in a control system for controlling frequency deviation and tie-line power, as these controllers are simple to implement, easy to understand and have low cost. The nature of their control technique is dependable and announced as vigorous for some working conditions [4]. However, the response of a system with these controllers is slow and poor in comparison to the intelligent controller. Zadeh presented a fuzzy set hypothesis and the first fuzzy logic control algorithm was implemented by Mamdani on a steam motor. The enormous, complex and interconnected power systems suffer with countless nonlinear properties subsequently, the fuzzy logic controller is one of the better controllers for the systems [5]. In this paper, Chhukha Hydro Power Plant and Rubesa Wind Power Plant are taken as the two-area network for frequency and power deviation control. The FGSPI and FGSPID controllers and conventional controllers (PI and PID) are used for LFC and they are compared base on their settling time and peak overshoot.

II. SYSTEM MODELLING

In this paper, Hydropower Plant and Wind Power Plant were taken as Area-1 and Area-2 respectively. Area-1 consists of four units and Area-2 with two units. The system model consists of hydro-governor, wind turbine, hydro turbine and generators of both wind and hydropower plants and each component is represented in the transfer function. The speed regulation constant and frequency bias factor are the feedback to the system. The frequency deviation Δf_1 is for Area-1 and Δf_2 for Area-2. ΔP_{L1} and ΔP_{L2} are the power demand increment for Area-1and Area-2 respectively and it is given in step load form. Area-1 and Area-2 are interconnected by the tie-line power. The area control error (ACE) for the two areas is given to the two controllers [19]. ACE is given in equation (1).

$$ACE_i = \sum_{j=1}^{n} \Delta P_{tie,ij} + B_i \Delta f_i \qquad (1)$$

$$\text{Where, } Bi = D_i + 1/R_i \qquad (2)$$

Where:

- ACE_i = area control error of the i^th^ area
- Δf_i = frequency error of i^th^ area
- $\Delta P_{tie,ij}$ = tie-line power flow error between i_{th} and j^{th} area
- B_i = frequency bias coefficient of i_{th} area

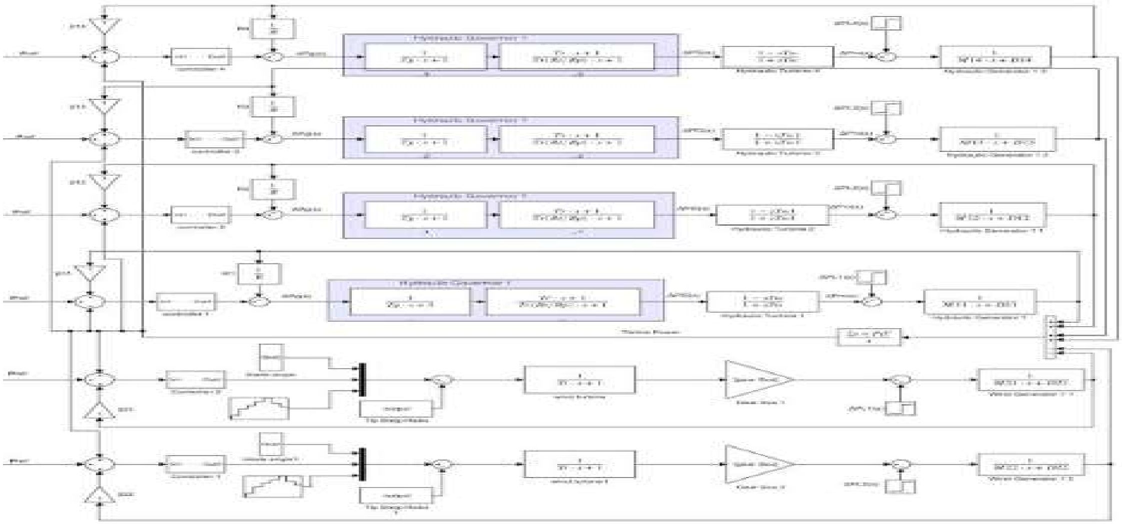

Fig. 1. Two area multi-unit Hydro and Wind power system

III. CONTROLLERs

In this study, PI, PID, FGSPI and FGSPID controllers are used to control the load frequency and tie-line power of the two-area network. The conventional controller PI and PID are compared with the proposed hybrid FGSPI and FGSPID controllers.

A. *PI Controller*

The proportional-integral controller produces an output, which is the combination of outputs of the proportional and integral controllers. PI controller will eliminate forced oscillations and steady-state error resulting in the operation of the on-off controller. PI controllers are very often used in industry, especially when the speed of the response is not an issue [23].

The value of the controller output u(t) is fed into the system as the manipulated variable input. Output power equals the sum of proportion and integration coefficients[24].

$$u(t) = K_P e(t) + K_I \int e(t)dt \qquad (3)$$

Apply Laplace transform on both sides

$$U(s) = (K_P + \frac{K_I}{s})E(s) \qquad (4)$$

$$U(s)/E(s) = K_P + \frac{K_I}{s} S \qquad (5)$$

Therefore, the transfer function of proportional integral controller is $KP + KIs$.

The block diagram of the unity negative feedback closed loop control system along with the proportional-integral controller is shown in the figure 2.

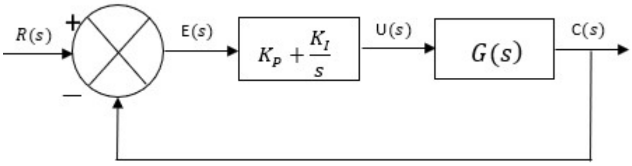

Fig. 2. Schematic diagram of PI controller

The proportional-integral controller is used to decrease the steady-state error without affecting the stability of the control system.

B. ***PID Controller***

The PID algorithm is the most commonly used feedback controller. It is a robust easily understood algorithm that can provide excellent control performance despite the varied dynamic characteristic of the process. As the name suggests, the PID consists of three basic modes namely the proportional, integral and derivatives mode. When utilizing the PID algorithm it is necessary to decide which mode to be used (P, I & D) and then specify the parameter for each mode used. Generally, three basic algorithms P, PI and PID are used to automatically adjust some variables to hold a measurement to the desired variable [25][26].

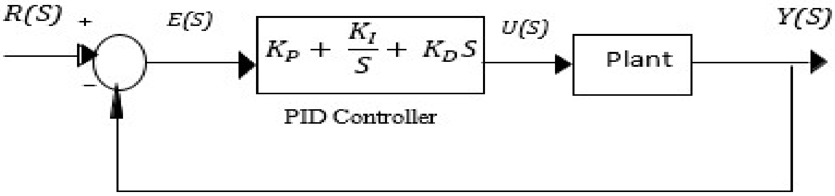

Fig. 3. Schematic diagram of PID controller

The output of PID controller in time domain

$$u(t) = K_P e(t) + K_I \int e(t)dt + Kd\, d/dt\, e(t)$$

Taking the Laplace on both the side:

$$U(s) = (K_P + \frac{K_I}{S} + K_D S)E(s) \qquad (6)$$

$$\frac{U(s)}{E(s)} = (K_P + \frac{K_I}{S} + K_D S) \qquad (7)$$

$$\frac{U(s)}{E(s)} = \frac{K_D S^2 + K_P S + K_I}{S} \qquad (8)$$

Whereas, E(s) and U(s) are the input and output of the plant respectively.

a. Ziegler-Nichol's Tuning Method

Ziegler and Nichols created two strategies for controller tuning during the 1940s. The idea was to tune the controller dependent on the following idea: Make a simple experiment, extract some features of process dynamics from the experimental data, and determine controller parameters from the features [27][28][29]. The following processes are followed:

- Increase the gain until the loop starts oscillating. Note that linear oscillation is required and that it should be detected at the controller output.
- Record the controller critical gain $K_p = K_c$ and the oscillation period of the controller output, Pc.
- Adjust the controller parameters according to the Table given below.

TABLE 1. ZiZIEGLER-NICHOLS TUNING RULE BASED ON CRITICAL GAIN Kc AND CRITICAL PERIOD Pc

	Kp	**Ti**	**Td**
P Controller	0.5Kc	∝	0
PI Controller	0.45Kc	Pc/1.2	0
PID Controller	0.6Kc	0.5Pc	Pc/8

Simultaneously, the value of K_i and K_d can be calculated using the following formula:

$$K_i = K_p/T_i \quad (9)$$

$$K_d = K_p * T_d \quad (10)$$

Whereas, T_i and T_d are the Integral time and Derivative time respectively.

C. ***Fuzzy Gain schedule PI and PID controllers***

Gain scheduling is the common technique used in the system whose dynamic changes non-linearly with operating conditions. Here, the fuzzy logic set supervises and modifies the operations, i.e., gain scheduling of the conventional controllers. FGSPI and FGSPID controllers are designed and used to control the frequency deviation of two area networks [30]. The design of FGSPI and FGSPID controllers can be divided into three parts:

- The allocation of the proper inputs
- The determination of the rules associated with inputs
- The defuzzification of the output

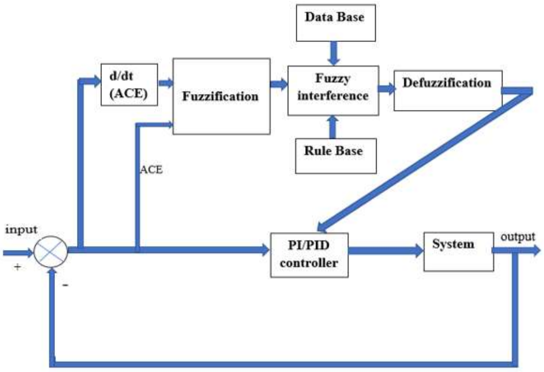

Fig. 4. Schematic diagram showing the working processes of FGSPI and FGSPID Controller

a. Fuzzification

In this process, the precise numerical values obtained by measurement are converted to membership values of the various linguistics. For this controller, the two inputs are the Area Control Error (ACE) and the change in error [d/dt (ACE)] [31].

b. Fuzzy Rule Base

For the proposed controller, the Mamdani method was selected and realized by five triangular membership functions for each of the three linguistic variables (ACE d/dt(ACE), K) with a suitable choice of intervals of the membership functions, where ACE and d/dt(ACE) act as the inputs of the controller and K is the output of the controller. In table II below, NB, NS, Z, PS, PB represent negative big, negative small, zero, positive small, and positive big respectively. The rule base has been formed in such a manner. For example; If ACE is NB and d(ACE)/dt is NB then the controller action is PB [33]. The appropriate rules used in the study are given in table 2.

TABLE 2. FUZZY LOGIC RULE FOR FGSPI AND FGSPID CONTROLLER

		ACE				
d/dt(ACE)		**NB**	**NS**	**Z**	**PS**	**PB**
	NB	PB	PB	PB	PB	Z
	NS	PB	PB	PS	Z	Z
	Z	PS	PS	Z	NS	NS
	PS	Z	Z	NS	Z	NB
	PB	Z	NS	NB	NB	NB

c. Defuzzification

The transformation of a fuzzy set into a numeric value is called defuzzification. Before feeding the data to the system it is very much important to do the defuzzification of the fuzzy set. The data needs to be converted into the numerical value from the membership function before feeding to the system[35]. The output from the fuzzy logic controller is used to schedule the gain of PI and PID controller.

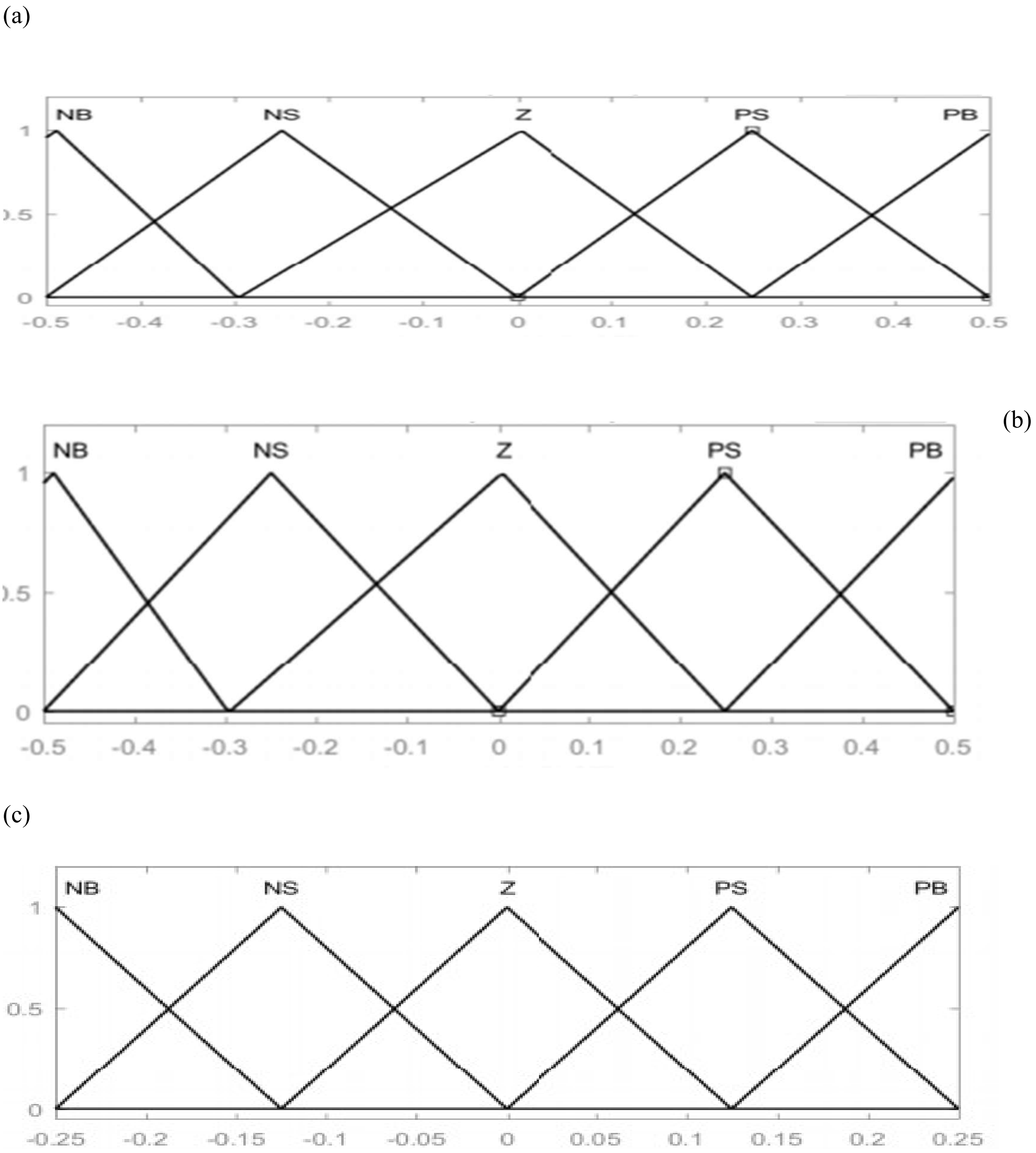

Fig. 5. Membership Function for FGSPI and FGSPID Controller of (a) ACE, (b) ΔACE and (c) output

IV. SIMULATED RESULT AND DISCUSSION

The load frequency control of the two area network was carried out using different controllers. The step load disturbance of 0.1 p.u. was applied in area-1 and the deviations in frequency and tie-line power flows were investigated. Conventional controllers like PI and PID controllers are used. The conventional controllers are compared with the proposed hybrid-type controllers like FGSPI and FGSPID controllers. The simulation of the two-area model with different controllers was carried out using the simulation toolbox in MATLAB. The simulated results were compared on the peak overshoot and the settling time of the output frequency.

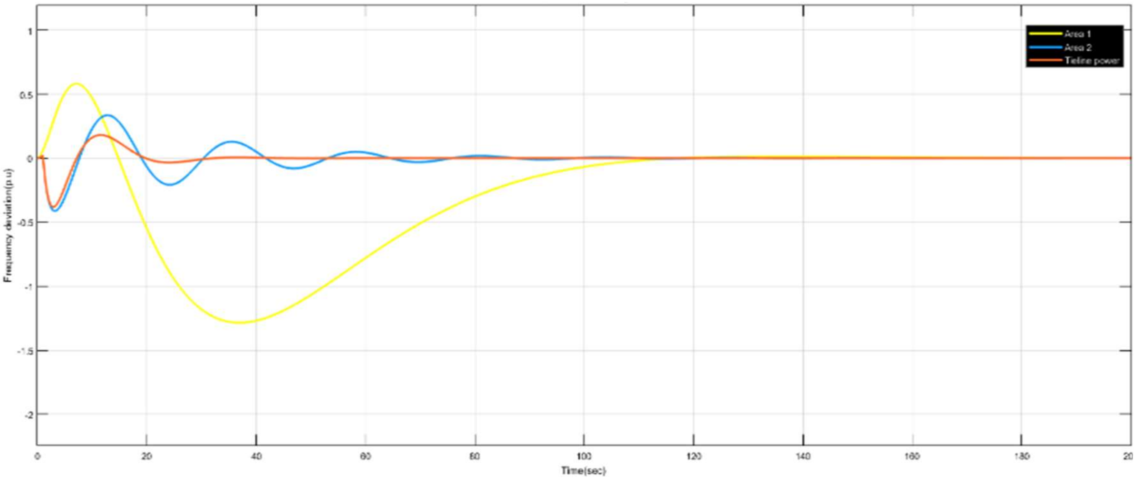

Fig. 6. Simulated result with PI controller

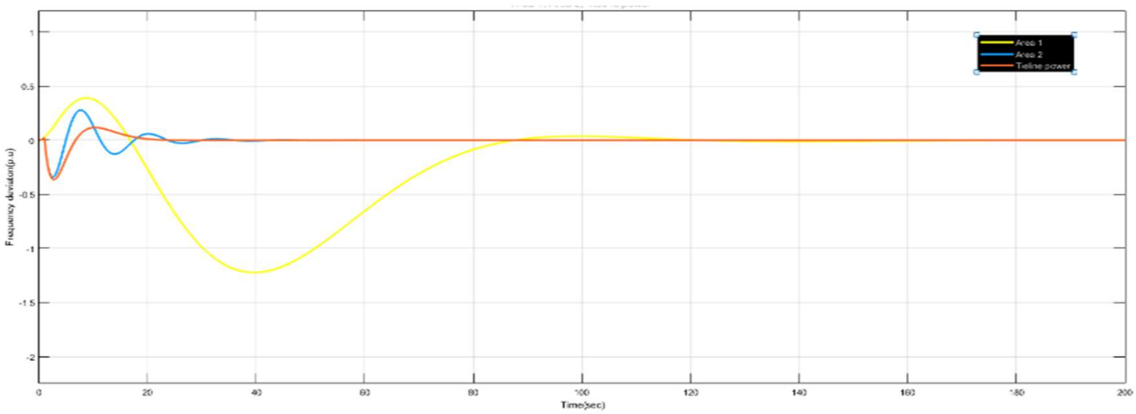

Fig. 7. Simulated result with PID controller

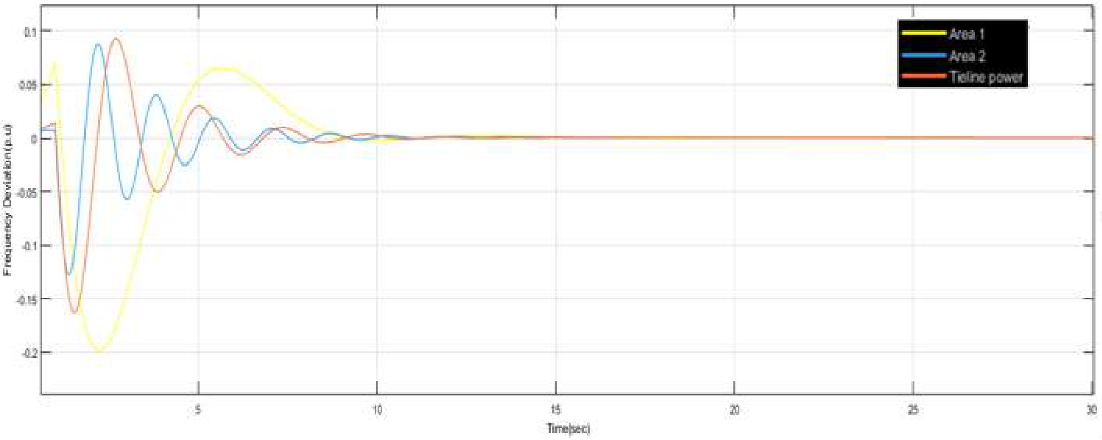

Fig. 8. Simulated result with FGSPI controller

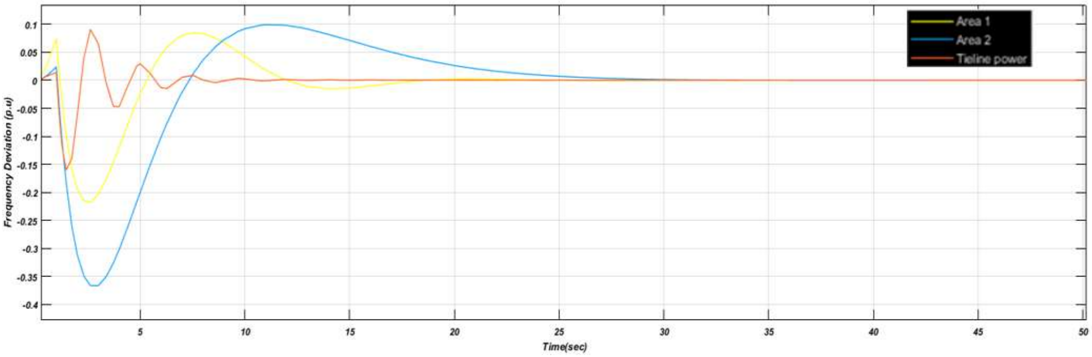

Fig. 9. Simulated result with FGSPID controller

The quantitative comparative analysis of the results with respect to frequency and tie-line power deviations for different controllers is given in Table III. The performance indices used are peak overshoot and settling time. As it is clear from Table III, that the response with FGSPID controller is the best among all the controllers because the values of peak overshoot and the settling time are minimum in the case of FGSPID controller.

TABLE 3. COMPARATIVE ANALYSIS OF RESULTS

Controllers	Areas	Peak Overshoot (p.u)	Settling Time (Sec)
PI Controller	Area-1	0.58	115
	Area-2	0.35	100
	Tie-lie power	0.15	30

PID Controller	Area-1	0.40	110
	Area-2	0.26	40
	Tie-lie power	0.12	20
FGSPI Controller	Area-1	0.08	18
	Area-2	0.10	28
	Tie-lie power	0.09	12
FGSPID Controller	Area-1	0.07	10
	Area-2	0.09	12
	Tie-lie power	0.08	11.5

V. CONCLUSION

In this research, the conventional controllers (PI and PID) and propose hybrid types controllers (FGSPI and FGSPID) approach are employed for load frequency control of an interconnected power system involving Chhukha Hydropower plant and Rubesa Wind power plant. The system was simulated using the Simulink toolbox in MATLAB. The proposed hybrid types of controllers like FGSPI and FGSPID are reported as with better performance (dynamic response improvement) in comparison to conventional controllers like PI and PID controllers. The system response is compared in terms of the peak overshoot (p.u) value and the settling time (sec). The proposed controllers are not only simple in design but also easy to implement. Moreover, the online adaptation of supplementary controller gain makes the proposed controllers more effective and it is expected that the controller will perform effectively under different operating conditions. Simulation results obtained demonstrate the usefulness of the proposed controllers. Taking PI and FGSPID controllers into consideration the peak overshoot in Area-1, Area-2 and tie-line power was reduced by 87%, 74% and 46% respectively. Similarly, the settling time in Area-1, Area-2 and tie-line power was reduced by 91.3%, 88% and 61.6% respectively. From the research that has been carried out it is possible to conclude that the proposed hybrid type FGSPID controller had a faster response to the system feedback error and it can be implemented in the system where a fast response is required.

VI. APPENDIX

Parameter	Description	Value	Unit
T_g	Time constant of governor of Area-1	5	Second
T_R	Reset time of governor of Area-1	10	Second
T_w	Water starting time of Hydro turbine in Area-1	15.8	Second
H_1	Inertia constant of generator of Area-1	3.04	MW.sec/MVA
D_1	Load damping constant Area-1	1	

R	Droop Characteristic of Area-1	10	Hz/pu MW
β_1	Frequency bias factor of Area-1	1.1	pu MW/Hz
ρ	Air density of Area-2	1.20735	Kg/m^3
V	Wind velocity of Area-2	Variable	m/s
T_t	Wind Turbine time constant	7.5	sec
C_p	Power coefficient of Area-2	0.53	
λ	Tip speed ratio	5.79	
θ	Pitch Angle	35.5	Degree
β_2	Frequency bias factor of Area-2	0.56	pu MW/Hz
G	Gearbox Ratio	1:120	
H_2	Inertia constant of wind generator of Area-2	3.79	MW.sec/MVA
D_2	Load Damping constant of Area-2	1	
r	Blade length	16.5	meter
T	Synchronizing Coefficient for Tie Line for Two Area Systems	0.08	MW/radian

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