

# Load Frequency Control in Two Area Power Systems Integrated with SMES Combination using Fuzzy-PID and ANFIS Controller

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**Abstract** - In this paper, the application of a ANFIS and Fuzzy- PID controllers are proposed for automatic generation control (AGC) and load frequency control (LFC) of two area reheat thermal power plant in interconnected power system. Additionally, a superconducting magnetic Energy Storage (SMES) unit is considering in two areas. The implementation of SMES combination arrests the initial fall in frequency deviation and tie-line power deviation after a sudden load disturbance. The simulation result shows that the system performances are improved significantly with the proposed SMES unit. The sensitivity analysis of the system is performed by varying the parameters and operating load conditions from their nominal values. It is observed that the optimized gains of the proposed PID and fuzzy PID and ANFIS controllers are need not be reset even if the system is subjected to wide variation in loading condition and system parameters. Finally, the effectiveness of the proposed controller design is verified by considering different types of load patterns. The simulated results show that the performance of ANFIS-PID controller is better than the Fuzzy- PID and PID controllers. The simulations have been performed using Matlab software.

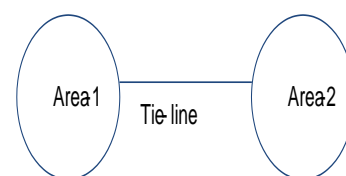
**Key Words:** Conventional PID controller, fuzzy PID controller, ANFIS controller, load frequency control, membership function, Inter-connected two-area system, Tie-Line power deviation.

## 1. INTRODUCTION

Load frequency control as one of the most important services in electrical power system design and it has been used for several decades to meet two main objectives, viz., maintain the system frequency deviation and tie-line power interchange deviations within specified values. The fundamental theory of load frequency control has been explained [1-5]. Load frequency control is generally considered as secondary level control and also a dominant operation in the area of automatic generation control (AGC). AGC is a feedback control system adjusting a generator output power to remain defined frequency. LFC system provides generator load control via frequency zero steady-state errors of frequency deviations and optimal transient behaviour are objectives of the LFC in multi-area interconnected power system [6]. Load frequency control (LFC) is being used for several years as part of the automatic

generation control scheme in electric power systems. Among the various types of load frequency controllers, the most widely employed is the conventional proportional integral (PI) controller. The PI, PID and Fuzzy-PID and ANFIS controllers are very simple for implementation and gives better dynamic response, but their performance deteriorate when the complexity in the system increases due to disturbance like load variation. Therefore, there is need of controllers which can overcome these problems. The artificial intelligent controllers like fuzzy and neural control approaches are more suitable in this respect. Literature survey shows that most of earlier work in the area of LFC pertains to interconnected reheat thermal power system. In this paper, the performance evaluation based on ANFIS, Fuzzy-PID and conventional PID for two area thermal interconnected system.

This paper is organized in six sections; the 1<sup>st</sup> section is the introduction part which is explained above. In section 2<sup>nd</sup> problem description and controller and objective description of interconnected system is shown. Section 3<sup>rd</sup> describes simulation model. 4<sup>th</sup> is devoted to the simulation results. Conclusion is derived in section 5<sup>th</sup>. 6<sup>th</sup> section gives appendix for simulation model.



**Fig.1** Block diagram for two area interconnected power system with tie line

## 2 Controller Structure and Objective

To control the frequency, PID controller and fuzzy PID controllers are provided in each area. The fuzzy PID controller is show in fig.2.[7] The error inputs to the controllers are the respective area control error (ACE) given by:

$$e_1(t) = ACE_1 = B_1 \Delta F_1 + \Delta P_{tie} \quad (1)$$

$$e_2(t) = ACE_2 = B_2 \Delta F_2 + \Delta P_{tie} \quad (2)$$

### 2.1 Fuzzy-PID Controller

Fuzzy gain scheduling is a procedure normally used for making controllers for power systems 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-variant model is not enough [14]. Nowadays, gain scheduling is performed according to the step frequency deviation response of the model for various gain values of the integral gain. A larger value of integral gain reduces the maximum overshoot value of the system frequency but the system oscillation takes place for a longer duration, but higher values of integral gain yield higher maximum frequency but the system oscillation takes place for a longer duration, but higher values 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, this methodology to control the performance parameters of the Fuzzy-PID controller according to the change of the new area control error (ACE) and the change in area control error (dACE) [15].

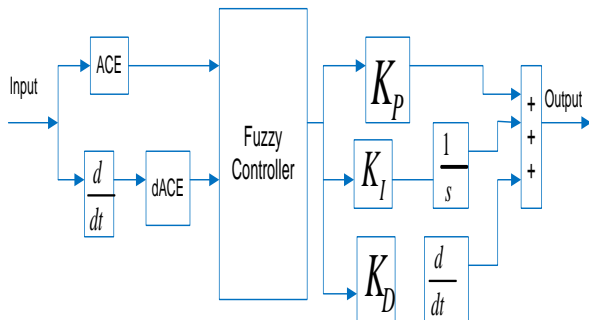
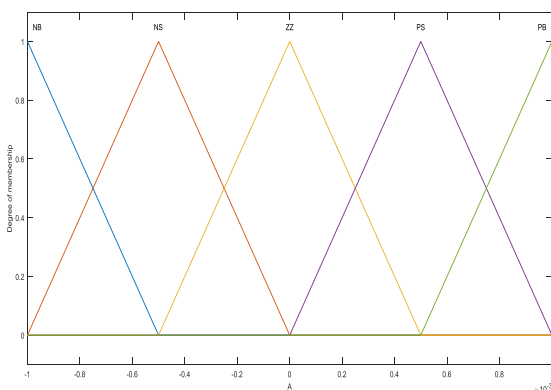
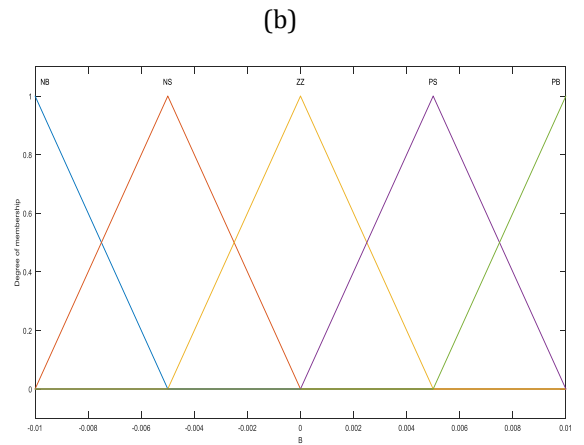


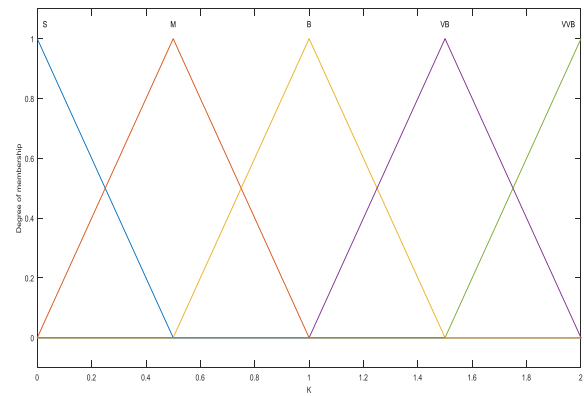
Fig. 3.. Block diagram for Fuzzy-PID controller



(a)



(b)



(c)

Fig. 4. Membership function of FGPID controller of a) ACE b) dACE c)  $K_p$ ,  $K_i$  and  $K_d$

Table 1. Rule base for Fuzzy Logic Controller

ACE/ $\Delta ACE$	NB	NS	ZZ	PS	PB
NL	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

For the fuzzy gain scheduled proportion, integral and derivative controller the Mamdani fuzzy inference engine was chosen and implemented by triangular membership functions for each of the four semantic variables ( $K_p$ ,  $K_i$  and  $K_d$ , a, ACE, dACE) with appropriate selection of intervals of the membership functions given.

### 2.2 ANFIS Controller Design

ANFIS architecture uses the two intelligent techniques like artificial neural network (ANN) and fuzzy logic. Normally

ANFIS is considered as an adaptive network and is closely related to ANN. The essential part of neuro-fuzzy modelling comes from a common framework called adaptive network which unifies the neural network and the fuzzy model. An easy rule base model is used for explaining the basic idea of ANFIS architecture. Consider the FIS having Takagi and Sugeno's controller with  $x$  and  $y$  as two inputs and  $z$  as an output. For a first order of Sugeno fuzzy model, distinctive rule set are expressed as [18]:

If  $x$  is  $A_1$  and  $y$  is  $B_1$  then  $f_1 = p_1x + q_1y + r_1$

If  $x$  is  $A_2$  and  $y$  is  $B_2$  then  $f_2 = p_2x + q_2y + r_2$

Where  $p$ ,  $r$  and  $q$  are linear output parameters. ANFIS architecture including inputs and outputs parameters are shown in fig. 5. The formation of the structure involved the use of five layers and two if-then rules.

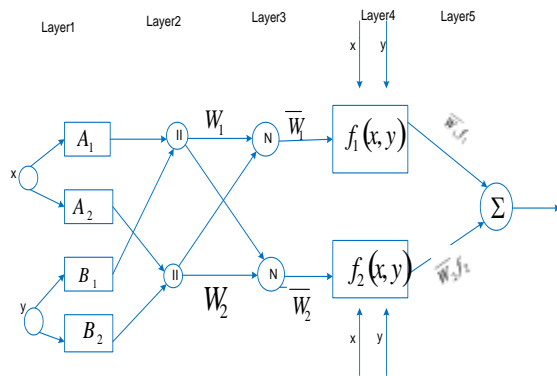


Fig. 5. Block Diagram of ANFIS Controller

### 2.3 Analysis of SMES and Its Control Strategy

Superconducting Magnetic Energy Storage (SMES) is a device which can store the electrical power from the grid in the magnetic field of a coil. The magnetic field of coil is made of superconducting wire with near-zero loss of energy. SMESs can store and refurbish huge values of energy almost instantaneously. Therefore the power system can discharge high levels of power within a fraction of a cycle to avoid a rapid loss in the line power. The SMES device is consisting of inductor-converter unit, dc super-conducting inductor, AC/DC converter and step down transformer. The stability of the SMES device is superior to other power storage device; because all parts of an SMES units are static. Superconducting coil will be charged to a normally less than the maximum charge from the utility grid. The DC magnetic coil is connected to the AC grid through a power conversion system which includes an inverter and rectifier. After being charged the superconducting coil conducts current, which supports an electromagnetic field. With virtually no losses. The coil is kept at extremely low temperature. When there is a sudden increase in load demand, the stored energy in the superconducting coil is released in the form of AC through

the power conversion system (PCS) to the electrical network. [11-13]

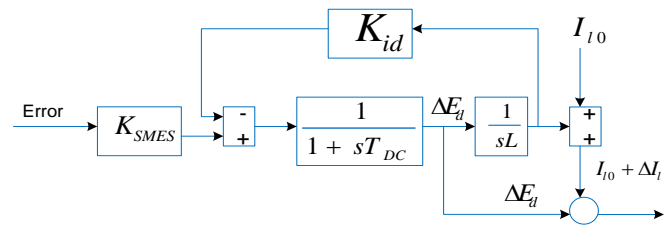


Fig.6. Block diagram of SMES unit with negative feedback signal

When after applying the negative feedback signal then inductor current deviation  $\Delta E_d$  becomes

$$\Delta E_d = \frac{1}{1 + sT_{DC}} [K_{SMES} (B_i \Delta W_i + \Delta P_{tieji}) - K_{id} \Delta I_l] \quad (3)$$

### 3. Simulation Model

Analysis of the different types of controllers has been implemented on different interconnected power system models. Once the tuning of the controller is done then we have to give a unit step function to over simulink model of the power system to check the simulation result for ANFIS and Fuzzy-PID controller with matlab/simulink.

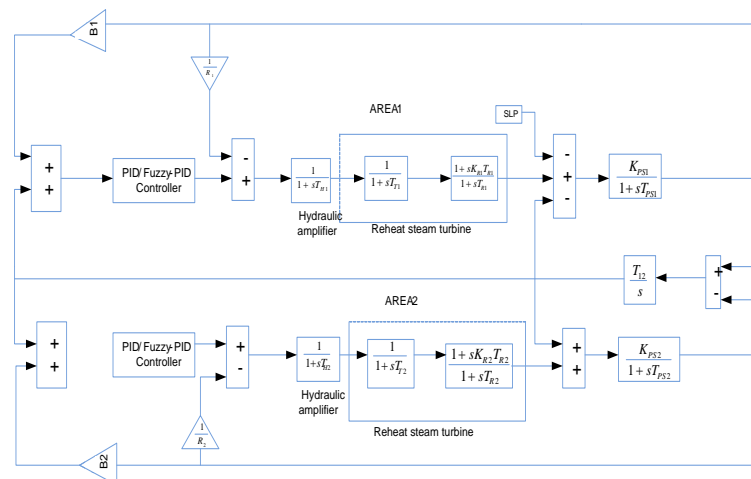


Fig. 7. Simulation model diagram for two area Reheat power system

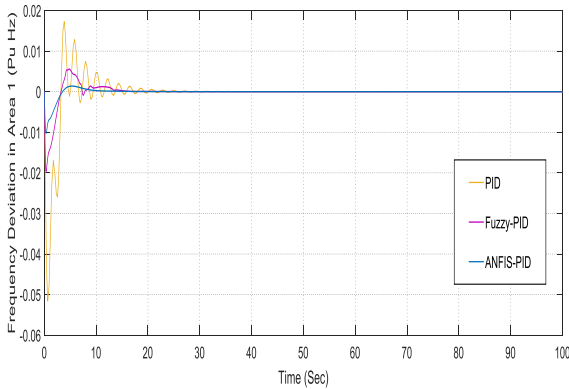
### 4. Result discussion

#### 4.1) Frequency and Tie-Line Power Response

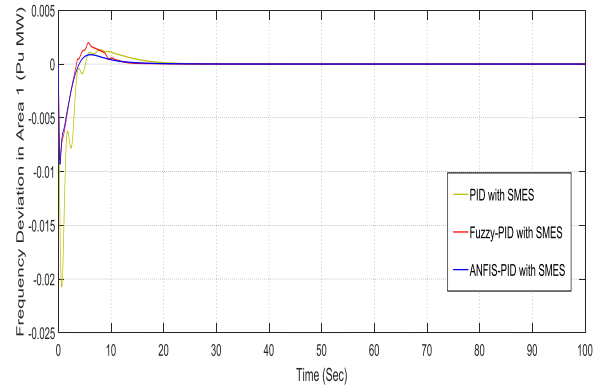
The frequency response of two area interconnected power system with PID, Fuzzy-PID and ANFIS-PID controllers are plotted. In figs. frequency response with respect to time of reheat thermal

interconnected power system respectively ANFIS-PID, Fuzzy-PID and PID controllers.

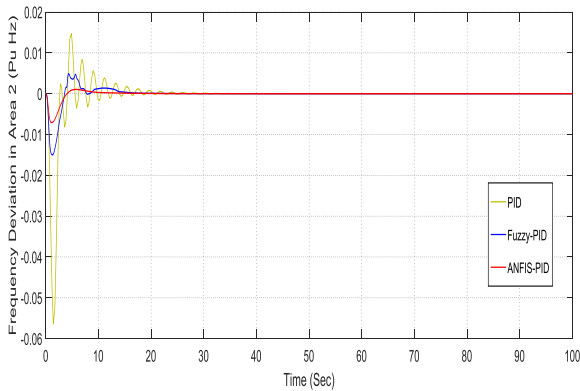
**4.1) Frequency and Tie-Line Power Response with SMES Unit**



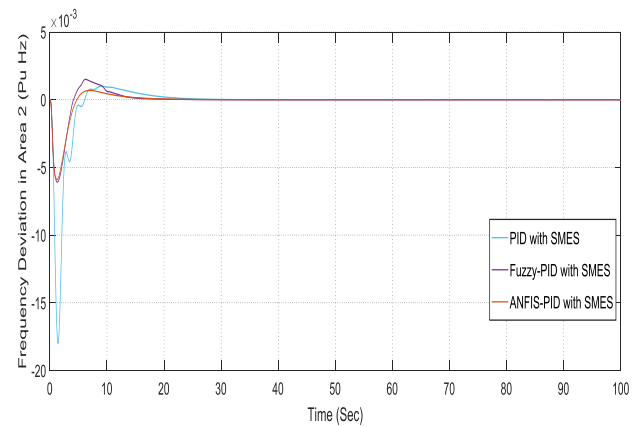
**Fig. 8.** Frequency Deviation in area 1 (Pu Hz)



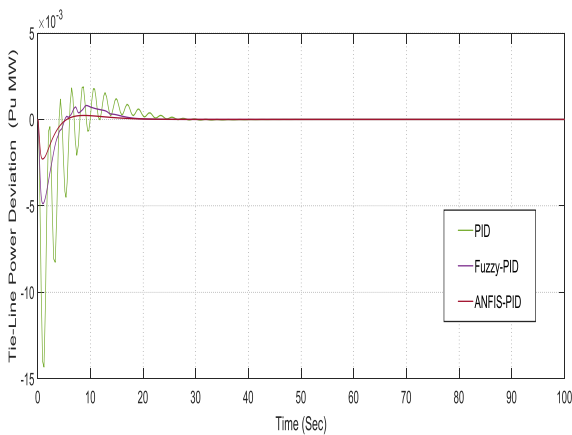
**Fig. 11.** Frequency Deviation in area 1 with SMES unit



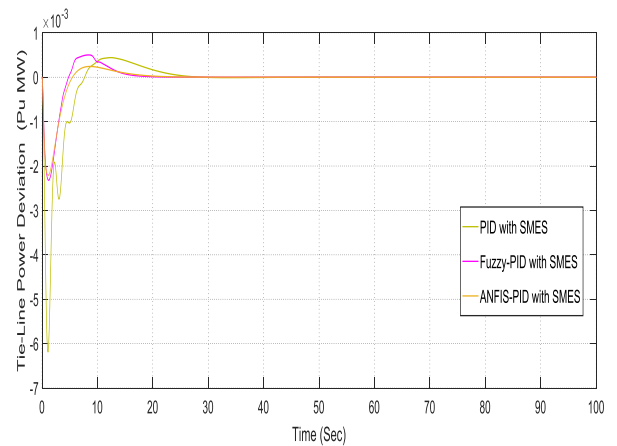
**Fig. 9.** Frequency Deviation in area 2 (Pu Hz)



**Fig. 12.** Frequency Deviation in area 2 with SMES unit

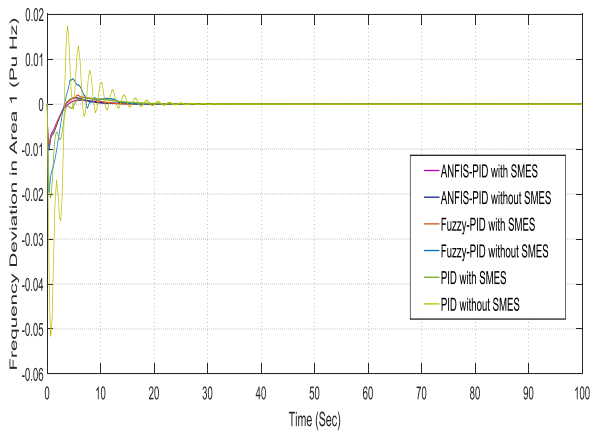


**Fig. 10.** Tie-Line Power Deviation in areas (Pu MW)

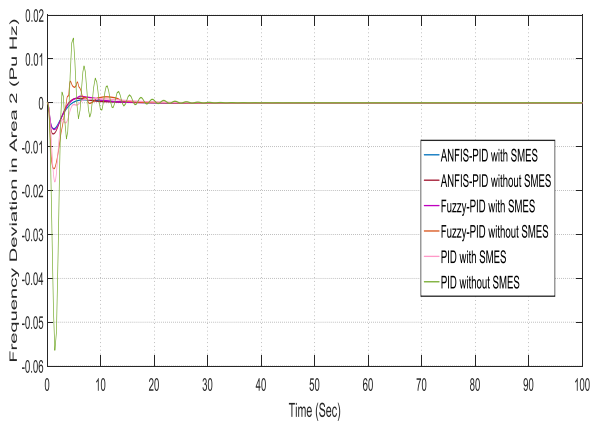


**Fig. 13.** Tie-Line Power Deviation In areas with SMES unit

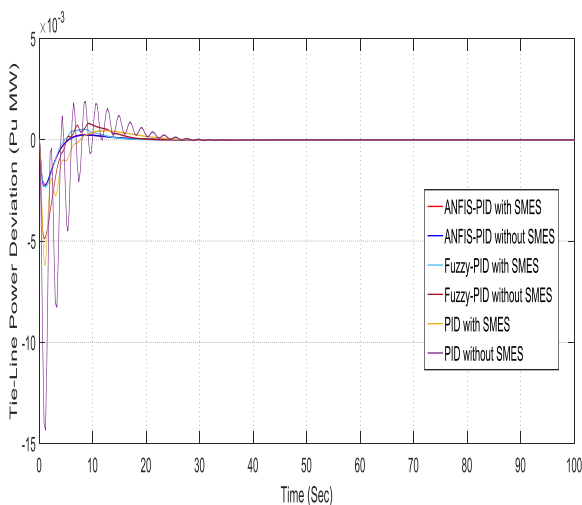
**4.1) Comparison of Frequency and Tie-Line Power Response with and without SMES**



**Fig. 14.** Comparison of Frequency Deviation in area 1



**Fig. 15.** Comparison of Frequency Deviation in area 2



**Fig. 16.** Comparison of Tie-Line Power Deviation in areas

**4.1) Controllers and Parameters Table for Results Discussion**

In table 2,3 analysis of frequency deviation is show with respect to settling time and minimum undershoot and overshoot value using PID and Fuzzy-PID and ANFIS-PID Controllers for each subarea of the two area system.

**Table 2.** Performance Analysis of Frequency Response for Area 1

S.NO.	Parameters	PID Controller	Fuzzy-PID Controller	ANFIS-PID Controller
1.	Peak Undershoot (Hz)	-0.05	-0.02	-0.01
2.	Peak Overshoot (Hz)	0.15	0.05	-
3.	Settling Time (Sec)	30	20	10

**Table 3.** Performance Analysis of Frequency Response for Area 2

S.NO.	Parameters	PID Controller	Fuzzy-PID Controller	ANFIS-PID Controller
1.	Peak Undershoot (Hz)	-0.052	-0.015	-0.005
2.	Peak Overshoot (Hz)	0.15	0.05	-
3.	Settling Time (Sec)	30	20	10

**Table 4.** Performance Analysis of Tie Line Power in areas

S.NO.	Parameters	PID Controller	Fuzzy-PID Controller	ANFIS-PID Controller
1.	Peak Undershoot (Hz)	-0.014	-0.005	-0.002
2.	Peak Overshoot (Hz)	0.002	0.001	-
3.	Settling Time (Sec)	30	20	10

**Table 5.** Performance Analysis of frequency Deviation in area 1 with SMES

S.NO.	Parameters	PID with SMES	Fuzzy-PID with SMES	ANFIS-PID with SMES
1.	Peak Undershoot (Hz)	-0.021	- 0.009	-0.008
2.	Peak Overshoot (Hz)	0.002	0.002	0.0001
3.	Settling Time (Sec)	25	15	10

**Table 6.** Performance Analysis of frequency Deviation in area 2 with SMES

S.NO.	Parameters	PID with SMES	Fuzzy-PID with SMES	ANFIS-PID with SMES
1.	Peak Undershoot (Hz)	- 0.016	- 0.006	-0.005
2.	Peak Overshoot (Hz)	0.002	0.002	0.0001
3.	Settling Time (Sec)	25	15	10

**Table 7.** Performance Analysis of Tie-Line Power Deviation in areas with SMES

S.NO.	Parameters	PID with SMES	Fuzzy-PID with SMES	ANFIS-PID with SMES
1.	Peak Undershoot (Hz)	- 0.006	- 0.0025	-0.0021
2.	Peak Overshoot (Hz)	0.002	0.002	0.0001
3.	Settling Time (Sec)	25	15	10

## 5. Conclusion

Investigation of two area system has been done with ANFIS-PID and Fuzzy-PID logic and PID controllers. This paper presents to contribute towards building an intelligent, fast and better controller for load frequency control (LFC) of consider nonlinear interconnected power system. In overview, it is observed with significant improvements of dynamic responses are obtained with coordinated

application of ANFIS-PID and Fuzzy-PID based controllers. Further, SMES unit is added in the system model in order to improve the system performance. It is observed that when the SMES unit is placed with the load line, dynamic performance of system is improved. Then the impact of SMES in the AGC along with UPFC is also studied. From the simulation results, it is observed that significant improvements of dynamic responses are obtained with coordinated application of SMES. Finally, sensitivity analysis is carried out to show the robustness of the controller by varying the loading conditions and system parameters in range of 1% to 2% from their nominal values. It is observed from simulation results that proposed controller performed well against random load patterns when system is incorporated with SMES compared to other.

## 6. APPENDIX

**Table 8.** Parameter of the system and their nominal values [5]

Parameter	Symbol	Values
Hydraulic time constant	$T_H$	0.08sec
Turbine Time constant	$T_T$	0.3sec
Reheat time constant	$T_R$	10.0sec
Reheat gain	$K_R$	0.5
Control area time constant	$T_P$	20sec
Control area gain	$K_P$	120
Regulation constant	R	2.4 Hz/MW
Frequency bias constant	B	0.425 MW/Hz
Synchronization time constant	$T_{12}$	0.086

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