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Load Frequency Control of a Four-Area Interconnected Thermal-Hydro-Nuclear-Wind Power System with Non-Linearity using Fuzzy Logic PID Controller

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***Abstract*—This paper illustrates the load frequency control of a four-area interconnected thermal-hydro-nuclear-wind power plant system using fuzzy PID controller. The settling time undershoot, and overshoot of the power system is observed with fuzzy-PID controller. The thermal system is fused with boiler dynamics and generation rate constraints [13]. The controlling approach assures that the frequencies and interchange of tie-line powers are kept in given limitations [8]. From the results it is clear that the peak overshoot and settling time for fuzzy-PID controller is better than conventional controller and fuzzy controller when non-linearity's is taken into consideration. It can also be observed that due to wind which is a non-conventional power system the settling time of the system increases as a whole. Time domain simulations are used to analyze the performance of the power system. The implementation of the four-area system is done in MATLAB/SIMULINK package.**

Keywords*—Boiler dynamics, Generation constraint, Load frequency control, fuzzy PID controller and Tie-line power

I. INTRODUCTION

Load frequency control is done in an electric power system to maintain consistent frequency. During loaded conditions the interconnected plants share power through tie-line control. Tie-line is used between power systems to allow by directional flow of power. Load frequency control becomes a necessity for power system because if the error in frequency exceeds more than 2% the blades of the turbine are likely to get damaged. The frequency and tie-line power will be fluctuated if any load variation happens which will further reduce system performance and can damage load, therefore it is mandatory to maintain frequency at stated limits.

Most of the research conducted in this field neglect non-linearity's, for example boiler dynamics and generation rate constraints in the thermal power plant for simplicity and better results [7] [9]. But if we go for practical solution, we need to incorporate these effects. In this paper we have taken non-linearity into consideration for our four-area interconnected system.

In literature controllers based on fuzzy, conventional PID and neural networks [11] are proposed [9]. There are various studies about different controlling mechanism having certain pros and cons. In most of the papers a LFC using a conventional PID controller is exercised and it is highlighted that the performance of this controller is better than others [12]. However, if non-linearity in a power system is taken into consideration then conventional controllers fail to give an optimum result. Intelligent controllers can be replaced with PID controllers for quick and better dynamic responses. Fuzzy logic controller is usually more useful than conventional controllers because it is faster and more productive in nonlinear applications. Fuzzy logic controller is used to reduce variations on system outputs. In this paper LFC of thermal-hydro-nuclear-wind power system is implemented using fuzzy-PID controller.

II. FOUR-AREA POWER SYSTEM

Power systems mostly comprise of multiple areas which may consist of non-linear behavior [4]. These areas are interconnected to each other by tie-line which need controlling of power flow and frequency [5]. “Fig. 1”, demonstrates a four-area interconnected power system used in our research.

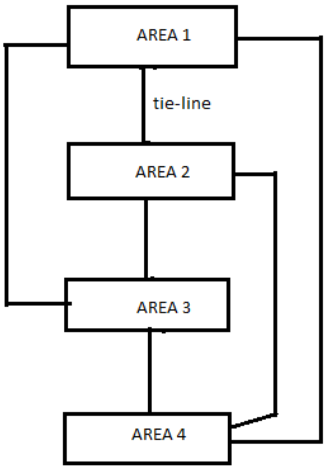

Fig. 1 four-area interconnected power system

Area 1 encompasses a thermal power plant consisting of a speed governor, steam turbine, electric generator and a single stage re-heater. In order to develop a realistic model all non-linearity's related to the system is incorporated. Non-linear mostly relates to how valve position are uninterrupted with respect to change in speed [1]. Boiler dynamics on the other hand relates to how re-heater can actively receive steam from boiler.

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III. MATHEMATICAL MODELLING OF FOUR-AREA POWER SYSTEM

$$\dot{x} = Ax + Bu + Fw \tag{1}$$

where A is system matrix, B is input matrix, F is disturbance matrix, x is state vector given in equation (2), u is control vector given in equation (3), ΔP_d is disturbance vector given in equation (4) [3].

$$x = \begin{bmatrix} x_1 \\ x_2 \\ x_3 \\ \bullet \\ \bullet \\ \bullet \\ x_{22} \end{bmatrix} \tag{2}$$

$$u = \begin{bmatrix} u_1 \\ u_2 \\ u_3 \\ u_4 \end{bmatrix} \tag{3}$$

$$w = \begin{bmatrix} w_1 \\ w_2 \\ w_3 \\ w_4 \end{bmatrix} \tag{4}$$

State vectors of matrix 2 is given below [3],

$$\begin{array}{llll} x_1 = \Delta f_1 & x_4 = \Delta f_2 & x_7 = \Delta f_3 & x_{10} = \Delta f_4 \\ x_2 = \Delta P_{g1} & x_5 = \Delta P_{g2} & x_8 = \Delta P_{g3} & x_{11} = \Delta P_{g4} \\ x_3 = \Delta Y_{E1} & x_6 = \Delta Y_{E2} & x_9 = \Delta Y_{E3} & x_{12} = \Delta Y_{E4} \\ x_{13} = \Delta P_{tie,12} & x_{14} = \Delta P_{tie,31} & x_{15} = \Delta P_{tie,41} & \\ x_{16} = \Delta P_{tie,34} & x_{17} = \Delta P_{tie,32} & x_{18} = \Delta P_{tie,42} & \end{array}$$

Control signals of matrix 3 is given as [3],

$$u_1 = -k_{i1}X_{19} = -k_{i1} \int ACE_1 dt = \Delta P_{c1}(S) \tag{5}$$

$$u_2 = -k_{i2}X_{20} = -k_{i2} \int ACE_2 dt = \Delta P_{c2}(S) \tag{6}$$

$$u_3 = -k_{i3}X_{21} = -k_{i3} \int ACE_3 dt = \Delta P_{c3}(S) \tag{7}$$

$$u_4 = -k_{i4}X_{22} = -k_{i4} \int ACE_4 dt = \Delta P_{c4}(S) \tag{8}$$

where $X_{19}, X_{20}, X_{21}, X_{22}$ is given below,

$$\begin{aligned} X_{19} &= \int ACE_1 dt \\ X_{20} &= \int ACE_2 dt \\ X_{21} &= \int ACE_3 dt \\ X_{22} &= \int ACE_4 dt \end{aligned} \tag{9}$$

where,

$$ACE_1 = \Delta P_{tie,12} + \Delta P_{tie,13} + \Delta P_{tie,14} + b_1 \Delta f_1 \tag{10}$$

$$\begin{aligned} ACE_2 &= \Delta P_{tie,21} + \Delta P_{tie,23} + \Delta P_{tie,24} + b_1 \Delta f_2 \\ ACE_3 &= \Delta P_{tie,31} + \Delta P_{tie,32} + \Delta P_{tie,34} + b_1 \Delta f_3 \\ ACE_4 &= \Delta P_{tie,41} + \Delta P_{tie,42} + \Delta P_{tie,43} + b_1 \Delta f_4 \end{aligned}$$

IV. NON-LINEARITY

A. *Boiler Dynamics*

In this paper a drum type boiler is incorporated. Pressure control, boiler storage and fuel system transfer functions are considered in the boiler leading or turbine modes of operation. The "Fig. 2" shows the simulated model of boiler [13].

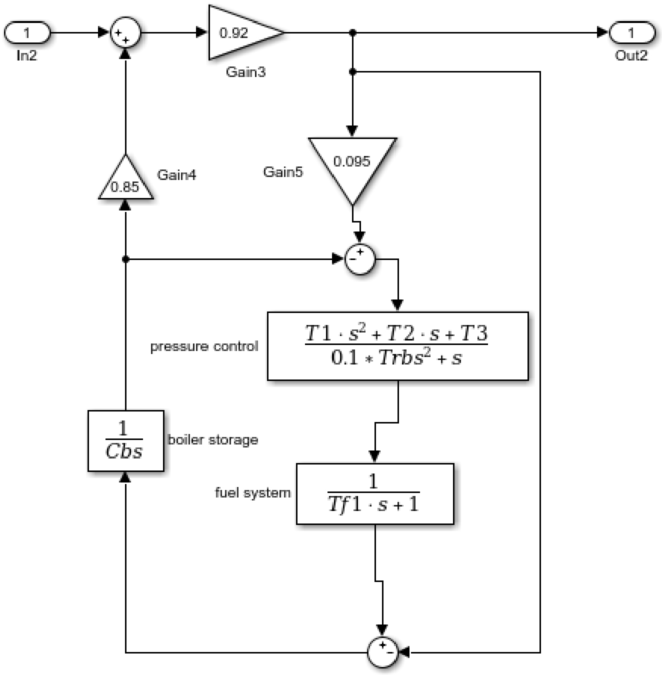

Fig. 2 Boiler

B. *Generation rate constraint*

In practical system due to mechanical and thermal restriction the rate at which output power can be adjusted has a limit specified to it [2]. This limit is termed as Generation rate constraint. "Fig. 3" shows the simulated model of Generation rate constraint [13].

$$\Delta \dot{P}_g \leq 0.1 p.u.MW/min = 0.0017 p.u.MW/s$$
$$(\delta = \pm 0.0017)$$

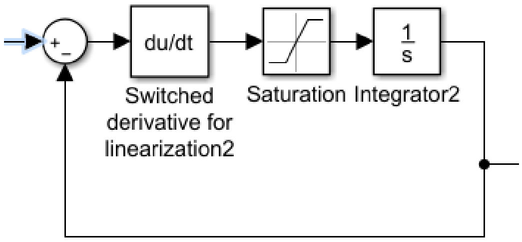

Fig. 3 Generation rate constraint

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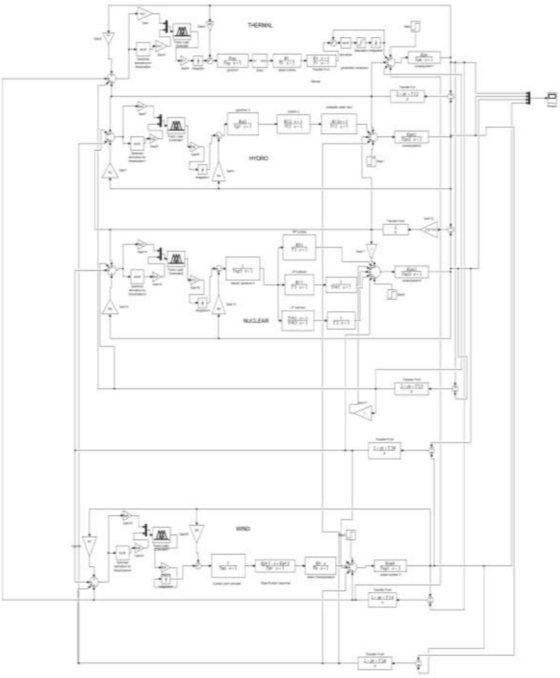
V. COMPLETE SIMULINK MODEL OF FOUR AREA POWER SYSTEM



VI. CONTROLLERS

A. *PID Controller*

A PID controller continuously evaluates an error value as the difference between a desired signal and a measured process variable and resultant error is multiplied with the proportional constant (K_p). Integral mode is used to remove the steady state error which could not be removed by proportional mode, (K_i) [10] is the integral constant. Derivative mode in the controller improves stability of the system and increases gain and decreases time constant thereby increasing speed of the controller response, (K_d) is the derivative constant.

B. *Fuzzy controller*

If we further want to improve the transient response and settling time we go for intelligent techniques such as fuzzy logic. This controller works on the basis of sets, these sets are represented by membership function [16] and output is based on degree of membership function. Therefore, the Fuzzy logic controller is used to get optimal result.

C. *Fuzzy-PID controller*

It the combination of fuzzy logic and conventional PID controller, which gives better transient response and setting time. “Fig. 4”, “Fig. 5”, “Fig. 6” shows the input output membership functions for this controller. Table 1 shows the rule table [11] of fuzzy logic where inputs are ACE and ΔACE.

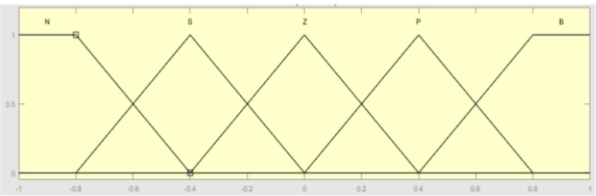


Fig. 4 Input1 membership function

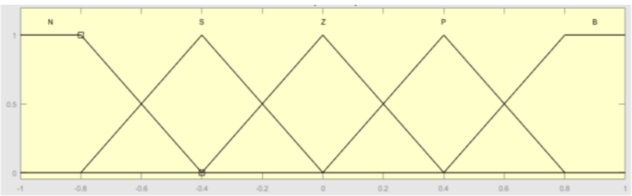


Fig. 5 Input2 membership function

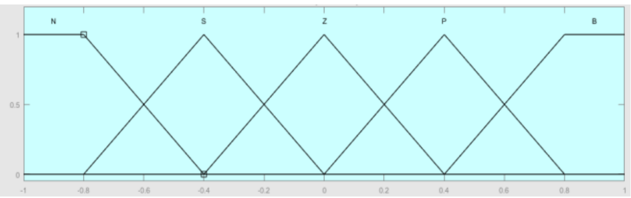


Fig. 6 Output membership function

TABLE 1: RULE TABLE WITH 5 MEMBERSHIP FUNCTIONS

	ACE				
Δ ACE	N	S	Z	P	B
N	N	N	N	S	Z
S	N	N	S	Z	P
Z	N	S	Z	P	B
P	S	Z	P	B	B
B	Z	P	B	B	B

VII. SIMULATION AND RESULTS

Simulations were performed with the parameters given in the appendix, with conventional PID controller, FLC and Fuzzy-PID controller for the four-area system. Simulation was carried out for step load change of 10% given simultaneously for each area. The GRC for thermal system is considered for 1%. The change in frequency of the system with PID, Fuzzy and fuzzy-PID is given in “Fig. 7”, the settling time, undershoot and overshoot are observed and tabulated in Table 2. “Fig. 8” shows the frequency response of three area (thermal-hydro-nuclear) which are conventional systems with Fuzzy-PID controller. “Fig. 9” shows the frequency response of four area with wind incorporated which is a non-conventional system. Table 3 shows the comparison table of conventional system with a non-conventional system. It is observed that for a four-area system as compared to fuzzy and PID, fuzzy-PID controller gives better response based on time domain parameters and maintains the system frequency. Also, the result shows that by introducing wind system the settling time increases but maintains the system frequency and is in constant steady state value.

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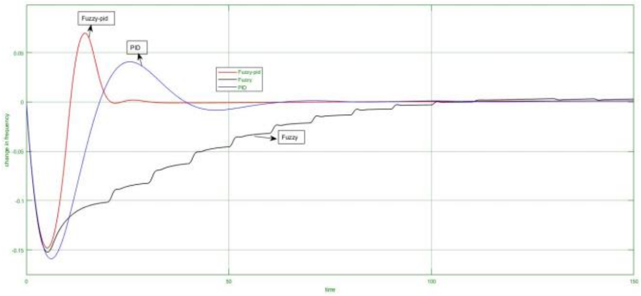

Fig. 7 Output response for PID, Fuzzy and Fuzzy-PID

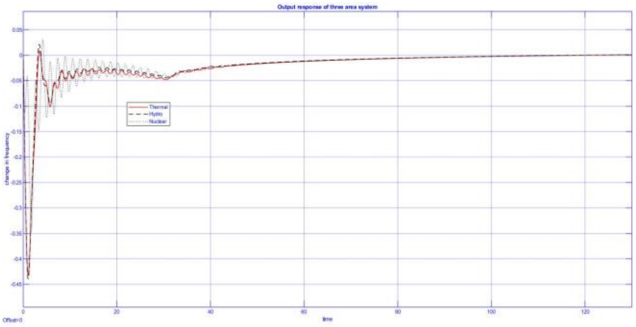

Fig. 8 Output response of conventional system

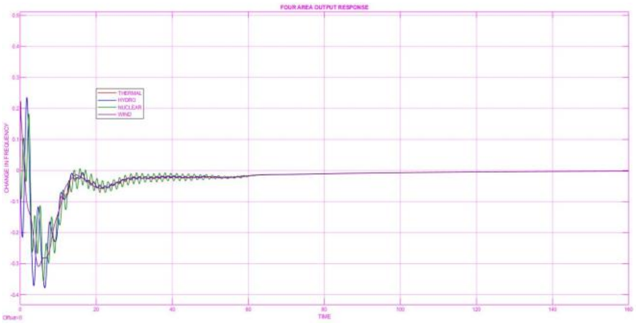

Fig. 9 Output response with non-conventional system

VIII. CONCLUSION

In this paper load frequency control of four area interconnected thermal-hydro-nuclear-wind power plant system is performed using Fuzzy-PID controller. From results we can analyze the settling time, overshoot and undershoot of Fuzzy-PID is better as compared to PID and Fuzzy controllers, Fuzzy PID controller gives the best response when uncertainty and non-linearity are considered.

TABLE 2: COMPARISION FOR 3 AREA AND 4 AREA

	Settling time (s)	Overshoot (%)	Undershoot (%)
PID	68.18	0.24	0.04
Fuzzy	100.7	-	-
Fuzzy-PID	30.542	0.46	0.0165

It can also be seen that when wind system is included the settling time, overshoot and undershoot of the area increases signifying that when non-conventional system is added it disturbs the time domain parameters to a certain extent.

TABLE 3: COMPARISION FOR 3 AREA AND 4 AREA

	Area 3			**Area 4**		
Areas	***Settling time(s)***	***Over shoot (%)***	***Under shoot (%)***	***Settling time(s)***	***Over shoot (%)***	***Under shoot(%)***
Thermal	53.175	0.1179	0.1648	79.95	0.77	0.12
Hydro	53.175	0.13	0.08	79.95	0.808	0.15
Nuclear	53.175	0.24	0.26	79.95	0.230	0.838
Wind	-	-	-	79.951	0.0519	0.1615

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IX. APPENDIX

Boiler - T1 = 53.82
T2 = 3.15
T3 = 0.030
C_b = 200
T_f = 10
T_{rb} = 69.2
thermal- K_{p1} = 0.000005225
K_{d1} = 1
K_{i1}= 0.000019605
K_{sg} = 1
T_{sg} = 0.08
K_t = 1
T_t = 0.3
K_r = 3.33
T_r = 10
hydro - K_{p2} = 0.000006127
K_{d2} = 1
K_{i2} = 0.000019605
K_{g2} = 1
T_{g2} = 0.487
K_t2 = 0.513
T_t2 = 10
K_r2 = -1
T_r2 = 0.5
Nuclear - K_{p3} = 0.0000043
K_{d2} = 0.04
K_{i2} = 0.0000012
T_{sg3} = 0.08
K_{h1} = 2
T_{h1} = 0.08
K_{r1} = 0.3
T_{r1} = 0.5
T_{rh1} = 7
T_{rh2} = 6
T_{rh3} = 10
T_2 = 0.08
wind - k_{p4} = -0.000001149
k_{d4} = 0.00006
K_{i4} = -0.000028278
T_{pa} = 0.041
K_{pr1} = 7.5
K_{pr2} = 1.25
T_{pr} = 1
K_b = 1.4
T_b = 1
K1 = k3 = k5 = k7 = 0.429
k2 = k4 = k6 = k8 = 0.4156
$T_{12} = T_{13} = T_{23} = T_{24} = T_{14} = T_{34}$ = 0.07064
$K_{ps} = K_{ps2} = K_{ps3} = K_{ps4}$ = 120
$T_{ps} = T_{ps2} = T_{ps3} = T_{ps4}$ = 20
[15] [6][10] [14]

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