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Performance Analysis of Automatic Generation Control of Multi-Area Power System Using Fuzzy-PID Controller

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***Abstract*—A large integrated power network is made up of large and small generating stations and all stations must have the same frequency.The Fuzzy-PID control method was used in this work for automatic generation control (AGC) of multi-area power system with generation rate constraints (GRC).The main feature of AGC is to keep the frequency of the system constant. In the control system, which has three steam turbine areas and one with a hydro turbine connected to the power lines, this approach is used. The performance analysis by AGC using the Fuzzy-PID controller is discussed in this paper.**

Keywords*— Fuzzy Logic Controller (FLC), Proportional Integral Derivative (PID) controller, Generation Rate Constraint (GRC), Automatic Generation Control (AGC), MATLAB/SIMULINK .

I. Introduction

Automatic generation control (AGC) is a major issue in the large interconnected power network and in its regulation. Whenever a small load shift happens within the network, It induces shifts in the tie-line power flow and frequency deviation[1]. In the past, a lot of work in the field of power system AGC has been done [1-4] and many control techniques have been intended to improve the efficiency of AGC.

AGC is used in realtime regulation to adjust changes in area generation to changesin area load to accommodate tie-line flows and hold the frequency at nominal value. AGC will determine if the load has changed in its own region or in the region around its neighbour, by processing frequency and tie line deviations. When the former is modified the unit generations under AGC before the deviations are null. The AGC issue with the integrated system is not only to see that the demand for generation balances, but also to distribute generation between various systems so that the system's overall operating schedules are preserved. Therefore, the role of the AGC in the interconnected system, either manually or automatically, is to reassign generation changes to preselected machines after initial randomization of the load accommodation by the governor's intervention. There is a need for much better frequency constancy than obtained by the speed governor itself.

AGC's main goal is to minimize the transient variance in a very short time and have zero steady state error[5]. The purpose of this paper is to study frequency control as load power changes and to use a Fuzzy PID controller to construct the AGC. For small variations in load per unit, the built controller is simulated with MATLAB.

The tool box and the result of the configured controller were compared to the regular PID controller[6].The key benefit of the Fuzzy PID controller is that device dynamics can adjust the controller parameter very quickly[7]. The PID controller increases the transient response to the the amplitude of error with increasing oscillation and eventually settles the output to a desired final value.For PID controllers, greater margin of reliability is assured. The disadvantage of traditional PID controller is slow and lack of efficiency in the non-linearity of the device handling. Fuzzy PID controller has some advantage I providing better copying method with imperfect details. (ii) Offers decision making versatility and, thirdly, offers a fascinating man / machine interface by simplifying the extraction of the human expert rule [8,9].Fuzzy logic controller is acknowledge-based controller[10].Fuzzy logic controller was therefore proposed as a better altenative approach to the design of control systems , particularly for the too large and complex system, which is very difficult to analyse from conventional methods[11]. The fuzzy-PID controller for automatic multiarea power system generation control is implemented in this paper which gives better response than traditional PID controller.

This paper was organized in 5 sections. The first section incorporates automatic generation control of the multi-area power system. The second section explains simulations of the system. Third segment concerns the traditional and smart controller used for monitoring behavior. The fourth section explains the result and debate and the fifth section deals with conclusion.

II. The power System Investigated

The multi-area AGC system used in this paper consists of four control regions linked by tie lines, shown in Fig.1.with each control field, all generators are assumed to form a coherent group. The four interconnected region power network consists of three thermal turbine reheating units and one hydropower unit.

Each area provides electricity to its consumer pool, and the tie lines allow power to flow between areas. Therefore, any load disturbance in one region influence the frequency of its own region, the frequency of other areas and the power flow of the tie line from other areas.

As a result, the control system needs information on the transitory situation in all areas of the local frequency to the permanent state interest for each zone. The information about each area is found in its frequency during perturbation, and the information about the other area in the disturbance is found in its tie-line strength flow.

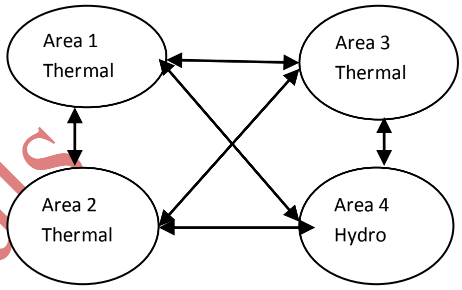

Fig.1 Schematic diagram of the four-zone power grid

The three areas consist of steam turbines that have administrator, reheated with restrictions on the rate of generation. In the fourth region, the hydro turbine has limitation of the rate of generation. Dead band effect of hydro turbine governor and steam turbines is ignored for simplicity.

An extended power network, using tie lines, can be split into a number of interconnected load frequency control zones.

The monitoring goals are as follows:

- Each control area should have its own load demand as far as possible and the flow of power via the tie line should be mutually agreed.
- All control areas should be controllable for monitoring of the frequency.

Below are the transfer functions of different blocks used in the power system model[12].

Transfer function (TF) of hydraulic Turbine is

$$\frac{-T_W s+1}{0.5T_w s+1}$$

(1)

TF of hydraulic Governor is

$$\frac{K_d s^2+K_p s+K_i}{K_d s^2+\left(K_p+\frac{f}{R_2}\right)s+K_i}$$

(2)

TF of Governor (thermal plant) is

$$\frac{1}{T_g s+1}$$

(3)

TF of Steam Turbine is

$$\frac{K_r T_r s+1}{T_r s+1}$$

(4)

TF of Re-heater is

$$\frac{1}{T_r s+1}$$

(5)

And transfer function of Generator is

$$\frac{K_p}{T_p s+1}$$

(6)

A. *Modeling of Tie-Line*

The equation for power transfer through the tie line is,

$$P_{12} = \frac{|V_1||V_2|}{x} \sin(\delta_1 - \delta_2)$$

(7)

In area 1 there is surplus capacity, which moves to area 2

P12 = power transferred via tie line from area 1 to area 2 $P_{12} = \frac{|V_1||V_2|}{x_{12}} \sin(\delta_1 - \delta_2)$

(8)

where$\delta_1, \delta_2, \delta_3$and δ_4= Power angel of end voltages $V_1V_2V_3$ and V_4 of equivalent machine of four area respectively.

x_{12}= reactance of tie line

For small deviation in the angles and the power of tie line varies with the quantity, i.e. small deviation in $\delta_1, \delta_2, \delta_3$ and δ_4 varies by $\Delta\delta_1, \Delta\delta_2, \Delta\delta_3$ and $\Delta\delta_4$ respectively.

Power P_{12} changes to $P_{12} + \Delta P_{12}$

Therefore, Power transferred as defined from Area1 to Area 2 as given is

$$\Delta P_{12}(s) = \frac{2\pi T^{\circ}}{s}(\Delta f_1(s) - \Delta f_2(s)) \qquad (9)$$

T°= Torque produced

The power on the tie-line in normal operation is derived from the equation i.e.

$$[\Delta P_{T1}(s) - \Delta P_{E1}(s) - \Delta P_{12}(s)]$$
$$= \frac{2H_1}{f_0} s\Delta f_1(s) B_1 \Delta f_1(s)$$
$$= \frac{2H_1}{f_0} \Delta f_1(s) B_1 \left[\frac{1}{B_1} s + 1\right]$$

(10)

If $\frac{2H_1B_1}{f_\circ} = \frac{1}{K_{p1}} \qquad \frac{1}{B_1} = T_{P_1}$

Equation (10) can be written as

$$\Delta f_1(s) = G_{P_1}(s)\left[\Delta P_{T_1}(s) - \Delta P_{E_1}(s) - \Delta P_{12}(s)\right]$$

(11)

$$G_{P_1}(s) = \frac{K_{P1}}{1+sT_{P1}}$$

(12)

$$\Delta P_{12} = \Delta P_{21} = \Delta P_{31} = \Delta P_{41}$$

whereΔP_E is the real load change

Due to the activity of the turbine controller, the generator increases its output by the amount of P T. The device would consume the net P T-PP (E) surplus electricity.

To eradicate frequency error in tie-line power flow from a steady state, tie-line bias control is used. This states that, in addition to taking care of their frequency control, each control area will contribute its shareown net interchange.

Let ACE$_1$=Area control error in area 1
ACE$_2$=Area control error in area 2
ACE$_3$= Error in Area control area 3

ACE_4= Error in Area control area 4

In this regular, ACE1, ACE2, ACE3 & ACE4 reflect a linear combination of the frequency and tie line power error.

$ACE_1 = \Delta P_{12} + b_1 \Delta f_1$ (13)

$ACE_2 = \Delta P_{21} + b_1 \Delta f_2$ (14)

$ACE_3 = \Delta P_{31} + b_1 \Delta f_3$ (15)

$ACE_4 = \Delta P_{41} + b_1 \Delta f_4$ (16)

Where the constant b1,b2,b3,&b4 is respectively called area frequency bias of area 1, area 2 , 3 & area 4.

Now, ACE1, ACE2, ACE3 and ACE4 are integral modes of ACE1, ACE2, ACE3 and ACE4.

$$\Delta PR_1 = -K_{i_1} \int_0^t \quad (\Delta P_{12} + b_1 \Delta f_1)dt$$

$$(17)\ \Delta PR_2 = -K_{i_2} \int_0^t \quad (\Delta P_{21} + b_2 \Delta f_2)dt$$

$$(18)\ \Delta PR_3 = -K_{i_3} \int_0^t \quad (\Delta P_{13} + b_3 \Delta f_3)dt$$

$$(19)\ \Delta PR_4 = -K_{i_4} \int_0^t \quad (\Delta P_{14} + b_4 \Delta f_4)dt$$

$$(20)\ \Delta P_{12} = \Delta P_{tie\,1},\ \Delta P_{21} = \Delta P_{tie\,2}$$

$$\Delta P_{31} = \Delta P_{tie\,3}, \qquad \Delta P_{41} = \Delta P_{tie\,4}$$

Therefore $\frac{\Delta P_{tie\,1}}{\Delta P_{tie\,2}} = -\frac{T_{12}}{T_{21}} = -\frac{1}{a_2} = constant$

Hence $\Delta P_{tie\,1} = \Delta P_{tie\,2} = \Delta P_{tie\,3} = \Delta P_{tie\,4} = 0$

$$\Delta PR_1 = \Delta PR_2 = \Delta PR_3 = \Delta PR_4$$

$$\Delta f_{1=} \Delta f_{2=} \Delta f_{3=} \Delta f_4 = 0$$

Therefore, under constant conditions, the shift in the tie-line power and frequency of each area is zero.

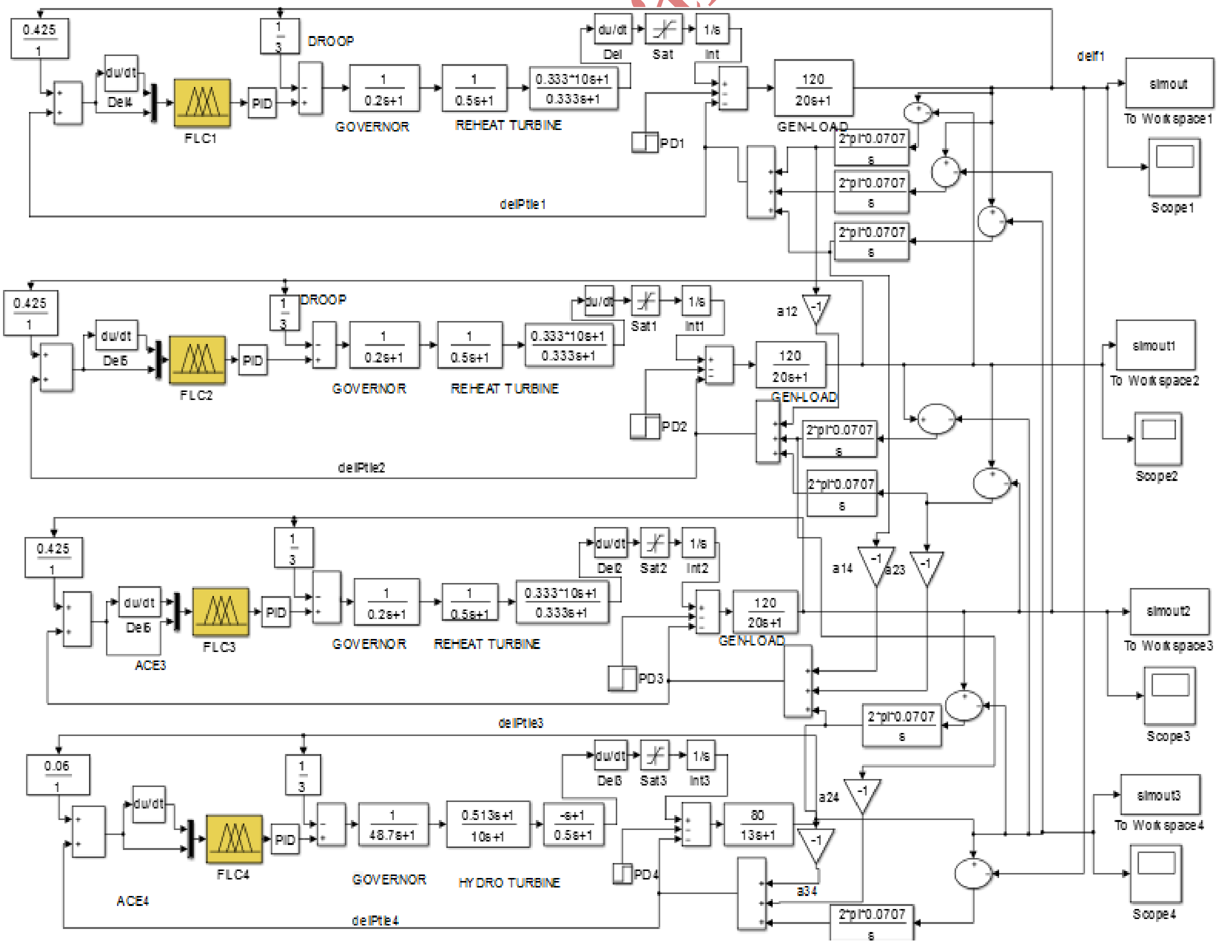

Fig 2: MATLAB Simulink Model of four area hydro-thermal reheat power system

III. Controller design

A. Load frequency controller 's role is to produce a control signal from Ui that preserves the frequency of the device and the strength of tie line interchange at default values.

B. *PID controller design*

The proportional-integral - derivative (PID) controller is well known control system and is widely used in in the industry for power control. The extensive use of the PID controller for most linear system is due to its simplicity of operation, ease of design , low cost maintenance, and performance.

It has been recognised, however, that conventional PID controllers usually do not work well without detailed mathematical models for nonlinear systems, higher order and time-delayed linear systems and especially complex systems.

There are three different parameters in the PID controller algorithm: additive, integral and derivative terms are summarised to provide the transfer function.of the controller as expressed in

$$PID(s) = k_p[1 + \frac{1}{sT_i} + sT_d] \tag{21}$$

whereKp is proportional gain, Ti is integral time and T_d is derivative time.

The PID controller enhances the transient response to the the amplitude of error with increasing oscillation, and finally settles the output to a desired final value. For PID controllers, greater margin of reliability is assured. Limiting conventional PID controllers is slow, and lack of efficiency in system handling is non-linear.

Generally, these gains are optimized using different methods of optimization, such as the Ziegler Nicholas process, Genetic algorithm, etc., and the optimal gain values are set for the controller once obtained. But significant fluctuations in load and change of device parameters also occur in the case of deregulated climate.

Previously determined optimum controller gains may not be optimal for new environments, resulting in controller malfunctioning. And the gains must be constantly calibrated to prevent these situations.

Fuzzy logic controller

Since the dynamic characteristics of the power system are complex and variable, traditional methods of control cannot achieve the desired results. Conventional controllers can be replaced with Smart controllers in order to obtain a fast and good dynamic response to load frequency problems. With regard to traditional controllers, the Fuzzy Logic Controller (FLC) can be more beneficial in solving large-scale problems.

Partial truths and multi-estimated truths are allowed by fuzzy logic. It is therefore particularly useful for problems that mathematical modelling can not easily express, because either the data is unavailable, incomplete, or the approach is too complex. The Fuzzy Logic Controller is designed to reduce variations in the output of devices.There are several studies on the power system with fuzzy logic controller consisting of three parts, namely fuzzifier, rule basis, and defuzzifier.

In this work ACE and ACE derivative are selected as the FLC input signals. The membership function is representation of the extent to which each member participates. There are different types of membership functions for each input and output typet. For input and output variable we use the triangular membership function in this analysis. Using FLC, they use seven membership functions to gain power. As the number of linguistic variables increases, both reaction quality and computational time improvements are increasing.

Hence, a choice is made in choosing the number of variables.

We derived 49 rules with two inputs each having 7 membership functions. The consequent rule is called the "THEN" part of the rule. FLC output is a linguistic attribute which must be converted to crisp meaning according to real world requirements. In this work Mamdani style defuzzification method is adopted among different methods.*ACE*

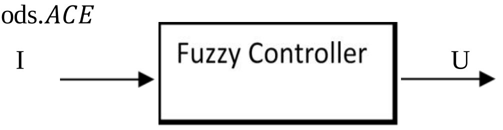

Fig.3: Block diagram of fuzzy logic controller

Membership Function: Membership function determines the fluffiness of a fluffy set, regardless of the discrete or continuous elements in the set. Membership function can be thought of as a methodology focused on experience rather than knowledge to solve scientific problems. A linear triangular membership function is utilised for both input and output variables. A collection of rules that uses the linguistic variables to describe the relationship between the input and output of the fuzzy controller we defined.

ACE dot								
		NB	NM	NS	ZE	PS	PM	PB
AC E	NB	PB						
	NM	PB	PM	PM	PM	PS	ZE	NS
	NS	PB	PM	PS	PS	ZE	NS	NM
	ZE	PM	PM	PS	ZE	NS	NH	NM
	PS	PM	PS	ZE	NS	NS	NM	NB
	PM	PS	ZE	NS	NH	NM	NM	NB
	PB	ZE	NS	NH	NM	`NB	NB	NB

IV. RESULTS AND DISCUSSION

Using PID and Fuzzy logic controllers, the MATLAB / SIMULINK model for automatic generation control of the four-area power system with GRC was developed for simulation, control and analysis.

Results for frequency deviation in different areas and change in tie-line power were obtained thus 1 percent change in area 1 and area 2 and 2 percent change in area 3 & area 4.The result supports better Fuzzy-PID than traditional PID controller. The findings were reported in Figs. 4–11. The parameters of power systems considered in simulation are as follows.

f = 50 Hz, R1 =R2= R3= R4 =3 Hz/ per unit MW, Tgi= Tg2= Tg3= Tg4= 0.2 sec, Tpi= Tp2= Tp3= Tp4= 20 sec; P tie, max = 200 MW ; Tr = 10 sec ; Kr = 0.5, H1=H2 =H3= H4 =5 sec ; Pri=2000MW, Tti= 0.3sec ; Kp1=Kp2=Kp3 = Kp4 = 120 Hz.p.u/MW ; Kd=4.0; Tw = 1.0 sec; B1=B2=B3= 0.425, B4=0.06 p.u.MW/hz;a=2*pi*T12=2*pi*T23=2*pi*T34=2*pi*T41=0.545, delPdi12= 0.01 delPdi34=0.02

The plot of four area power system frequency deviation is shown in Figure 4-11From the statistics, it can be seen that undershooting is almost the same for all areas with a fuzzy-PID controller.

The frequency deviation plot for area 1 with the Fuzzy-PID and PID controllers is shown in Figures 4 and 5.

The answer settles at 0.03 per cent steady at 44 sec Status error with Fuzzy-PID controller and 0.2 per cent steady status error with PID controller at 60 sec. In area 2 (Fig.6-7) an error of 0.11 percent is observed at 45 sec using fuzzy-PID and 61 sec using PID controller with 0.15 percent error. In area 3 (Figure 8-9), the settling time is 42 sec with 0.18 percent steady state error using the Fuzzy-PID controller and 63 sec with PID error of 0.2 percent Controller. The settling time in the fourth area (Figure 10-11) is 46 sec with a steady state error of 0.02 percent with fuzzy-PID and 60 sec with a PID controller error of 0.19 per cent.

In terms of settling time and steady state error, it is also evident from the above analysis that the Fuzzy-PID controller is better than the PID controller.

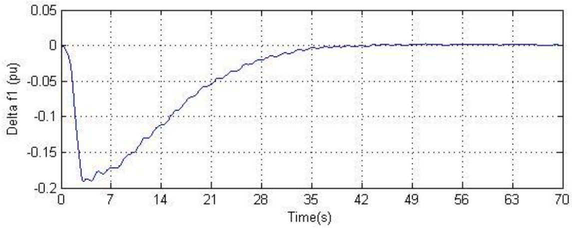

Fig.4: Frequency deviation in area 1 fuzzy-PID controller

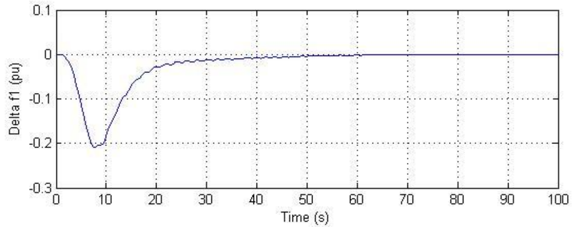

Fig.5: Frequency deviation in area 1 with PID controller

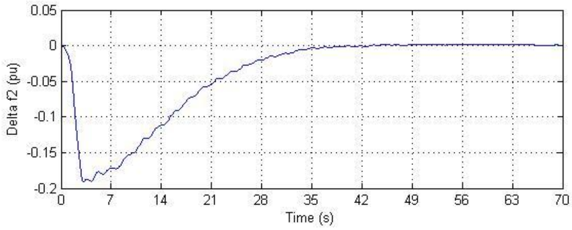

Fig.6: Frequency deviation in area 2with fuzzy-PID controller

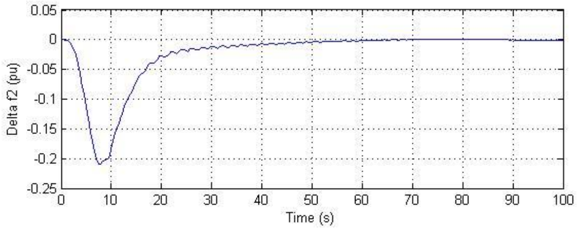

Fig.7: Frequency deviation in area 2 with PID controller

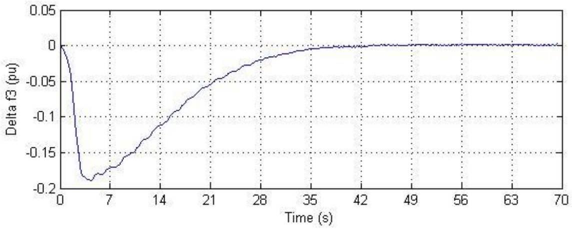

Fig.8: Frequency deviation in area 3 fuzzy-PID controller

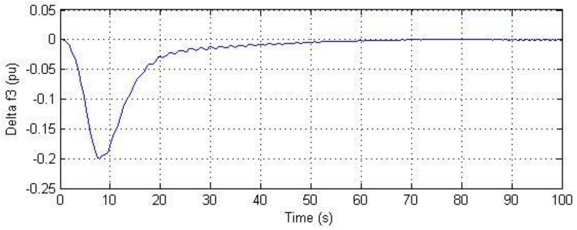

Fig. 9: Frequency deviation in area 3 with PID controller

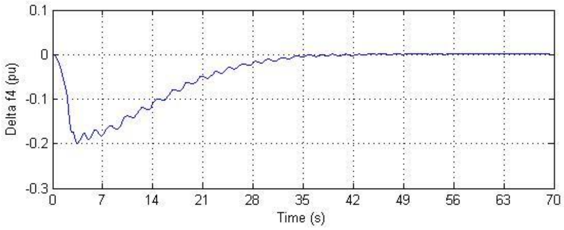

Fig.10: Frequency deviation in area 4 fuzzy-PID controller

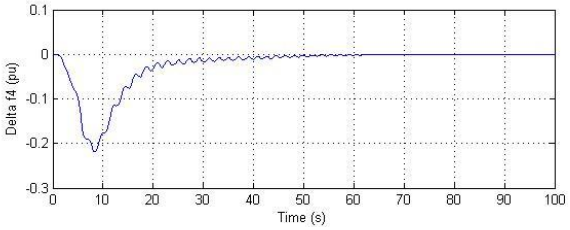

Fig. 11: Frequency deviation in area 4 with PID controller

V. CONCLUSIONS

The goal of this research is to develop a Fuzzy-PID controller to track a four-area(three thermal and one hydro) GRC frequency power system.

A comparative simulation results performance review verifies that the Mamdani FIS Fuzzy-PID controller is beneficial over traditional PID controller.

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