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FUZZY LOGIC CONTROLLER PLUS PROPORTIONAL INTEGRAL CONTROLLER BASED LOAD FREQUENCY CONTROL OF HYBRID GENRATOR NETWORK

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ABSTRACT

This paper is a study on the design of fuzzy logic controller plus proportional integral (FLC plus PI controller) based load frequency control (LFC) for hybrid generator network (HGN), which is the combination of the diesel generator and the solar PV panels. The different variations are considered as a step to the solar PV panels. The transfer function models of the HGN and the PV are simulated at first and then they can be linked with each other through Tie-Line. Next, in order to control the created disturbance of the network, a FLC plus PI controller is developed. The performance of complete model with FLC plus PI controller is verified at transient region through the computer simulation with help of the MATLAB/Simulink software platform. In comparison with the PI controller and the FLC, the simulation results are clearly evident that the designed controller is proficient over the PI controller and the FLC.

Keywords: *Hybrid Generator Network (HGN), Solar PV panels, Fuzzy Logic Controller (FLC), Proportional Integral (PI) controller, Load Frequency Control (LFC)*

1. INTRODUCTION

Currently, environmental pollution is a big issue because of the over utilizing of fossil fuels (non-renewable source) for example: coal, nuclear, diesel, etc., to produce electricity. Excessive use of fossil fuel cause harm for both human life and earth and it may even lead to scarcity of fuel. Keeping this factor in mind, many researchers have started to undergo a full-fledged research towards renewable sources such as solar energy, wind energy, hydro energy, etc. These energy sources are not offered in particular time they will not harm anything. Now, the power is generated by using both renewable and nonrenewable source. Among these renewable source, photovoltaic (PV) is much interesting because of its clean, steadiness operation and also, the cost of PV panel is less. The maximum power point tracking using stand alone PV has been reported [1]-[2]. Changes that happens in load power system, can affect the frequency and in addition it will make the power quality crisis on the customer super sensitive equipment's to evade. So, this frequency must be regulating inside the limit. In the power system the load changes are arbitrary without control and there is unbalance in real and reactive power. For controlling frequency in power system a load frequency control (LFC) is needed and it plays an essential task in power system control. The LFC helps to maintain the frequency and tie-line power within the set limit [3]. The conventional controllers such as proportional, proportional integral and proportional integral derivative are utilized for LFC. However, these control methods has the capacity to control the two areas, performed well under load variation, and good robustness. It also has some crisis such as damping oscillation, long settling time and maximum overshoot of frequency. As the load varies constantly the control is actually difficult due to the gain value of the controller is fixed of these controller [4]. The conventional controller plus artificial intelligent controller (AIC) use for LFC to control three area interconnected power system and also it enhances the system dynamic performance, reduces the oscillation & settling time [5]. Still, the conventional plus AIC is much complex, the main goal of the LFC is to maintain the steady state error as zero in an interconnected multi area power system without multifaceted control. As a result the

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research moves towards a single control such as fuzzy logic control (FLC) and it has been applied for power system control [6]-[8]. The FLC for two area system consist of thermal - thermal power system. However, the FLC has better control over the other controllers in dynamic operating conditions [9]-[10]. Three areas like HVDC and two AC tie-lines are interconnected in power system, which is controlled by LFC through FLC [11]. Sun is the key source for the PV panels. When the solar radiation is changed, the voltage is also changed except maximum power point tracking (MPPT) concept, which is used to make fixed output DC voltage from the positive output elementary split inductor type boost converter (POESITBC) and then an inverter is used to convert the DC voltage to AC voltage the AC supply is connected to the tie-line. The problems in the conventional schemes of the LFC in power system have been rectifying by this hybrid generator network (HGN).

In this paper, the PV panels with POESITBC network and power generator is connected to get appropriate power without creating any injury for the environment using FLC plus PI controller. The combination of PV panels and diesel generator is called as HGN. The performance of the complete model is validated at transient operating conditions using MATLAB/Simulink.

2. MODELING OF HYBRID GENRATOR NETWORK

The complete PV panel is made up of the collection of small solar cells joined together. This is either connected in series or parallel to made PV panel. The small solar cells do the similar operation of the PN junction diode. When it operates in forward bias the power will flow through it (refer the Fig.1).

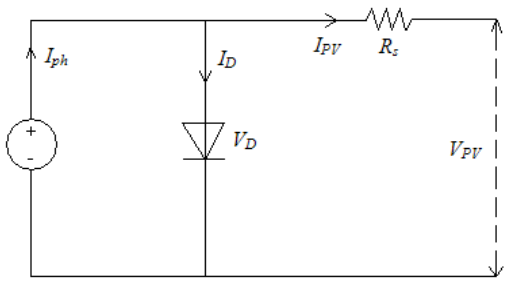

Figure 1: Solar cell equivalent circuit

In Fig. 1, the reference current is taken as I_{PV} and total resistance of the circuit is R_s. So, the equations (1) and (2) can be written as

$$I_{PV} = I_{ph} - I_{sat}\left(\frac{q(V_{PV} + I_{PV}R_s)}{(AKT-1)}\right) \quad (1)$$

$$I_{ph} = \left(\frac{\lambda}{1000}\right)[I_{SC} + K_I(T-25)] \quad (2)$$

The values applied in equation (2) are as follows:

I_{SC} = Short circuit current (A)
I_{PV}= Photovoltaic current (A)
I_{ph} = Photo current (A)
I_{sat} = Saturation current (A)
I_D = Diode current (A)
q = 1.602 X 10^{-19} (C)
R_s = Resistance (Ω)
λ = Solar Irradiance (W/m^2) = 1000
T=Temperature of solar array (^{o}C)
K=Boltzmann's constant
K_I = Temperature coefficient of I_{sc}

The PV panel output voltage is changing along with the solar radiation. And at the same time the output voltage is essential to regulate. As the result utilize suitable controller and then, the controlled output from the PV is applied as input for the POESITBC to step-up the output voltage (see Fig. 2).

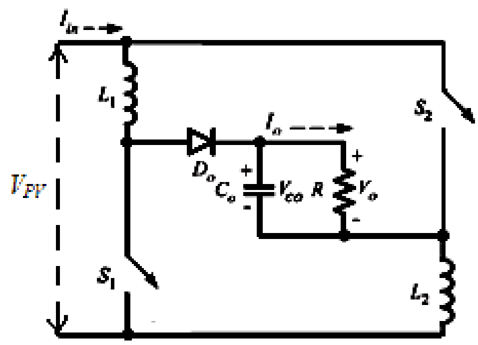

Figure 2: Topology of POESITBC

In mode 1, the switches S_1 and S_2 are turned on. Therefore, the voltage across L_1 and L_2 is input voltage V_{in} due to this the inductors are magnetized. At the same time the energy required by the load is delivered by output capacitor C_o.
The state – space equation for mode 1 can be given

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$$\begin{cases} L_1 \dfrac{di_{L1}}{dt} = V_{in} \\ C_0 \dfrac{dV_0}{dt} = \dfrac{V_0}{R} \end{cases} \quad \text{Switch ON} \tag{3}$$

In mode 2, S_1 and S_2 are turned off. The output diode D_o is in forward biased, inductors L_1 and L_2 and the dc source are connected in series. Due to this action the total energy was transfer to R and Co.
The state – space equation for mode 2 can be given as

$$\begin{cases} L_1 \dfrac{di_{L1}}{dt} = \dfrac{V_{in} - V_0}{2} \\ C_0 \dfrac{dV_0}{dt} = i_{L1} - \dfrac{V_0}{R} \end{cases} \quad \text{Switch OFF} \tag{4}$$

The operating specifications of POESITBC as follows:

f_{sw} = 100KHz (switching frequency)
V_{PV}(min) = 45.6V (Minimum output voltage)
V_{PV}(max) = 56.8V (Maximum output voltage)
V_o(max) = 230V (Maximum output voltage)
I_o = 0.97 A (Load current)
L_1, L_2 = 100μH
C = 300μF

Using equations (3) and (4), the transfer function model of the POESITBC is obtained and it can be expressed as equation (5)

$$\frac{-1.776e^{-15}S + 1.067e^{7}}{S^2 - 13.34S + 2.667e^{6}} \tag{5}$$

Transfer function model of diesel generator network can written in equation (6)

$$\begin{aligned} &\text{Generator} && \frac{K_G}{T_G s + 1} \\ &\text{Turbine} && \frac{K_T}{T_T s + 1} \\ &\text{Governor} && \frac{K_{GO}}{T_{GO} s + 1} \\ &\text{Re-heater} && \frac{K_R T_R s + 1}{T_G s + 1} \end{aligned} \tag{6}$$

The basic model of the diesel generator network is as shown in Fig. 3

3. DESIGN OF CONTROLLERS

In this study, the FLC plus PI controller is used to regulate the frequency deviation of the HGN (refer the Fig. 4).

3. 1 DESIGN OF FLC

The universal step-step design evaluation of the FLC is as follows:
Step 1: Identification of inputs and outputs,
Step 2: Fuzzification of the inputs,
Step 3: Rules and inference engine, and
Step 4: Defuzzification of the output.

In this case, the triangular membership function of FLC is chosen as the inputs (error and change in error) and its corresponding output of the controller (refer the Fig. 5). The fuzzy sets are [NB, NM, NS, Z, PS, PM, PB] where, NB (negative big), NM (negative medium) NS (negative small), Z (zero), PS (positive small), PM (positive medium), PB (positive big), respectively. Here, the FLC 49 rules are framed entirely based on the model performance, which is listed in the Table 1. Next, the centroid method (defuzzification-method) is utilized to complete the FLC operation and it can be engraved as (7)

$$c_{FLC} = \frac{\sum_{i=1}^{N} w_i . \theta_i}{\sum_{i=1}^{N} w_i} \tag{7}$$

Where, N is the optimum number of effective rules, θ_1 θ_2 …, θ_i represent the centroids of N membership functions which are assigned to c_{FLC} and w_i represents the firing strength of the ith rule.

3. 2 DESIGN OF FLC PLUS PI CONTROLLER

The PI controller is selected and employing the proficient regulation of frequency deviation of the HGN is illustrated in the Fig. 4. In this work, the PI controller, proportional gain (K_p) and integral times (T_i), are evaluated using Zeigler – Nichols tuning method using HGN. The PI controller parameters, proportional gain (K_p) and integral time (T_i), are obtained by using Zeigler–Nichols tuning method

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[14-15]. Using this method the values of K_p = 0.5 and integral gain K_i =Kp/T_i= 500 are found and its corresponding transfer function becomes

$$T(s)_{LPIC} = K_p(1+\frac{1}{T_i s}) \quad (8)$$

Then, control signal of the FLC plus PI controller can be expressed as (9)

$$C_{FLC\ plus\ LPIC} = C_{FLC} + T(s)_{LPIC} \quad (9)$$

4. SIMULATION RESULTS AND DISCUSSIONS

In this section is to discuss about the simulation results of the FLC plus PI controller based LFC for HGN in comparison with FLC and PI controller. The parameters of the HGN are listed in Table 2. Figs. 6, 7 and 8 show the diesel generator output, tie-line output and PV network output of the HGN using various controllers (FLC plus PI controller, FLC and PI controller) in transient operating conditions. From these figures and Table 3, it is clearly showed that the output of HGN using FLC plus PI controller has less overshoots, quick settling time and small steady state error in comparison with FLC and PI controller.

5. CONCLUSIONS

In this paper, the FLC plus PI controller based LFC for HGN has been constructed effectively using MATLAB/Simulink software platform. The main merits of this controller over the conventional controllers have stability during load variations, excellent transient and dynamic responses. The simulation results are provided to show the proficient of controller based LFC for HGN (combination of Diesel Generator and PV panel) at transient operating conditions in comparison with PI controller and FLC. In future, the current limit of this converter can be solving by using current controller.

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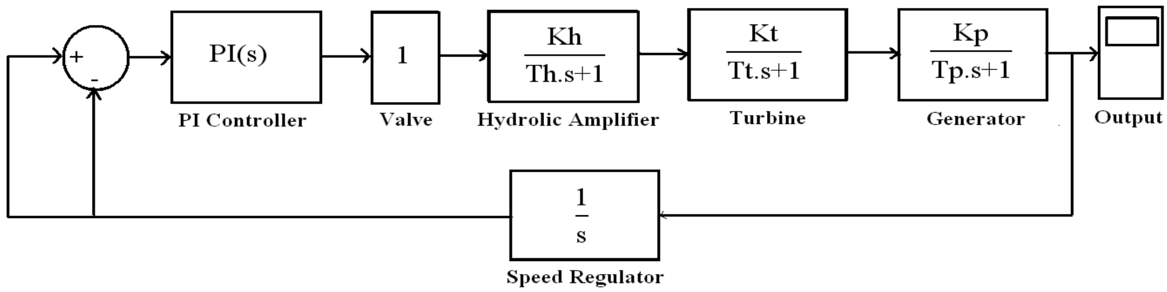

Figure 3: Block Diagram Model Of Diesel Generator Network

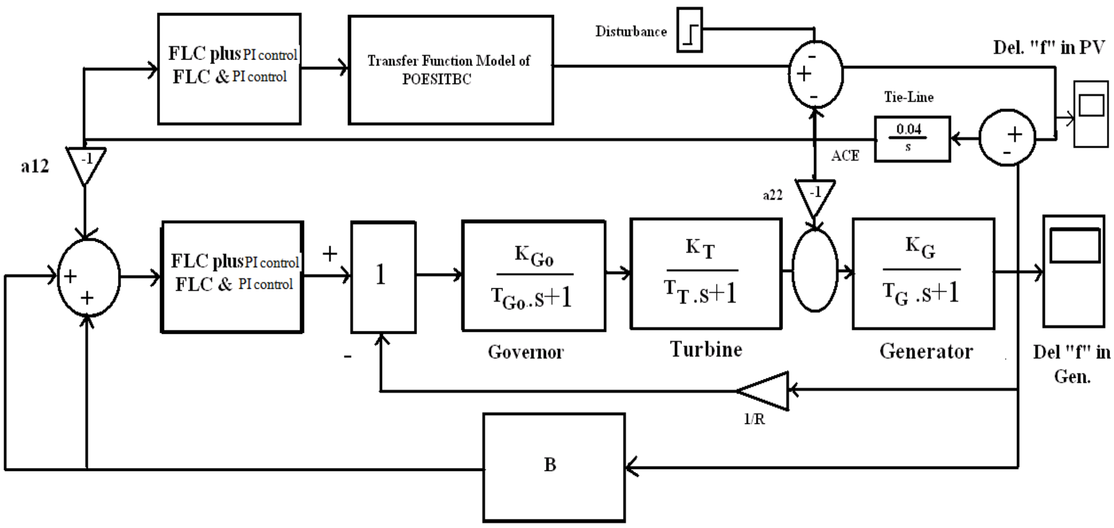

Figure 4: Block Diagram Based Transfer Function Model Of HGN Using Controllers

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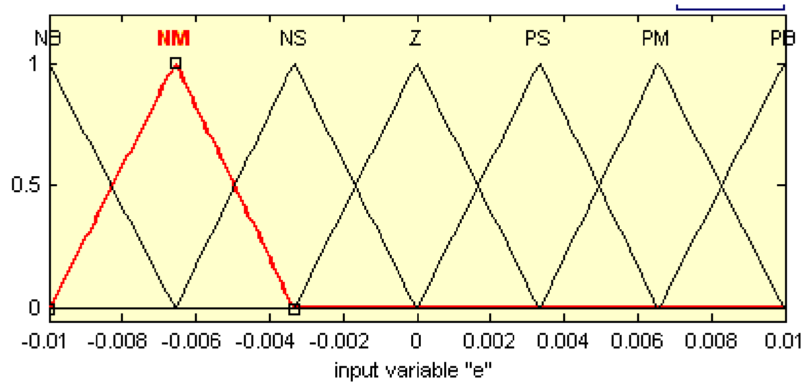
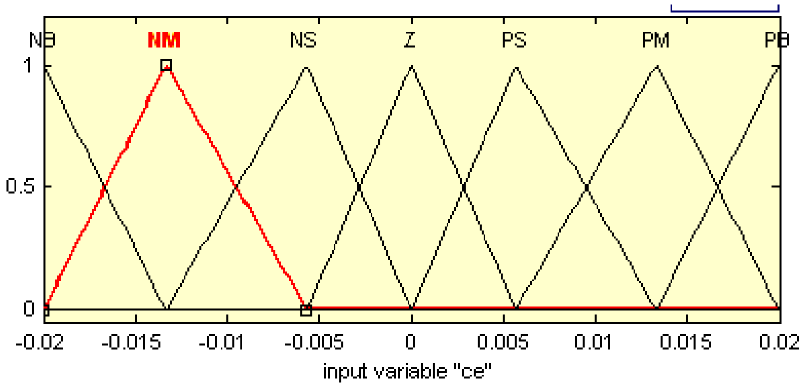
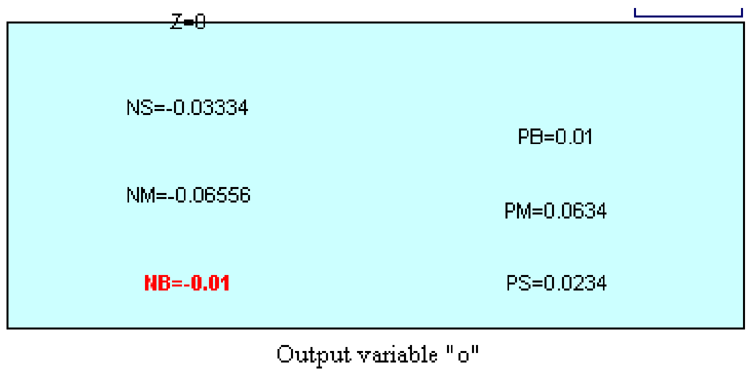


(a)



(b)



(c)

Figure 5: Triangular Membership's Functions Of FLC, (A) Error (E), (B) Change In Error (Ce), And (C) Output (O)

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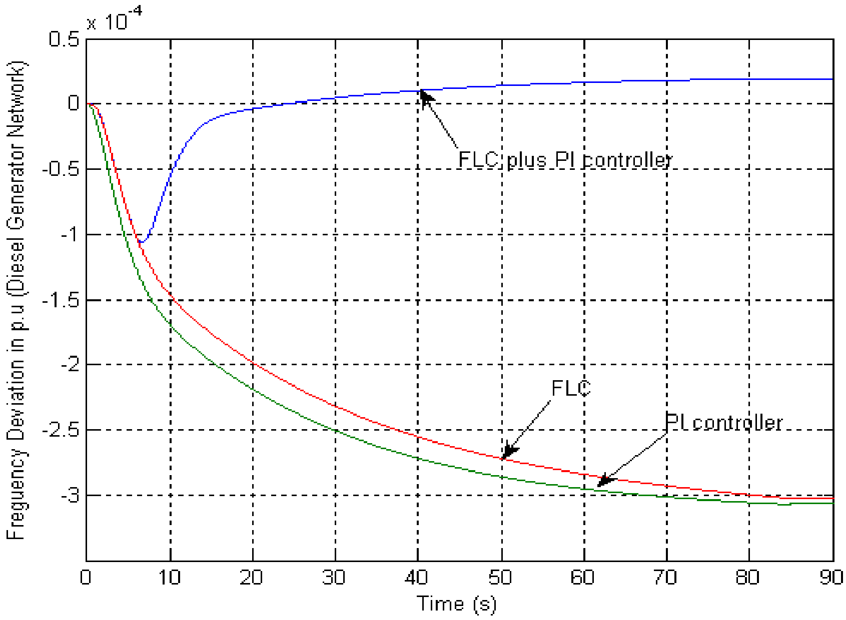

Figure 6: Diesel generator network output using various controllers

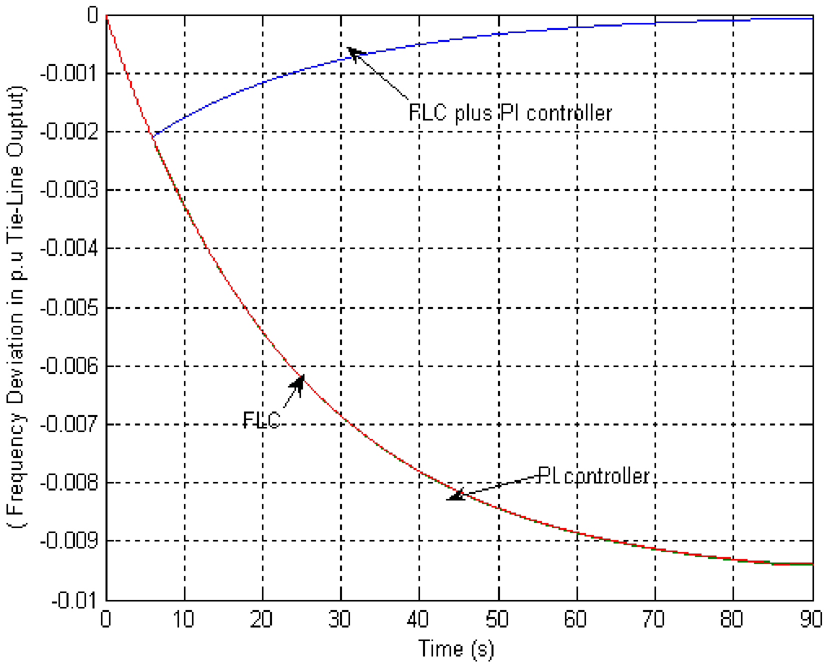

Figure 7: Tie-Line Output Using Various Controllers

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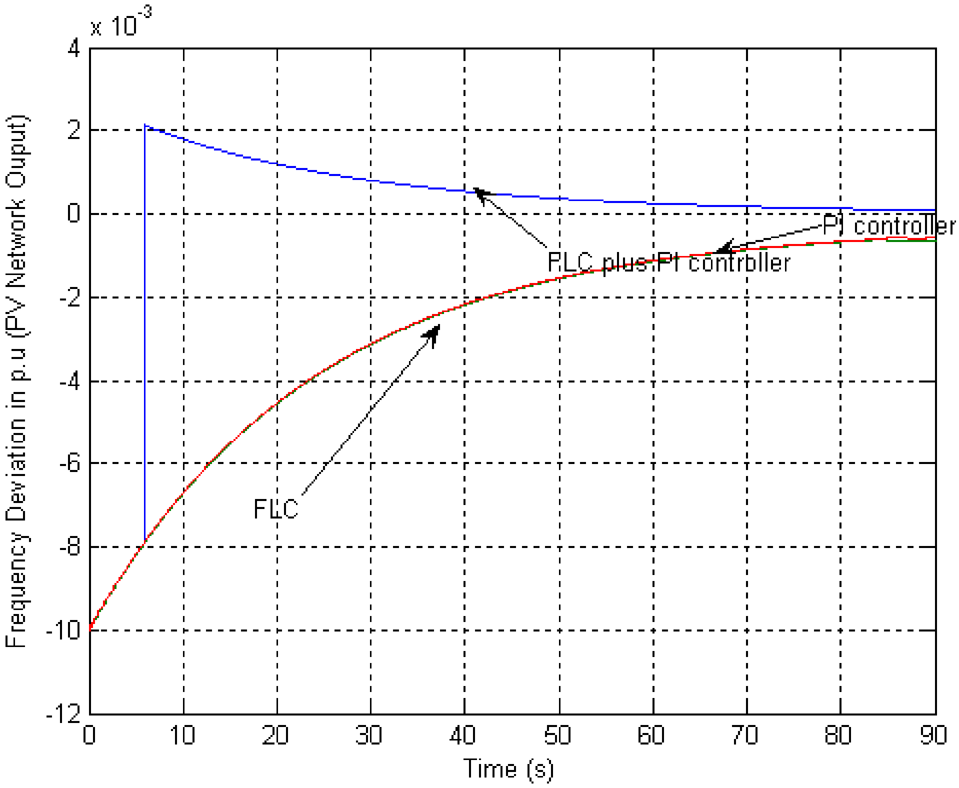

Figure 8: PV Network Output Using Various Controllers

Table 1: Fuzzy Rules Base Table Of HGN

ce \ e	NB	NM	NS	Z	PS	PM	PB
NB	NB	NB	NB	NB	NM	NS	Z
NM	NB	NM	NM	NM	NS	Z	PS
NS	NB	NM	NS	NS	Z	PS	PM
Z	NB	NM	NS	Z	PS	PM	PB
PS	NM	NS	Z	PS	PS	PM	PB
PM	NS	Z	PS	PM	PM	PM	PB
PB	Z	PS	PM	PB	PB	PB	PB

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Table 2: Specifications Of HGN

Parameters name	Symbol	Value
Regulation of the speed governor in generator	R	0.4 Hz/p.u MW
Hydraulic amplifier time constant of the thermal plant	T_{H1}	0.08 s
Time constant of turbine	T_T	0.3 s
Power system gain constant	K_G	120
Power system time constant	T_G	20 s
Hydro governor gain constant	K_{Go}	1.0
Hydro governor time constant	T_{Go}	0.08 s
Re-heater time constant	T_R	10 s
Synchronizing power coefficient	a12 and a22	-1
Frequency bias constant	β	0.8

Table 3: Performance Analysis Of HGN Using Different Controllers

Simulation Results	**Controllers**	**Transient Region**	
		Maximum Overshoots (mHz)	**Settling Time (s)**
Del. "f" in PV output	LPIC	-10.2	85
	FLC	-10	84
	FLC plus LPIC	-9.8	80
Del. "f" in Gen. output	LPIC	32	84
	FLC	31	82
	FLC plus LPIC	10	72
Del. "f" in Tie-Line	LPIC	-0.0092	85
	FLC	-0.009	84
	FLC plus LPIC	-0.002	80