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Comparison of Frequency Controllers for Frequency Control of PV Generator in a Grid Interconnected PV-Diesel System

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Abstract: Frequency is an important parameter which is to be controlled in a power system. In PV system power is fluctuating in nature due to changing insolation condition . Hence frequency has to be controlled . Fluctuating PV power causes frequency deviations in the power utilities when the penetration is large. Usually, an energy storage system (ESS) is used to smooth the PV output power fluctuations and then the smoothed power is supplied to the utility . Here, PI based frequency controller is implemented which is a fixed gain feedback controller. Then it is compared with a fuzzy based frequency controller ; Where fuzzy control is used to generate the PV output power command. This fuzzy control uses average insolation, change in insolation, and frequency deviation as the inputs. Fuzzy based frequency controller is found to be effective in performing duties like frequency control . PI Controller cannot compensate the parameter variations like insolation variations. They cannot adapt to changes in the environment. The settling time and peak time of PI controller is found to be more than Fuzzy controller. Simulation results shows that fuzzy based controller is more effective than conventional PI controller..Simulation platform used is MATLAB simulink.

Keywords*:* Frequency control ; insolation ; frequency deviation ; PI controller ; fuzzy logic**.**

I. INTRODUCTION

Frequency is an important parameter which is to be controlled in a power system . One of the inherent advantages of PV electricity generation is the absence of any mechanical parts (unless tracking of the sun is included). Professionally installed PV arrays are characterized by a long service lifetime, exceeding20 years, high reliability, and low maintenance requirements, which are highly desirable for remote area power supplies. In sunny locations**,** PV generators compare favorably with wind generators, despite the higher by the damage in strong winds. investment cost for PV.

The penetration of PV systems is rising. Two factors have been boosting this: improved generation efficiency of PV modules and governmental subsidies for the initial cost of residential PV generation systems. However, PV power fluctuates depending on the weather conditions*,* season, and geographic location, and may cause problems like voltage fluctuation and large frequency deviation in electric power system operation. To date, it has not been necessary for small PV generators to provide frequency-regulation services to the isolated utility. In the future, with an increasing penetration of PV generation, their impact upon the overall control of the power system will become significant**.** This will lead a situation, where the PV generators will be required to share some of the duties, such as frequency control. Therefore, for the large penetration of PV system's output power in the isolated utility, suitable measures must be applied to the PV system's side [5].

For the frequency control by the PV generator, a new control method based on simple fuzzy logic is proposed for the PV–diesel hybrid system [6]. This method uses fuzzy control to produce the output power command*.* Three inputs are considered for fuzzy control: frequency deviation of the isolated utility; average insolation; and change of insolation. The output power command of the system is decreased to response to a low frequency and is increased to response to a high frequency. Fuzzy based frequency control method is compared with frequency control using PI controller. It was proved that fuzzy controller has better performance than the latter.

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This paper is organized as follows. Section II provides thesystem description and methodology. It includes the modeling of PV ,Diesel generator and speed governor , Fuzzy logic controller design and PI frequency controller design. Section III describes the results and discussions. Conclusion is drawn in Section IV. Here the simulation platform used is MATLAB SIMULINK.

II. METHODOLOGY

The power utility used in this paper is shown in Fig. 1.This is actually a parallel PV–diesel system consisting of a diesel-generator set, a PV generator equipped with an ESS, an Inverter, grid and ac load.. The diesel generator supplies the load demand when no PV power or a /few PV power is available The isolated power system model used for simulation is shown in Fig. 2. where Si is the insolation, V_{oc} is the open circuit voltage of the PV array, I_{sc} is the short-circuit current of the PV array, P_{max} is the boost converter output power, P^*_{inv} is the command power of the PV Inverter, P_{inv} is the output power of the PV inverter, P^*_{ESS} is the ESS command power, P_{ESS} is the ESS output power, P_d is the generated power by diesel-generator set, R is the droop and K_i is the integral control gain of speed governor, T_{sm} is the time constant of the valve actuator servo mechanism, T_d is the time constant of diesel engine ,M is the inertia constant and D is the damping constant of the diesel-generator set, Δf_e is the frequency deviation, P_L is the ac load, and P_{sys} is the PV–diesel system's output power.

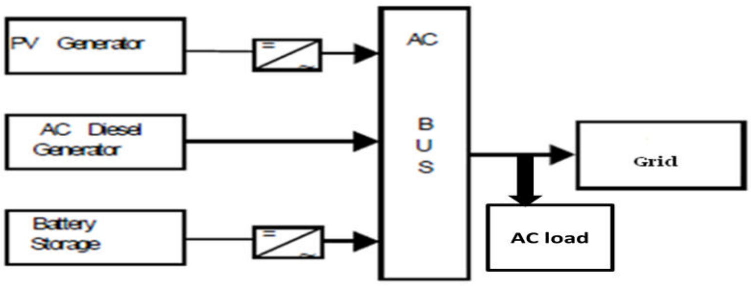

Fig. 1 Grid interconnected PV-Diesel system.

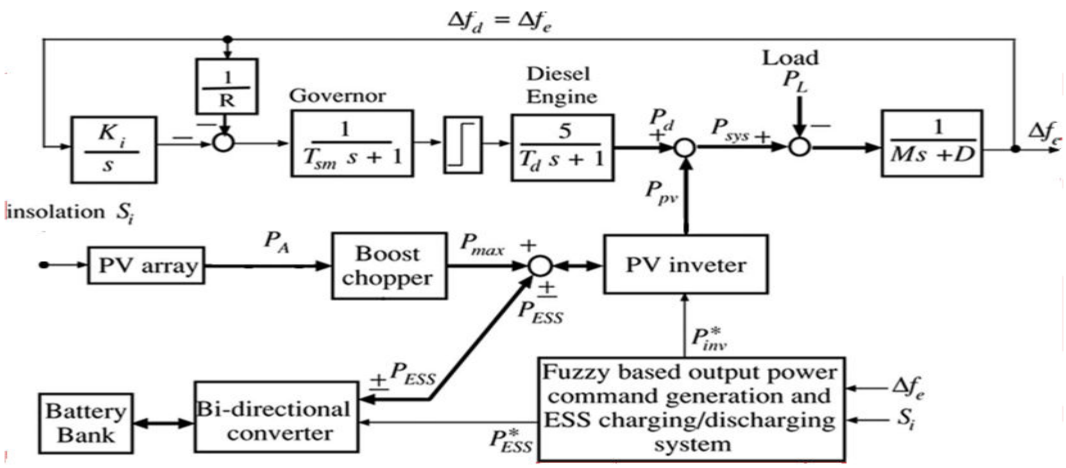

Fig. 2 Proposed model

A. Modelling of PV array

A photovoltaic system is a system which uses one or more solar panels to convert solar energy into electricity. It consists of multiple components, including the photovoltaic modules, mechanical and electrical connections and mountings and means of regulating and/or modifying the electrical output. The PV module is a nonlinear device and can be represented as a current source model, as shown in figure 3.The traditional I − V characteristics of a PV module, neglecting the internal series resistance, is given by the equation (1)

$$I_o = N_p I_g - N_p I_{sat}\left\{exp\left(\frac{qV_o}{AKT}\right) - 1\right\} - I_{rsh} \qquad (1)$$

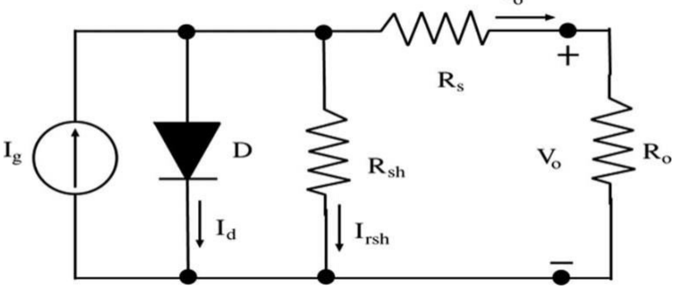

Fig. 3. Equivalent circuit of a PV module.

Where I_o and V_o are the output current and output voltage of the PV module, respectively, I_g is the generated current under a given insolation, I_{sat} is the reverse saturation current, q is the charge of an electron, K is the Boltzmann's constant, A is the ideality factor, T is the temperature (K) of the PV module, N_p is the number of cells in parallel, and I_{rsh} is the current due to intrinsic shunt resistance of the PV module. The saturation current I_{sat} of the PV module varies with temperature according to the following equation (2).

$$I_{sat} = I_{or}\left[\frac{T}{T_r}\right]^3 exp\left[\frac{qE_g}{KT}\left(\frac{1}{T_r} - \frac{1}{T}\right)\right] \qquad (2)$$

$$I_g = I_{sc}\frac{S_i}{1000} + I_t(T - T_r) \qquad (3)$$

where I_{or} is the saturation current at T_r , T_r is the reference temperature (K), E_g is the band-gap energy, I_t is the short circuit current temperature coefficient, and I_{sc} is the short-circuit current of PV module. The current due to the shunt resistance is given by (4)

$$I_{rsh} = \frac{V_{oc}}{N_s R_{sh}} \qquad (4)$$

Where Ns is the number of cells in series and R_{sh} is the internal shunt resistance of the solar module. For the solar MATLAB/SIMULINK based computer simulations

B.Diesel Generator Model.

The standard model of the diesel generator and speed governor is illustrated in Fig 4. This model is widely used and describes well the dynamic behavior of small diesel generator sets, as it has been shown in [2]. The diesel engine and the valve actuator servomechanism are represented by first-order lags, with time constants T_d and T_{sm} Parameters of the speed governor are the droop R and the integral control gain K_i The objective of the integral control is to eliminate the steady-state frequency error. The diesel engine must be able to follow the variation of loads and PV power. The size of frequency variation indicates how well the diesel and its governor maintain the balance of active power in the system .Under transient conditions, the frequency and the voltage will not be absolutely constant because PV power and load variations change constantly

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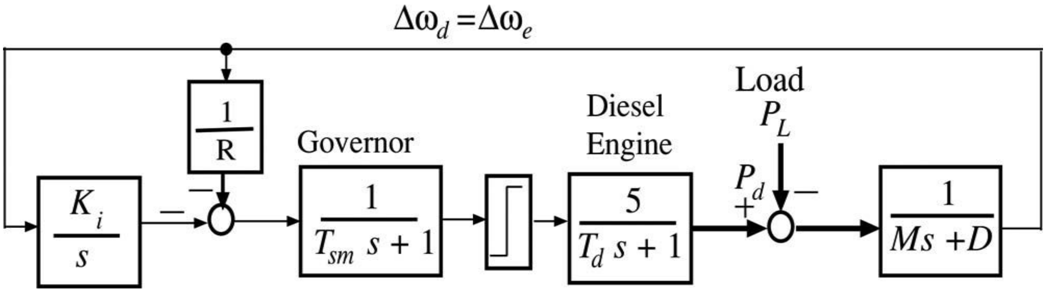

Fig. 4. Standard model of diesel generator and speed governor.

C . Modelling of PV inverter.

Circuit diagram of the PV inverter is shown in the figure 5. Here the inverter that is being used is a three phase 3level diode clamped inverter .Here diode is used as the clamping device to clamp the dc bus voltage so as to achieve steps in the output voltage. Three-level inverters have a circuit configuration consisting of (3) DC bus levels and (12) IGBT's. A 3-level inverter has 3 levels of switching namely 0, $+V_{dc}/2$, and $V_{dc.}$ Advantages of using multilevel inverter is that as the number of levels is high the harmonic content can be reduced. Lower switching frequencies can be used and hence reduction in switching losses.

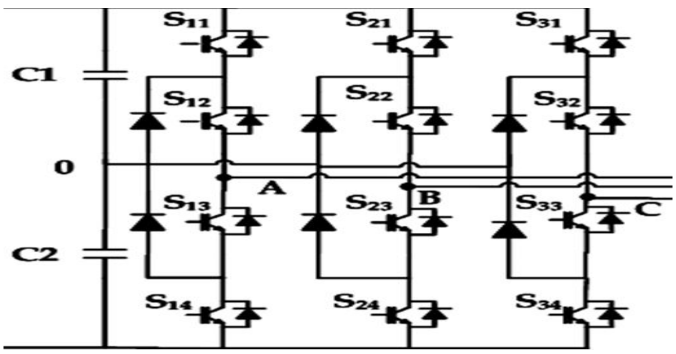

Fig. 5. Three phase three level diode clamped inverter

D. Fuzzy Logic Controller Design

Here a simple active power control according to the load and isolation variations is presented by using the fuzzy logic. In order to control the output power of PV system considering the power utility and insolation conditions, output power command P^{*}_{inv} is generated by the output power command generation system shown in Fig. 6. This command system consists mainly of two fuzzy reasonings. Fuzzy reasoning is described by a set of "if-then"-based fuzzy rules. Fuzzy reasoning [3]-[4] is effective when mathematical expressions are difficult by inherent complexity, nonlinearity, or unclarity. Therefore, no deterministic model is required.

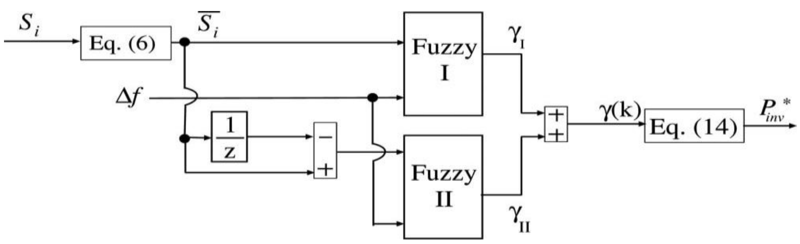

Fig. 6. Output power command generation system.

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TABLE I-FUZZY RULES OF FUZZY REASONING I

		Δf_e						
		NB	NM	NS	ZO	PS	PM	PB
$\bar{S}_i^*$	NB	NS	NS	NM	NM	NB	NB	NB
	NM	ZO	NS	NS	NM	NM	NB	NB
	NS	ZO	ZO	NS	NS	NM	NM	NB
	ZO	PM	PS	ZO	ZO	ZO	NS	NM
	PS	PB	PM	PM	PS	PS	ZO	ZO
	PM	PB	PB	PM	PM	PB	PB	ZO
	PB	PB	PB	PB	PM	PM	PS	PS

NB=Negative Big NM=Negative Medium NS=Negative Small
PB=Positive Big PM=Positive Medium PS=Positive Small
ZO=Zero

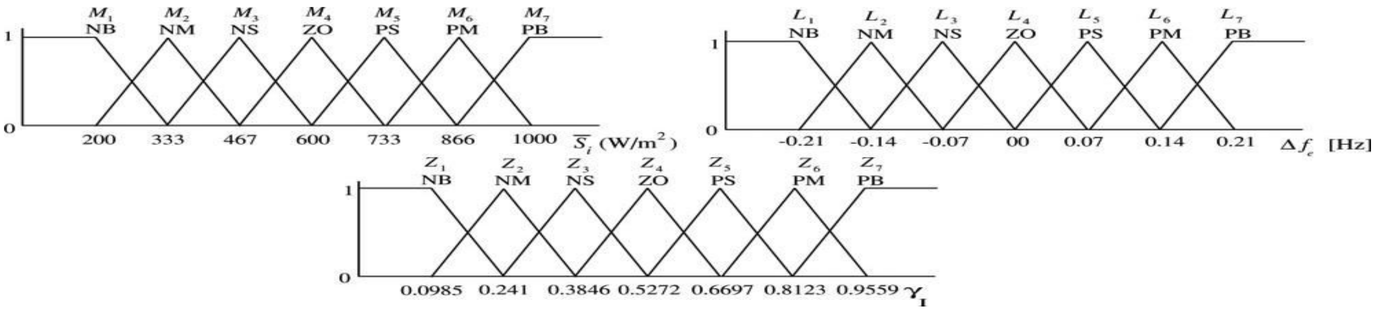

Fig. 7. Membership functions of fuzzy reasoning I .

For fuzzy reasoning I there are two inputs frequency deviation Δf_e , and the average insolation $\vec{S}i$ which is given by (5).

$$\overrightarrow{S}i = \int_{t-T}^{t} Si\, dt \qquad (5)$$

where *t* is the present time, *T* is the integral interval, an S_i is the instantaneous insolation of PV system. Fuzzy rules and membership functions of fuzzy reasoning I are shown in Table I and Fig. 7, respectively. Here, the power control of the PV system according to the power system condition is accomplished by using frequency deviation Δf_e as the input of the fuzzy reasoning. Fuzzy rules and membership functions that yield an output to reduce the frequency deviation are defined by trial and error.

TABLE II
FUZZY RULES OF FUZZY REASONING II

		Δf_e						
		NB	NM	NS	ZO	PS	PM	PB
ΔS_i	NB	NB	NB	NB	NM	NM	NS	ZO
	NM	NB	NB	NM	NM	NS	ZO	PS
	NS	NB	NM	NM	NS	ZO	PS	PM
	ZO	NM	NM	NS	ZO	PS	PM	PM
	PS	NM	NS	ZO	PS	PM	PM	PB
	PM	NS	ZO	PS	PM	PM	PB	PB
	PB	ZO	PS	PM	PM	PB	PB	PB

NB=Negative Big NM=Negative Medium NS=Negative Small
PB=Positive Big PM=Positive Medium PS=Positive Small
ZO=Zero

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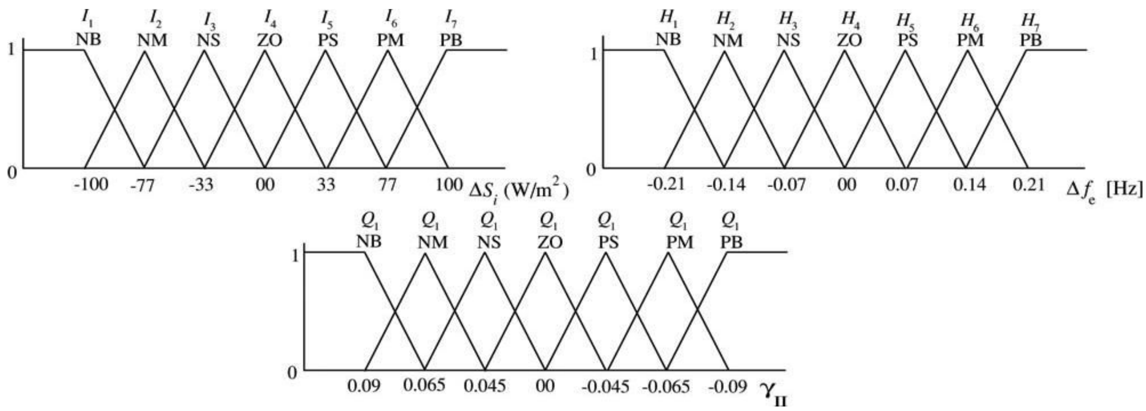

Fig. 8 . Membership functions of fuzzy reasoning II.

Frequency deviation Δf_e and the change of insolation ΔS_i are used as inputs o fuzzy reasoning II, where ΔSi is expressed as follows.

$$\Delta S_i = S_i(t-1) - S_i(t) \qquad (6)$$

Power command that depends on the power system condition rather than the insolation condition is decided by using the frequency deviation Δf_e as input for both of the fuzzy reasonings. In addition, the change of insolation ΔS_i is used as one of the inputs since the objective is to decrease the frequency deviation .Fuzzy rules and membership functions of fuzzy reasoning II are shown in Table II and Fig 8. respectively. rules and parameters of membership functions are determined to prevent the increase of frequency deviation

The sum of the outputs of fuzzy control I γ_I and fuzzy control II γ_{II} become the central power command by using the following:

$$P^*_{inv} = P_{rated}\{\gamma(k) + \frac{\gamma(k+1)-\gamma(k)}{Ts} f(t)\} \qquad (7)$$

where P_{rated} is the rated power of the PV system, T_s is the sampling time, and $f(t)$ is a periodic function .

E. Comparison of Fuzzy Based Frequency Controller and PI Based Frequency Controller.

Frequency controller based on PI controller is shown in the Fig 9 .

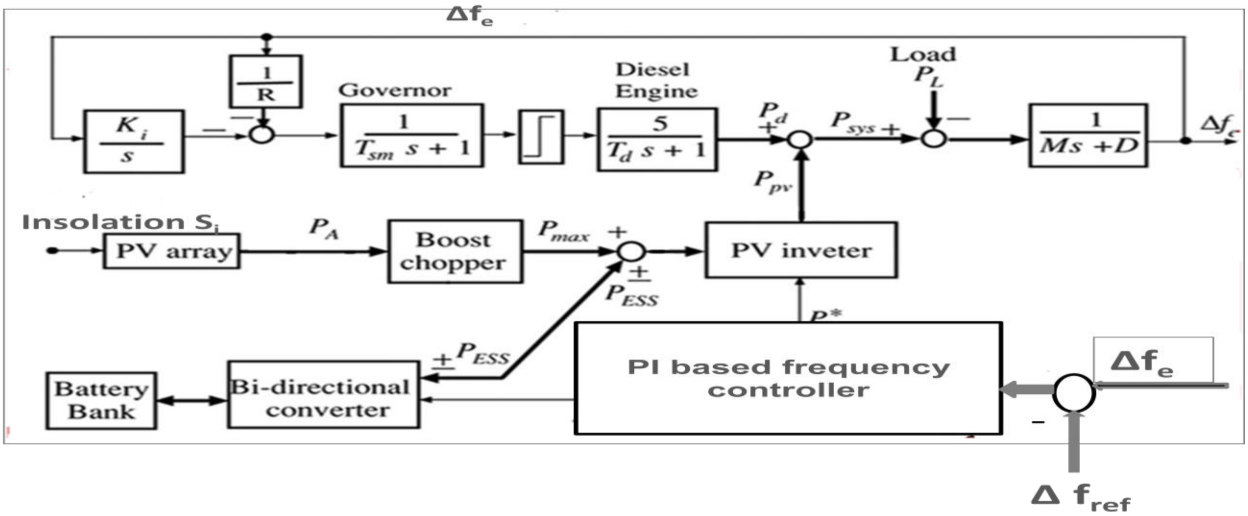

Fig. 9 . Proposed system with PI based frequency controller.

III RESULTS AND DISCUSSIONS

In this paper, effectiveness of the proposed method to provide frequency regulation is examined by simulation with the system model [5] and parameters mentioned in Table III. Simulation parameters of the power utility, the PV array, the power conversion system, and the diesel generator are shown in Table III. Here, the integral time *T* is 100 s, and the sampling time *Ts* to obtain discrete value of output power command is10 s. The total simulation time is 30 min.

Table III Simulation Parameters

Parameters of small power system	
Inertia constant ,*M*	0.150 puMW.s/Hz
Damping constant, *D*	0.008 puMW/Hz
Governor time constant, T_{sm}	0.10 s
Diesel time constant, T_d	5.0 s
Speed regulation,*R*	2.5 Hz/puMW

Parameters of PV array	
Rated output power	225 kW
Open circuit voltage, V_{oc}	584 V
Short circuit current, I_{sc}	526.50 A
Number of module in series	16
Number of module in parallel	65
Total no. of cells	62,400

Proportional constant ,K_p	1
Integral constant, K_i	-1

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A.Frequency control performance with Fuzzy controller.

From the simulation results shown in Fig 10 the variation of inverter and diesel power according to change in insolation condition is shown. Fig 11. a shows the frequency deviation with fuzzy controller. From the figure we can understand that the frequency deviation settles to zero at 8 seconds From these results we can understand that the power produced by the proposed method is controlled according to the load variation to minimize the frequency deviations. Therefore ,it can be said that the proposed method can provide frequency control effectively.

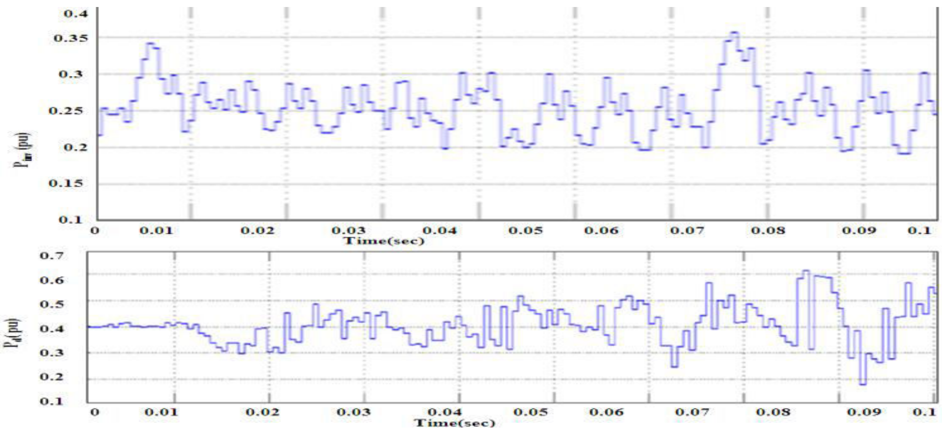

Fig 10 a.PV power supplied to the utility 10.b Diesel power supplied to the utility.

B. Comparison of PI and Fuzzy controller

The frequency response of both PI and fuzzy controller is compared.. The frequency response curve with PI controller mentionedin Fig 9 is shown in Fig 11 .b in which the frequency deviation settles to zero only at 8 seconds .Comparison of the frequency control performance of both fuzzy and PI controller is shown below.

Table IV
Comparison of PI and Fuzzy Controller

Title	Settling time(sec)	Peak time(sec)
Fuzzy	6.5	2.3
PI	8	2.7

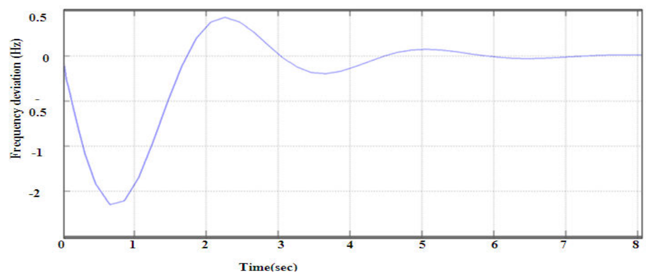

Fig11 .a Frequency deviation with fuzzy controller.

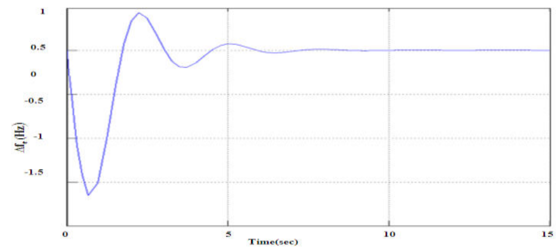

Fig 11.b Frequency deviation with PI controller

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IV.CONCLUSION

This paper presents a fuzzy based frequency control method for the PV generator in a PV–diesel grid connected system considering load condition and insolation condition.. This method uses fuzzy control to produce the output power command. Three inputs are considered for fuzzy control: frequency deviation of the isolated utility; average insolation; and change of insolation. The output power command of the system is decreased to response to a low frequency and is increased to response to a high frequency.PV-Diesel system is extended to grid and is found to be effective in performing duties like frequency regulation. Comparison of fuzzy with PI based frequency controller is done. As PI controllers are fixed gain feedback controllers , they cannot compensate the parameter variations like insolation variations.They cannot adapt to changes in the environment. Therefore it can be concluded that the proposed method is effective in performing frequency control.

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