Load Frequency control of a Renewable Hybrid Power System with Simple Fuzzy Logic controller

Swati Rawat
Department of Electrical Engineering,
G.B.P.E.C.,
Pauri ,India
rawat.swatieee@gmail.com

Bhola Jha
Department of Electrical Engineering
G.B.P.E.C.,
Pauri ,India
bholajhaeee@gmail.com

Manoj Kumar Panda
Department of Electrical Engineering
G.B.P.E.C.,
Pauri ,India
pandagbpec@gmail.com

Bibhuti Bhusan Rath
Department of Electrical Engineering,
G.B.P.E.C.,
Pauri ,India
bibhutibhusanrath2007@gmail.com

***Abstract*— In this paper an attempt has been made to control the frequency of stand-alone hybrid power system with a simple fuzzy logic control technique which can be used to fulfill the load demand at remote areas. This hybrid system consists photovoltaic (PV) system, diesel engine generator (DEG) and micro hydro power system. The model of fuel cell system is introduced as an energy storing element to improve frequency deviation due to mismatch between power generation and load demand. The proposed methodology is simulated in MATLAB and tested for 24 hours load conditions. A comparative evaluation of frequency deviation for proposed hybrid system in presence of both control techniques reflects the improvement in frequency variation in the presence of fuzzy controller as compared to PID controller.**

Keywords*— *Fuel cells (FC); micro hydro plant; Photovoltiac (PV); diesel engine generator (DEG); fuzzy logic; PID controller

I. INTRODUCTION

The complexity has been increased by use of different type of power sources in modern power systems. Renewable energy sources are commonly used as an alternate source of energy in present time. For various applications, in the electric power system they are progressively replacing nonrenewable energy sources [1]. Energy generation schemes from renewable energy sources such as solar, micro hydro plants, wind, bio-fuels etc are popular because of the many advantages for example low transmission losses, eco friendly nature and price effectiveness.

The integrated renewable energy scheme which consists PV, micro hydro and fuel cell system as an energy storage scheme is considered a bright option to overcome the nonrenewable sources like coal, gas and fuel [2]. There are some technical challenges caused by renewable energy sources. These problems are of maintaining and protecting of the RESs, contributing in the system voltage and frequency regulation. [3] .Hydrogen is an attractive fuel because it is pollution free [4]. In comparing of battery storage, the FC storage system is suitable because of its inherent high mass energy density leakage from storage tank. For installation it is very easy [5]. CHP (combined heat and power) is a very useful application of fuel cell units. [6]

PV system is the best answer for rural power supply area. Solar light at once changed into electricity using PV system [7]. In reference [8] an isolated power system has been discussed which contains micro hydro and PV system. This hybrid system is useful for low priced electricity production in rural area. In research paper [9] a good management has been represented of fuel cell with MHP (micro hydro power). The installation, design and realistic operation of MHP (micro hydro power) system has been proposed by researchers in Taiwan [10]. The dynamic performance of a solar (PV) system with MHP (micro hydro power) system demonstrated in [11].

Reference [12] has discussed DG (distributed generation) to offer maintenance of stability such as voltage regulation, frequency regulation, etc. Reference [13] has presented low-signal stability of an isolated hybrid RES (renewable energy system) which is connected to isolated loads using time-domain simulations. Reference [14] attempted a control approach for active power i.e. frequency control of a hybrid DG (distributed generation) system. Reference [15] has discussed the dynamic operation of an isolated system, containing a DEG (diesel engine generator) and a wind turbine. References [16] proposed the dynamic modeling of grid connected FC (Fuel cell) system.

There are several studies for the FLC (fuzzy logic controller) based frequency control schemes [17].Some technique differs from each other by type of input and output fuzzy sets and the membership functions, or by the type of control rules, inference engine, and the defuzzification method. There are several defuzzification methods to convert fuzzified output into crisp signal.

This paper concentrates on the control and modeling of PV, MHP (micro hydro), DEG hybrid energy system, which account for the popular of RES installed today. This type of promising application of RES (renewable energy system) is very useful for rural areas. In this paper an intelligent approach using FLC (fuzzy logic) based frequency controller in hybrid system has discussed. The FC (fuel cell) system acts as an ESS (energy storage system). To demonstrate the effectiveness of the proposed control scheme, the result is compared with PID controlling technique using Ziegler-Nichols technique. Section II provides the system description and methodology in present paper. Section III describes simulation results and their analysis. Section IV provides conclusion.

ISBN: 978-1-5090-1666-2/16/$31.00 ©2016 IEEE

II. SYSTEM DESCRIPTION AND METHODOLOGY

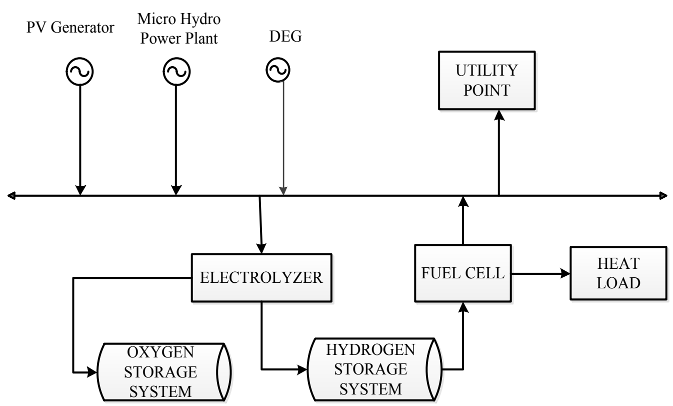

Fig. 1.Stand-alone hybrid power system with energy storage as fuel cell system.

A stand alone hybrid power system has been presented in figure 1. It consists micro hydro, PV power, DEG, fuel cell, electrolyzer and a hydrogen storage facility, which is connected to a variable loads. H_2 stored in hydrogen storage system, which consists of all equipment, which converts the hydrogen in volume format to, stored in storage tank. H_2 has been used as input to the fuel cell system.

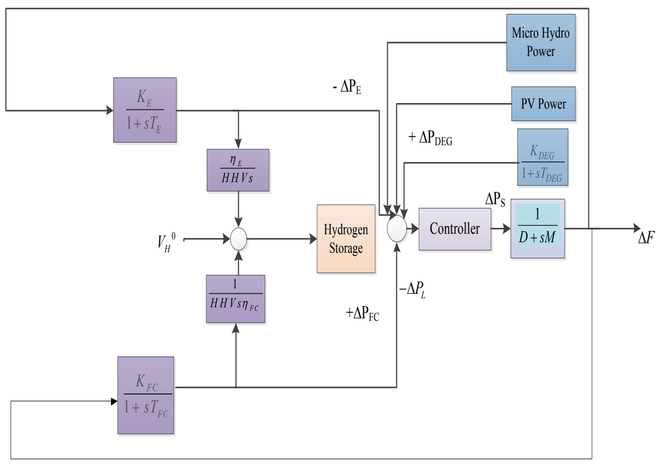

Fig. 2.Mathematical block diagram of hybrid model.

TABLE I. SPECIFICATION OF THE INTEGRATED RENEWABLE ENERGY SYSTEM

K_{FC} = 0.03, and T_{FC} = 3s	System power rating =1 MW
K_{DEG} = 5 , and T_{DEG} = 5s, R =.5	Fuel cell power = 10 KW, DEG. Power = 30 KW, Peak PV Power = 50 KW, MHP Power = 100KW Electrolyzer Power = 10KW
K_E = 0.1,andT_E = 0.05s	H_2 max. volume = 500Nm^3, H_2 min. Volume = 60 Nm^3, Intial H_2 Vol. = 250Nm^3
M = 10, and D = 0.8	η_E = 85%, η_{FC} = 50% , HHV =3.509 Kwh/Nm^3, Frequency 50 Hz

A mathematical model of hybrid power generation system has been presented in figure 2. A block diagram describes the modeling of the hybrid power system containing PV, MHP,FC and DEG. Block diagram represents the mathematical analysis of each block separately. Change in total generated power can be determined as-

$$\Delta P_T = \Delta P_{PV} + \Delta P_{FC} + \Delta P_{MHP} + \Delta P_{DEG} - \Delta P_E \quad (1)$$

Where ΔP_V, ΔP_{FC}, ΔP_{MHP}, ΔP_{DEG} and ΔP_E are the change in-PV generation, fuel cell power, micro hydro power generation ,diesel engine generator and power consumption by the electrolyzer in per units

Control strategy has determined by the difference between power demand ΔP_D and change in total generation ΔP_T.

$$\Delta P_S = \Delta P_T - \Delta P_D \quad (2)$$

Where ΔP_S is net change in power.

The system frequency variation ΔF is calculated by-

$$\Delta F = \frac{K_{PS}}{1+T_{PS}} \Delta P_S \quad (3)$$

There is an inbuilt time delay between system frequencies .The transfer function for system frequency deviation to per unit power deviation can be represented as:

$$\Delta F = \frac{1}{D+sM} \cdot \Delta P_S \quad (4)$$

$$D = \frac{1}{K_{PS}} , \quad M = \frac{T_{PS}}{K_{PS}}$$

Where M and D are, the equivalent inertia constant and a damping constant in per unit of the hybrid power system.1 MW power generation has been considered as base value for the whole system. [18]

The transfer function for system frequency variation to per unit fuel cell power is expressed by

$$\Delta P_{FC} = \frac{K_{FC}}{1+sT_{FC}} \cdot \Delta F \quad (5)$$

The transfer function of the electrolyzer is expressed by

$$\Delta P_E = \frac{K_E}{1+sT_E} \cdot \Delta F \quad (6)$$

All specifications related to proposed hybrid system has been mentioned in table I.

A. Micro hydro power system

Flow of water has potential energy. In micro hydro power system, power comes from converting potential energy of flowing into useful mechanical power for turbines. This power is converted into electricity using generator.

A MHP (micro-hydropower) system is generally classified as having a generating power of less than 100 kW [19].

MHP (micro-hydro power) is the small-scale harnessing of energy from falling water; for example, harnessing enough water from a local river to supply power in remote area. In table II, parameters for the modeling of MHP have been mentioned.

TABLE II. PARAMETERS AND RATINGS FOR MICRO HYDRO POWER SYSTEM [20]

Turbine	Francis
Selected design Head	28 m.
Rated Capacity	40-110%
Rated Power	100Kw

$$P_R = Q_R\, 9.8 H \eta_T \eta_G \tag{7}$$

Where P_R= Rated power of Generator (KW), Q_R= Rated capacity in % (discharge), η_T = % Efficiency of Turbine, η_G = % Efficiency of generator.

Figure 3 shows variation in discharge of water in a day and figure 4 represent a curve between turbine efficiency and discharge in percentage for a MHP.

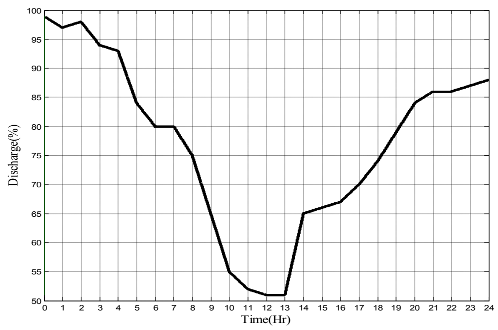

Fig. 3.Variation in discharge of water.

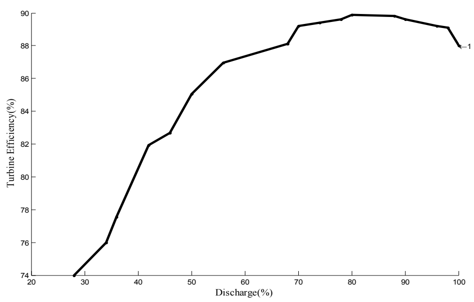

Fig. 4.Curve between turbine efficiency and discharge.

B. Diesel Engine Generator Model

Standard model of DEG (diesel engine generator) system contains, speed governor, diesel engine, droop connected to a power system. The typical model of the DEG (diesel engine generator) with speed governor is illustrated in block diagram form in figure 5.

Transfer Function Equation of Diesel generator and speed governor is as follows,

$$P_d = -\left(\frac{1}{R} + \frac{K_I}{s}\right)\left(\frac{1}{T_{sg}s+1}\right)\left(\frac{K_{\deg}}{T_{\deg}+1}\right)\Delta f_e \tag{8}$$

Where:

P_d= Diesel Engine Generator Power

K_I = Integral gain constant

R = Speed regulation

T_{sg} = Speed Governor Time constant

K_{deg} = Diesel Engine gain constant

T_{deg} = Diesel Engine time constant

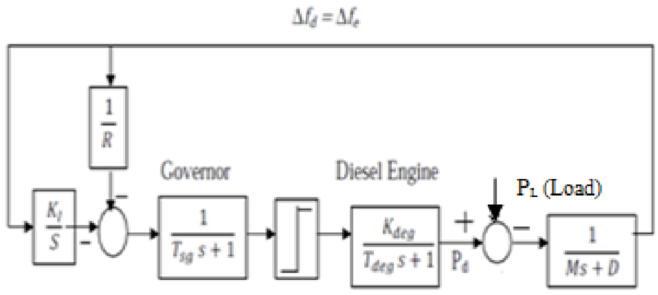

Fig. 5.Standard model of DEG .[21]

C. PV Model

The simplest equivalent circuit of a solar cell is current source parallel with a diode is shown in figure 6. The output of the current source depends on the sun light which falls upon the cell.

Equation of ideal solar cell which represents the ideal PV (photovoltaic) model is [22]

$$I = I_L - I_R\left[\exp\left(\frac{V}{AV_i}\right) - 1\right] \tag{9}$$

Where:

"I_L" is photocurrent (A); "I_R" is reverse saturation current (A); "V" is diode voltage (V); "V_i" is thermal voltage, "A" is diode ideality factor.

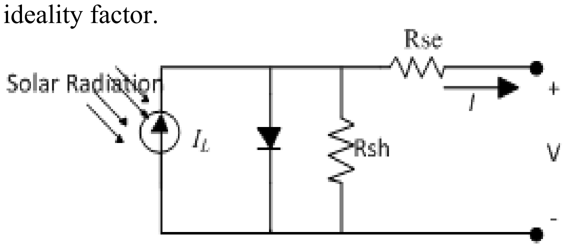

Fig. 6. Equivalent circuit diagram of PV model.

D. Energy Storage System Model

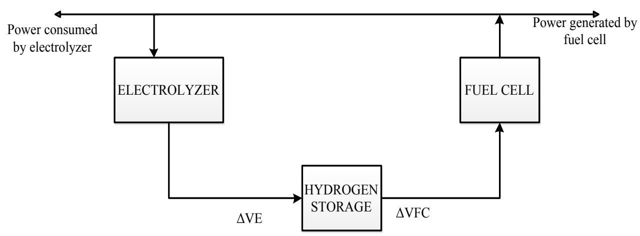

Fig. 7.Operation of fuel cell with hybrid system.

$$\Delta V_E = \frac{\eta_E}{HHV} \times \frac{\Delta P_E}{S} \quad (10)$$

$$\Delta V_{FC} = \frac{1}{HHV\eta_{FC}} \times \frac{\Delta P_{FC}}{S} \quad (11)$$

$$V_H = V_{H(initial)} + \Delta V_E - \Delta V_{FC} \quad (12)$$

Where ΔV_E=Net change in H_2 volume due to processing of electrolyzer, ΔV_{FC}=Change in H_2 volume due to process of fuel cell, ΔP_{FC}= Change in fuel cell power ΔP_E= Change in power consumption by electrolyzer, V_H= Net H_2 volume stored in tank, η_E= Efficiency of electrolyzer, η_{FC} =Efficiency of fuel cell, HHV=Higher heating value of H_2. [23]

E. Fuzzy Logic Controller Design

Fuzzy Logic is a more useful controlling technique to avoid frequency variation in hybrid renewable system [24]. Fuzzy logic controller has been designed to minimize fluctuation in load frequency for proposed hybrid system. Following rules have been used for the hybrid system

If input is NL then output is NL.
If input is Z then output is Z.
If input is PL then output is PL.

Where NL is negative large, Z is zero and PL is positive large. Figure 8 shows rule viewer for the simplified fuzzy logic controller.

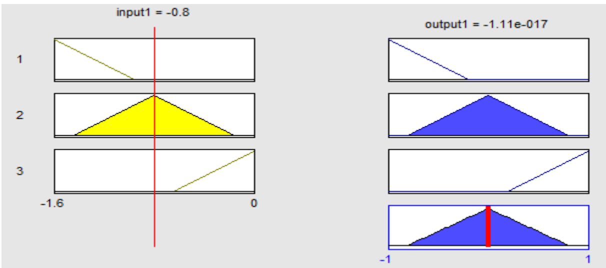

Fig. 8. Rule Viewer.

F.PID Controller Design

A PID controller is represented by the following transfer function in the continuous s domain:

$$G(s) = K_P + K_D s + \frac{K_I}{s} \quad (13)$$

Where K_P is the proportional gain, K_I is the integral coefficient and K_D is the derivative coefficient. PID controller is tuned through ziegler-nichols tuning technique as mentioned in table III.

TABLE III. ZIEGLER-NICHOLS TUNING FORMULA FOR PID CONTROLLER AND OBTAINED VALUES AFTER TUNING.

Controlling Parameters	K_P	K_I	K_D
Z-N Criteria	$0.6K_U$	$P_U/2$	$P_U/8$
Obtained Parameters	120	20	5

Where K_U ultimate gain and P_U is ultimate period of one cycle after getting sustained oscillation.

G. ESS (energy storage system) Control strategy

Figure 9 shows a flow chart which represents a control strategy of ESS (energy storage system). Fuel cell system is used here as an ESS. Frequency of power system is inversely proportional to load demand of consumer. To maintain stability in power system, load frequency must remain constant. When variation in frequency becomes negative, fuel cell system will produce power to fulfill load demand. Before its operation volume of hydrogen of tank will be compared with maximum volume. If it is less than its maximum volume, then electrolyzer runs which will produce hydrogen as a fuel for fuel cell. If change in frequency is positive, fuel cell does not supply power and extra power supply to the electrolyzer, If there is zero variation in frequency it means generation is equal to load demand i.e. standstill condition.

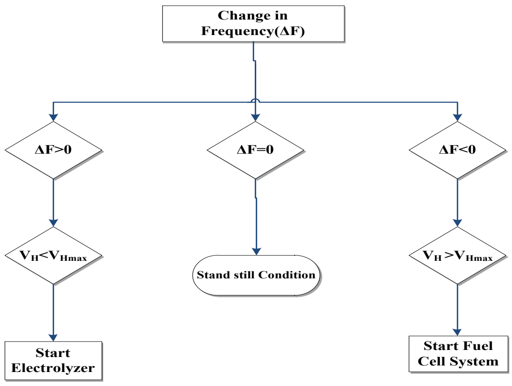

Fig. 9. Flow chart of methodology.

III. SIMULATION RESULTS & ANALYSIS

This section represents time domain simulation analysis for 24 hours in MATLAB software. To reduce complicated calculations, all output and input responses of the hybrid system shown in per unit value. Real-time simulation results of PV model are also analyzed. Real-time demand load is taken from a substation of G.B. Pant Engineering College, Pauri (Uttarakhand). Variation in load demand with respect to real-time has been shown in figure 11.

Figure 10, figure 12 and figure 13 shows variation in MHP, PV and FC power in per unit according to load demand of consumer. Figure 14 shows variation in frequency when hybrid system is not connected to any controller. The maximum variation in frequency is up to 50.7 Hz and minimum variation point is at 48.1 Hz. For comparing the simplified fuzzy and PID controller, simulation tests are carried out and performances of the proposed control methods are evaluated (figure 15 and 16). The proposed simplified fuzzy controller regulates the load frequency variation quite better than classical PID controller. The simplified fuzzy logic controller has suitable performance in terms of settling time as well as minimizing of frequency deviation. Table IV represents a comparative analysis of performance of both controllers with proposed hybrid system.

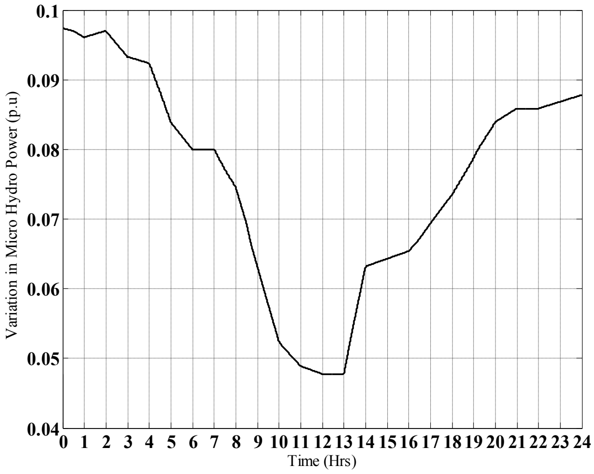

Fig. 10. Variation in micro hydro power.

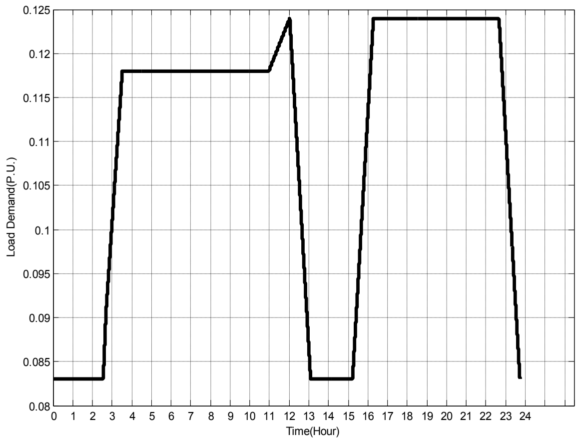

Fig.11 .Variation in load demand.

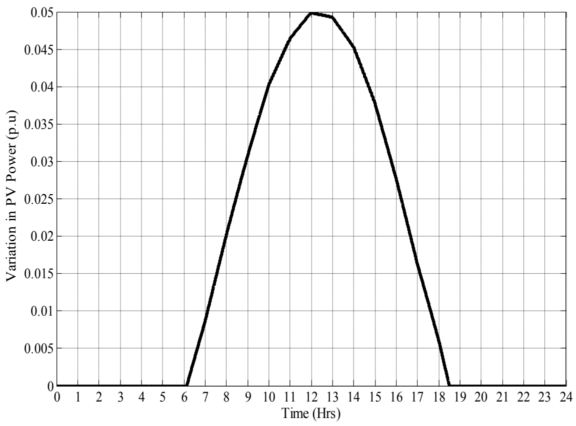

Fig.12. Variation in PV power.

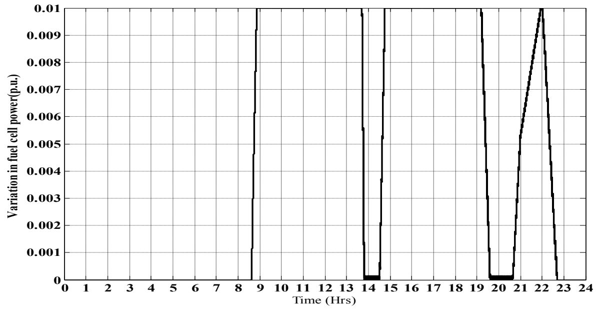

Fig.13.Variation in fuel cell power.

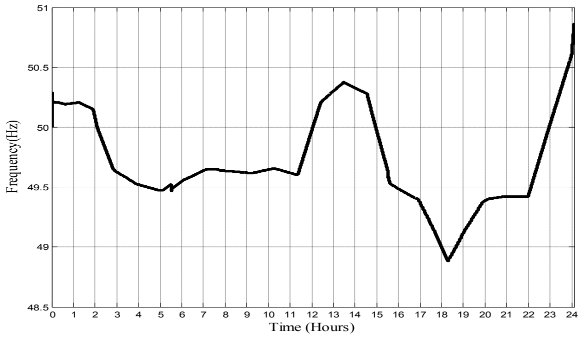

Fig. 14.Variation in frequency without controller.

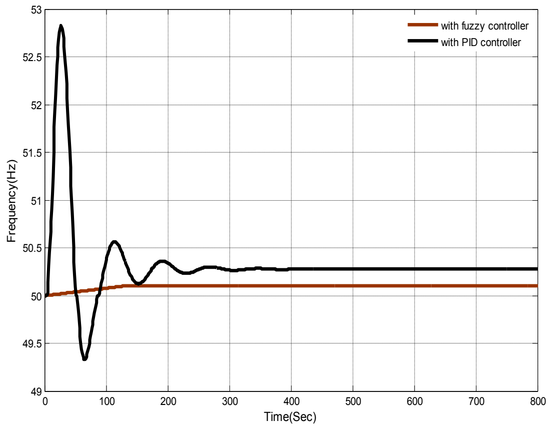

Fig.15.Variation in frequency for 800 seconds.

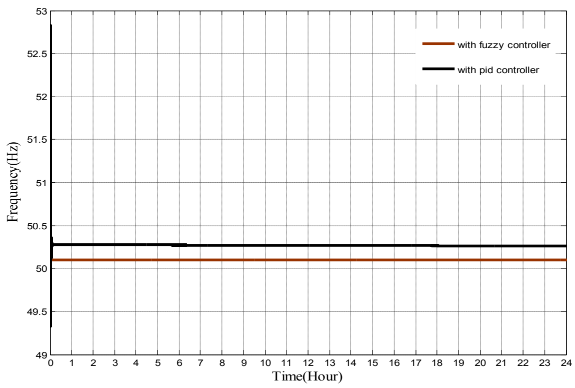

Fig.16. Variation in frequency for a day.

TABLE IV.PERFORMANCE ANALYSIS OF CONTROL TECHNIQUES USED IN PROPOSED HYBRID SYSTEM.

Transient response characteristics/Controller	**PID**	**Fuzzy**
Settling time	400 sec	150 sec
Rise time	300 sec	120 sec
Peak Time	40 sec	100 sec

IV. CONCLUSION

In this paper two control techniques have been tested and compared for the load frequency control of proposed hybrid system consisting photovoltaic (PV) system, diesel engine generator (DEG) and micro hydropower system. In practice, PID controllers are commonly used that provide poor performance in regulating the frequency fluctuation for the hybrid system. With response to this challenge in the present work, a simple fuzzy logic controller is proposed, tested and compared. This is found the performance of fuzzy controller is superior to PID in terms of settling time, rise time, peak time, minimizing the frequency deviation and diminishing the transients. The simulation results obtained from MATLAB/Simulink demonstrating the effectiveness of proposed fuzzy control technique in comparison of PID controller.

REFERENCES

[1] H. Chen, R. Ye, X. Wang and R. Lu, "Cooperative Control of Power System Load and Frequency by Using Differential Games," in *IEEE Transactions on Control Systems Technology*, vol. 23, no. 3, pp. 882-897, May 2015.

[2] Leon Freris and David Infield, "Renewable energy in Power Systems", John Wiley & Sons, U.K., 2008.

[3] T. Zhou and B. François, "Energy management and power control of a hybrid active wind generator for distributed power generation and grid integration," *IEEE Trans. Ind. Electron.*, vol. 58, no. 1, pp. 95–104, Jan. 2011.

[4] M. Patterson, N. F. Macia and A. M. Kannan, "Hybrid Microgrid Model Based on Solar Photovoltaic Battery Fuel Cell System for Intermittent Load Applications," in *IEEE Transactions on Energy Conversion*, vol. 30, no. 1, pp. 359-366, March 2015.

[5] P. Thounthong *et al.*, "DC Bus Stabilization of Li-Ion Battery Based Energy Storage for a Hydrogen/Solar Power Plant for Autonomous Network Applications," in *IEEE Transactions on Industry Applications*, vol. 51, no. 4, pp. 2717-2725, July-Aug. 2015.

[6] Bhubaneswari Parida, S. Iniyan, Ranko Goic, "A review of solar photovoltaic technologies", Science Direct Renewable and Sustainable Energy Reviews 15, pp.1625–1636, January 2011.

[7] Wandhare, R.G.; Thale, S.; Agarwal, V., "Reconfigurable hierarchical control of a microgrid developed with PV, wind, micro-hydro, fuel cell and ultra-capacitor," Applied Power Electronics Conference and Exposition (APEC), 2013 Twenty-Eighth Annual IEEE , vol., no., pp.2799,2806, 17-21 March 2013.

[8] Sharaf, A.M.; El-Gammal, A.A.A., "Optimal PID-self regulating controller for micro hydro-fuel cell green Energy Management Scheme," Electric Power and Energy Conference (EPEC), 2010 IEEE , vol., no., pp.1,6, 25-27 A.

[9] Kusakana, K.; Munda, J.L.; Jimoh, A.A., "Feasibility study of a hybrid PV-micro hydro system for rural electrification,"AFRICON '09. , vol., no., pp.1,5, 23-25 Sept. 2009.

[10] Li Wang; Dong-Jing Lee; Jian-Hong Liu; Zan-Zia Chen; Zone-Yuan Kuo; Huei-Yuan Jang; Jiunn-Ji You; Jin-Tsang Tsai; Ming-Hua Tsai; Wey-Tau Lin; Yeun-Jong Lee, "Installation and practical operation of the first micro hydro power system in Taiwan using irrigation water in an agriculture canal," Power and Energy Society General Meeting - Conversion and Delivery of Electrical Energy in the 21st Century, 2008 IEEE , vol., no., pp.1,6, 20-24 July 2008.

[11] Rawat, Swati; Singh, Shailendra; Gaur, Kshitij, "Load frequency control of a hybrid renewable power system with fuel cell system," Power India International Conference (PIICON), 2014 6th IEEE , vol., no., pp.1,6, 5-7 Dec. 2014.

[12] In-Su Bae, Jin-O Kim, Jae-Chul Kim and C.Singh, "Optimal Operating Strategy for Distributed Generation Considering Hourly Reliability worth". IEEE Trans. On Power Systems, V0l.19 No.1, February 2004

[13] Ray, P.K.; Mohanty, S.R.; Kishor, N., "Dynamic modeling and control of renewable energy based hybrid system for large band wind speed variation," Innovative Smart Grid Technologies Conference Europe (ISGT Europe), 2010 IEEE PES , vol., no., pp.1,6, 11-13 Oct. 2010.

[14] Amin Hajizadeh, Masoud Aliakbar Golkar, "Intelligent power management strategy of hybrid distributed generation system", Science Direct, Electrical Power and Energy systems 29, pp. 783-795, June 2007.

[15] NishadMendis, kashem M. Muttaqi. Saad Sayeef, Sarath Perera, "Hybrid Operation of Wind- diesel-Fuel Cell Remote Area Power Supply System", IEEE ICSET 2010, Kandy Shri Lanka, 6-9 December 2010.

[16] C.j. Hatziadoniu, A. A. Lobo, F. Pourboghrat, M. Daneshdoost, "A Simplified Dynamic model of Grid-Connected Fuel-Cell Generators", IEEE Transactions On Power Delivery, vol.17, no.2, pp. 467-473, April 2002.

[17] H. Bevrani and P. R. Daneshmand, "Fuzzy logic-based load-frequency control concerning high penetration of wind turbines," IEEE Syst. J., vol. 6,no. 1, pp. 173–180, Mar. 2012.

[18] Singh, S.; Singh, A.K.; Chanana, S., "Operation and control of a hybrid photovoltaic-diesel-fuel cell system connected to micro-grid," Power India Conference, 2012 IEEE Fifth , vol., no., pp.1,6, 19-22 Dec. 2012.

[19] Tony Tung, Jinxing Huang, Ghanashyan Ranjitkar: ‘’ Emerging Canadian Technology for Small Hydropower ‘’, Hydro vision 2006 Conference, July 31 – August 4, 2006.

[20] "Standards /manuals/Guidelines for small hydro development Electro-Mechanical Works– Selection of Turbine and Governing System for Hydroelectric Project" Sponsor:Ministry of New and Renewable Energy Govt. of India Lead Organization, Alternate Hydro Energy Center Indian Institute of Technology Roorkee May 2011.

[21] Manoj Datta a, Tomonobu Senjyu, Atsushi Yona, Toshihisa Funabashi, "A fuzzy based method for leveling output power fluctuations of photovoltaic-diesel hybrid power system", Science Direct Renewable Energy 36, pp. 1693-1703, January 2011.

[22] Chen Qi, Zhu Ming, "Photovoltaic Module Simulink Model for a Stand-alone PVSystem", Science Direct International Conference on Applied Physics and Industrial Engineering, Physics Procdia 29, pp. 94-100, 2012.

[23] Magnus Korpas and T.Holen, "Operation planning of hydrogen Storage connected to wind power operating in a power market", IEEE Trans. On Energy Conversion, Vol. 21, No.3, pp. 742-49, September 2006.

[24] M. Mohamed Thameem Ansari, S. Velusami, "DMLHFLC (Dual mode linguistic hedge fuzzy logic controller) for an isolated winde-diesel hybrid power system with BES (battery energy storage) unit", Science Direct Energy 35, pp. 3827-3837, 1 July 2010.