Frequency Regulation of Microgrid through PID tuning

Swati Jain[1] Kaushal Sen[2]
[1,2]Department of Electrical and Electronics Engineering
[1,2]Oriental College of Technology, Bhopal, India

Abstract— This paper presents an independent detached microgrid including solar, wind, diesel generator (DG), electrolyzer, fuel cell (FC) as power producing source and BESS, flywheel as vitality stockpiling component. The produced hydrogen by an electrolyzer is utilized as fuel for a FC. The force framework recurrence veers off for the abrupt change in load request. The yield intensity of sources is managed by utilizing regulator with the end goal that frequency of the framework is controlled. Regulator utilized is relative in addition to essential in addition to subordinate (PID). Burden Disturbance Rejection (LDR) is utilized for tuning of proposed half breed framework's regulator gains. The framework reaction of LDR strategy is contrasted and gives better results than the old style strategy.

Keywords: Load Disturbance Rejection, Aqua Electrolyzer, Fuel Cell, Diesel Generator, Battery Energy Storage System, Fly Wheel, Frequency and Power Deviation, Proportional, Integral And Derivative Control, Wind Power System, Solar/Pholtovoltaic System, Chien-Hornes-Resnick

I. INTRODUCTION

In the present quickly developing world, vitality in any structure is of utmost significance. Among the distinctive vitality types, electric vitality is one of the most significant types of vitality and one can't envision the existence without electric vitality in nowadays. Customarily, this vitality prerequisite has been met by providing the vitality through long transmission. Usually traditional source, for example, hydro, atomic, coal and diesel are utilizing. Presently a-days, it has become an intense assignment to meet the prerequisites because of expanding request just as ecological limitations. Thus the individuals, including the specialists just as strategy producers, are taking a gander at the new idea known as distributed generation (DG). DGs are little limit generators, ideally utilizes sustainable power source sources(RES), situated at scattered areas. The power creating sources in DG are called as disseminated vitality assets (DERs). These DGs interconnected together to shape a force network of littler limit, known as microgrid[1].

For the most part, DGs are situated in nearness to the load centers, which overcomes the long transmission. The microgrid may work in a self-ruling mode or it can work in a matrix interconnected mode, chose by the working conditions. Since, the idea of microgrid envolves numerous little limit generators, may likewise be with variable power yield, associated together requires profoundly organized activity among the various units to keep up the framework stability[2]-[3].

The different sorts of small scale generations utilized in a microgrid can be arranged into two categories specifically essential sources comprising of sun oriented and wind vitality frameworks and optional sources, for example, diesel generator, water electrolyzer , battery and flywheel [4]-[6]. The sun based and wind fall into the classification of not accurately unsurprising vitality sources in which the power fluctuates with time i.e., not a steady force source. This outcomes in force and recurrence changes in the microgrid. To conquer this difficult auxiliary sources are utilized to flexibly capacity to adjust the expansion in load request or the decrease in power age. Because of the postponement in the yield attributes of optional sources, the recurrence motions are as yet present in the microgrid [7]-[8]. Subsequently there is a need of planning appropriate regulators for optional hotspots for ideal usage of vitality and to keep up least frequency deviations.

In the ordinary Automatic Generation Control (AGC), droop characteristics shows the variation of power with frequency [9]. Technique depicted in ziegler and Nichols has been utilized for the tuning of ordinary PID controller[11]. The regulator gains once tuned for a given working point are just appropriate for restricted working point changes. Hence, the utilization of the ordinary PID regulator doesn't meet the prerequisites of the hearty presentation [12]. Essentials of LDR are represented in MATLAB. The consequences of applying the LDR PID regulator with regular PID regulator are compared. Reproduced results show that the LDR PID regulator gives improved powerful execution than fixed addition ordinary regulator. The LDR regulator additionally shows better transient execution for load disturbances [20-23].

II. MODELLING OF MICROGRID

The considered isolated microgrid consisting of wind generator (300 kW), PV (300 kW), diesel generator (400 kW), fuel cell (200 kW), aqua-electrolyser (100 kW) and battery (30 kWh). The all power from inexhaustible sources and from the controllable sources is equivalent to 600 kW. The battery is utilized for providing power just during transient period.[10]

The block diagram of the proposed framework is appeared in Fig.1. The power provided to the load is the aggregate of yield powers from wind and PV, diesel generator, energy unit, battery vitality stockpiling framework and fly wheel. The aqua electrolyzer is utilized to retain the variances of wind and sun and produce the hydrogen gas which is utilized as contribution to energy unit generator. The mathematical modelling of sources is given in this section.

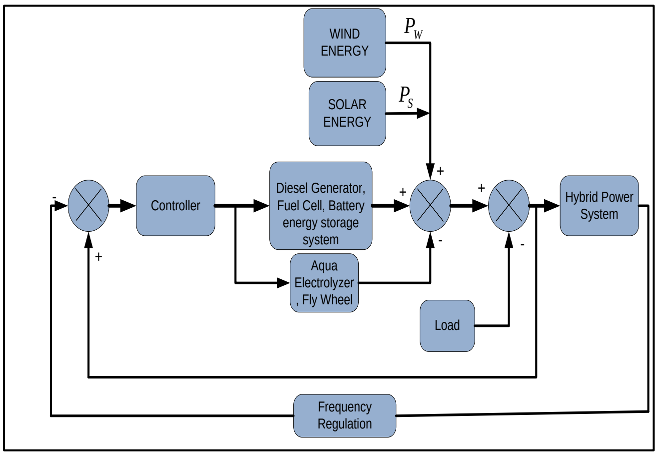

Fig. 1: The block diagram of the microgrid.

A. *Wind Generator*

Normally maximum power point tracking (MPPT) is executed in wind vitality transformation system. Nonetheless, in view of this wind energy system loses its capacity yield controllability. Subsequently, It can not be utilized for frequency guideline of microgrid. So as to utilize wind energy system for this reason we have to make a few adjustments in its control circles.

B. *PV*

MPPT is additionally utilized if there should arise an occurrence of photovoltaic (PV) systems. Along these lines, it doesn't overcome the force yield. Thus, it is treated as grid supporting source.

C. *Diesel Generator*

Diesel generator can follow the heap request by methods for its lead representative control and speed droop. The governor representative controls the fuel contribution to a motor by means of a valve system. The engine goes about as a turbine and drives the coordinated generator. The modeling of diesel generator as delineated:

$$G_{dg}(s) = \frac{1}{1 + sT_{dg}} \tag{1}$$

Similarly, the turbine of the diesel generator can be modeled as presented in (2).

$$G_{dt}(s) = \frac{1}{1 + sT_{dt}} \tag{2}$$

Therefore the overall transfer function of a diesel generator will be

$$G_{dgt}(s) = \frac{1}{1 + sT_{dg}} \times \frac{1}{1 + sT_{dt}} \tag{3}$$

Where T_{dg}, T_{dt}, is the time constant of governor and turbine respectively. Fig. 2 is representation of bock diagram of diesel generator in a microgrid.

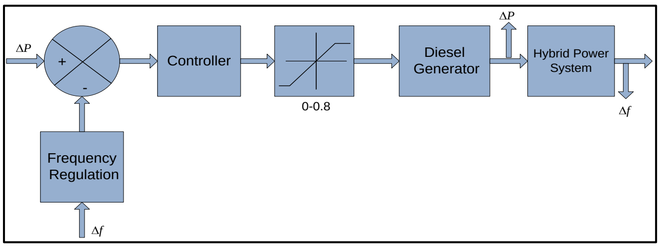

Fig. 2: The block diagram of the diesel generator.

D. *Battery Energy Storage System (BESS)*

It is consistently a bit of leeway on the off chance that we are utilizing RES to run power framework rather than our ordinary vitality sources. One of the issue of utilizing RES in power framework activity is the change happening in the measure of sustainable power source acquired. Only for instance, we won't get a consistent progression of wind over a more extended timeframe. Comparative change is likewise seen if there should be an occurrence of PV. Our prime goal of utilizing optional flexibly is to oblige load variance and essential source vacillation. So any type of vacillation in optional capacity is unfortunate. Subsequently we can not legitimately use RES as immediate optional gracefully. In any case, we as a whole know about the upside of RES over ordinary vitality sources. So to oblige RES in the optional flexibly side an elective technique called as BESS is utilized. The power produced from RES is put away inside a battery. This power is utilized to deal with the load variance and additionally essential source vacillation circumstance. From the battery we can get consistent intensity with no variance and furthermore by this framework we can utilize RES viably. The exchange work model of battery vitality stockpiling framework communicated by first request as [13] and actualized in microgrid as appeared in Fig. 3.

$$G_{BESS}(s) = \frac{1}{1 + sT_{BESS}} \tag{4}$$

where T_{BESS} is time constant of battery energy storage system.

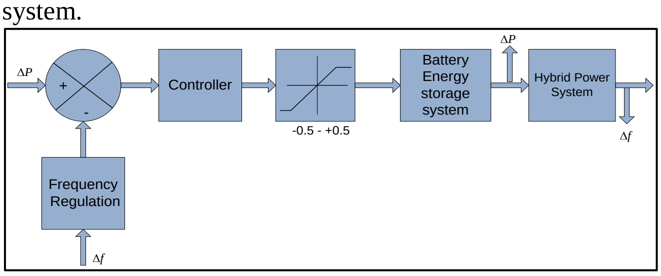

Fig. 3: The block diagram of BESS

E. *Fly Wheel*

A flywheel is an electromechanical stockpiling framework, as vitality can be changed over between both electrical and mechanical structure. In this framework energy is put away as dynamic vitality of a rotating body. During charging, electric flow moves through the engine speeding up the flywheel while during releasing flow streams out of the framework because of generator, which further prompts easing back of the wheel[2].

The flywheel is modeled as a first order equation (5) and implemented in microgrid as shown in Fig. 4.

$$G_{fw}(s) = \frac{1}{1 + sT_{fw}} \tag{5}$$

Where T_{fw} is the time constant of fly wheel.

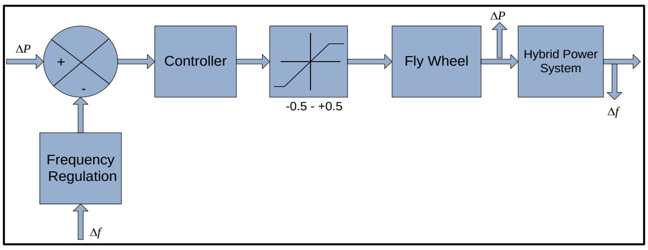

Fig. 4: The block diagram of the fly wheel in hybrid power system.

F. Fuel cell

Power in fuel cell is electrochemical response among hydrogen and oxygen. One of the upside of utilizing power device over traditional generators. Normally a power device delivers a little voltage which isn't adequate to address our issues. So as to make huge enough voltage, the cells are orchestrated in arrangement equal blend to shape a power module stack. Hydrogen, is a costly source when contrasted with other customary vitality sources. This is the main downside of power module. Typically an energy component generator has a higher request model and furthermore non-linearity. Anyway during low recurrence area examination we can be consider it to have a first request slack exchange work model given as [13] and actualized in microgrid as appeared in Fig. 5.

$$G_{fc}(s) = \frac{1}{1 + sT_{fc}} \tag{6}$$

Where T_{fc} is time constant of fuel cell.

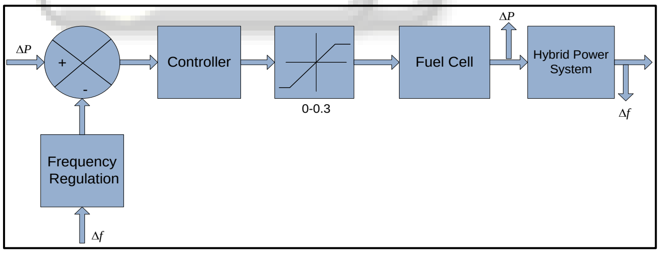

Fig. 5: The block diagram of the fuel cell in microgrid.

G. Aqua electrolyzer (controllable source)

So as to beat the above mentioned disadvantage we use water electrolyzer that produses hydrogen. Hydrogen is produces in water electrolyzer by technique for "electrolysis of water" for which electric momentum is acquired from the power framework. The exchange work model of water electrolyzer can be communicated by [13] and actualized in microgrid as appeared in Fig.6.

$$G_{ae}(s) = \frac{1}{1 + sT_{ae}} \tag{7}$$

where T_{ae} time constant of the aqua electrolyzer.

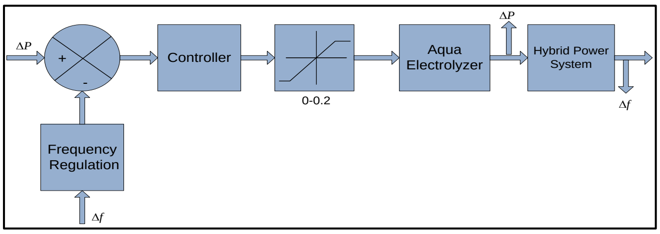

Fig. 6: The block diagram of the aqua electrolyzer in hybrid power system.

H. Power and frequency Deviations

In a power framework comprising of synchronous generator, if the harmony between the load request and generation isn't kept up, the frequency varies [17]-[19]. The power deviation is the contrast between the force age PG and the force request PL. From the swing condition of a synchronous machine, the generator numerical model can be composed as

$$\Delta f = \frac{f_{sys}}{2Hs}\left[\Delta P_G - \Delta P_e\right] \tag{8}$$

where

$$P_G = P_W + P_S + P_{dgt} + P_{fc} - P_{ae} \pm P_{bess} \pm P_{fw} \tag{9}$$

Generally, the loads are of mixed type like frequency dependant and non-dependant. So speed load characteristics of composite load is approximated by

$$\Delta P_e = \Delta P_L + D\Delta f \tag{10}$$

$$\Delta P_G - \Delta P_L = \left(\frac{2H}{f_{sys}}s + D\right)\Delta f \tag{11}$$

Therefore the transfer function for system frequency variation to per unit power deviation is given by (20)

$$G_{sys}(s) = \frac{\Delta f}{\Delta P_G - \Delta P_L} = \frac{1}{D + \left(2H/f_{sys}\right)s} = \frac{K_{ps}}{1 + sT_{ps}} \tag{12}$$

where K_{ps} and T_{ps} are $1/D$ and $\left(2H/f_{sys}\right)$, respectively. It is to be noted here that (8) is valid only when there is a synchronous machine in the microgrid.

III. TUNING OF PID CONTROLLER GAIN

The goal of the regulators is to manage the power yield of auxiliary sources, to limit the frequency deviation. Within the sight of numerous auxiliary sources there is an opportunity of antagonistic connection between their controllers which prompts weakening of recurrence solidness of the microgrid. So far there is no single definition for best tuning that applies to all circles. In this way, to maintain a strategic distance from the unfavorable collaboration there is a need of suitable tuning of the individual PID regulator [13].

In this paper MATLAB SISO tool is utilized for PID tuning. To create this compensator Ziegler-Nichols open loop is utilized as a tuning calculation with LDR as tuning algorithm. This strategy utilizes the Chien-Hrones-Resnick (CHR) setting with 20% overshoot. It merits referencing here that Ziegler-Nichols closed loop can not be applied to first-request or second-request frameworks with time delay. On the off chance that Ziegler-Nichols closed loop is chosen for these cases, the tuning calculation will consequently be changed to Ziegler-Nichols open loop[20]. From the compensator "C" the Values of additions are determined utilizing

$$C = K_p + \frac{K_i}{S} + K_d S \qquad (13)$$

Where, Kp, Ki and Kd are Proportional, integral and derivative gain and The Frequency bias is selected at which ITSE (Integral time square error) is minimum and given by

$$ITSE = \int_0^t t\left|\Delta f\right|^2 dt \qquad (14)$$

The outcomes got from the LDR strategy are contrasted and old technique and it is discovered that proposed technique gives the better reaction over the old style strategy.

Microgrid Components	Frequency Regulation K_f	K_p	K_i	K_d
Diesel Generator	4	0.0397	0.0756	3.3084
Aqua Electrolyzer	0.2	0.35	0.03	0.07
Fuel Cell	2	0.1220	0.2154	3.1608
Battery	0.1	0.4188	0.01666	0.01
Fly wheel	0.1	0.3654	0.01666	0.01

Table 1: Tuning of PID Controller Gains According To Conventional Method

Microgrid Components	Frequency Regulation K_f	Modified K_p	Modified K_i	Modified K_d
Diesel Generator	4	0.1025	0.0073	0.3013
Aqua Electrolyzer	0.2	1.498	4.5399	0.1044
Fuel Cell	2	0.1858	0.0464	0.156
Battery	0.1	3.380	0.1251	0.098
Fly wheel	0.1	3.380	0.1251	0.098

Table 2: Tuning of PID Controller Gains According To LDR Method

IV. RESULTS AND DISCUSSIONS

The Detailed simulation diagram of the microgrid is shown in Fig. 7. The analysis of microgrid is in time frame of 80 sec. During this time the system observes power variations of source and load. Before creating disturbance in all the cases, constant wind power supply of approximately 0.3 p.u., solar power supply of 0.3 p.u. and a load demand of 0.6 p.u. are considered. The time period shown in some plots is the different from the simulation time since in those cases the system is settling before the simulation time[13].

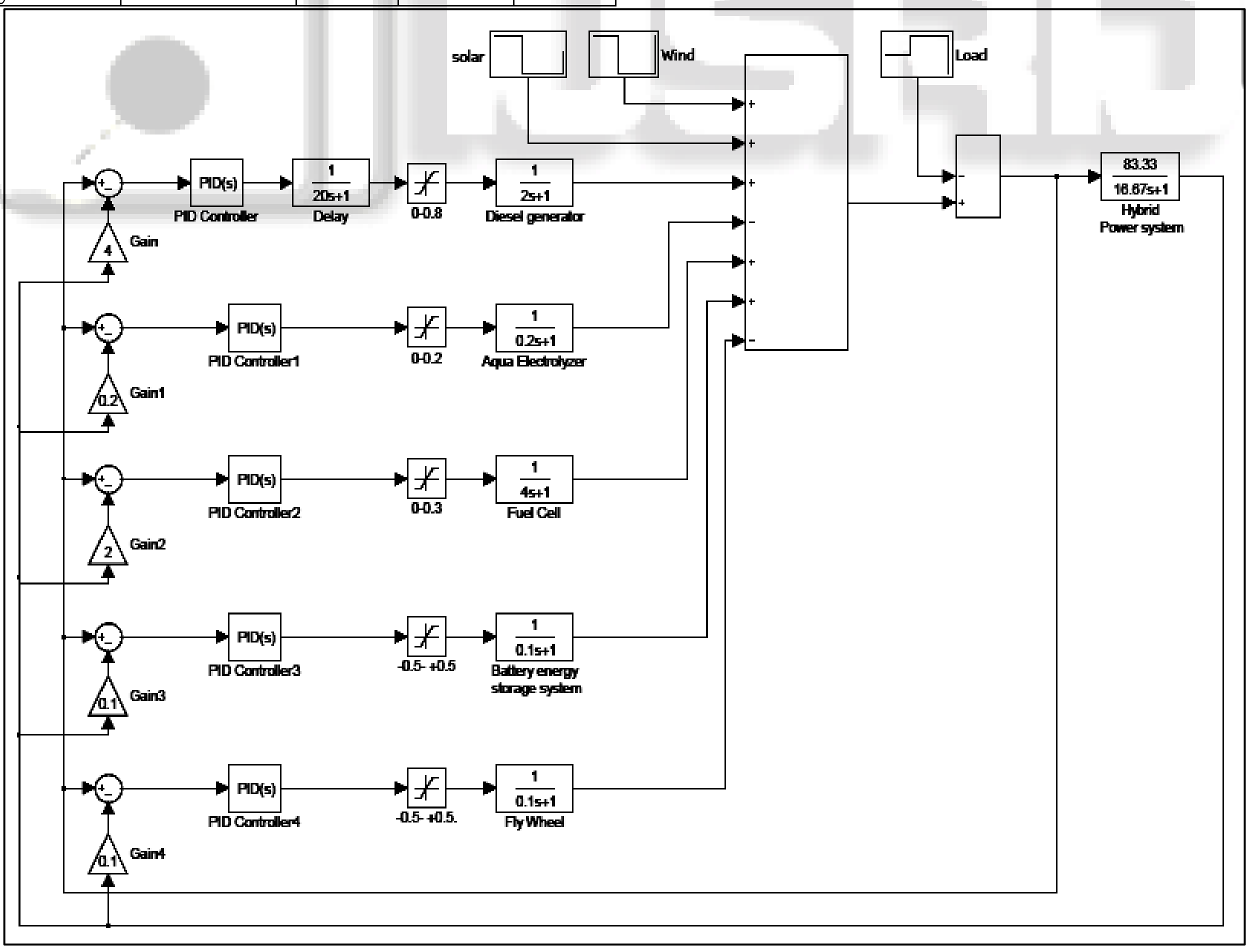

Fig. 7: SIMULINK block Diagram of the microgrid in MATLAB.

In this case the load is increased from 0.6 pu to 0.66 pu. and the wind (0.3 pu) and solar power (0.3 pu) sources are kept constant for the time period of 20 sec.(Time Doamin Analysis). Because of the load variety the microgrid elements are giving their dynamic execution and are appeared in fig.(8). In the transient time frame the BESS and fly wheel are providing the power in such a way, that when BESS is providing power, fly wheel is charging and the other way around. The variance in the power system frequency is because of the abrupt change in the Renewable vitality sources power and load request and the PID regulator is utilized to control the recurrence deviation. The yield of framework parts are consequently acclimated to comparing an incentive to limit the blunder in flexibly request and the frequency deviation. The increase estimations of PID regulator acquired through classical and LDR method and are given in Table 1 and table 2 separately. In the arrangement of tables appeared in figure.8.

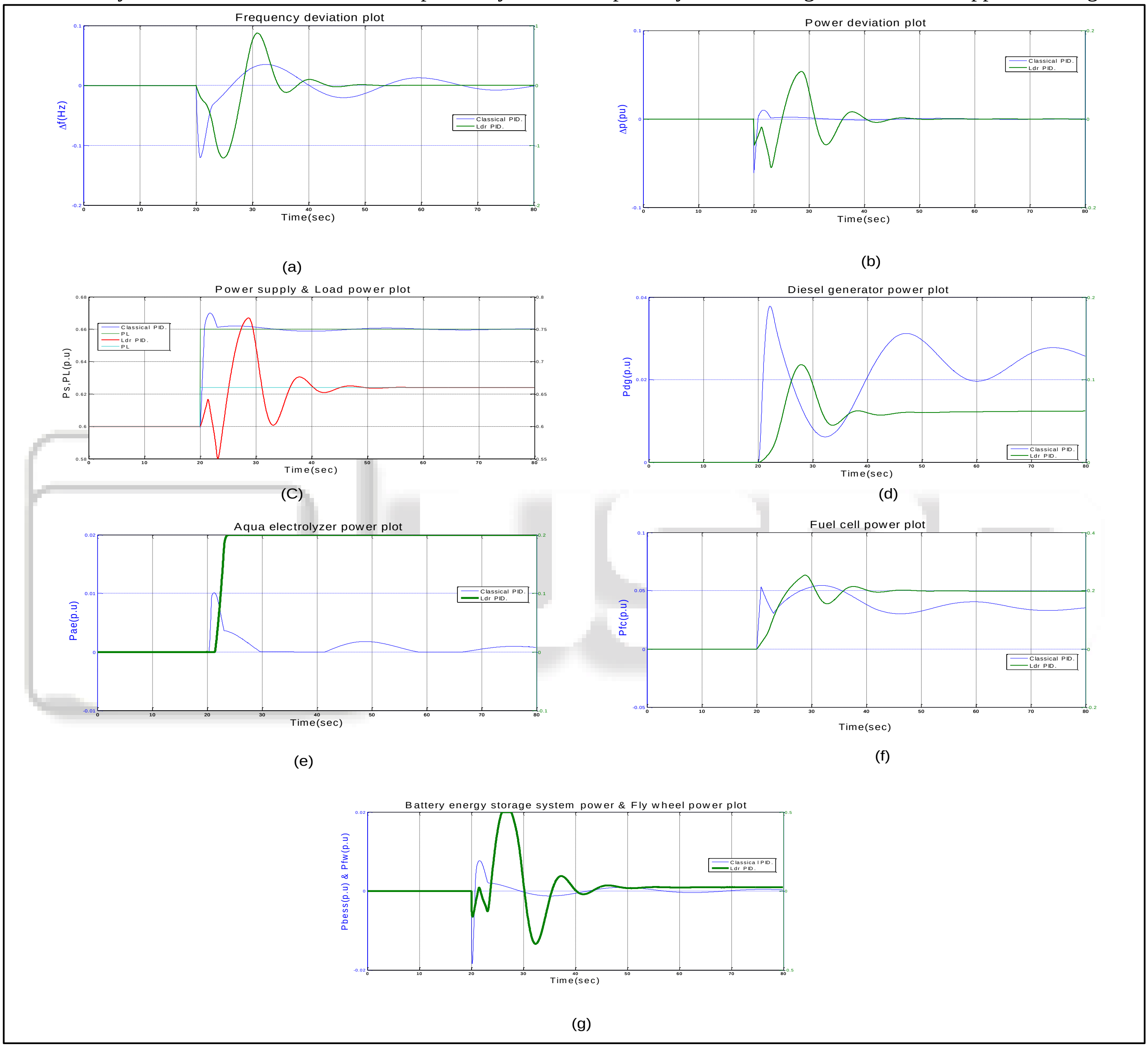

Fig. 8. Simulation results of proposed system Case 1: (a) Frequency deviation of power systems Δf (b) Error in power supply and demand ΔP_e (C) Supply power P_S and load power P_L (d) Power supply form diesel generator P_{dg} (e) Aqua electrolyzer P_{ae} (f) Fuel cell P_{fc} (g) Battery P_{bess} & Flywheel P_{fw}

It is clear from above results that transient time taken by LDR method is much better than transient time taken by classical method which proves the efficacy of proposed method.

V. Conclusion

Under variation in load and generation there is deviation of frequency. Different sources like solar, wind, diesel generator, fuel cell, flywheel, aqua electrolyzer and BESS have been taken into consideration. The tuning of PID controller with classical and LDR method is proposed in this paper. The results obtained by proposed method are promising and are much better than the conventional method.

REFERENCES

[1] Chowdhury, S.P., Crossley, P., Chowdhury, S., Clarke, E.: ‘Microgrids and active distribution networks’ (Institution of Engineering and Technology, London, 2009)
[2] N. Hatziargyriou, M. Ddonnelly, S. Papathanassiou, J.A. Pecas-Lopes, J. Usaola, R. Lasseter, A. Efthymiadis, K. Karoui, S. Arabi, M.Takasaki, and H.chao, “Modeling new forms of generation and storage,” *Electra*, no. 195, pp. 54-63, Apr. 2001.
[3] Senjyo, T., Nakaji, T., Uezato, K., Funabashi, T.: ‘A hybrid power system using alternative energy facilities in isolated island’, IEEE Trans. Energy Convers., 2005, 20, (2), pp. 406–414
[4] D. J. Hall and R. G. Colclaser,“Transient modeling and simulation of a tubular solid oxide fuel cell,” IEEE Trans. Energy Convers., vol. 14, no. 3, pp. 749-753, Sep. 1999.
[5] M. D. Lukas, K. Y. Lee, and H. Ghezel-Ayagh, “Development of a stack simulation model for control study on direct reforming molten carbonate fuel cell power plant,” IEEE Trans. Energy Convers., vol. 14, no. 4, pp.1651-1657, Dec. 1999.
[6] P. S. Dokopoulos, A. C. Saramourtsis, and A. G. Bakirtzis, “Prediction and evaluation of the performance of wind-diesel energy systems,” IEEE Trans. Energy Convers., vol. 11, no. 2, pp. 385-393, Jun. 1996.
[7] N. Kodama, T. Matsuzaka, and N. Inomata, “The power variation control of a wind generator by using probabilistic optimal control,” Trans. Inst. Elect. Eng. Jpn, vol. 121-B, no. 1, pp. 22-30, 2001.
[8] R. B. Chedid, S. H. Karaki, and C. El-Chamali, “Adaptive fuzzy control for wind-diesel weak power systems,” IEEE Trans. Energy Convers., vol. 15, no. 1, pp. 71-78, Mar. 2000.
[9] Lee, D., Wang, L.: “Small signal stability analysis of an autonomous hybrid renewable energy power generation/energy storage system time domain simulations”, IEEE Trans. Energy Convers., 2008, 23, (1), pp. 311–320.
[10] S. Mishra, G. Mallesham, and A. N. Jha, “Design of controller and communication for frequency regulation of a smart microgrid,” *IET Renew. Power Gener.*, vol. 6, no. 4, pp. 248–258, Jul. 2012
[11] J. Nagarath, M. Gopal, Control Systems Engineering, 3rd Edition. New Age International: 2001.
[12] M. Gopal, Control Systems Principles and Design, 3rd Edition. Tata Mc Graw Hill 2008.
[13] Mallesham, G., Mishra, S., Jha, A.N.: ‘Ziegler- Nichols based controller parameter tuning for load frequency control in a microgrid’. Proc. Int. Energy, Automation, and Signal (ICEAS), 2011 International Conference on, 2011,pp. 1–8
[14] B. Kroposki, R. Lasseter, T. Ise, S. Morozumi, S. Papathanassiou and N. Hatziargyriou, “Making microgrid work,” *IEEE Power and Energy Magazine*, vol. 6, no. 3, pp. 40-53, May-June 2008.
[15] R.H. Lasseter, “Microgrids,” *Proc. IEEE Power Eng. Soc. Winter Meeting*, Jan. 2002, vol. 1, pp. 305-308.
[16] P. Agrawal, “Overview of DOE Microgrid Activities,” Symposium on Microgrid, Montreal, June 23, 2006.
[17] O. I. Elgerd, Electric energy system theory: an introduction(2nd ed.), McGrawHill, New York(1982).
[18] P. Kundur, Power system stability and control, Tata McGraw Hill, New York,1994.
[19] Dulal ch. Das, A.K.Roy, N.Sinha, “Genetic Algorithm Based PI controller for frequency control of an autonomous hybrid generation system”, IMECS hong cong. vol 2,march 16-18, 2011
[20] MATLAB 7.10.0 (R2010a).
[21] Jeya. Veronika, N.S. Kumar, “ Internal Model based Load frequency Controller Design for Hybrid Microgrid System”, Energy Procedia, vol. 117 1032–1039, 2017.
[22] S. Khosravi, M.T. H. Beheshti, H. Rastegar, “Robust Control of Islanded Microgrid Frequency Using Fractional-Order PID”, Iranian Journal of Science and Technology, Transactions of Electrical Engineering, 2020, https://doi.org/10.1007/s40998-019-00303-6