Frequency Control of Microgrid under Islanded Conditions using Fuzzy Logic Based on PI Controller

Rupinder Kaur[1] Manpreet Kaur[2]
[1,2]Department of Electrical Engineering
[1,2]PTU, India

Abstract— This paper presents fuzzy-PI based controller for frequency control of microgrid under islanded condition. In islanded mode the entire control is regulated by the microgrid controller. Any difference between generation and demand causes frequency to deviate from nominal value which effects the microgrid operation and reliability of power flow. For evaluating the performance of controller, a microgrid is considered consisting of PV system, wind turbine generator set, diesel generator set along with storage units. The proposed control scheme is compared with autotuned PI control scheme. The results for both the control schemes are presented and comparison is made between them. The developed model is simulated in Matlab/Simulink environment.

Keywords: Microgrid, Fuzzy-PI

I. Introduction

As the power demand is increasing at an alarming rate, pressure on conventional energy resources has increased leading to depletion of fossil fuels. So, nonconventional sources such as wind, PV, fuel cells, microturbines are being used to generate electrical power[1]. MG is a concept that utilizes the energy generated by these DER's. Microgrids not only help in extracting power from non-conventional resources but have also improved the power reliability and helped the concept of smart grid to emerge[2]. The concept of microgrid was first introduced by a company named, the consortium for Electric Reliability Technology Solutions (CERTS) in 1998[3]. There are various advantages and disadvantages related with a microgrid. One major advantage of MG is that it provides clean power as there is little or negligible pollution associated with microsources unlike burning of fossil fuels which act as a major source of pollution and global warming. Second is, these systems can be used in geographically isolated conditions where it is not possible to extract power from conventional sources and set up large plants. Hence, power can be extracted from locally available micro sources like wind, biomass, solar, geothermal, etc. [4]. Output power fluctuation is one major problem associated with MG, which further leads to frequency and voltage fluctuation. A microgrid can function in two modes namely grid connected and islanded mode [5]. In grid connected mode the MG is connected to the utility grid, whereas in islanded mode it behaves as an independent entity having no interaction with utility grid. When operating in grid connected mode, the control of the system is majorly taken care of by utility grid. But working under islanded condition the control of system is purely regulated by microgrid central controller. So in order to ensure a continuous and reliable supply of power from microgrid a proper control system for microgrid is required. There are various control strategies available for frequency control of microgrid; droop control is one of the conventional control strategies used for frequency restoration [6]. Nowadays intelligence based controllers are used as the control scheme which needs to be fast and efficient. In this paper fuzzy PI based controller is used where output of fuzzy is fed as an input to PI in order to adjust the control parameters P and I [7]. In this study, PV and wind generators have been used for the consideration of a MG. Since power output from these two completely depends on weather condition that is the solar insolation and wind speed. So a backup system is required to continue power supply at times when it is not possible to extract required power from renewable sources. A diesel generator set and storage system for backup purpose has been incorporated. For storage a flywheel and battery systems are employed.

II. A Proposed Hybrid MG System

A hybrid MG system has been considered as presented in [8].The proposed load frequency control model of MG is presented in Fig.1. The Mathematical model of this system is considered and is represented in the form of transfer function [9]. All the values are considered in per unit. The p.u. values required for LFC model are given in Table 1. Microgrid consists of photovoltaic system, wind turbine generator set and a diesel generator set for generating the required power. The energy storage systems used are flywheel and a battery. These storage systems store the surplus power i.e. they store the excess power when demand is less than the generation and provide the required power when the renewable sources are not able to cope up with the load demands. The diesel generator set can also be used to meet load demands when power generated by PV and wind system is insufficient. So flywheel system, battery storage system and diesel generator system can also be termed as backup systems.

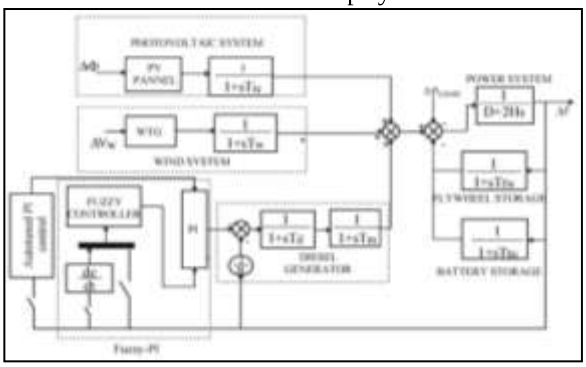


Fig. 1: A proposed single area hybrid microgrid model

PARAMETER	VALUE (p.u.)
T_m	0.42
T_d	0.081
T_{ic}(s)	0.004
T_{fw}(s)	0.1
T_{bs}(s)	0.12
R(Hz/pu)	3

D(pu/Hz)	0.0156
T_i(s)	0.041
2H(pu/s)	0.166

Table 1: Parameters for proposed mode

The net power generated (Pnet) can be expressed by

$P_{net} = P_{PV} + P_{WTG} + P_{DEG} \pm P_{BES} \pm P_{FES}$ (1) where,

P_{PV} is power generated by PV system, P_{WTG} is power generated by WTG, P_{DEG} is power of DEG, P_{BES} is power of battery storage system, P_{FES} is power of flywheel system For simulation means a load of 350 kW is advised and rated power of all generating units used in microgrid system is presented in table 2.

Generating unit	Rated power(kW)
PV panel	30
WTG	100
Diesel gen set	160
Battery storage	45
Flywheel storage	45
Applied load	350

Table 2: rated power of system

A. *Photovoltaic System*

Photovoltaic is a trained term for sun oriented vitality. PV cells are generally made of silicon material that discharges electrons when presented to light. The measure of electron discharge depends upon the power of light occurrence on it. This Silicon is secured with matrix that aide's electrons specifically bearing to give electric current. These currents are guided into wire which is associated with battery or DC apparatus to convert the DC into AC [10]. Block diagram of a PV system is represented in fig.2. For analysis purpose the rating of PV module is set at 150W. Maximum current and voltage are taken 4.35A and 34.5V respectively, which delivers a maximum power of 150.07W.

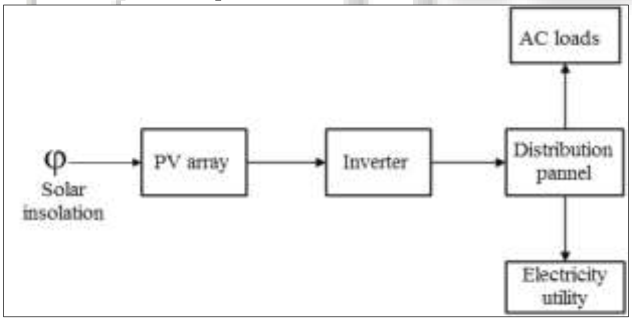


Fig. 2: Block diagram of PV system

The transfer function for PV system is given as below:

$$G_{PV}(s) = \frac{K_{PV}}{1 + sT_{PV}} = \frac{\Delta P_{PV}}{\Delta \phi}$$

Where,

ΔP_{pv} = Change in output power of PV system

$\Delta \phi$ = Change in solar irradiation.

For analysis purpose change in solar irradiation is considered using a step function.

B. *Wind Generator System*

The wind generator system generates power by the virtue of blowing winds. The energy encapsulated by the blowing winds is used to run the wind generator set as shown in Fig.3.The output power produced by WTG set totally depends upon velocity of wind. For the motive of simulation the wind speed is assumed to be constant 10m/s; and it supplies a constant power of 100kW to the microgrid[11].

The transfer function for wind generator system is represented as

$$G_{WTG} = \frac{K_{WTG}}{1 + sT_{WTG}} = \frac{\Delta P_{WTG}}{\Delta P_W}$$

ΔP_{WTG} =Change in output power of wind generator system.

ΔP_W = Change in mechanical power of wind turbine.

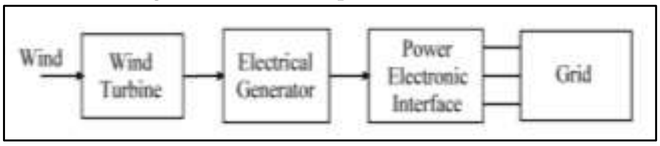


Fig. 3: Block diagram of WTG set

C. *Diesel Generator Set*

Diesel generator set is used to make sure the continuous supply of power, when the PV and wind systems are not able to deliver the power demand; the extra power demand is met by DEG. Fuel consumption in diesel engine model depends upon mechanical power output and speed [12]. The governor adjusts the fuel inrush and thus regulates the power output of engine and generator and helps in frequency restoration, the controller unit is used in conjugation with diesel model.

The transfer function for DEG is:

$$G_{DEG} = \frac{K_{DEG}}{1 + sT_{DEG}} = \frac{\Delta P_{DEG}}{\Delta f}$$

ΔP_{DEG} =Change in output power of DEG.

Δf= Deviation in system frequency.

D. *Storage System*

Battery system and flywheel system are used for storage purpose; they play a vital role in maintaining system stability [13].When the power generated by renewable sources is in surplus it is captured and stored by storage systems, and the same is delivered back to the system when power generated by renewable sources in insufficient to meet load demand.

The transfer function for flywheel system is:

$$G_{FES} = \frac{K_{FES}}{1 + sT_{FES}} = \frac{\Delta P_{FES}}{\Delta f}$$

ΔP_{FES} =Change in exchanged power of flywheel system.

Δf =System frequency deviation

Transfer function for battery storage system:

$$G_{BES} = \frac{K_{BES}}{1 + sT_{BES}} = \frac{\Delta P_{BES}}{\Delta f}$$

ΔP_{BES} =Change in exchanged power of battery storage system

Δf = Deviation in system frequency

E. *Power System/ Utility Side*

There are two important terms associated with power system; inertia and power oscillation damping.

Reliability of any power plant depends upon the inertia related with big rotating masses. The imbalance between supply and demand of power system is overcome by

inertia. Damping in system can take place on account of any fault condition in the system.
Transfer function for microgrid system:

$$\Delta f = \frac{1}{D + 2Hs}$$

D = Load damping constant
$2H$= inertia constant

III. MICROGRID FREQUENCY CONTROL METHADOLOGIES

A lot of frequency control techniques are available. Earlier techniques like frequency droop control, tie line frequency control were used. These systems were slow, complex and not very efficient. With advancements in power system the requirement for intelligent controllers has emerged. In this paper

PI-fuzzy controller is used. Where frequency error and rate of change of error are provided as input to the fuzzy controller and the output of fuzzy is provided as input to PI controller.

A. *Autotuned PI*

Autotuning is a process that automatically computes the value of control parameters for any given system, to bring out the best possible control, without user interaction. It is much more efficient and reliable as compared to manual computing of parameters.
Autotuning process basically includes three main steps:

1) Choosing the model to be processed
2) Collecting the data related with the process and fitting it into the model.
3) Computing the control parameters.

The process identification is done basically by two methods; first step response method and relay feedback method.

The data about the process can be provided either by triggering the process intentionally or by observing the process behavior under normal conditions. After the data is attained it is converted into process description.
The tuning rules can be composed in three ways:

1) Tuning the parameters in such a way that our process output matches with the reference model used.
2) Computing parameters based on some closed loop system description.
3) Tuning based on human description.

All these methods are established on solving a certain set of equations.

The values of P and I attained by autotuning the model are 2.82108 and 7.3689784.the detailed process of autotuning is presented in [14]

1) *Controller Modes*

PI controller utilises proportional (P) mode and integral mode (I) for computing a control signal.
The PI control signal is computed as:

$$u(t) = K_p e(t) + K_i \int e(t)dt$$

The equivalent form of given equation is:

$$u(t) = K\left(e(t) + \frac{1}{T_i}\int e(t)dt\right)$$

a) Proportional Mode

The control law for proportional mode is described by the below equation

$$u_p(t) = Ke(t) + u_b$$

Here,
$u_p(t)$ is the output of proportional controller.
K represents the gain of the system and
u_b is the bias or reset value.

The P arranges the action of controller proportional to the error. The P action depends on instantaneous values of error. Only for non zero values of error the output value of controller will be non zero. This means that the value of P at steady state will be zero but this is not appropriate. So in order to maintain value of P controller at a constant level a bias is added to the system. Which means that even if value of error is zero the value of controller output will be some constant and hence maintain the controller action. But if an integral controller is also used in conjugation with P controller then there is no need to add an external bias the reset is attained by action of I controller. Some characteristics of P control are:

1) By increasing the value of P control will decrease the steady state error.
2) Increasing the value of P after certain point will only result in increased overshoot.
3) It helps in reducing the rise time.

b) Integral Mode

The output achieved by integral action is proportional to accumulated error. The I control signal is given as:

$$u_1(t) = \frac{K}{T_i}\int e(t) + u(0)$$

Here;
T_i is the reset time or integral time constant
$u(0)$ is the output of controller at t=0

The integral controller takes into consideration the sum of all the errors. When input of integrator is e, steady state cannot be achieved unless e is non-zero. So it establishes a zero error at steady state. The I-control not only considers the present value of error but also accounts for the previous value of error. The action of I controller is slow and it does not respond to sudden changes quickly
Some key features of the I-controller are:

1) It helps in disposing of the steady state error.
2) Increasing the value of I after certain limit leads to increase in overshoot.
3) It reduces the rise time.

B. *Fuzzy Based PI Controller*

For a PI controller the values of P and I are generally preassigned. If any fluctuations occur in the system model the PI controller is not able to take account of them and hence the performance of controller degrades. Therefore we use fuzzy based PI controller which provides an intelligent control by updating the PI controller parameters if there is any variation in system operation condition. As represented in fig.4 fuzzy system output is provided as input to PI controller which further controls the plant by updating P and I values.

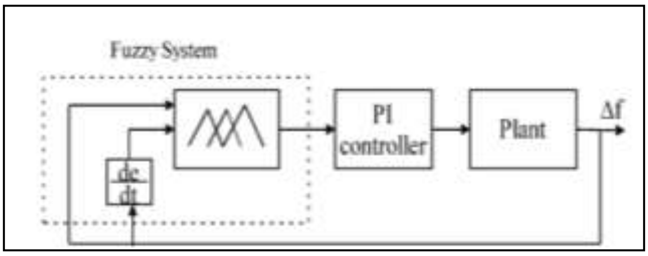
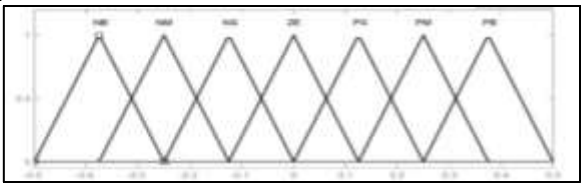
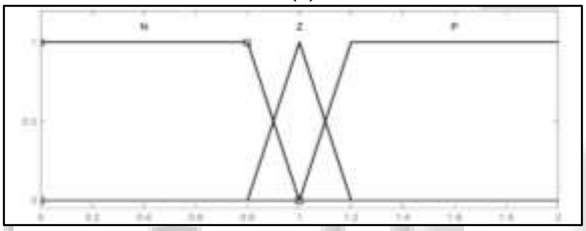


Fig. 4: Fuzzy PI control structure

The fuzzy inputs i.e. the error and change in error are given to fuzzy logic controller. They are fuzzified using seven membership functions Positive big (PB), Positive medium (PM), Positive small (PS), Zero (ZE), Negative big (NB), Negative medium (NM), Negative small (NS). The membership functions for input and output are depicted in Fig. 5.



5 (a)



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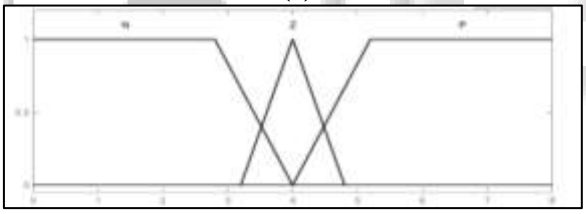


5 (c)

Fig. 5: Membership function of (a)error or change in error (b)Kp (c)Ki

A fuzzy controller consists of four main elements [15]

1) Fuzzification

It is the process of converting the user inputs provided to controller into a form that inference system can implement the provided rules.

2) Rule Base

It is a set of 'if' and 'then' rules, which consists the fuzzy logic representation of users description on attaining the best possible control. Rule base for planned control scheme is represented in Table 3.

	NB	NM	NS	ZE	PS	PM	PB
NB	N	Z	N	N	N	Z	P
	P	Z	N	N	N	Z	P
NM	P	P	Z	N	Z	P	P
	P	Z	Z	N	Z	Z	P
NS	P	P	Z	N	Z	P	P
	P	P	Z	N	Z	P	P
ZE	P	P	P	Z	P	P	P
	P	P	P	Z	P	P	P
PS	P	P	Z	N	Z	P	P
	P	P	Z	N	Z	P	P
PM	P	P	Z	N	Z	P	P
	P	Z	Z	N	Z	Z	P
PB	P	Z	N	N	P	Z	P
	P	Z	N	N	P	Z	P

Table 3: Rules for proposed fuzzy-PI controller

3) Inference Mechanism

It replicates the user's idea of attaining a best possible control, in order to understand and apply the rules for achieving a good control.

4) Defuzzification

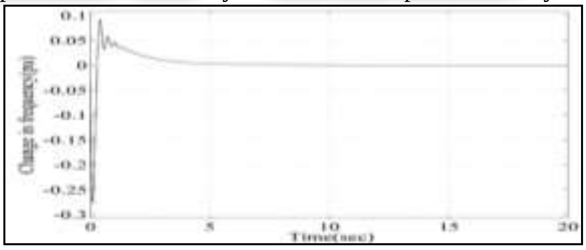
It is the process which finally provides the input to the system, by converting the decision of inference system.

IV. Results and Discussion

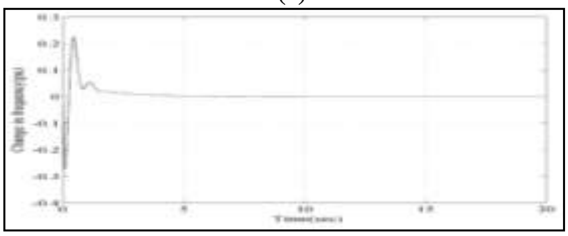
For performing simulations three different cases have been considered by varying input signals of PV, wind and change in load. To carry out comparative analysis of Fuzzy PI controller and autotuned PI controller the results for both the schemes have been depicted. The effectiveness of proposed control scheme is illustrated by simulating the model in MATLAB/simulink environment using Sim-Power blocks.

A. CASE 1

The model is simulated by taking into account a disturbance of 0.2 pu in load and keeping other two signals i.e. solar insolation and wind speed constant to value of 1000 W/m2 and 10m/s respectively. Both the systems are studied and the values of ITAE (Integral of time absolute error) are observed. The outputs for both the schemes are presented in Fig.6 (a) and (b). It is assured that the values of ITAE in both cases are relatively equal. The autotuned scheme has shown fast response time and steady-state level compared to fuzzy-PI.



6(a)



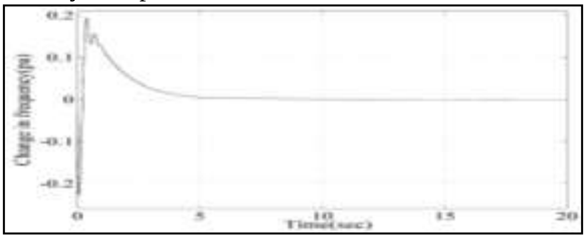
6(b)

Fig. 6: Change in frequency vs. time graph of (a) autotuned-PI controller (b) Fuzzy-PI controller.

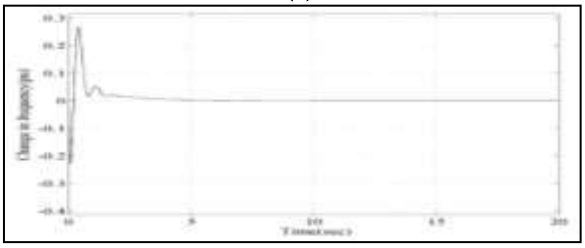
B. CASE 2

Under second case the wind speed is taken constant 10m/s and a change of 0.2 pu in both load and PV system is taken into consideration. The response for autotuned and Fuzzy-PI scheme is presented in Fig.7 (a) and (b) respectively. The values for control parameters and ITAE are given in Table 4.

It can be inferred from the values that error in case of autotuned PI is less than that in fuzzy-PI control scheme. But the fuzzy-PI scheme also gives a good response based on the referred system problem.



7(a)

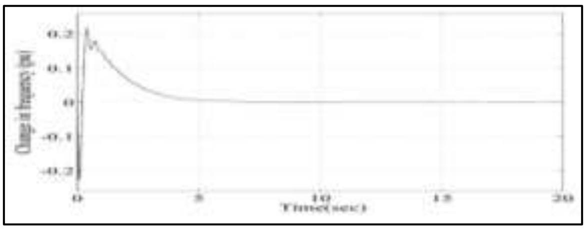


7(b)

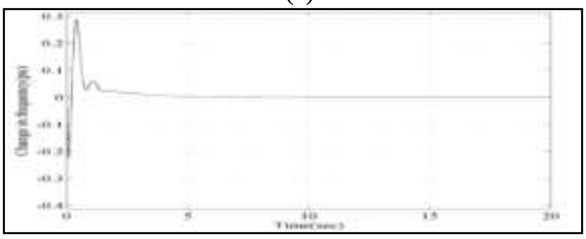
Fig. 7: Change in frequency vs. time graph of (a) autotuned PI (b) Fuzzy-PI control scheme

C. CASE 3

The simulation in this case is done where change in all three signal i.e. load, solar insolation and wind speed of 0.2 pu is considered. Based on the simulation results presented in Fig.8 (a) and 8(b) it can be inferred that the peak values in both the cases are almost same. The autotuned controller improves the performance of system with minimum value of ITAE. But the value of ITAE for Fuzzy-PI is also near to that obtained from autotuned controller. The mapping between autotuned and fuzzy based PI controller is presented in Fig. 9 corresponding to ITAE. It is observed that value of ITAE in autotuned-PI controller is less as compared to fuzzy-PI controller for all three cases.



8(a)



8(b)

Fig. 8: Change in frequency vs. time graph of (a) autotuned PI (b) Fuzzy-PI controller.

Case	Fuzzy- PI			AutotunedPI		
	P	I	ITAE	P	I	ITAE
I	1.000011	7.000045	0.1944	1.4999	8.7186	0.1808
II	1.000048	7.000192	0.1886	1.4999	8.7186	0.176
III	1.000028	7.000810	0.2137	1.4999	8.7186	0.2045

Table 4: PI controller parameters

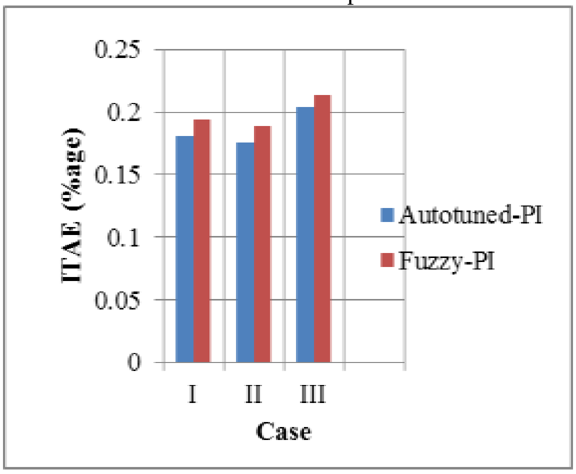


Fig. 9: Mapping of autotuned and fuzzy-PI based on ITAE.

V. CONCLUSION

The integration of DER's into a microgrid system consisting of varying load can cause a frequency fluctuation issue. So to resolve this, fuzzy-PI based controller is designed which would minimize the frequency deviation in the system. The performance of fuzzy-PI controller is evaluated by considering three different cases of disturbance. The disturbances include causing variation in input signal to PV panel, wind speed and change in load. Further the proposed scheme is compared with autotuned PI control scheme. It is evident from the results that both the schemes generate satisfactory results. The overshoot in both cases is relatively same. The value of ITAE in case of autotuned PI is observed slightly less as compared to fuzzy-PI controller. In future the autotuned and fuzzyPI control technique would be extended to case of two-area hybrid microgrid system.

VI. FUTURE SCOPE

The work done in the thesis may be extended in the following directions:

– The frequency control developed may be used for deregulated power system models.
– This control can also be made adaptive using artificial neural networks (ANN).
– The proposed adaptive control may be used as power system stabilizer for controlling excitation system.

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REFERENCES

[1] R. H. Lasseter, "Dynamic Distibution using (DER) distributed energy resources," Proc. IEEE Power Eng. Soc. Transm. Distrib. Conf., pp. 932–934, 2006.
[2] T. Senjyu, T. Nakaji, K. Uezato, and T. Funabashi, "A Hybrid Power System Using Alternative Energy Facilities in Isolated Island," IEEE Trans. Energy Convers., vol. 20, no. 2, pp. 406–414, 2005.
[3] H. Nikkhajoei and R. H. Lasseter, "Distributed generation interface to the CERTS microgrid," IEEE Trans. Power Deliv., vol. 24, no. 3, pp. 1598–1608, 2009.
[4] S. Baudoin, I. Vechiu, and H. Camblong, "A review of voltage and frequency control strategies for islanded microgrid," Syst. Theory, Control Comput. (ICSTCC), 2012 16th Int. Conf., vol. 33, no. 0, pp. 1–5, 2012.
[5] J. A. P. Lopes, C. L. Moreira, and A. G. Madureira, "Defining control strategies for microgrids islanded operation," IEEE Trans. Power Syst., vol. 21, no. 2, pp. 916–924, 2006.
[6] A. Klem, M. H. Nehrir and K. Dehghanpour, "Frequency stabilization of an islanded microgrid using droop control and demand response," 2016 North American Power Symposium (NAPS), Denver, CO, 2016, pp. 1-6.
[7] M. S. Bisht and Sathans, "Fuzzy based intelligent frequency control strategy in standalone hybrid AC microgrid," 2014 IEEE Conference on Control Applications (CCA), Juan Les Antibes, 2014, pp. 873-878.
[8] Maneesh, "Frequency control of a microgrid by using PI controller," 2015 Int. Conf. Energy, Power Environ. Towar. Sustain. Growth, ICEPE 2015, 2016.
[9] D. J. Lee and L. Wang, "Small-signal stability analysis of an autonomous hybrid renewable energy power generation/energy storage system part I: Time-domain simulations," IEEE Trans. Energy Convers., vol. 23, no. 1, pp. 311–320, 2008.
[10] S. Satapathy, K. M. Dash, and B. C. Babu, "Variable step size MPPT algorithm for photo voltaic array using zeta converter - A comparative analysis," 2013 Students Conf. Eng. Syst. SCES 2013, 2013.
[11] P. Wang and R. Billinton, "Reliability benefit analysis of adding WTG to a distribution system," IEEE Trans. Energy Convers., vol. 16, no. 2, pp. 134–139, 2001.
[12] G. S. Stavrakakis and G. N. Kariniotakis, "A general simulation algorithm for the accurate assessment of isolated diesel-wind turbines systems interaction. I. A general multimachine power system model," in IEEE Transactions on Energy Conversion, vol. 10, no. 3, pp. 577-583, Sep 1995.
[13] S. Singh, M. Singh, and S. C. Kaushik, "Optimal power scheduling of renewable energy systems in microgrids using distributed energy storage system," IET Renew. Power Gener. , 2016.
[14] C. Andersson and M. Lindberg, "Autotuning of a PID-controller," no. October, p. 38, 2004.
[15] M. S. Bisht and Sathans, "Fuzzy based intelligent frequency control strategy in standalone hybrid AC microgrid," 2014 IEEE Conf. Control Appl. CCA 2014, pp. 873–878, 2014.