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Frequency control of PV-connected micro grid system using fuzzy logic controller

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ABSTRACT

Frequency is a variable parameter in a power system, and it denotes the balance among the generation and the requirement. The operator of the system has to maintain the frequency within certain acceptable limits. The tediousness of integrating Distributed Generators (DGs), like solar photovoltaic (PV) system or wind turbines is the intermittency in power system that balances the power and regulates the frequency and voltage. If a number of electric motors are connected along with PV, the frequency of rotor speed will be varied. Hence, this paper intends to propose a Fuzzy Logic Controller (FLC) for controlling the frequency of rotor speed to enhance the power system performance. Hence, the major objective of the proposed model is to provide control over the output signal by reducing the error between the reference signal and control signal. The performance evaluation of the proposed model is done and proved over other controllers with respect to switching time, and the performance metrics, namely settling time, rise time, and percentage overshoot.

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1. Introduction

In the present era, the regulated and the centralized utilities of electric power mainly depends on fossil fuels to satisfy the requirement of energy. Traditional power generating plants are normally centralized, and thus the power is needed to be forwarded over wide distances. This results in losses of energy and affects the effectiveness of the system. One of the important limitations of the traditional technique is the discharge of pollutant gases in huge amount that acts as reason for global warming [1]. With the increasing need for energy, renewable energy oriented systems possess high interest in research. Thus, to satisfy the needs of energy, it is important to produce electric power using different renewable sources of energy, like solar, wind, geothermal, and so on.

At present, generation of power using PV system acts as an important method because of number of reasons, like pollution free generation of power, no need for fuel cost, and less cost for maintenance. Hence, it is generally selected as a best alternative as compared with the rapidly depleting reserves of fossil fuels. Even with the present enhancement of the materials of solar cell, the effectiveness in conserving the energy of PV model stays moderate [1]. These effectiveness decreases when there arise no match in load among the input and the output terminal. In general, when a module of PV is connected to the load directly, the operating point does not lead the maximum power of power voltage (PeV) graph. In addition, the MPP changes with the irradiance level of solar and operating temperature of cell. Thus, it is necessary to raise the power conversion efficiency of the module by forcing it to operate at its MPP, without considering the variations in weather conditions. This is carried out using a power electronic converter in the presence of algorithm for maximum power point tracking (MPPT) [2].

Even though Renewable energy sources (RESs) are deployed as zero-emission energy, the uncertainty nature of Distributed Generators (DG) may result in frequency control and stability problems. Frequency stability represents the capability of a system to provide

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steady frequency even under severe upset of the system that lead to significant imbalance among the generation and the load. Thus, the stability controlat reduced inertia with higher RESs penetration remains a major concern. To solve this issue, the inertia of Micro Grids is needed to be increased via energy storage. Thus, it is necessary to find out the appropriate inertia constant value for such systems so that the frequency stability is maintained at a minimal cost. In addition, frequency of Distributed Energy Resources (DERs) and loads also have an impact on the Frequency Control of Micro Grids.

In this proposed paper, the micro grid comprises of PV system, which works independently in order to supply power to the loads without any disturbance to the supply. For controlling the three phase VSC, the primary control circuit with the loop for maintaining the power and voltage is used. The developed technique enhances the performance of the system by smoothly handling the flow of power between the distributed generation units and the load. In addition, it maintains the frequency of the micro grid within a particular range even at the time of sudden changes in load and environmental conditions.

2. Literature review

Different types of sources of power are utilized for developing the micro grid to be operated either in autonomous or grid connected mode. The traditional PI controller is used for controlling the voltage source converter (VSC). The general limitation in developing this type of system is the dependency of the modeling of plant. In various cases, the systems are not elaborated clearly. Even after knowing the parameters of the whole system, there occur variations in parameter at the time of system operation, which is considered as the major drawback in design. In addition, it may not perform well during sudden load variations or disturbances. In recent years, advanced controllers, such as sliding mode controller, and predictive controller are commonly utilized to enhance the characteristics of the system. However, the drawbacks associated with these methods are the requirement of tedious analytical evaluations.

To solve the limitations, intelligent methods are generally used. In [4], particle swarm optimization (PSO) was considered for tuning PI controller parameters to enhance the quality of power in the micro grid. In [5,6], the neural network (NN) is used for tuning the parameters of the controller of a SOFC system. FLC is an enhanced technique that does not need the plants mathematical model whose characteristics is not known in a detailed manner. The FLC is generally easy to be implemented with better control accuracy. On enhanced tuning, the FLC is capable of providing enhanced performance compared to the traditional controllers. In addition, the FLC is effective over variations in parameter of the system. In [3,4], MPPT oriented FLC was developed for a PV system and the battery is used for back-up. In the proposed work, the FLC is used to regulate the frequency within acceptable limits [2].

3. Modelling of the components

3.1. Modelling of PV system

The conventional arithmetical design of a PV system by neglecting the interior shunt resistance is expressed in Eqs. (1), (2) and (3).

$$I_o = I_p - I_{rev}\left\{\exp\left[\frac{e}{BIT}(V_o + I_oR_s)\right] - 1\right\} \tag{1}$$

$$I_{rev} = I_{rt}\left[\frac{R}{R_r}\right]\exp\left[\frac{pF_{BG}}{IT}\left(\frac{1}{D_r} - \frac{1}{D}\right)\right] \tag{2}$$

$$I_g = [I_{sc} + T_{SH}(D_c - 25)]\frac{\delta}{100} \tag{3}$$

where, V_o indicates the solar arrays output voltage, and I_o represents the solar arrays output current, I_{rev} specifies the reverse saturation current, I_p denotes the produced current beneath a specified insolation, e refers to electron charge, I_{rt} indicates the saturation current at reference temperature R_r, B signifies the Boltzmanns constant, I indicates the ideal parameter at p-n junction, T denotes temperature, R_s denotes the series resistance of solar array, F_{BG} represents the semiconductor band-gap energy, T_{SH} indicates the temperature coefficient of short circuit current and δ indicates the insolation in mW/cm2. Fig. 1 depicts the structure of PV system being interconnected with the utility grid.

3.2. PV controller

In this paper, a boost converter is utilized for connecting the PV system to the dc-bus and to obtain the maximum power [7–9]. P&O algorithm is the algorithm considered in tracking the voltage corresponding to maximum power and the simulink diagram of the P&O MPPT is depicted in Fig. 2.

The complete diagram of PV setup is depicted in the Fig. 3. For controlling the boost converter, the cascaded control loop comprising of inner loop of current control and outer loop of voltage control is utilized [10–13]. The Cascaded arrangement offers high enhanced control with the reduction of oscillations on comparison with other basic control. The PI controller is used and is developed with the frequency characteristics using the MATLAB tool as shown in Figs. 4 and 5.

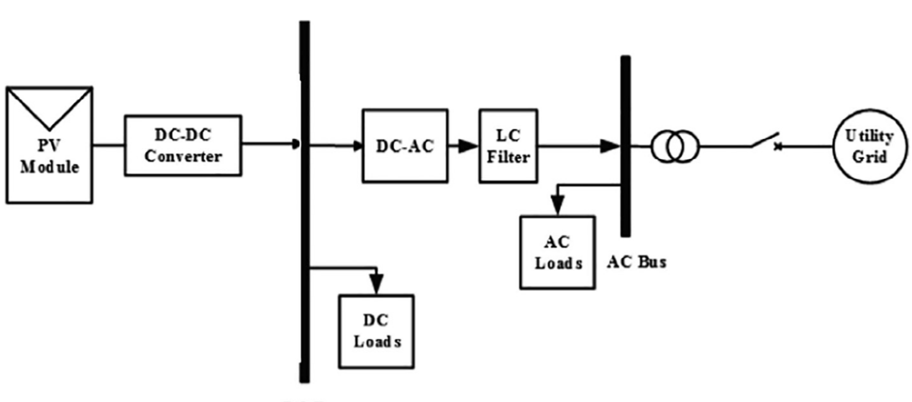

Fig. 1. Structure of PV interconnected with utility grid.

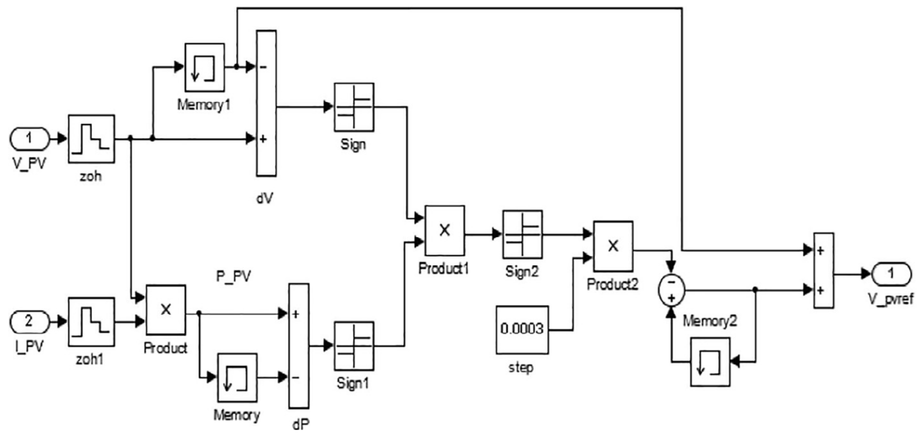

Fig. 2. Simulink diagram of P&O MPPT algorithm.

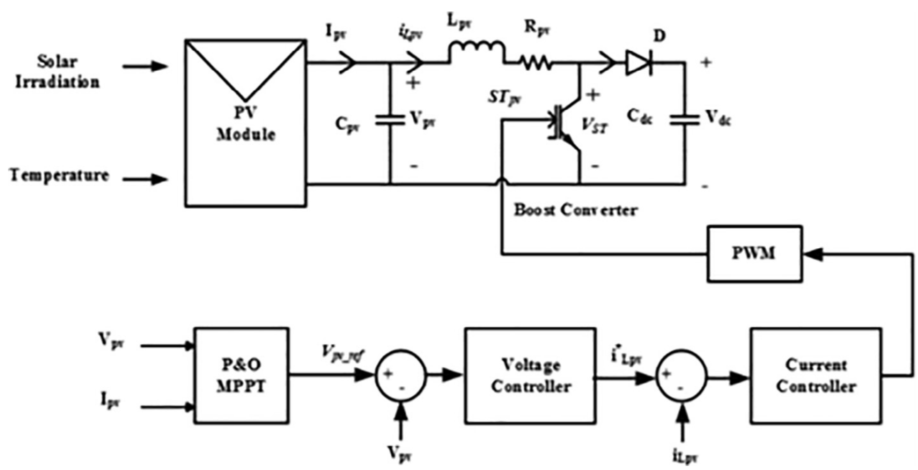

Fig. 3. Control diagram of PV system.

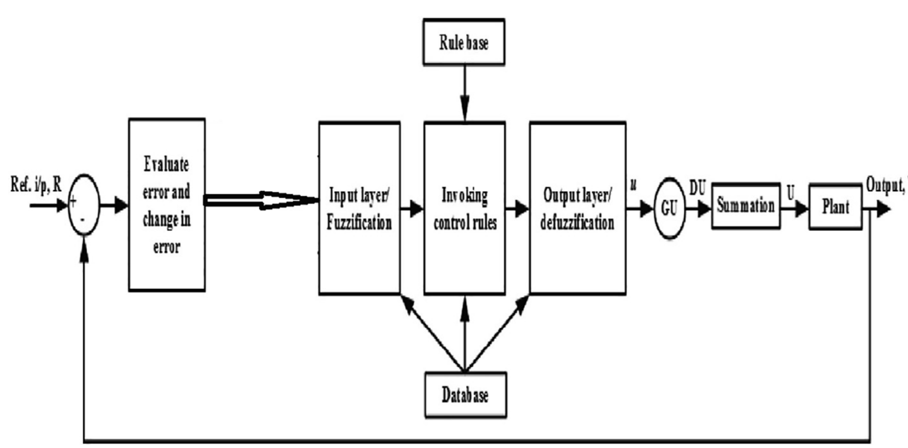

Fig. 4. Fuzzy feedback control system.

4. Proposed fuzzy Logic controller for frequency control

4.1. Fuzzy logic control

In the proposed paper, frequency control using FLC is carried out in order to enhance the performance of the system. The traditional PI controller is normally sensitive to the variation in parameters, and thus it offers low stability margin [3]. But, FLC acts effective to the variations in parameters. In addition, the tediousness in developing the control system of the VSC is eliminated clearly using FLC. It possesses three different stages, such as fuzzification, processing, and de-fuzzification stage. It acts by evaluating the error value and the change in error value among the actual output and reference input. These values are measured to change

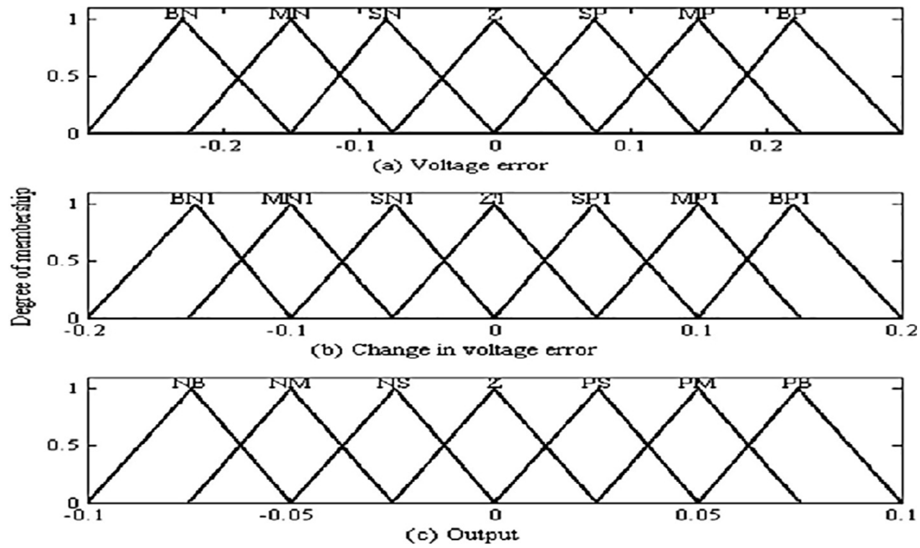

Fig. 5. Membership functions of voltage error, change in voltage error, and output.

them as per unit values [14,15]. Then, it is fed to the input layer, where the crisp values are changed to their corresponding fuzzy set values. The second stage produces the set of rules. Finally, the fuzzy variables are changed as crisp values with the use of defuzzification. The basic structure possessing the fuzzy feedback control system is depicted in the Fig. 8.

5. Results and discussions

5.1. Simulation procedure

The term frequency defines the value of voltage changes per second. The adopted frequency control in PV based MG model using FLC isimplemented in MATLAB and the corresponding outcomes were attained.

5.2. Frequency analysis

The frequency of the system is shown in Fig. 6. In general the frequency analysis is held by varying the amplitude with respect to time. System inertia is stated as the capability of a system to show opposition to the variation in frequency because of the resistance created by the kinetic energy of rotating masses in each of the generator. Fig. 7 depicts the power system with the impact of reduction in inertia.

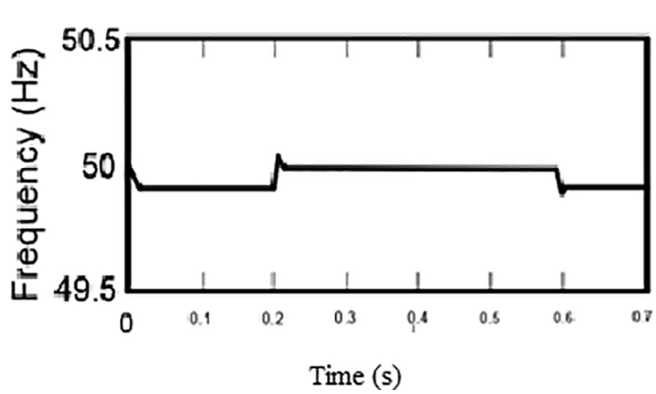

Fig. 6. System frequency.

The reduction of inertia increases variation in frequency during sudden disturbances, including loss or variation in the generation or demand. Thus, it is strongly advised to lower the settling time at the time of disturbance. Hence, the need for FC in power system is increased. A fast response of frequency from the side of generation is a commonly recommended solution to solve the issue of increased frequency deviation.

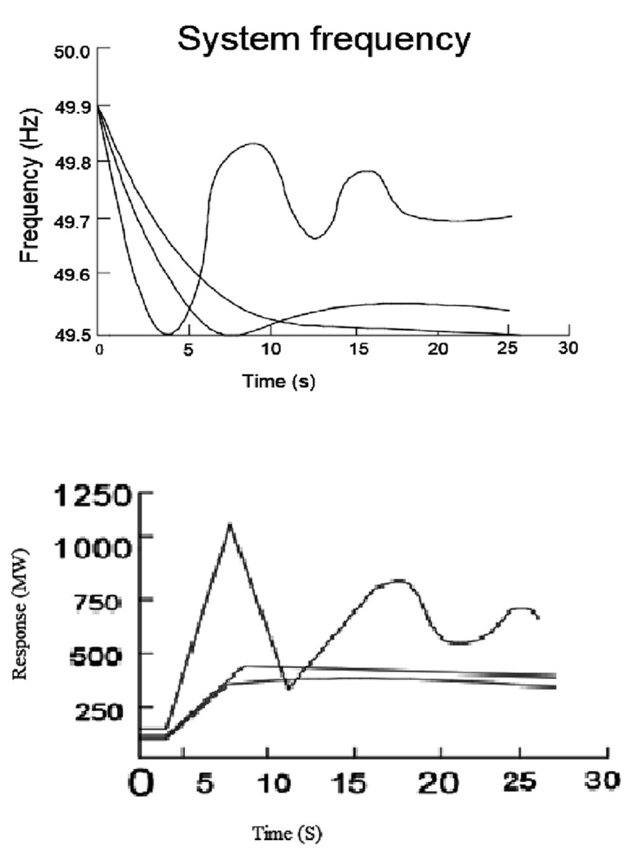

Fig. 7. Power system with the impact of reduction in inertia.

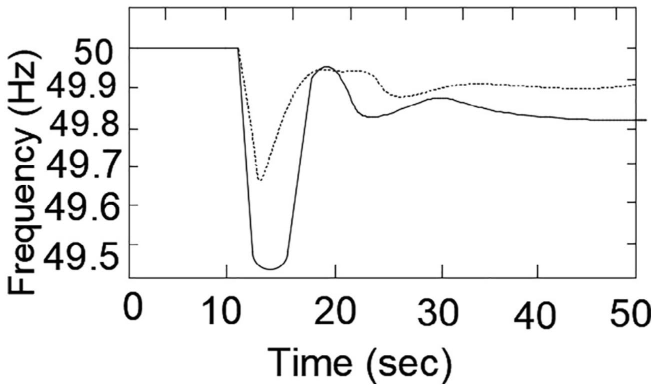

Fig. 8. Frequency control using FLC.

Table 1
Comparative table of existing method with FLC.

Metrics	Condition (1)		Condition (2)	
	PI	Proposed technique	PI	Proposed technique
Overshoot	3.82	0.2	2.58	0.18
Rise time	0.005 sec	0.0068 sec	0.0066 sec	0.0078 sec
Settling time	0.015 sec	0.012 sec	0.015 sec	0.016 sec

5.3. Switching Time analysis

For better frequency control, the value attained with respect to the fault intervals should be minimal. From the observed outcomes, the standard deviation for the presented FLC method is found to be much minimal over the compared models. Thus, the adopted scheme has shown higher efficiency in attaining better frequency control in micro grid systems. The frequency analysis of the presented scheme without frequency control and with FLC control is depicted in Fig. 8.

Table 1 tabulated the outcomes of the proposed frequency control method in terms of metrics, such as rise time, percentage overshoot, and settling time. It is evident from the analysis that the proposed technique provides enhanced control of frequency in power system.

6. Conclusion

This paper proposes the Fuzzy Logic Controller for controlling the frequency of rotor speed to enhance the power system performance. Hence, the major objective of proposed model is to lower the error that occurs among the reference signal and control signal. From analysis, the conventional schemes had experienced the sudden trigger at the respective fault intervals, however, the presented approach have not experienced much trigger. The betterment of the adopted scheme has been proved from the simulation results.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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