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RESEARCH ARTICLE

Design of fuzzy logic controlled hybrid model for the control of voltage and frequency in microgrid

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Abstract

Objective: To propose a fuzzy controlled hybrid model for the control of voltage and frequency in the microgrid system to improve the efficiency of the control system in the microgrid. The adapted hybrid model reduces the harmonic distortion to a certain level and controls the voltage and frequency of the microgrid. The performance of proposed fuzzy-based control model is analyzed and compared with existing droop control model. **Methods/Findings:** This proposed hybrid model of photovoltaic fuel cell model employs a DC/DC converter along with DC/AC inverter. A case study has been carried out and the proposed methodology is efficient in the control technique of the microgrid. To reduce the harmonic distortion in the microgrid and fluctuation in voltage and frequency, a comparison with the droop control technique. **Novelty:** The microgrid system commonly uses a droop control technique for the control of voltage and frequency to enhance efficient control with the reduction of losses in the system. Even though the droop control method is reliable, the method depends on line parameters and not suitable for the bulk system. The performance is low for a complex system and hence it is not suitable. Various methods for the reliable power with the harmonic reduction has been already proposed. In this paper, a method called fuzzy controlled hybrid model is reviewed and this newly proposed technique is independent of line parameters, reduces the harmonic distortion and can operate for a bulk system with a reliable power supply in the microgrid.

Keywords: AC Micro grid; droop control; fuzzy logic; hybrid system; load scenario

1 Introduction

Under the influence of high demand in energy and reliable power supply, the green technology has been improved. The interest for the supply of reliable power supply and developing power utilization has been brought about by expanding the daily life causes and the rising number of delicate or basic burdens. The distributed generation [DGs] and Microgrids [MGs] are developed to meet the demand, which leads to the intelligent and advanced control technique in between the generation and distribution, these control techniques will help in reduction of voltage losses and it is suitable for low/middle voltage levels [(1)]

A little scope framework situated close to the consumer is known as the Microgrid framework. Miniaturized scale framework is a low voltage or medium voltage distribution community which comprises a bunch of smaller scale sources/appropriated generators, vitality stockpiling frameworks and burdens, working as a solitary controllable framework. In an MG, the circulated generators should have adequate ability to convey all, or most of the load associated with the MG [(2)]. Distributed generators are situated at key focuses, typically at the dissemination level, close to stack focuses, and also utilized for the capacity support, voltage backing and guideline, and line misfortune decrease. The microgrid idea can possibly tackle serious issues emerging from enormous infiltration of conveyed age in circulation frameworks. Microgrids (MG) are getting progressively appealing to customers and as such later on, an incredible number of them will be introduced at purchaser's locales. Microgrids can give such coordination by collecting DG, burdens, and capacity in little scope systems which can work in framework associated and islanded mode [(3)] [(4)] [(5)]. It has been observed that the microgrid require insight and adaptability for the control and optimization in order to guarantee the capacity of monitoring balance among age and appropriation affected by aggravations and symphonious contortion. Control of voltage and frequency are usually observed as a main challenge in the activity of microgrid in framework associated mode

In this paper, I am focusing on hybrid system of PV and Fuel Cell. It is observed that the droop control method is usually helpful for the control of voltage and frequency on the interconnection of microgrid with main grid, but the method is dependent on line parameters, the control of voltage and frequency in both grid connected and islanded modes are presented in [(6)] [(7)]. The problems and technical issues related to voltage and frequency control, battery storage and islanded operation are discussed in [(8)] [(9)]. Results and behavior of the micro grid when they are in grid connected and isolated from grid has been studied in [(9)] [(10)]. There are two unique methodologies that can be recognized for the architecture of micro grid control: centralized and decentralized. A completely centralized control relies upon on a lot of information transmittance among along with devices and afterwards the consideration has to be made at solitary point. Consequently, it will introduce a major issue in execution since interconnected force a framework for the most part spread broadened geographic areas and includes a gigantic quantity of units. Thereafter, again, in a complete decentralized control, overall unit is constrained on its neighborhood controller without knowing the situation of others. Tradeoffs between the ones two first-rate manipulate plans may be performed by way of methods for a modern manage comprising three manipulate stages:

- Primary, secondary, and tertiary.
- Primary control is the droop control used to share load between converters and stabilize the voltage and frequency.
- Secondary control is used for the reduction of a steady state error which is observed from the droop control.
- Tertiary control includes a global responsibility which recognizes the import or export of power concerned with the micro grid.

The first two levels manage a local control on the issues of stability and power quality. As the top-level control, tertiary control does not only handle the power flow, additionally it is also concerned for the quality on the point of common coupling (PCC), e.g. low voltage ride-through capability [(11)] [(12)]. Furthermore, tertiary control will help to exchange the related information related to the distribution system operator (DSO) for feasible operation and for the optimization of micro grid operation inside the utility grid. In this work stabilization of voltage and frequency which is a primary control scheme in microgrid operation is undertaken [(13)] [(14)]. Hence, the droop control technique is utilized in micro grid and its simulation results are observed with the known values of reactive power control methods. The present paper addresses the technical issues in microgrid control method. Droop control technique is primarily applied for the control of output voltage a frequency, but droop controller depends on line parameters and the performance is low. Hence, to solve the problem, a fuzzy controller-based hybrid system of photovoltaic-fuel cell (PVFC) is implemented and integrated with an AC grid of 14-bus system and the Simulink model of microgrid is simulated in a MATLAB Simulink and the function of hybrid system is verified and necessary control action is implemented with the help of fuzzy logic characteristics. The fuzzy logic controller is reliable and independent of line parameters, reduces the harmonic distortion which enables to provide improved performance with the help of changing system parameters with the operating condition [(15)] [(16)]. Fuzzy logic is one the latest tools which connects human cognitive relations to computers, it provides innovative insights into a comprehensive range of soft fuzzy logic techniques applied in various fields of engineering problems like fuzzy set theory, adaptive neuro fuzzy inference system and hybrid fuzzy logic algorithms belief networks I industrial and engineering setting. Fuzzy logic is becoming popular in the field of research; it found its application in decision-making, identification, time series, pattern recognition, optimization and control.

1.1 Droop control

Figure 1 shown below represents the droop control method which is connected to different AC sources without any intercommunication. These methodologies are very much useful in the relation across the frequency and active power flows in the latest existing in energy system. Rather than utilizing basic communication links, a droop control technique permits DER (Distributed Energy Resources) units to naturally distributes the overall load by the estimation of the local accessible factors (output voltage and current), in this manner outfitting higher unwavering quality and adaptability. Usually, droop control technique can be additionally part into two sorts, for example the master-slave, multi-slave droop control. Master slave droop control is a combined utilization of master slave control and droop control. This is suitable in the case of single or a few DER unit which acts as a grid forming (master) units [17,18]. Then again, in the multi-master droop control, there will be no connection between grid forming units and grid feeding units. Moreover, all DER units works as a grid forming units [19–21].

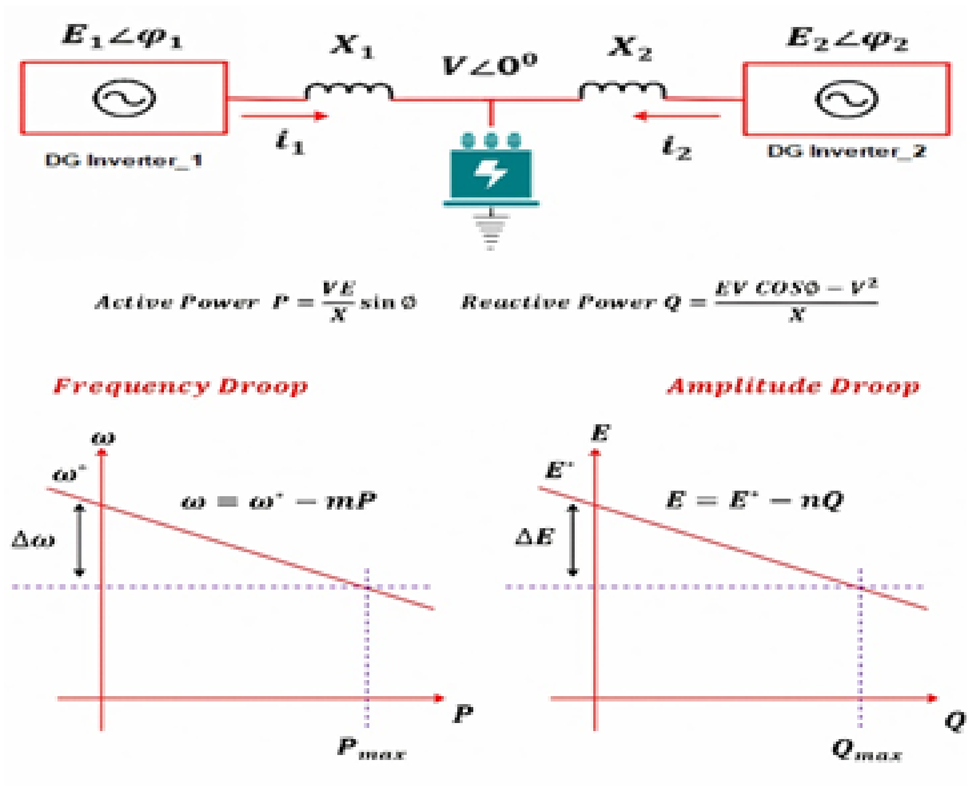


Fig 1. Droop control of AC System

According to droop control technique, there must be a only single line should be defined in between the local loads an DG. In case of enormous scales in MG's, the quantity of boundaries and time computation will be considerable. Droop control fundamentally relies upon line parameters (R & X) to overcome this problem a fuzzy control method which is independent on line parameters is proposed.

2 Proposed hybrid system of photovoltaic and fuel cell system

These two sustainable power sources groups the helpful energy change to DC power. An inverter framework which is utilized to change over the DC power into AC which is consumed by the most of the industrial and domestic loads. For the best possible transformation into AC with required voltage level, frequency and phase sequence, appropriate inverter control must be made.

The proposed hybrid model consists of a photovoltaic and fuel cell system; both the frameworks have a DC/DC converter along with DC/AC inverter as appeared in a Figure 2. Both PV and a fuel cell system generates DC power that is fed to the DC/DC converter in order to get an essential DC voltage, an MPPT is included in PV array to enhance high efficiency. In order to integrate the microgrid with the utility grid an inverter is adapted which helps to transform the DC voltage to AC.

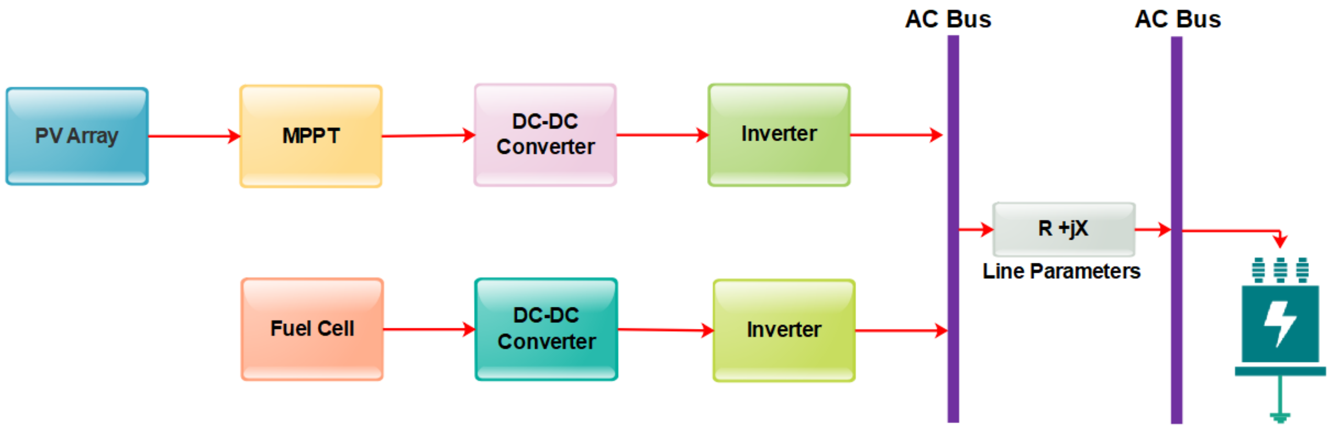


Fig 2. Proposed hybrid system

2.1 Proposed PV system

Figure 3 shows the square outline of a fundamental power transformation unit of PV generator framework 3

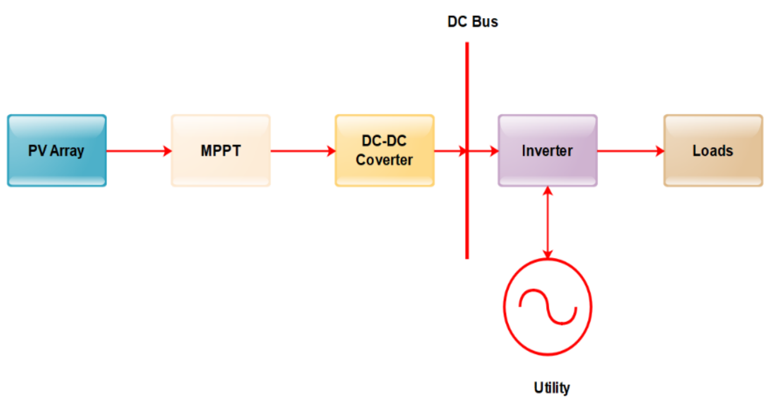


Fig 3. Square outline of a proposed PV framework

A photovoltaic framework utilizes at least one sunlight-based modules or boards to change over solar energy to electrical energy. This change happens in materials which have the property to catch photon and radiate electrons. The primary material utilized in PV framework is Silicon. PV module commonly comprises various PV cells which are all arranged in series. A PV cell will be of non-linear voltage-current (V-I) characteristics that is able to modeled utilizing current sources, diode(s) and resistors. Single-diode and double diode models are generally used to simulate PV characteristics. A single-diode structure matches the characteristics of the PV cell decently and also precisely. The producer gives data of the electrical characteristics of a PV cell by indicating some of the points in a V-I characteristics that is well-known as a striking point. Solar insulation and cell temperature will be responsible for an output characteristic in a PVmodule. Because of the nonlinear characteristics of the PV module, it's an important for the modeling of structure along with the simulation of maximum power point tracking (MPPT) for a PV framework usage. MPPT works on the principle of extracting maximum power from PV module, MPPT check the output of PV module and forces PV module to operate at voltage close to maximum power point to draw maximum power available than fixes the best power that PV module can produce to supply DC-DC converter. An ideal power collecting technique which is named as maximum power point tracking, that will be applied for the PV framework to upgrade the efficiency. The perturb and observe (P&O) algorithm with altered structure will be broadly utilized now in power tracking DC-DC converter which will be utilized for a PV system is a boost converter which is driven by the MPPT beats from the P&O algorithm with an output which is connected with the basic DC bus where every other source feed their power.

The DC-AC converter that utilized in the described framework is three stage sinusoidal PWM controlled inverter which is combined with an appropriately designed filter to create the sinusoidal output with 50 Hz frequency. Table 1 gives the data regarding parameters of the proposed PV system.

Table 1. Parameters of the proposed PV System.

Parameters of PV System	Specifications
Number of Sunlight based cells per module	60
Number of Series associated modules per string	10
Number of Parallel strings	40
Solar irradiance (input)	1000 W/m^2
Output voltage	380V
Output power	213.5W
Operating temperature	25°C
V_{OC}	36.3V
I_{SC}	7.84A
V_{MP}	29V
I_{MP}	7.35A

At standard test condition of 25° temperature, and irradiance of 1000 W/m, the panel is designed to give an output voltage of 380V.

2.2 Proposed Fuel cell System

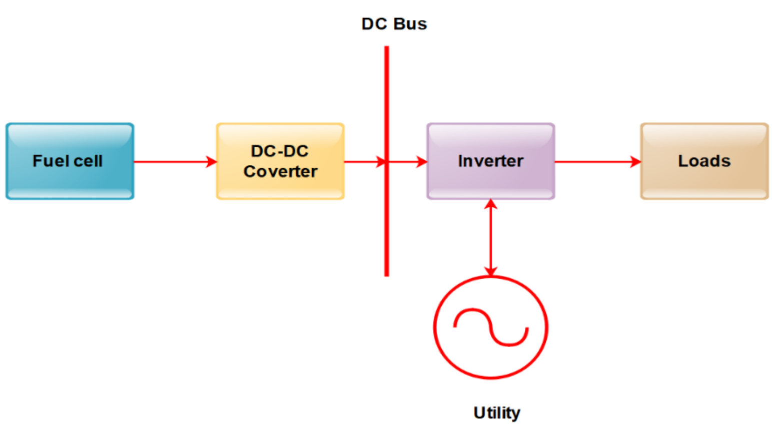


Fig 4. Schematic diagram of a proposed fuel cell system.

The fuel cell energy framework takes a shot at the standard of electro-chemical response of hydrogen with oxygen. Because of the response of hydrogen and oxygen it creates power, heat and the side-effect is water. The voltage rating and power rating of the fuel cell energy unit framework is characterized by the movement of hydrogen and oxygen from the storage tank and the concentration of hydrogen atoms. The Fuel Cell framework likewise needs to have a DC-DC converter on order to change over necessary DC level voltage which is approved constant DC bus. The DC-DC converter used in Figure 4 is BOOST converter, it helps to convert the required DC level voltage which is fine with the constant DC bus to avoid the fluctuation in the in voltage and frequency in Micro grid. An inverter framework which is utilized to change over the DC power into AC which the greater parts of the industrial and local loads consume. Integrating FC into microgrids is rather promising, as it can continuously generate the electricity as well as the fuel is supplied. Moreover, the electrolyzer and FC combination can provide a long-term energy storage solution to supplement the battery banks. The excess electricity is converted into hydrogen by means of an electrolyzer and can be further stored in a hydrogen tank in the states of gas, liquid or metal hydrides. In the case of insufficient electricity supply, the hydrogen is converted into electricity by FC. For the best possible change into AC with required voltage level, frequency and phase sequence, proper inverter control must be made as appeared in Figure. 4. Table 2 gives the data regarding parameters of the proposed fuel cell framework.

Table 2. Parameters of proposed fuel cell framework

Parameters of fuel cell framework	Specifications
Output Power	6 kW
Output voltage	65 V
Number of cells	65
Operating Temperature	65°C

3 Modeling of hybrid system in MATLAB

MATLAB/SIMULINK gives an option using the Simulation of Power Systems toolbox for SIMULINK. Notwithstanding, it has not overseen yet to accomplish an all-inclusive spread in the force gadgets/circuit structure and simulation network. The constrained writing accessible is generally engaged in solving the differential conditions getting from circuits utilizing MATLAB while the all-encompassing utilization of SIMULINK as of late began increasing further interest.

3.1 Modeling of PV system

A 215 W capacity PV module is readily available in MATLAB is chosen with the voltage of 380V as output and solar irradiance of 1000 W/m2 as an input at a particular temperature 25oC. A PV cluster is made of hemp of PV modules associated in a similar way. Each string comprises modules associated in arrangement or series as shown in Figure 5. Array data: Parallel strings=40, modules connected in series per string =10, cells per module=60.

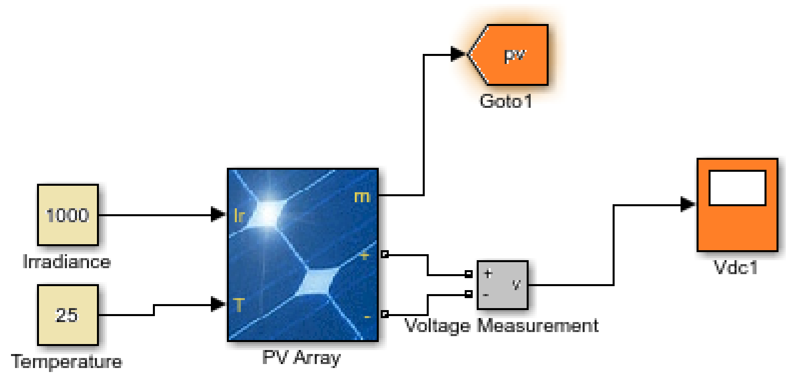


Fig 5. PV array system

Figure 6 describes a Simulink representation of a suggested PV in which the fuzzy controller is not implemented. It uses MPPT, DC to DC converter, PWM IGBT inverter and LC filter. PV array generates DC electricity which can be transformed into AC. Each of the blocks is explained in further sections.

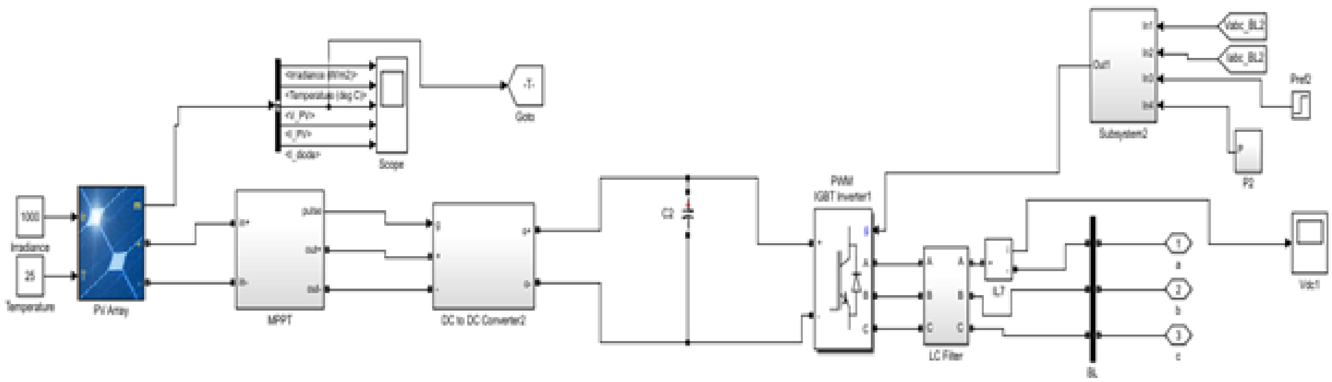


Fig 6. A simulink representation of a suggested PV framework

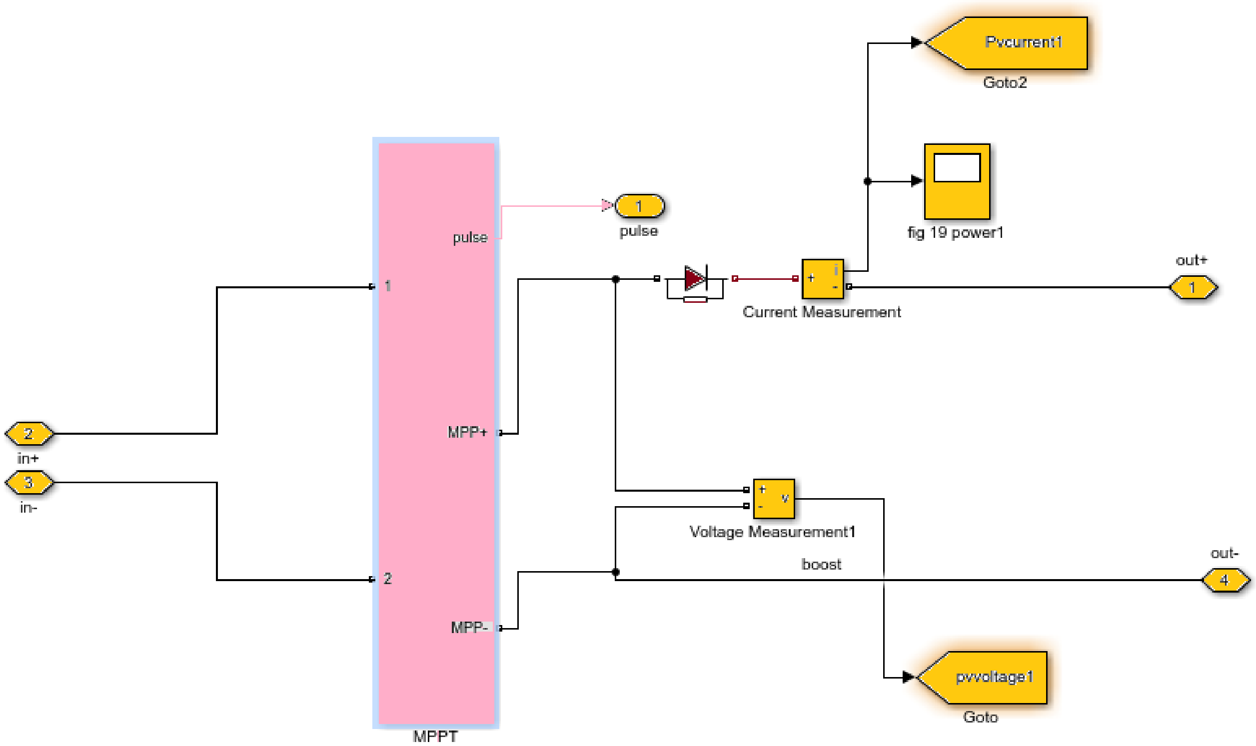


Fig 7. MPPT algorithm

MPPT: Figure 7 shows a maximum power point tracking (MPPT) figuring completed in a photovoltaic (PV) inverters in order to alter the electrical impedance seen with a sun based group for the proper working of PV at, or close to the peak power point of the PV board under fluctuating conditions, for example, changing daylight based irradiance, temperature, and load.

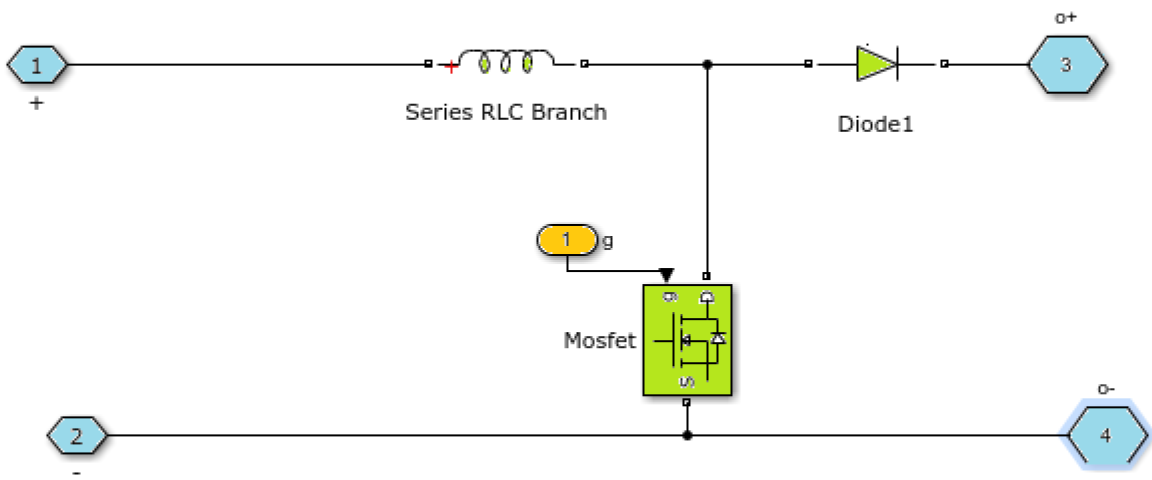


Fig 8. DC to DC converter

DC to DC converter: it is a necessary section of the MPPT framework. At the point when an immediate connection is done among the supply and the load, the output of the PV module is irregularly moved far from the most electricity factor. It's an important to defeat this issue by including an adjustment circuit among the source and load. A MPPT controller in addition with the DC-DC converter circuit is utilized as an adaptive circuit as appeared in Figure 8.

PWM IGBT Inverter: As in the single stage voltage source inverters PWM method will be utilized for the three-stage inverters, so that there will be three sine waves stage moved to 120° along with the frequency of ideal output voltage which is measured and a heavy frequency carrier triangle, two Signs are jumbled together a comparator whose output is excessive when the sine wave is greater than the triangle and the comparator output is less while the sine wave or normally called the adjustment sign is littler than triangle.

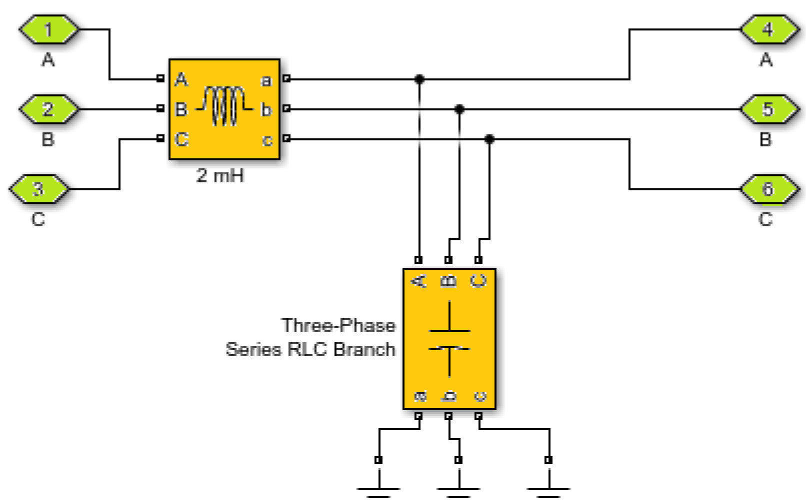


Fig 9. LC filter.

LC Filter: it is additionally well-known as a resonant circuit, tank circuit, an electric circuit which is composed of inductor, which is represented in an alphabet L, also a capacitor, indicated in an alphabet C, connected in close addition as appeared in Figure 9. It is utilized at the inverter circuit in order to reduce the harmonics.

3.2 Modeling of a fuel cell

Since a fuel cell blocks are available in the Simulink library, a 6 KW capacity fuel cell stack is chosen.

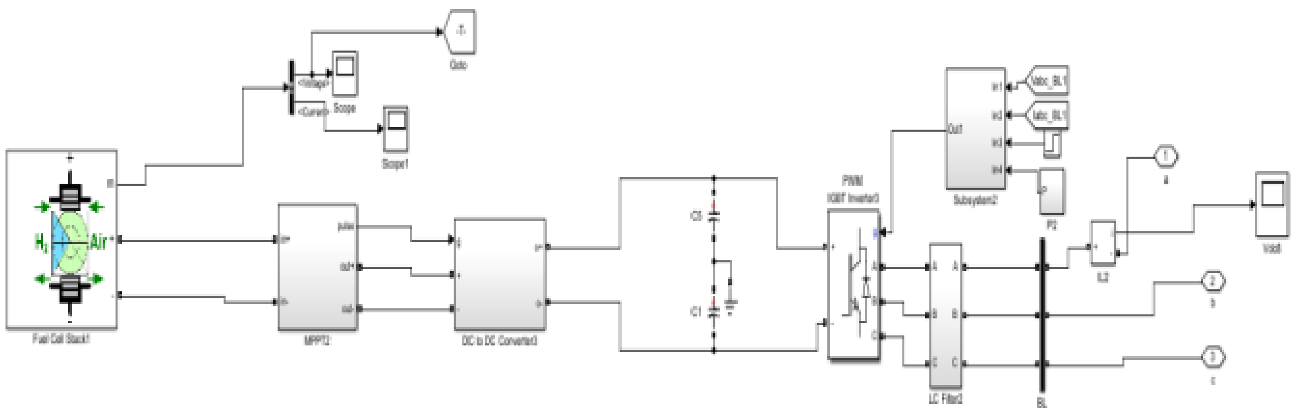


Fig 10. Fuel cell model

Figure 10 shows a fuel cell model in which the fuzzy controller is not implemented. It uses MPPT, DC to DC converter, PWM IGBT inverter and LC filter. Fuel cell generates DC electricity which can be transformed into AC using the following blocks explained below.

- MPPT: Maximum power point tracking (MPPT), an algorithm which is involved in this technique to improve high productivity.
- DC to DC converter: The FC framework additionally needs to have a DC-DC converter to change over the necessary DC level voltage which approves with the steady DC bus.
- PWM IGBT Inverter: An inverter framework which is utilized to change over the DC power into AC in which the greater part of the load is consumed by the industrial and domestic loads.
- LC Filter: it is additionally well-known as resonant circuit, tank circuit, an electric circuit composed of an inductor, represented by the alphabet L, a capacitor, represented by the alphabet C. It is utilized at the inverter circuit for the reduction of harmonic distortion. Demonstration of proposed microgrid the hybrid system of PV and fuel cell system are designed and are connected to the AC micro gird through 14 bus system. In which PV model connected to 6th bus whereas fuel cell model is connected to 8th bus as shown in Figure 11. These two sustainable power sources have the advantageous energy conversion to DC power. An appropriate inverter is utilized to change over the DC power into AC power. The voltages are measured in per unit system in the microgrid.

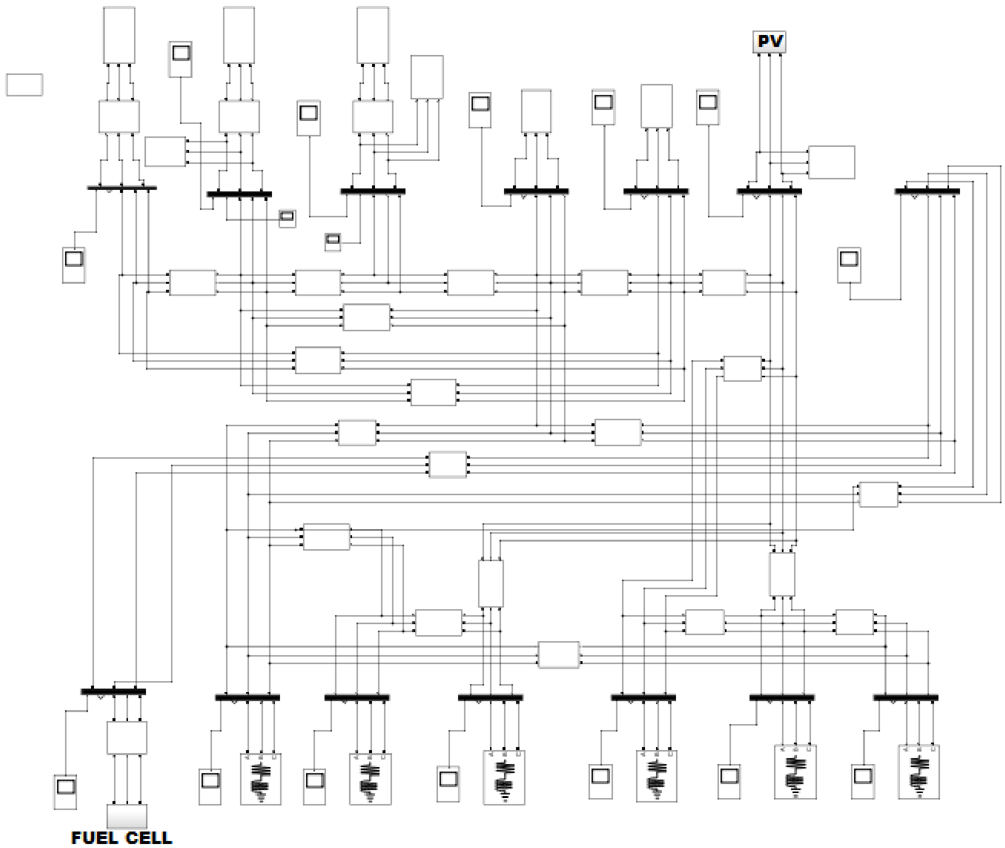


Fig 11. Microgrid

4 Modeling of hybrid system with fuzzy controller in MATLAB

Fuzzy logic is a part of esteemed logic wherein Truth estimations of factors might be any actual quantity somewhere inside the variety of 0 and 1. Its miles utilized to deal with the concept of incomplete fact, whereas the truth will be going among overall true and overall wrong. From the Boolean logic, truth Estimations of things may additionally simply be the quantity qualities zero or 1. A fluffy controller or deals with the fuzzy principles, those are linguistic if-then statement with the fuzzy rules, fuzzy logic and fuzzy inference. Fuzzy standards take a key job in speaking to master control/demonstrating information and experience and in connecting the input factors of fuzzy controllers/models to the output variables.

4.1 Fuzzy controller

With the contrast of direct PI controller, this will be a type of non-linear controller that can give good execution affected by changing system parameters and working conditions. The fuzzy controller is valuable as it mitigates the framework from definite and awkward numerical demonstrating and calculation. The presentation of fuzzy controller is settled for enhancements in both transient and consistent state for droop control in 14 bus frameworks. The fuzzy controller involves four primary practical modules to be specific; Knowledge base, Fuzzification, Inference instrument and Defuzzification.

4.2 Knowledge base

It comprises information (data) base and rule base that maps all input and output with certain level of vulnerability in process parameters and outside unsettling influences to acquire great powerful reaction. Data base scales the input-output factors as enrollment works that characterizes it in a range fitting to give data to the fuzzy standard based framework and output factors or control activities to the framework under perception.

4.3 Fuzzification

It is the way toward characterizing a fresh information or computerized information working on discrete estimations of either 0 or 1 regarding consistent factors somewhere in the range of 0 and 1 for example fuzzy set.

4.4 Inference mechanism

These mechanisms are well-known as appropriate reasoning that utilizes knowledge information to lead deductive inference of IF-THEN rules. A mamdami inference system of 49 rules is framed as shown in Table 3.

Fuzzy standard based framework uses a collection of fuzzy restrictive statements got from a knowledge base to appropriate and develop the control surface. Here in this work so as to keep up the voltage and frequency at adequate range the following rules were formed.

Table 3. Fuzzyrule based system.

V/ F	NL	NM	NS	Z	PS	PM	PL
NL	**L**	**L**	**L**	**M**	**Z**	**S**	**Z**
NM	**L**	**L**	**M**	**Z**	**Z**	**Z**	**S**
NS	**L**	**M**	**S**	**Z**	**Z**	**S**	**S**
Z	**M**	**S**	**S**	**Z**	**S**	**S**	**M**
PS	**S**	**S**	**Z**	**Z**	**S**	**M**	**L**
PM	**S**	**Z**	**Z**	**Z**	**M**	**L**	**L**
PL	**Z**	**S**	**Z**	**M**	**L**	**L**	**L**

There are seven fuzzy subsets that is NL (Negative Large), NM (Negative Medium), NS (Negative Small), Z (Zero), PS (Positive Small), PM (Positive Medium), and PL (Positive Large). Using this rule-based system in a fuzzy controller the voltage and frequency can be maintained at acceptable limit.

4.5 Modeling of fuzzy controlled PV system

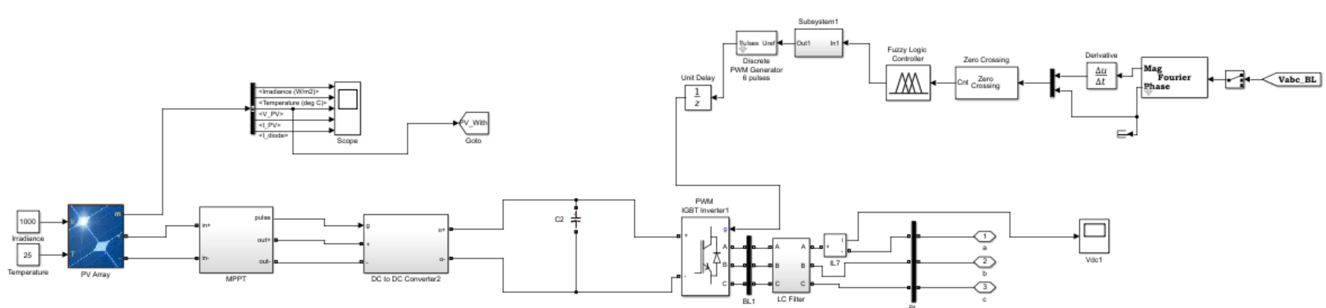


Fig 12. Fuzzy Controlled PV Model

Figure 12 shows a Simulink model of proposed fuzzy controlled PV system in which the fuzzy logic technique is implemented. It uses MPPT, DC to DC converter, PWM IGBT inverter and LC filter (which were explained in the previous section).

4.6 Modeling of fuzzy controlled fuel cell framework

Since the fuel cell system is readily available in mat lab Simulink library, a 6 KW capacity fuel cell stack is chosen.

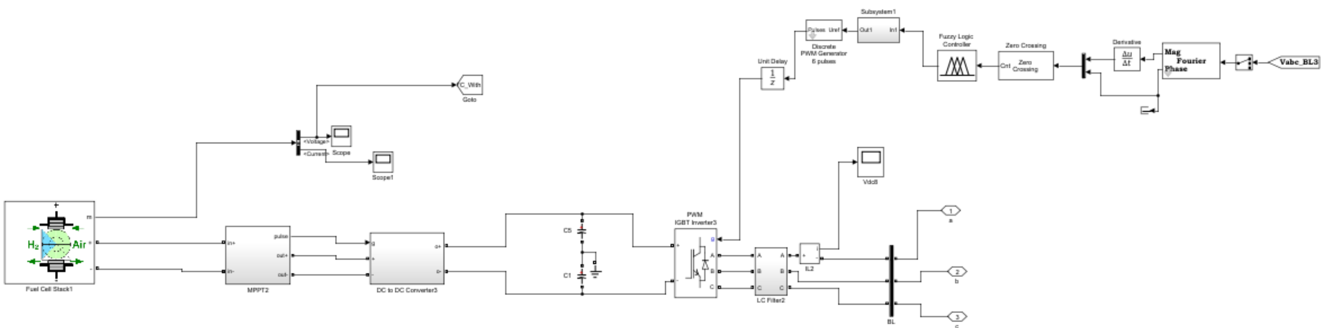


Fig 13. Fuzzy controlled fuel cell model

Figure 13 shows a Simulink model of proposed fuzzy controlled fuel cell system in which the fuzzy logic technique is implemented. It uses MPPT, DC to DC converter; PWM IGBT inverter and LC filter (which were explained in previous).

4.7 Modeling of proposed fuzzy controlled microgrid

The proposed fuzzy controlled PV and fuel cell hybrid system are designed and are connected to the AC micro gird through 14 bus system. In which PV model connected to 6th bus and fuel cell fixed to the 8th bus as shown in Figure 14. These two sustainable power sources have the advantageous energy conversion to DC power. A proper inverter is used to convert the DC power into AC power. The voltages are measured in per unit system in the microgrid.

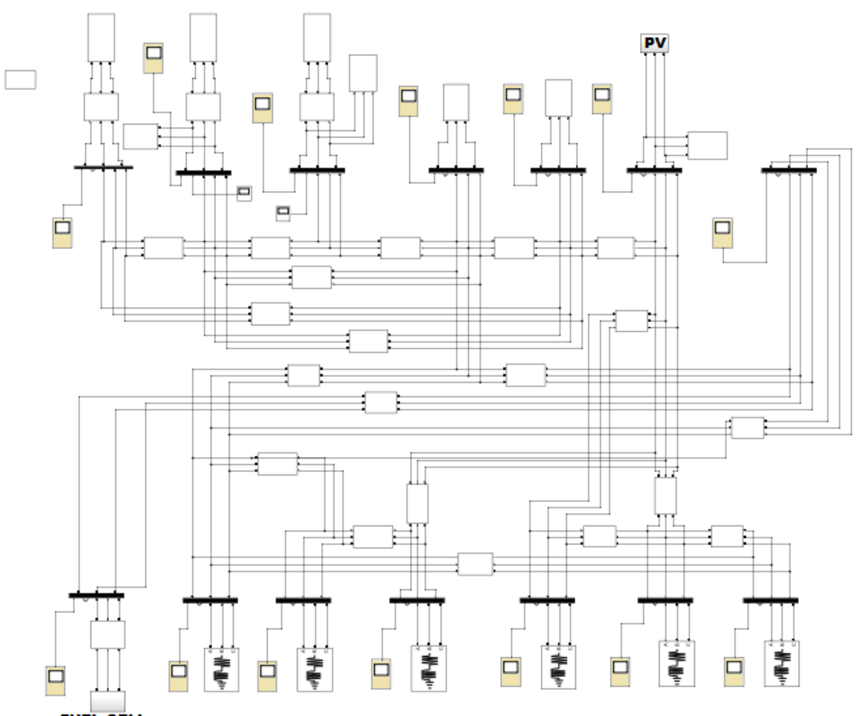


Fig 14. Fuzzy controlled microgrid.

5 Results & Discussions

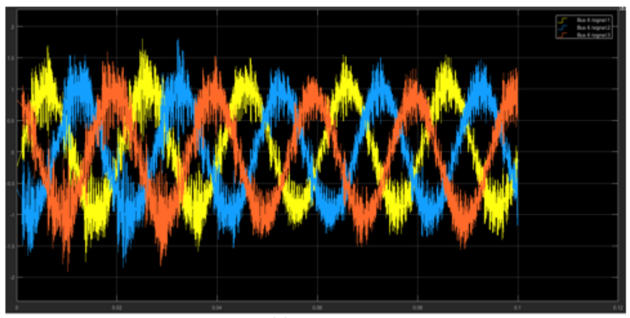
The simulation of microgrid is done in MATLAB/Simulink software. The developments of Simulink model for proposed system with their results are discussed in this section.

- The proposed microgrid without Fuzzy Controller for different load
- The proposed microgrid with Fuzzy Controller for different load.

Case 1: Without Fuzzy Controller

Load: P+jQ =0.112+j0.075

The bus voltages are measured in per unit system and it is observed that the voltage varies around 1.7pu which is beyond the acceptable limit i.e., 1pu due to the line parameters and harmonic distortion, the voltage waveform of 6th and 8th bus are as shown in Figure 15. Total harmonic distortion will be 22.30 % as shown in Figure 16.



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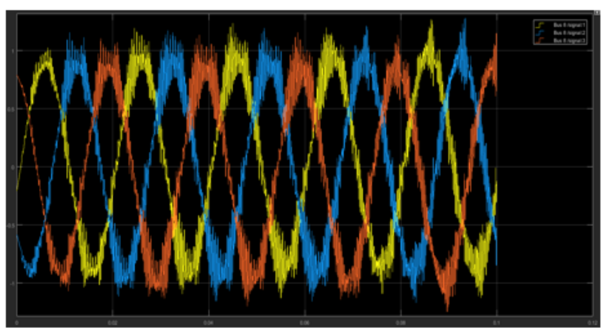


(b).

Fig 15. (a): 6^{th} Bus Voltage in Per Unit System. (b): 8^{th} Bus Voltage in Per Unit System.

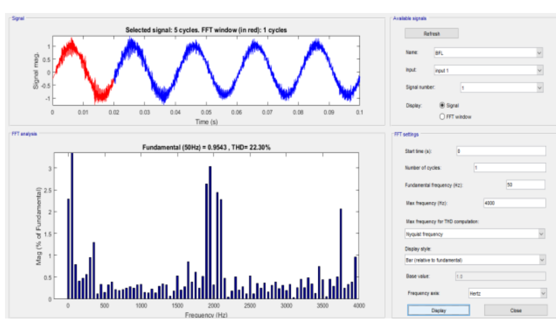
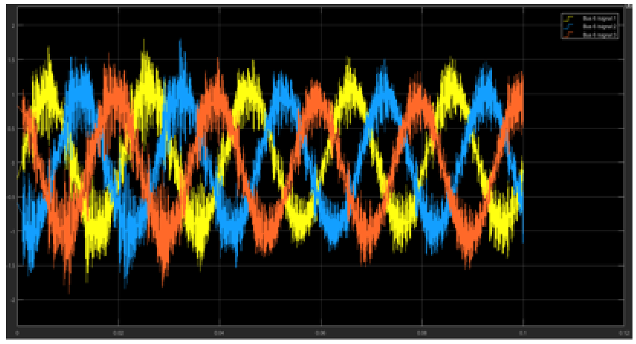


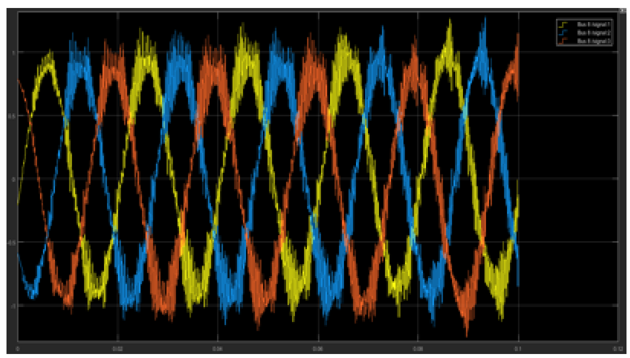
Fig 16. HD of 14 bus system without fuzzy controller.

Load: P+jQ=0.420+j0.365

The bus voltages are measured in per unit system and it is observed that the voltage varies around 1.7pu which is beyond the acceptable limit that is 1pu due to the line parameters and harmonic distortion, the voltage waveform of 6th and 8th bus are as shown in Figure 17. The total harmonic distortion will be 25.54% as shown in Figure 18.



(a):



(b).

Fig 17. (a): 6th Bus voltage in per unit system. (b): 8th Bus voltage in per unit system

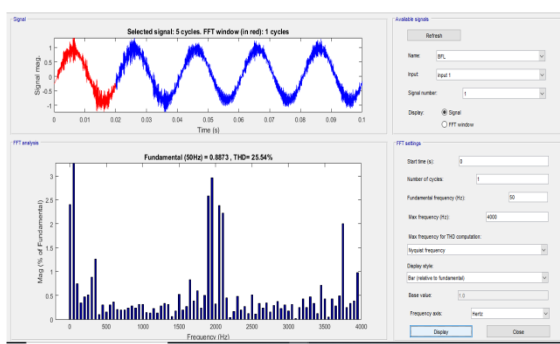


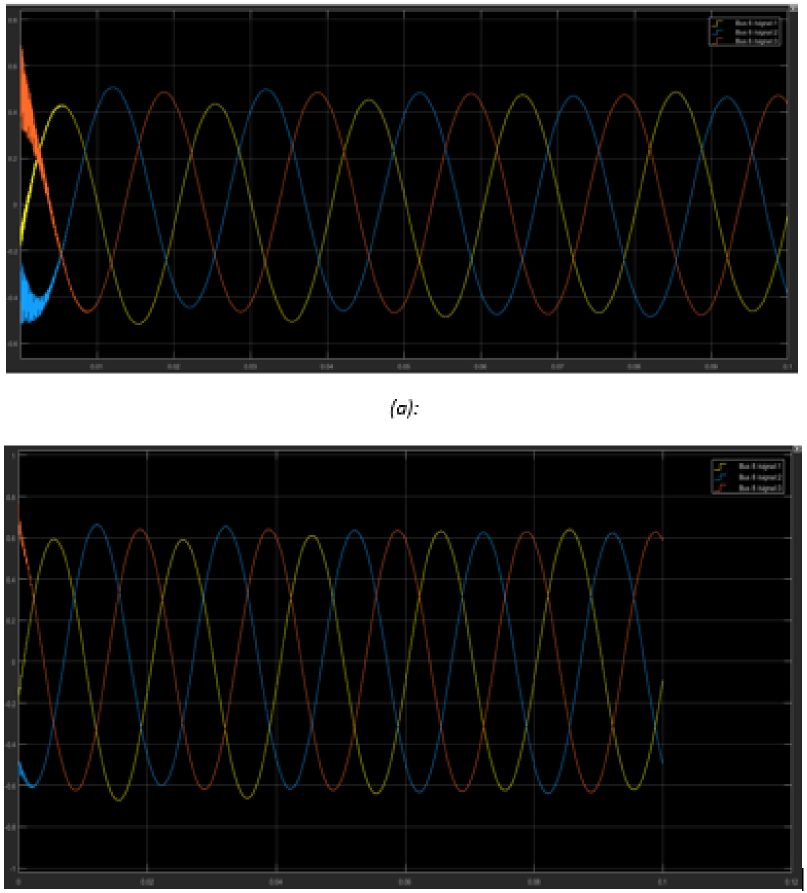
Fig 18. THD of 14 bus system without fuzzy controller

In order to bring the voltage to their acceptable limit that is 1pu with the reduction of total harmonic distortion a fuzzy logic technique is utilized and the results are discussed in next section.

Case.2: With Fuzzy Controller

Load: P+jQ=0.112+j0.075

The bus voltages are measured in per unit system. After the implementation of the proposed fuzzy controller it is observed that the voltage varies within the acceptable limit that is 1pu, the waveform of 6th and 8th bus are as shown in Figure 19. The total harmonic distortion will be reduced from 22.3% to 2.32 % as shown in Figure 20.



(a):

(b):

Fig 19. (a): 6th Bus voltage in per unit system. (b): 8th Bus voltage in per unit system

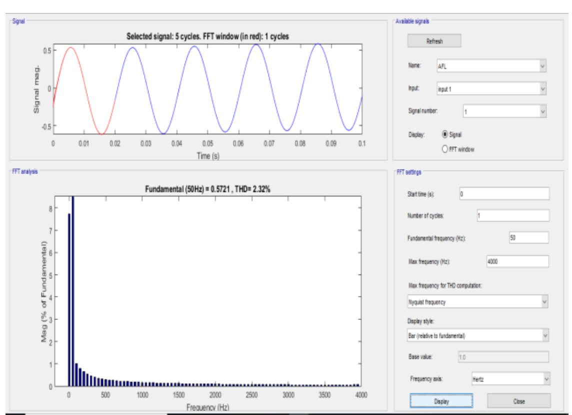
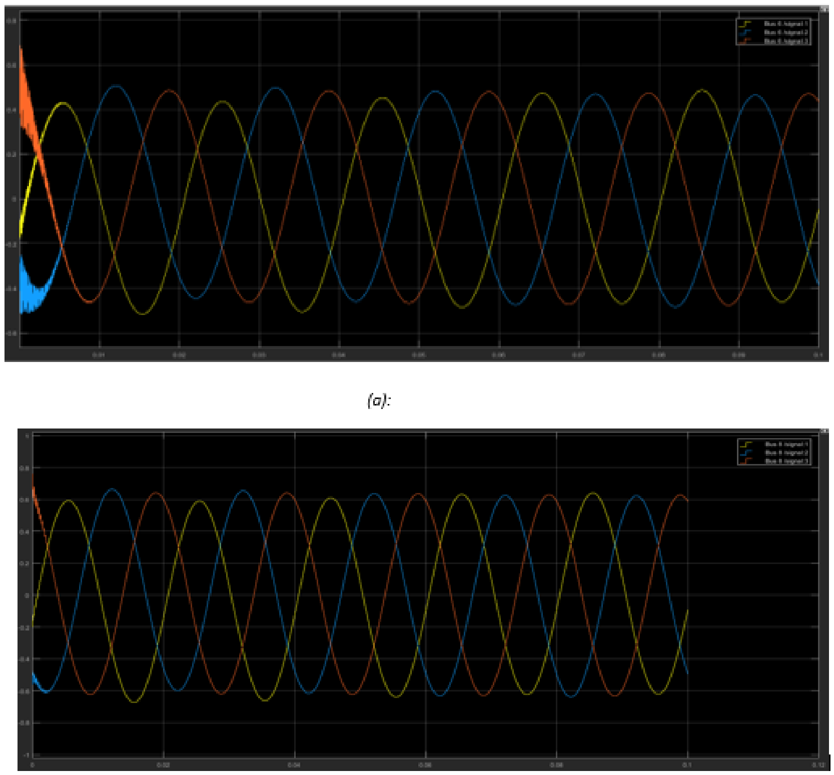


Fig 20. THD of 14 bus system with fuzzy controller

Load: P+jQ=0.420+j0.365

The bus voltages are measured in per unit system. After the implementation of the proposed fuzzy controller it is observed that the voltage varies within the acceptable limit that is 1pu, the waveform of 6th and 8th bus are as shown in Figure 21. The total harmonic distortion will be reduced from 25.54% to 2.49 % as shown in Figure 22.



(a):

(b):

Fig 21. (a): 6th Bus voltage in per unit system. (b): 8th Bus voltage in per unit system

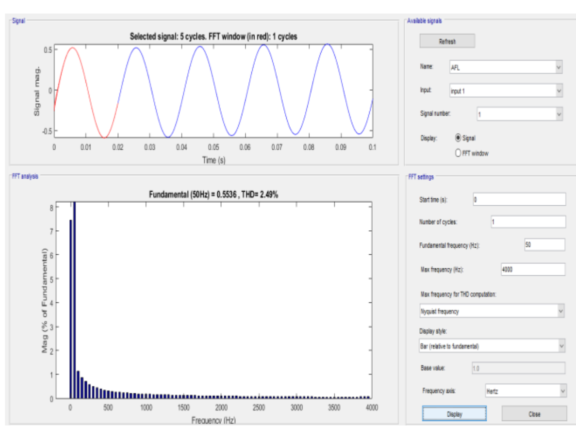
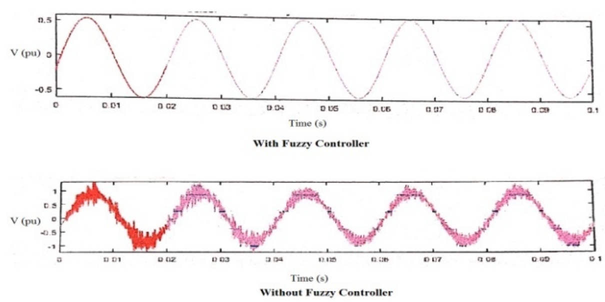


Fig 22. THD of 14 bus system with fuzzy controller.

With the help of simulation consequences, it can be concluded as the harmonics and the distortions in the voltage waveform are reduced to a great extent with the use of fuzzy logic controller for different loads compared to that without a fuzzy controller.

6 Conclusion

Comparison analysis Graphs of microgrid with fuzzy and without fuzzy controller



A study has been carried out on a hybrid model of PV and Fuel Cell. Control techniques is designed without a fuzzy controller and integrated with MG. The voltage is measured in the per-unit system across the 14-bus system and it is observed that the waveforms are distorted due to harmonics and line parameters. Hence to overcome this problem, we have introduced a hybrid system of PV and Fuel Cell with Fuzzy Controller and integrated with MG.

- With the help of the simulation result, it is seen that the proposed Fuzzy Controlled MG reduces the harmonic distortion from **22.32% to 2.32%** and the voltage across the 14-bus system for different load varies within the acceptable limit that is 1pu compared to a hybrid model without a fuzzy controller. Hence from the simulation results in the micro-grid, the system is capable of operating in the grid-connected mode with fuzzy controller effectively.
- The fuzzy controller is reliable and independent of line parameters, reduces the harmonic distortion and provides the satisfactory performance with the effect of changing system parameters and working conditions.

From the simulation results it is observed that the harmonics and the distortions in the voltage waveforms are reduced to a great extent with the use of fuzzy logic controller for different loads compared to that without a fuzzy controller.

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