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Photovoltaic array and fuel cell based hybrid microgrid

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Abstract
Solar energy is one of the most inexhaustible and renewable form of energy available in the nature. It can be used to generate electricity. A photovoltaic array generates electricity from solar energy. The output of a solar cell highly depends on the concentrated solar irradiance and the operating temperature. This is the main disadvantage of the PV generation so; it has to be operated at maximum power point mode, so that maximum power can be extracted at any time. In bad weather conditions or in the night there is no output from a PV array so, it must be accommodated with some energy storage elements so that in such conditions the electricity continuous to the load. In this paper, a fuel cell is used to supply power when power available from the PV cell is not enough to feed the load. The power available from the hybrid system can be used to supply the local load as well as to power grid. There are two modes of operation of the hybrid system, one is grid connected mode and second is islanded mode. Both mode switches depending upon the requirement and availability of the power at certain time of the day. This arrangement increases the flexibility of the overall system in addition to the improved performance and high efficiency.

Keywords: photovoltaic, renewable energy, fuel cell, microgrid

1. Introduction
In today's environment, the trend of electricity generation is changing regularly. More emphasis is on the generation of electricity from the renewable sources of energy. Solar energy is available almost for a complete year with small variations and in an inexhaustible amount. This draws the attention of the researcher to develop techniques to extract maximum energy from the solar radiation to generate electricity. A solar cell is the most commonly used energy conversion device which converts solar irradiance into heat and electricity. Even at the places where there is no electricity available from the national grid or central supply system, a PV cell can be installed to provide electricity for their daily needs. The main disadvantage of solar array for generating electricity is the intermittent nature of the solar energy available during a complete day, as from morning to next morning the concentration of solar irradiance varies from maximum to zero. So the electricity produced by the PV cell varies respectively. In such conditions, a hybrid generation system can be developed to overcome the limitation of PV cell when there is no generation from it. There are multiple options which can be operated in parallel with the PV cell such as battery energy storage, fuel cell, small hydro power plants, tidal power plant, geothermal source and wind generation etc.
In this paper a PV array is connected with a proton exchange membrane fuel cell (PEMFC). Both sources are intended to feed the local load as well as to the grid, in case of grid connected mode. In grid connected mode, if the hybrid power generation lacks the total power demand, then extra power can be extracted from the grid and the PV array and fuel cell are operated at maximum rating. In grid connected mode power reference for these units are decided by the grid. This increases the overall efficiency of the hybrid microgrid. In Island mode, the microgrid has to supply its load by deciding the reference value according to the load requirement, such as the voltage and frequency rating of the load.

2. Photovoltaic Cell
Photovoltaic cell is a semiconductor diode designed in such a way that when exposed to the solar radiation it produces electricity and if any load is connected to it the power flows through it. As light incident on its surface it emits the charge from the semiconducting material. As generation of electrons depends on solar irradiance, a PV array is behaves like a current source. The emission from the surface of the previous cell depends upon the frequency of the incident light and temperature. The minimum frequency required for the emission of an electron is known as threshold frequency. However if the incident light is having higher energy than the threshold, it is converted into kinetic energy of the emitted recharge. Figure 1 shows the I-V characteristics of a PV array with respect to the different level of solar irradiance.

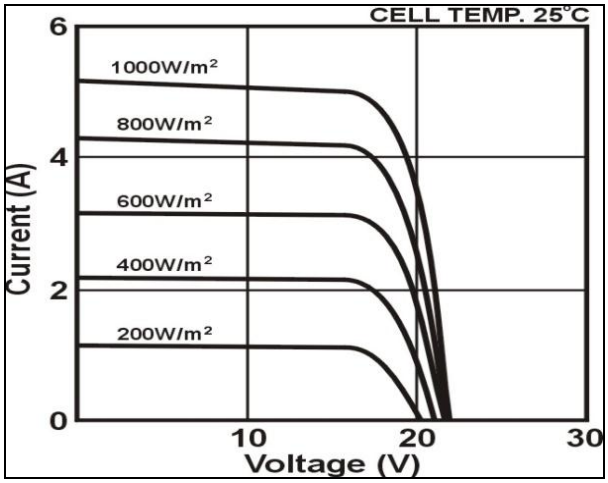

Fig 1: I-V Characteristics of PV

A solar cell unit produces only about 1/2 (.5) of a volt potential difference across its terminals. For larger value of voltage and current multiple modules are connected in series and parallel combination. The main advantage of using the PV array to generate electricity is that, it is completely free from pollution and main drawback is that, it is not available throughout the day [1-10].

3. MPPT technique used

Maximum power point is a point on the I-V characteristics of the PV array, which corresponds to the maximum power extraction corresponding to the available in irradiance and temperature. MPPT techniques are most effective under cold weather, hazy days, cloudy, shading effects and seasonal availability of the solar irradiance. 1) Perturbation and Observation 2) Incremental Conductance method and 3) Constant Voltage technique are the three types MPPT techniques available in literature. In this paper perturbation and observation technique is used for MPP tracking because it requires lesser number of sensors as compared to the incremental conductance technique to track the MPPT point [11-22]. If the number of sensors are much larger than it will take more time to track the MPPT and if solar radiations are changing frequently maximum energy will be lost during the tracking time, while in perturbation and observation technique only two sensors are required so, conversion time reduces and the efficiency of the PV array increases. Figure 2 shows the PQ MPPT algorithm.

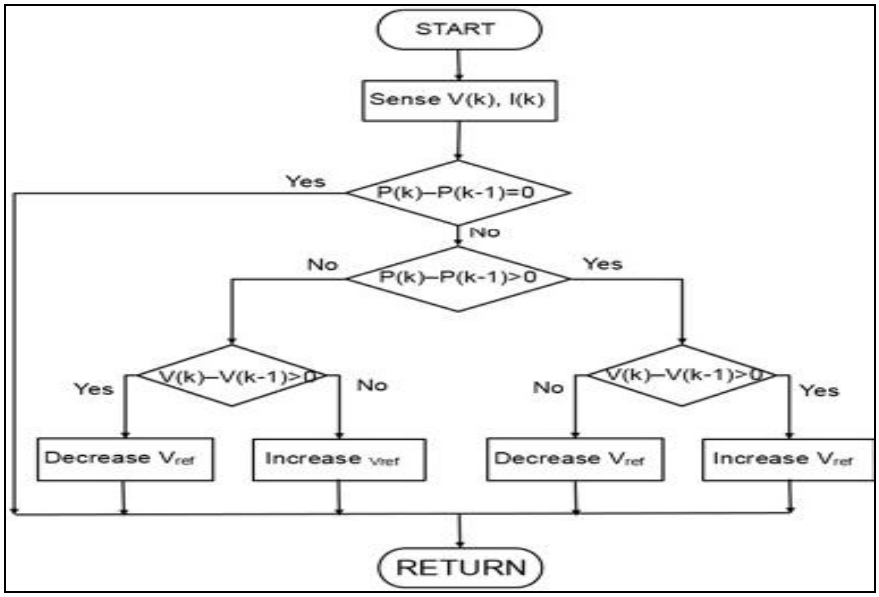

Fig 2: PQ MPPT Algorithm

4. Fuel Cell

Fuel cell is an electrochemical cell, which generates electricity by chemical reaction of fuel and oxidant in the presence of an electrolyte. The electrolyte triggers the reaction between fuel and oxidant. The input in the form of fuel is fed to the fuel cell while the waste comes out from it and electrolyte remains in the cell. The main advantage of fuel cell is that, it generates electricity continuously if fuel is fed to it in regular way. One of the most common examples of a fuel cell is hydrogen fuel cell where hydrogen is fed as a fuel and oxygen behaves like

an oxidant. Fuel cells come in a variety size and power rating. All of these cells works on the same principle and differ only in fuel type. A fuel cell has there three parts sandwiched together, 1) Cathode 2) Anode and 3) Electrolyte. The chemical reaction takes place at the interfaces of the segments. In this reaction fuel is consumed and water or Carbon dioxide is created as waste and electricity is generated that can be used to supply the load [23-34].

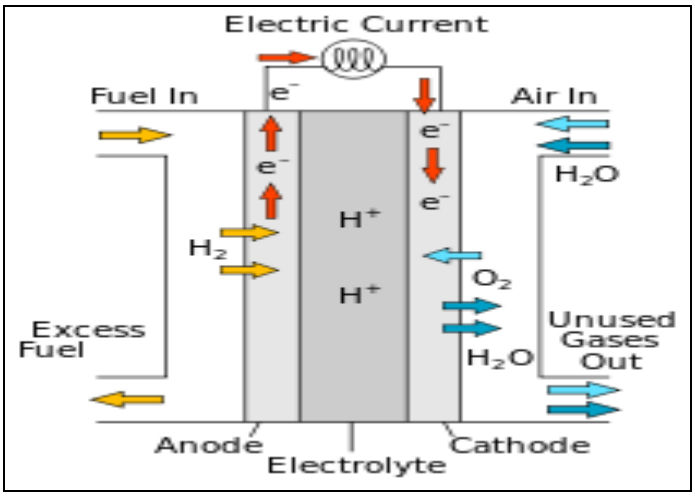

Fig 3: Fuel Cell

5. Hybrid power system

Power generated from the solar cell is not constant at all the times and the amount of power extracted is the function of a voltage and current [35-50]. Maximum power point tracking technique is used the PV cell continuously deliver the highest power available at irrigation and temperature available at that time. Hybrid power systems are designed to overcome the limitations of the one source by the use of the other sources that can operate in parallel. There can be many combinations of hybrid systems such as, a wind operating with hydro/diesel generator/petroleum fuelled or thermoelectric generation. The combination selection depends upon the availability of the fuel at the installation site, cost of installation, transportation cost, season or geographical location of the load.

The hybrid systems can be installed on small or large scale depending upon the load requirements. For example, for a single household a system which can generate an overall about 5 kilowatt power is enough while to generate high level of electricity such as 100 kilowatt or 1 megawatt to supply number of consumers the components of the hybrid system will be more.

6. Grid connected operation of microgrid

Renewable base generation lacks to generate the power at fixed voltage and frequency which are the most desirable features of supplied power. The power generated from such sources completely depends upon the availability of the renewable fuel which is very intermittent. In addition to that, loading to the microgrid vary anonymously intensifying the voltage and frequency deviation and causing power quality issues, which are not a desirable for the system and threats the security and reliability of the network [51-60]. In some condition, this is a possible situation that when the load on the hybrid microgrid is lower as compared to the power generated the extra power can be delivered to the main grid through the grid connected lines. This feature enables a microgrid to operate at maximum rating and in case of higher demand the extra power is extracted from the utility grid to keep the power quality and demand managed.

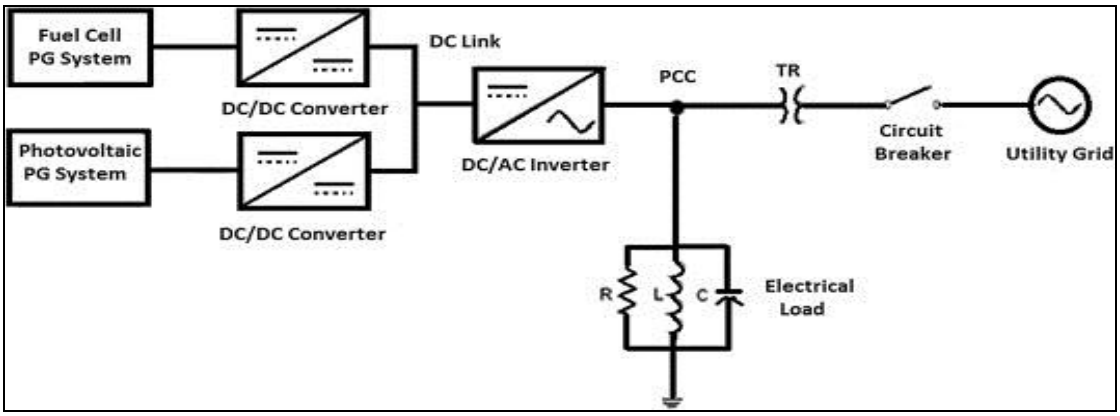

Fig 4: Block Diagram of PV-FC Hybrid Microgrid

In this paper both the fuel cell and the photovoltaic array are modeled as nonlinear voltage sources. To keep the output voltage from the sources approximately fixed DC to DC converters are used at their output. MPPT Controller is used to track the maximum power point of the photovoltaic array. Variety of MPPT control techniques available in the literature such as incremental conductance method, perturbation and observation technique etc. At the other end, the fuel cell only operates at its maximum efficiency if it is operated within the specified power range [60-75].

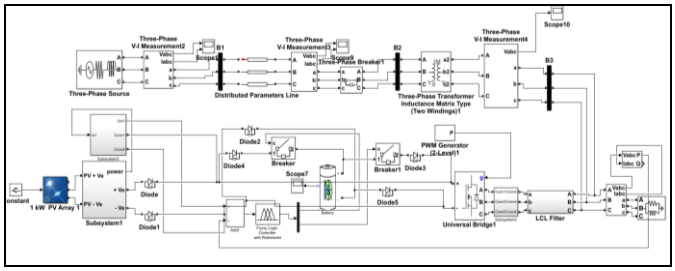

Fig 5: MATLAB Simulation of PV-FC Hybrid Microgrid

7. Results

Figure 6 and 7 shows the output of the voltage source converter used to supply the ac loads connected to the hybrid microgrid and output voltage of the MPPT controller. It is clear from the figure that the MPPT controller keeps the output voltage of PV array almost fixed.

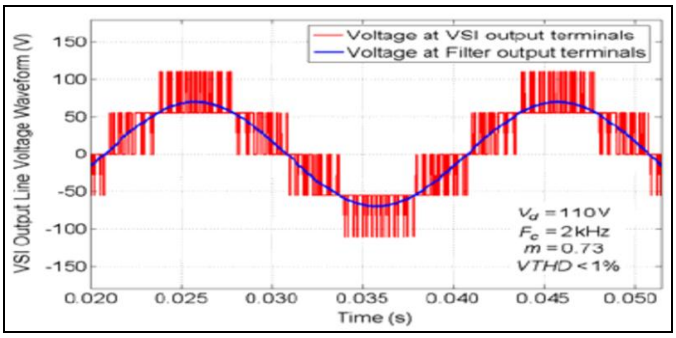

Fig 6: Output Waveforms of VSI

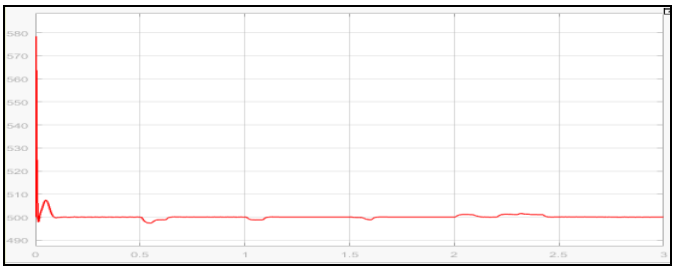

Fig 7: Output Waveform of Solar MPPT

8. Conclusions

An island in microgrid fulfills the local requirement of the electricity while in grid connected mode the deficit power is drawn from the utility grid. If in certain condition the power availability from the microgrid is higher than the local or requirement the extra power can be delivered to the utility which provides multiple benefits to the utility grid. The operating efficiency of the hybrid microgrid can be increased by using the multiple renewable based generating units to share a common load with respect to their rating. This is the responsibility of the designed controller to adjust output of every unit corresponding to the maximum power point and within the limits of the DG rating. The technique proposed here exploits the maximum solar energy available and at the same time increases the flexibility and efficiency of the hybrid microgrid. The research can be extended to operate more than two renewable base generating units to produce electricity and reduce the fossil fuel based generation to minimize the environmental effect of such units.

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