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UNIT POWER CONTROL AND FEEDER FLOW CONTROL STRATEGIES FOR A GRID-CONNECTED HYBRID SYSTEM

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Abstract

This paper explains about the design and implementation of a hybrid power system consisting of solar and fuel cell as the sources. The main objective is to improve the performance of the system operation and enhance the system stability. It coordinates two control modes and determines the reference values for them by satisfying all the constraints. The performance of the system with and without using the controller is to be analyzed based on THD analysis. The harmonic content has to be calculated using different PWM techniques and is to be compared. It also increases the system stability by reducing the harmonics so that the system performance can be improved using the MATLAB/SIMULINK software.

Keywords: Unit Power Control, Feeder Flow Control, Hybrid System, Solar Cell, Fuel Cell

1. INTRODUCTION

Many of the renewable sources can be utilized simultaneously to maintain the continuous delivery of power to the load. Among the available sources solar energy is the most promising one. By using the PV arrays the electric power can be generated from solar. But, the disadvantage of solar energy is that PV output power depends on irradiation and cell temperature, which makes it an uncontrollable source.

Electrical energy requirements for many remote applications are too large to allow the cost-effective use of stand-alone or autonomous PV systems. In these cases, several different types of power sources are combined to form a "hybrid" system. In order to overcome the mentioned drawbacks of solar energy, alternative sources, such as PEMFC (Proton Exchange Membrane Fuel Cell) can be installed in the hybrid system. By changing the FC output power, the hybrid source output power becomes controllable. The hybrid system can either be connected to main grid or work autonomously. The power delivered from main grid and the hybrid system must be coordinated to meet the load demand. In this project two control modes namely, the unit power control (UPC) mode and the feeder-flow control (FFC) mode are used.

All of these energy technologies provide a DC output which requires power electronic interfaces with the distribution power networks and its loads. In most cases the conversion is performed by using a voltage source inverter (VSI) with a possibility of pulse width modulation (PWM) that provides fast regulation for voltage magnitude.

Power electronic interfaces introduce new control issues, but at the same time, new possibilities. For example, a system which consists of micro-generators and storage devices could be designed to operate in both an autonomous mode and connected to the power grid.. It must be remembered that the current power systems have storage in generators' inertia, and this may result in a slight reduction in system frequency. As these generators become more compact, the need to link them to lower network voltage is significantly increasing.

However, without any medium voltage networks adaptation, this fast expansion can affect the quality of supply as well as the public and equipment safety because distribution networks have not been designed to connect a significant amount of generation. Therefore, a new voltage control system to facilitate the connection of distributed generation resources to distribution networks should be developed. The Maximum Power Point Tracking (MPPT) technique is used for PV array to deliver power continuously to the load.

2. FUEL CELL AND PHOTO-VOLTAIC CELL TECHNOLOGIES

2.1FUEL CELL

A fuel cell is an electrochemical cell that converts a source fuel into an electrical current. It generates electricity inside a cell through reactions between a fuel and an oxidant, triggered in the presence of an electrolyte. The reactants flow into the cell, and the reaction products flow out of it, while the electrolyte remains within it. Fuel cells can operate continuously as long as the necessary reactant and oxidant flows are maintained. Fuel cells are different from conventional electrochemical cell batteries in that they consume reactant from an external source, which must be replenished[1] – a thermodynamically open system. By contrast, batteries store electrical energy chemically and hence represent a thermodynamically closed system. Many combinations of fuels and oxidants are possible. A hydrogen fuel cell uses hydrogen as its fuel and oxygen (usually from air) as its oxidant. Other fuels include hydrocarbons and alcohols. Other oxidants include chlorine and chlorine dioxide. Fuel cells come in many varieties; however, they all work in the same general manner. They are made up of three segments which are sandwiched together: the anode, the electrolyte, and the cathode. Two chemical reactions occur at the interfaces of the three different segments. The net result of the two reactions is that fuel is consumed, water or carbon dioxide is created, and an electrical current is created, which can be used to power electrical devices, normally referred to as the load. At the anode a catalyst oxidizes the fuel, usually hydrogen, turning the fuel into a positively charged ion and a negatively charged electron. The electrolyte is a substance specifically designed so ions can pass through it, but the electrons cannot. The freed electrons travel through a wire creating the electrical current. The ions travel through the electrolyte to the cathode. Once reaching the cathode, the ions are reunited with the electrons and the two react with a third chemical, usually oxygen, to create water or carbon dioxide. In the archetypal hydrogen–oxygen proton exchange membrane fuel cell (PEMFC) design, a proton-conducting polymer membrane, (the electrolyte), separates the anode and cathode sides. This was called a "solid polymer electrolyte fuel cell" (SPEFC) in the early 1970s, before the proton exchange mechanism was well-understood. (Notice that "polymer electrolyte membrane" and "proton exchange mechanism" result in the same acronym.) On the anode side, hydrogen diffuses to the anode catalyst where it later dissociates into protons and electrons. These protons often react with oxidants causing them to become what is commonly referred to as multi-facilitated proton membranes. The protons are conducted through the membrane to the cathode, but the electrons are forced to travel in an external circuit (supplying power) because the membrane is electrically insulating. On the cathode catalyst, oxygen molecules react with the electrons (which have traveled through the external circuit) and protons to form water . The materials used in fuel cells differ by type. In a typical membrane electrode assembly (MEA), the electrode–bipolar plates are usually made of metal, nickel or carbon nano tubes, and are coated with a catalyst (like platinum, nano iron powders or palladium) for higher efficiency. Carbon paper separates them from the electrolyte. The electrolyte could be ceramic or a membrane. Hydrogen and ambient air flow into the fuel cell, which contains an anode and a cathode. At the anode, the hydrogen separates into a proton and an electron. The proton migrates to the cathode, where it reacts with the oxygen to form water. The electrons, which cannot pass through the membrane, flow from the cell to provide useful electrical power. Fuel cells are quiet, have no moving parts, and produce no particulate emissions. They are virtually maintenance free and can be both tested and operated remotely. Because they are modular, they can be configured for any size power needs, from a few kilowatts for a remote telecommunications tower to megawatt-scale for hospitals and airports. Hydrogen is safely stored on-site or produced within the fuel cell itself.

2.2 PHOTOVOLTAIC TECHNOLOGY

Photovoltaic's is the field of technology and research related to the devices which directly convert sunlight into electricity using semiconductors that exhibit the photovoltaic effect. Photovoltaic effect involves the creation of voltage in a material upon exposure to electromagnetic radiation. The solar cell is the elementary building block of the photovoltaic technology. Solar cells are made of semiconductor materials, such as silicon. One of the properties of semiconductors that makes them most useful is that their conductivity may easily be modified by introducing impurities into their crystal lattice. For instance, in the fabrication of a photovoltaic solar cell, silicon, which has four valence electrons, is treated to increase its conductivity.

On one side of the cell, the impurities, which are phosphorus atoms with five valence electrons (n-donor), donate weakly bound valence electrons to the silicon material, creating excess negative charge carriers. On the other side, atoms of boron with three valence electrons (p-donor) create a greater affinity than silicon to attract electrons. Because the p-type silicon is in intimate contact with the n-type silicon a p-n junction is established and a diffusion of electrons occurs from the region of high electron concentration (the n-type side) into the region of low electron concentration (p-type side).

When the electrons diffuse across the p-n junction, they recombine with holes on the p-type side. However, the diffusion of carriers does not occur indefinitely, because the imbalance of charge immediately on either sides of the junction originates an electric field. This electric field forms a diode that promotes current to flow in only one direction.

Ohmic metal-semiconductor contacts are made to both the n-type and p-type sides of the solar cell, and the electrodes are ready to be connected to an external load. When photons of light fall on the cell, they transfer their energy to the charge carriers. The electric field across the junction separates photo-generated positive charge carriers (holes) from their negative counterpart (electrons). In this way an electrical current is extracted once the circuit is closed on an external load. Fig. 1 shows electric current extraction from a solar cell.

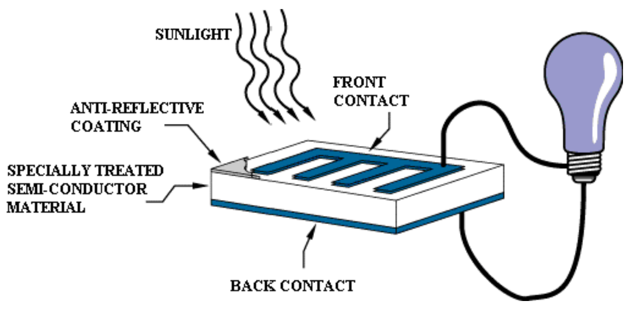

Fig. 1 .Electrical current extraction from a solar cell

The electrical output of a single cell is dependent on the design of the device and the Semi-conductor material(s) chosen, but is usually insufficient for most applications. In order to provide the appropriate quantity of electrical power, a number of cells must be electrically connected. There are two basic connection methods: series connection, in which the top contact of each cell is connected to the back contact of the next cell in the sequence, and parallel connection, in which all the top contacts are connected together, as are all the bottom contacts. In both cases, this results in just two electrical connection points for the group of cells. A PV array consists of a number of PV modules, mounted in the same plane and electrically connected to give the required electrical output for the application. The PV array can be of any size from a few hundred watts to hundreds of kilowatts, although the larger systems are often divided into several electrically independent sub arrays each feeding into their own power conditioning system.

The orientation of the module with respect to the direction of the Sun determines the intensity of the sunlight falling on the module surface. Two main parameters are defined to describe this. The first is the tilt angle, which is the angle between the plane of the module and the horizontal. The second parameter is the azimuth angle, which is the angle between the plane of the module and due south (or sometimes due north depending on the definition used). Correction of the direct normal irradiance to that on any surface can be determined using the cosine of the angle between the normal to the Sun and the module plane.

Fig.2 shows the percentage variation in annual insolation levels for the location of London as tilt angle is varied between 0 and 90 degrees and azimuth angle is varied between –45o (south east) and +45o (south west). The maximum insolation level is obtained for a south-facing surface at a tilt angle of about 35 degrees, as would be expected for a latitude of about 51oN. However, the insolation level varies by less than 10% with changing azimuth angle at this tilt angle. A similarly low variation is observed for south facing surfaces for a variation of +/- 30 degrees from the optimum tilt angle.

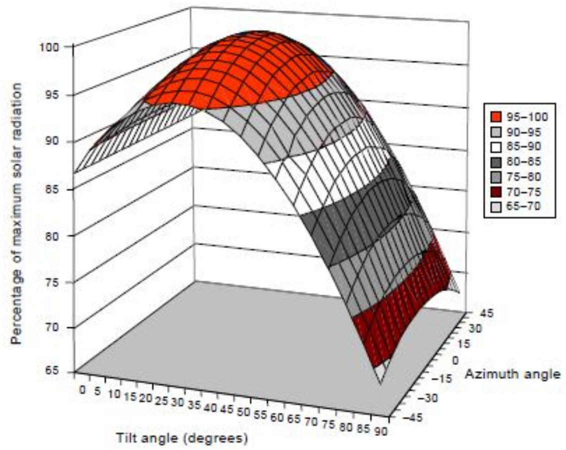

Fig. 2 Percentage variation of annual sunlight levels as a function of tilt angle and azimuth angle

The calculations were carried out for the location of London using Meteonorm Version 3.0. The final aspect to consider when deciding on array orientation is the incorporation in the support structure. For building-integrated applications, the system orientation is also dictated by the nature of the roof or façade in which it is to be incorporated. It may be necessary to trade off the additional output from the optimum orientation against any additional costs that might be incurred to accomplish this. The aesthetic issues must also be considered.

3. HYBRID POWER SYSTEMS

Electrical energy requirements for many remote applications are too large to allow the cost-effective use of stand-alone or autonomous PV systems. In these cases, it may prove more feasible to combine several different types of power sources to form what is known as a "hybrid" system. To date, PV has been effectively combined with other types of power generators such as wind, hydro, thermoelectric, petroleum-fueled and even hydrogen. The selection process for hybrid power source types at a given site can include a combination of many factors including site topography, seasonal availability of energy sources, cost of source implementation, cost of energy storage and delivery, total site energy requirements, etc.

- Hybrid power systems use local renewable resource to provide power.
- Village hybrid power systems can range in size from small household systems (100 Wh/day) to ones supplying a whole area (10’s MWh/day).
- They combine many technologies to provide reliable power that is tailored to the local resources and community.
- Potential components include: PV, wind, micro-hydro, river-run hydro, biomass, batteries and conventional generators.

To realize the emerging potential of distributed generation one must take a system approach which views generation and associated loads as a subsystem or a “microgrid”. During disturbances, the generation and corresponding loads can separate from the distribution system to isolate the microgrid’s load from the disturbance (and thereby maintaining service) without harming the transmission grid’s integrity.

The difficult task is to achieve this functionality without extensive custom engineering and still have high system reliability and generation placement flexibility. To achieve this we promote a peer-to-peer and plug-and-play model for each component of the microgrid. The peer-to-peer concept insures that there are no components, such as a master controller or central storage unit that is critical for operation of the microgrid. This implies that the microgrid can continue operating with loss of any component or generator. With one additional source (N+1) we can insure complete functionality with the loss of any source.

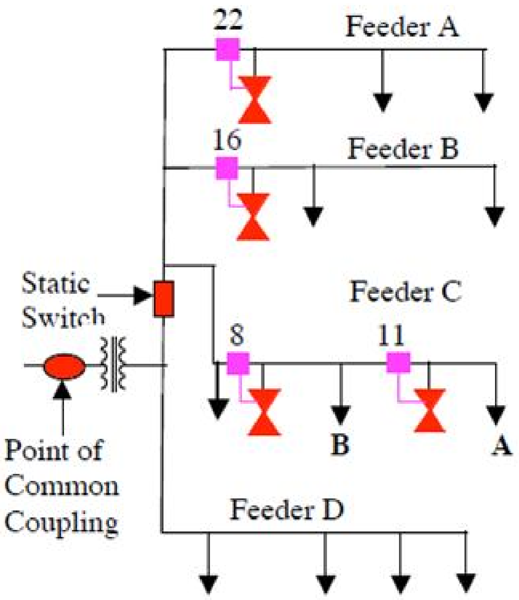

Fig. 3 Micro grid

It is also much easier to place small generators near the heat loads thereby allowing more effective use of waste heat. Basic Microgrid architecture is shown in figure 3.3. This consists of a group of radial feeders, which could be part of a distribution system or a building's electrical system. There is a single point of connection to the utility called point of common coupling. Some feeders, (Feeders A-C) have sensitive loads, which require local generation.

The noncritical load feeders do not have any local generation. In our example this is Feeder D. Feeders A-C can island from the grid using the static switch which can separate in less than a cycle. In this example there are four micro sources at nodes 8, 11, 16 and 22, which control the operation using only local voltages and currents measurments. When there is a problem with the utility supply the static switch will open, isolating the sensitive loads from the power grid. Feeder D loads ride through the event. It is assumed that there is sufficient generation to meet the loads' demand. When the Microgrid is grid-connected power from the local generation can be directed to feeder D.

4.MODELLING OF PV-FC HYBRID SYSTEM

The system consists of a PV-FC hybrid source with the main grid connecting to loads at the PCC as shown in Fig. 1. The photovoltaic and the PEMFC are modeled as nonlinear voltage sources. These sources are connected to dc–dc converters which are coupled at the dc side of a dc/ac inverter. The dc/dc connected to the PV array works as an MPPT controller. Many MPPT algorithms have been proposed in the literature, such as incremental conductance (INC), constant voltage (CV), and perturbation and observation (P&O). The P&O method has been widely used because of its simple feedback structure and fewer measured parameters. The P&O algorithm with power feedback control is shown in Fig. 5.

As PV voltage and current are determined, the power is calculated. At the maximum power point, the derivative (dP/dV) is equal to zero. The maximum power point can be achieved by changing the reference voltage by the amount of ΔV_{ref} .

The mathematical model of PV array can be expressed as

$$I = I_{ph} - I_{sat} \{ \exp [q / AKT (V + IR_s)] - 1 \} \quad (1)$$

Equation (1) shows that the output characteristic of a solar cell is nonlinear and vitally affected by solar radiation, temperature, and load condition. Photocurrent I_{ph} is directly proportional to solar radiation G_a.

$$I_{ph} (G_a) = I_{sc} (G_a / G_{as}) \quad (2)$$

The short-circuit current of solar cell I_{sc} depends linearly on cell temperature

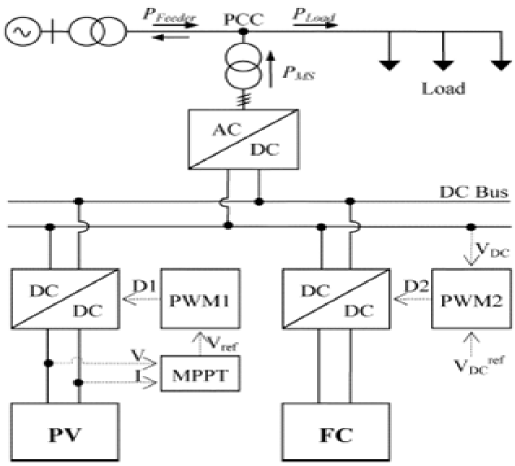

Fig. 5 Grid connected PV-FC Hybrid system

Thus, I_{ph} depends on solar irradiance and cell temperature I_{sat} also depends on solar irradiation and cell temperature and can be mathematically expressed as follows:

$$I_{ph} (G_a , T) = I_{sc} (G_a / G_{as}) (1 + \Delta I_{sc} (T - T_s)] \quad (3)$$

The PEMFC steady-state feature of a PEMFC source is assessed by means of a polarization curve, which shows the nonlinear relationship between the voltage and current density.

The PEMFC output voltage is as follows:

$$V_{out} = E_{Nerst} - V_{act} - V_{ohm} - V_{conc} \quad (4)$$

Where E_{Nerst} is the "thermo dynamic potential" of Nerst, which represents the reversible (or open-circuit) voltage of the fuel cell. Activation voltage drop V_{act} is given in the Tafel equation as

$$V_{act} = T [a + b\ln (I)] \quad (5)$$

where are the constant terms in the Tafel equation (in volts per Kelvin)

The overall ohmic voltage drop V_{ohm} can be expressed as

$$V_{ohm} = IR_{ohm} \quad (6)$$

The ohmic resistance R_{Ohm} of PEMFC consists of the resistance of the polymer membrane and electrodes, and the resistances of the electrodes.

The concentration voltage drop V_{conc} is expressed as

$$V_{conc} = - (RT / Zf) \ln (1- (I / I_{limit})) \quad (7)$$

The control modes in the microgrid include unit power control, feeder flow control, and mixed control mode. The two control modes were first proposed by Lasserter. In the UPC mode, the DGs (the hybrid source in this system) regulate the voltage magnitude at the connection point and the power that source is injecting. In this mode if a load increases anywhere in the microgrid, the extra power comes from the grid, since the hybrid source regulates to a constant power. In the FFC mode, the DGs regulate the voltage magnitude at the connection point and the power that is flowing in the feeder at connection point. With this control mode, extra load demands are picked up by the DGs, which maintain a constant load from the utility viewpoint.

In the mixed control mode, the same DG could control either its output power or the feeder flow power. In other words, the mixed control mode is a coordination of the UPC mode and the FFC mode. Both of these concepts were considered. In this paper, a coordination of the UPC mode and the FFC mode was investigated to determine when each of the two control modes was applied and to determine a reference value for each mode. Moreover, in the hybrid system, the PV and PEMFC sources have their constraints. Therefore, the reference power must be set at an appropriate value so that the constraints of these sources are satisfied.

The proposed operation strategy presented in the next section is also based on the minimization of mode change. This proposed operating strategy will be able to improve performance of the system's operation and enhance system stability.

It is well known that in the microgrid, each DG as well as the hybrid source has two control modes: 1) the UPC mode and 2) the FFC mode.

In the aforementioned subsection, a method to determine in the UPC mode is proposed. In this subsection, an operating strategy is presented to coordinate the two control modes.

The purpose of the algorithm is to decide when each control mode is applied and to determine the reference value of the feeder flow when the FFC mode is used. This operating strategy must enable the PV to work at its maximum power point, FC output, and feeder flow to satisfy their constraints. If the hybrid source works in the UPC mode, the hybrid output is regulated to a reference value and the variations in load are matched by feeder power. With the reference power proposed in Subsection A, the constraints of FC and PV are always satisfied. Therefore, only the constraint of feeder flow is considered. On the other hand, when the hybrid works in the FFC mode, the feeder flow is controlled to a reference value.

And, thus, the hybrid source will compensate for the load variations. In this case, all constraints must be considered in the operating algorithm. Based on those analyses, the operating strategy of the system is proposed as demonstrated in Fig. 4.7. The operation algorithm in Fig. 4.7 involves two areas (Area I and Area II) and the control mode depends on the load power. If load is in Area I, the UPC mode is selected. Otherwise, the FFC mode is applied with respect to Area II. In the UPC area, the hybrid source output.

Table 1 System Parameters

Parameter	Value	Unit
P_{FC}^{LOW}	0.01	MW
P_{FC}^{UP}	0.07	MW
P_{FEEDER}^{max}	0.01	MW
ΔP_{MS}	0.03	MW

In summary, in a light-load condition, the hybrid source works in UPC mode, the hybrid source regulates output power to the reference value P^{ref}_{MS} , and the main grid compensates for load variations. P^{ref}_{MS} is determined by the algorithm shown in Fig. 4 and, thus, the PV always works at its maximum power point and the PEMFC always works within the high efficiency band $P^{low}_{FC} \div P^{up}_{FC}$. In heavy load conditions, the control mode changes to FFC, and the variation of load will be matched by the hybrid source. In this mode, PV still works with the MPPT control, and PEMFC operates within its efficiency band until load increases to a very high point. Hence, FC only works outside the high efficiency band $P^{up}_{FC} \div P^{max}_{FC}$ in severe conditions. With an installed power of FC and load demand satisfying (27), load shedding will not occur. Besides, to reduce the number of mode changes, must be increased and, hence, the number of mode changes is minimized when is maximized. In addition, in order for system operation to be seamless, the reference value of feeder flow must be set at P^{max}_{Feeder}..

The selection of L,C value in the dc-dc converter is the key issues, because inorder to implement the MPPT algorithm ,a buck boost dc/dc converter is used.

For DC-DC converter L value should satisfy

$$L > (1-D)^2R/2f$$

For DC-DC converter C value should satisfy

$$C > D/Rf(\Delta V/V_{out})$$

5. RESULTS & ANALYSIS

The overall topology is related to the controlling of hybrid system. There are two power sources namely PV and PEMFC used in the system. The power generated from these two systems is controlled and coordinated to supply the load demand by using the UPC method as shown in Fig.6. As the power of PV system depends on the irradiation value and the temperature it continuously varies. As a result, the power from PEMFC also changes and so the hybrid system power also oscillates and becomes unstable. In order to overcome these drawbacks, a hysteresis is used to control the change of hybrid power as shown in Fig.7.

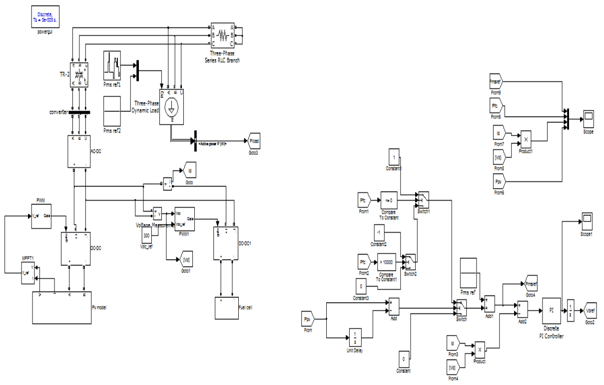

Fig. 6 Simulation diagram of Grid-connected Hybrid system with controller using SPWM

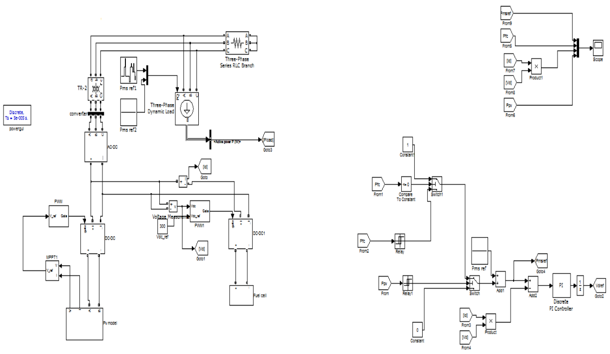

Fig. 7 Simulation diagram of Grid-connected Hybrid system with controller using Hysteresis PWM

The feeder power is also connected to the grid at PCC along with the hybrid system. So, the powers from hybrid system and the feeder are to be controlled and coordinated to supply the power to the load. In this situation the controlling is done by using the FFC method as shown in the Fig. 8.

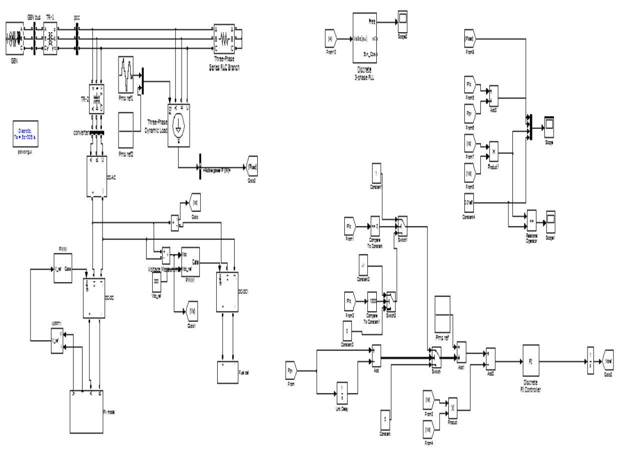

Fig. 8 Simulation diagram of Grid and feeder connected Hybrid system with controller using SPWM

The feeder flow changes due to the change of load and the hybrid system output in order to match the load demand. As both the powers are not constant they become unstable. In order to remove the harmonics and get the stability of the system the hysteresis PWM is used as shown in Fig. 9.

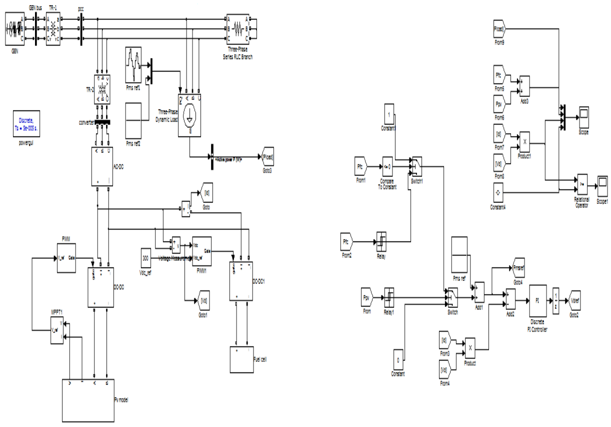

Fig. 9 Simulation diagram of Grid and feeder connected Hybrid system with controller using Hysteresis PWM.

Simulation circuit of PV system is shown in Fig. 10. The PV power depends on both the irradiance value and the temperature at an instant. So, an irradiance value of 400 and the temperature of 25^{o}C is taken in this paper. The output voltage and current are converted to the signal forms by using the controlled voltage and current sources respectively. And by multiplying the voltage and the current values the output power from the PV system is obtained.

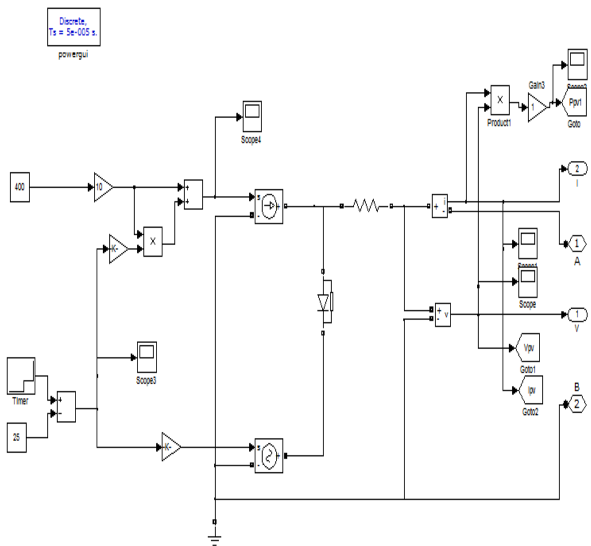

Fig. 10 Simulation circuit of PV system

The output voltage and current from PV system are given as input values to the P&O algorithm. In this technique the voltage, current, and the power are compared with their respective values with some delay. This process continues until the power at that instant and the power with delay becomes similar and so the difference becomes zero. This means that the maximum amount of power is extracted from the system. And the voltage value at the maximum power is taken as reference value from the algorithm as shown in Fig. 11.

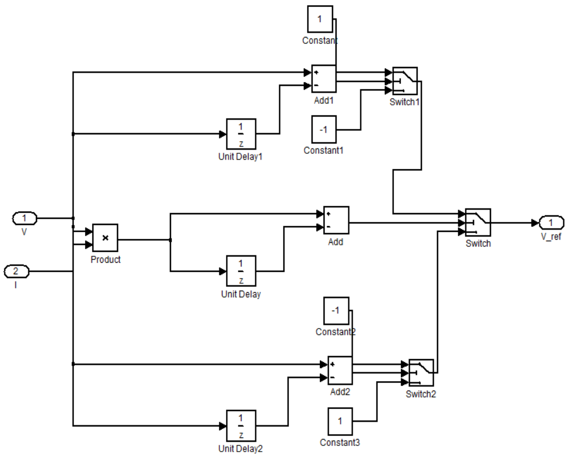

Fig. 11 Simulation circuit of P&O algorithm

The output power of the PEMFC system mainly depends on the fuel flow rate. The number of cells used in this stack is 65. In order to control the output power the flow rate is regulated by using a flow rate regulator as shown in Fig. 12.

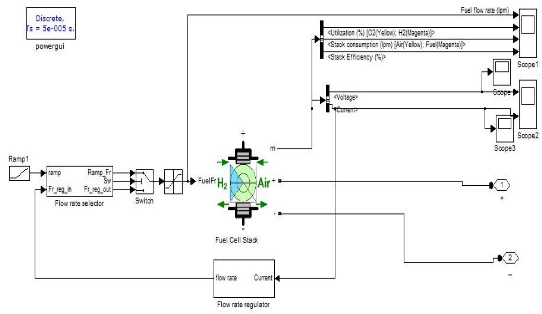

Fig. 12 Simulation circuit of PEMFC system

The output power from PV and FC system is increased by using a DC-DC boost converter. The DC output from the converter is fed to the AC-DC inverter to get an AC output power. The ac output power is connected to the grid through a transformer as shown in Fig.13.

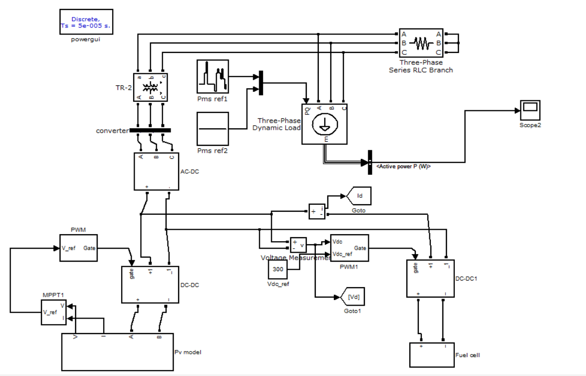

Fig. 13 Simulation circuit of hybrid system without controller

The standalone PV system output voltage is of above 121.7V as shown in Fig. 14.

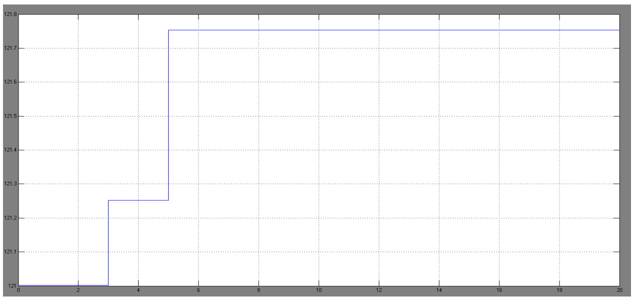

Fig. 14 PV system standalone output voltage

The voltage shown in the above fig. is obtained from the PV system by connecting the circuit as shown in Fig.5.5. The output current of PV system is 3.5.A which is shown in Fig. 15.

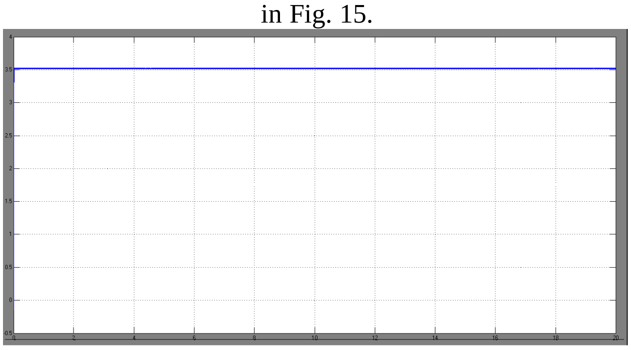

Fig. 15 PV system standalone output current

The Fig. 16 shows the output power of standalone PV system which is equal to the product of voltage and current.

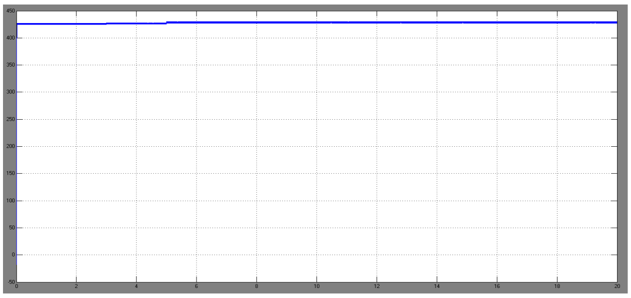

Fig. 16 PV system standalone output power

The output voltage of standalone PEMFC system is 53.25V as shown in the Fig.17. The output current is 135A as shown in the Fig.18.

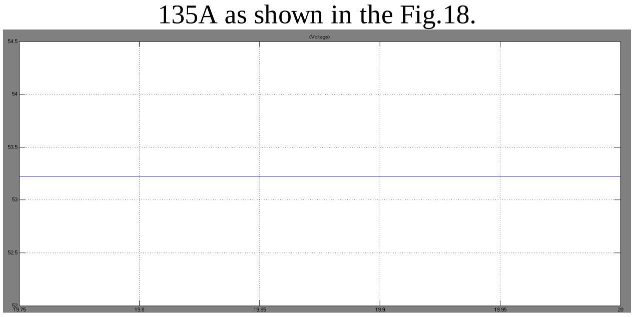

Fig. 17 PEMFC system standalone output voltage

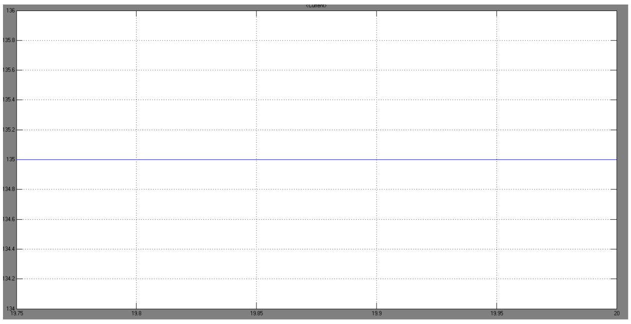

Fig. 18 PEMFC system standalone output current

The output power from the PV-FC hybrid system without using any controller is of 4.5×10^4 W as shown in the Fig. 19.

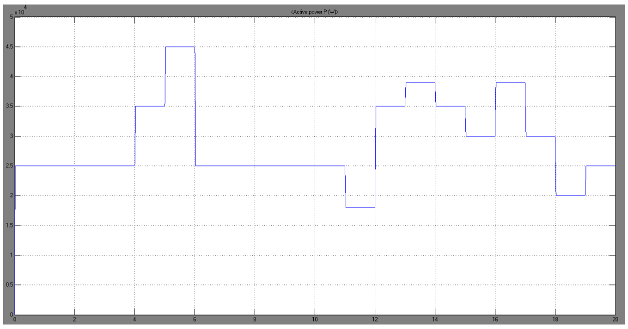

Fig. 19 The hybrid system output power without controller

Based on P_{PV} and the constraints of P_{FC} shown in Table-1, the reference value of hybrid source is determined as shown in Fig. 20 & Fig. 21.

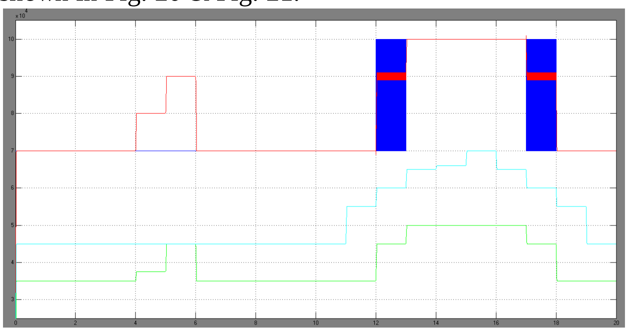

Fig. 20 Controlled output power of hybrid system without feeder using SPWM

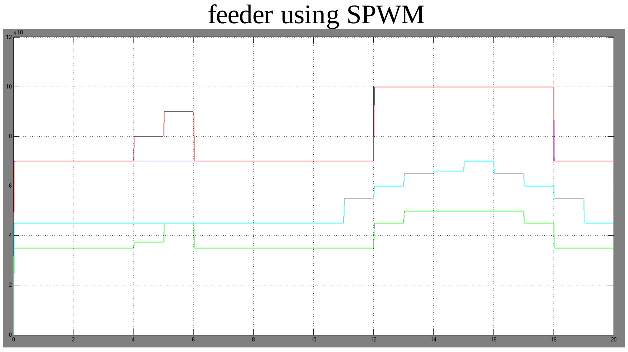

Fig. 21 Controlled output power of hybrid system without feeder using Hysteresis PWM

The controlled output power of hybrid system with the feeder connection is shown in Fig. 22 and Fig. 23 by using SPWM and Hysteresis PWM respectively.

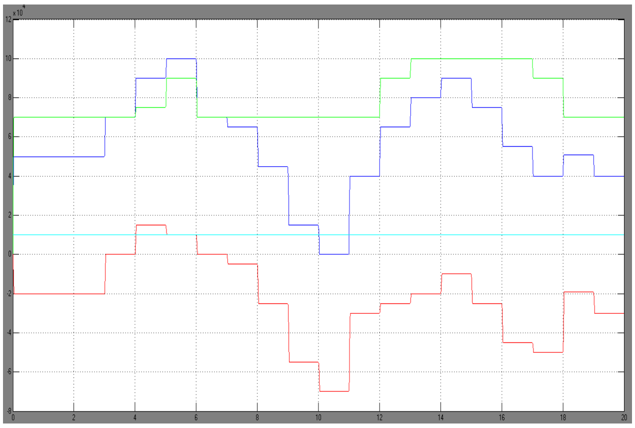

Fig. 22 The controlled output power of hybrid system without feeder using SPWM

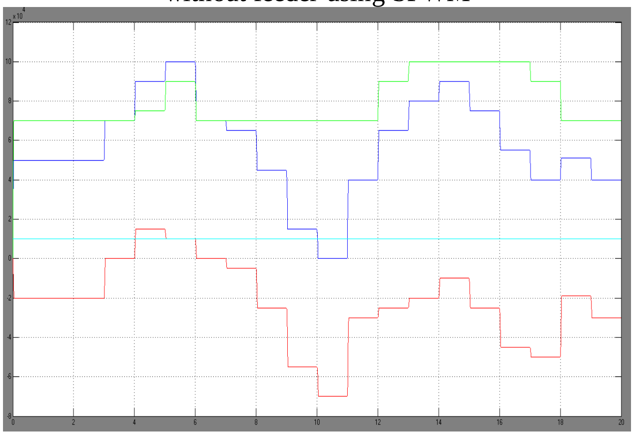

Fig. 23 The controlled output power of hybrid system without feeder using Hysteresis PWM

From the results of hybrid power system it is observed that if the power of PV system changes continuously, then the FC power also changes. As a result, the reference power of hybrid system (P_{MS}^{ref}) also changes. These oscillations are mainly observed in the duration of 11 to 13 sec and also in 16 to 18 sec. So, the harmonic content has to be calculated in this duration without and with the controller to make the system work in stable condition by minimizing it.

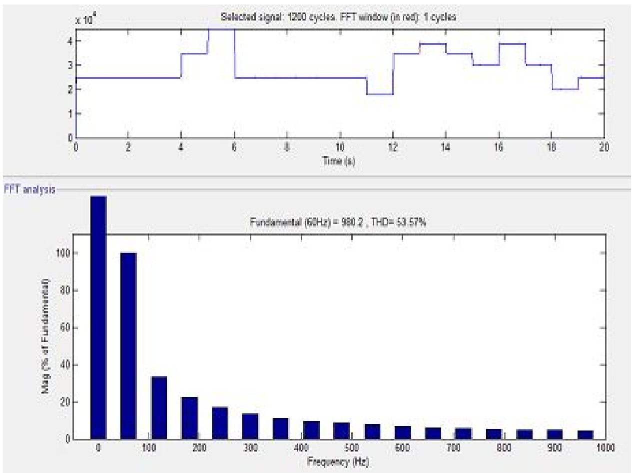

Fig. 24 FFT analysis of hybrid power without the controller at 12sec

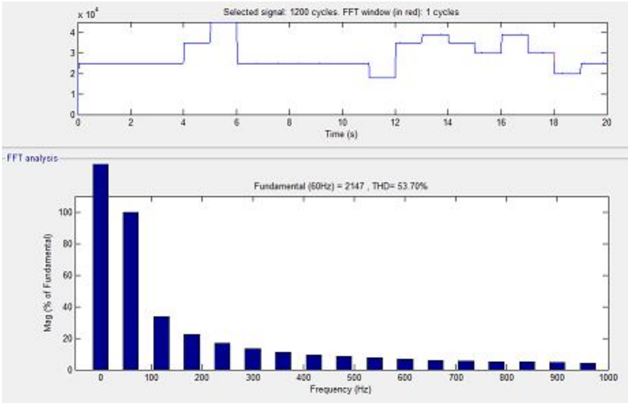

Fig. 25 FFT analysis of hybrid power without the controller at 17sec

From the above analysis it is clear that the THD content in the hybrid power without using any controller is very high at 12 sec and also at 17 sec i.e., of 53.57%. In order to minimize this value the THD analysis is done for different powers which affect the hybrid power at respective time intervals by using controllers.

Table 2 THD Analysis Of Power Using SPWM Technique In Controller

Power	**Without Feeder**		**With Feeder**	
	12 Sec	**17Sec**	**12 Sec**	**17 Sec**
P_{MS}^{ref} (Reference power of hybrid system)	48.26%	47.8%	53.6%	53.5%
P_{FC} (fuel cell power)	53.47%	53.4%	NA	NA
P_{FEEDER} (feeder power)	NA	NA	34.4%	34.5%

From the information given in Table 2 it is clear that by using SPWM technique in the controllers the harmonic content is still present. In order to overcome this problem, a hysteresis is used to control the change of P_{MS}^{ref} and the THD analysis is given in Table 3.

Table 3 THD Analysis Of Power Using Hysteresis PWM In Controller

Power	**Without Feeder**		**With Feeder**	
	12 Sec	**17Sec**	**12 Sec**	**17 Sec**
P_{MS}^{ref} (Reference power of hybrid system)	0.19%	0.19%	0.19%	0.19%
P_{FC} (fuel cell power)	0.19%	0.19%	NA	NA
P_{FEEDER} (feeder power)	NA	NA	25.2%	6.46%

It is observed that usage of Hysteresis PWM technique in the controller, harmonic content is decreased to a large extent when compared with SPWM technique and the analysis is shown in Table 3. By comparing the harmonic content in the power of hybrid system with and without using the controller a large variation has been observed. The harmonics are completely eliminated at the respective intervals and so, the system works in stable condition.

6. CONCLUSSIONS

This project has presented an available method to operate a hybrid grid connected system, and this project is to specify the control mode i.e. either UPC or FFC mode. The system can maximize the generated power when load is heavy and minimizes the load shedding area. When load is light, the UPC mode is selected and, when the load demand is maximum then FFC mode is selected. The change of operating mode depends on the current load demand, the PV output and the constraints of PEMFC and feeder power.

Besides, the variation of hybrid source output power is eliminated by means of hysteresis. In addition, the number of mode changes is reduced. As a consequence, the system works more stably due to the minimization of mode changes and reference value variation.

In brief, the proposed operating algorithm is a simplified and flexible method to operate a hybrid source in a grid-connected microgrid. It can improve the performance of the system's operation, the system works more stably while maximizing the PV output power.

For further research, the operating algorithm, taking the operation of the battery into account to enhance operation performance of the system, will be considered. Moreover, the application of the operating algorithm to a microgrid with multiple feeders and DGs will also be studied in detail.

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