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MODELLING AND SIMULATION FOR POWER MANAGEMENT OF A GRID-CONNECTED PHOTO VOLTAIC AND FUELL CELL BASE HYBRID POWER SYSTEM

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ABSTRACT: The Hybrid system refers to those applications in which multiple energy conversion devices are used together to supply an energy requirements. The hybrid system can either be connected to the main grid or work autonomously with respect to the grid-connected mode. In the grid-connected mode, the hybrid source is connected to the main grid at the point of common coupling (PCC) to deliver power to the load. When load demand changes, the power supplied by the main grid and hybrid system must be properly changed. The power delivered from the main grid and PV (Photo Voltaic) array as well as FC (Fuel Cell) must be coordinated to meet load demand. The hybrid source has two control modes: 1) unit-power control (UPC) mode and feeder-flow control (FFC) mode. In the UPC mode, variations of load demand are compensated by the main grid because the hybrid source output is regulated to reference power. Therefore, the reference value of the hybrid source output must be determined. In the FFC mode, the feeder flow is regulated to a constant, the extra load demand is picked up by the hybrid source, and, hence, the feeder reference power must be known. The proposed operating strategy is to coordinate the two control modes and determine the reference values of the UPC mode and FFC mode so that all constraints are satisfied. This operating strategy will minimize the number of operating mode changes, improve performance of the system operation, and enhance system stability. This paper presents a method to operate a grid connected hybrid system. The hybrid system composed of a Photovoltaic (PV) array and a Fuel cell (FC) is considered. Two operation modes for hybrid system are considered, the unit-power control (UPC) mode and the feeder-flow control (FFC) mode. In the UPC mode, variations of load demand are compensated by the main grid because the hybrid source output is regulated to reference power. The photovoltaic (PV) array systems normally use a maximum power point tracking (MPPT) technique to continuously deliver the highest power to the load when there are variations in irradiation and temperature. To improve the performance of PV array systems, alternative sources such as FC, should be installed in the hybrid system. By changing the FC output power, the reference value of the hybrid source output will be determined. This output can be obtained for two modes of operation using perturbation and observation algorithm. The effectiveness of the proposed method was tested on grid connected PV-FC system using Simulink in MATLAB.

I. INTRODUCTION

General

Renewable energy is currently widely used. One of these resources is solar energy. The photovoltaic (PV) array normally uses a maximum power point tracking (MPPT) technique to continuously deliver the highest power to the load when there are variations in irradiation and temperature. The disadvantage of PV energy is that the PV output power depends on weather conditions and cell temperature, making it an uncontrollable source. Furthermore, it is not available during the night. In order to overcome these inherent drawbacks, alternative sources, such as PEMFC, should be installed in the hybrid system. By changing the FC output power, the hybrid source output becomes controllable. However, PEMFC, in its turn, works only at a high efficiency within a specific power range $(P_{FC}^{low} \div P_{FC}^{up})$. The hybrid system can either be connected to the main grid or work autonomously with respect to the grid-connected mode or islanded mode, respectively. In the grid-connected mode, the hybrid source is connected to the main grid at the point of common coupling (PCC) to deliver power to the load. When load demand changes, the power supplied by the main grid and hybrid system must be properly changed. The power delivered from the main grid and PV array as well as PEMFC must be coordinated to meet load demand. The hybrid source has two control modes: 1) unit-power control (UPC) mode and feeder-flow control (FFC) mode. In the UPC mode, variations of load demand are compensated by the main grid because the hybrid source output is regulated to reference power. Therefore, the reference value of the hybrid source output P_{MS}^{ref} must be determined. In the FFC mode, the feeder flow is regulated to a constant, the extra load demand is picked up by the hybrid source, and, hence, the feeder reference power P_{feeder}^{ref} must be known. The proposed operating strategy is to coordinate the two control modes and determine the reference values of the UPC mode and FFC mode so that all constraints are satisfied. This operating strategy will minimize the number of operating mode changes, improve performance of the system operation, and enhance system stability.

Distributed generation

Distributed generation, also called on-site generation, dispersed generation, embedded generation, decentralized generation, decentralized energy or distributed energy generates electricity from many small energy sources.

Currently, industrial countries generate most of their electricity in large centralized facilities, such as fossil fuel (coal, gas powered) nuclear or hydropower plants. These plants have excellent economies of scale, but usually transmit electricity long distances and negatively affect the environment. Most plants are built this way due to a number of economic, health & safety, logistical,environmental, geographical and geological factors. For example, coal power plants are built away from cities to prevent their heavy air pollution from affecting the populace. In addition, such plants are often built near collieries to minimize the cost of transporting coal. Hydroelectric plants are by their nature limited to operating at sites with sufficient water flow. Most power plants are often considered to be too far away for their waste heat to be used for heating buildings. Low pollution is a crucial advantage of combined cycle plants that burn natural gas. The low pollution permits the plants to be near enough to a city to be used for district heating and cooling. Distributed generation is another approach. It reduces the amount of energy lost in transmitting electricity because the electricity is generated very near where it is used, perhaps even in the same building. This also reduces the size and number of power lines that must be constructed. Typical distributed power sources in a Feed-in Tariff (FIT) scheme have low maintenance, low pollution and high efficiencies. In the past, these traits required dedicated operating engineers and large complex plants to reduce pollution. However, modern embedded systems can provide these traits with automated operation and renewable, such as sunlight, wind and geothermal. This reduces the size of power plant that can show a profit. Today, new advances in technology and new directions in electricity regulation encourage a significant increase of distributed generation resources around the world. As shown in Fig.1.1 the currently competitive small generation units and the incentive laws to use renewable energies force electric utility companies to construct an increasing number of distributed generation units on its distribution network, instead of large central power plants. Moreover, DES can offer improved service reliability, better economics and a reduced dependence on the local utility. Distributed Generation Systems have mainly been used as a standby power source for critical businesses. For example, most hospitals and office buildings had stand-by diesel generation as an emergency power source for use only during outages. However, the diesel generators were not inherently cost-effective, and produce noise and exhaust that would be objectionable on anything except for an emergency basis.

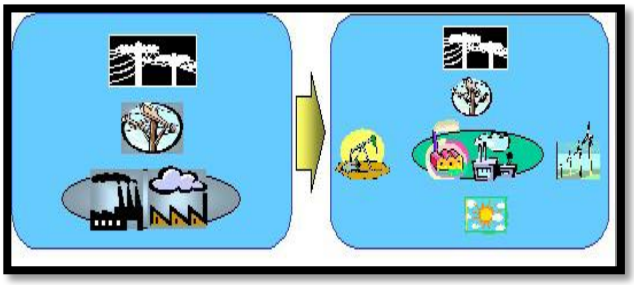

Fig-1.1 a large central power plant and distributed energy systems

Meanwhile, recently, the use of Distributed Energy Systems under the 500 kW level is rapidly increasing due to recent technology improvements in small generators, power electronics, and energy storage devices. Efficient clean fossil fuels technologies such as micro-turbines and fuel cells, and environmentally friendly renewable energy technologies such as solar/photo voltaic, small wind and hydro are increasingly used for new distributed generation systems. These DES are applied to a standalone, a standby, a grid-interconnected, a cogeneration, peak shavings, etc. and have a lot of benefits such as environmental-friendly and modular electric generation, increased reliability, high power quality, uninterruptible service, cost savings, on-site generation, Expandability, etc. The major Distributed Generation technologies that will be discussed in this section are as follows: micro-turbines, fuel cells, solar/photovoltaic systems, and energy storage devices.

Objectives

It has been well-proven that a photovoltaic power source should be integrated with other power sources, whether used in either a stand-alone or grid-connected system, as it cannot produce power during night hours or under cloudy weather conditions. The system under study in this thesis is a stand-alone hydrogen PVFC power system, which is constituted of a photovoltaic generator, an alkaline water electrolyser, a proton-exchange membrane fuel cell stack, battery as a secondary back-up unit and a tank used for hydrogen storage. This system is intended to be a future competitor of hybrid PV/Diesel systems, especially from an environmental point of view. Hydrogen production in this system, as mentioned before, is produced by electrolyzing water molecules electrically through the electrolyser and is used to produce electricity via the PEM fuel cell stack. This method is a very effective way of producing and using pure hydrogen.

For the study of the system the physical properties of the components were studied, and the corresponding mathematical formulas were derived. Then Matlab/Simulink was used for a dynamic simulation of the system. In general the goals of this thesis are:

- Proper data collecting and/or data synthesizing that describes the system operation and the load profile
- Visualizing and analyzing the system dynamic behaviour using power flow trace over middle-term duration, such as one week or one day.
- Creating an accurate simulation system model to predict the real performance of the hydrogen PVFC power system
- Making the parameters of the system as configurable as possible in order the models to be used for a larger variety in applications (mostly different sized applications or components with different datasheets)

II. OVERVIEW OF PV-FC BASED HYBRID SYSTEM

The utilization of intermittent natural energy resources such as solar, wind and hydro energy requires some form of energy storage. The concept of utilizing hydrogen as a substance for storage of energy is shown in Figure 2.1. In this paper, a hybrid system based on hydrogen technology is considered. It needs hydrogen producing unit (electrolyser), a unit for hydrogen storage (tank), and a hydrogen utilizing unit (PEM fuel cell stack). However, the system based on intermittent energy sources and is likely to experience large minutely, hourly and daily fluctuations in energy input. Thus, it should be emphasized that the main purpose of the hydrogen storage system is to store energy over short and long periods of time, i.e., hour to hour and season to season.

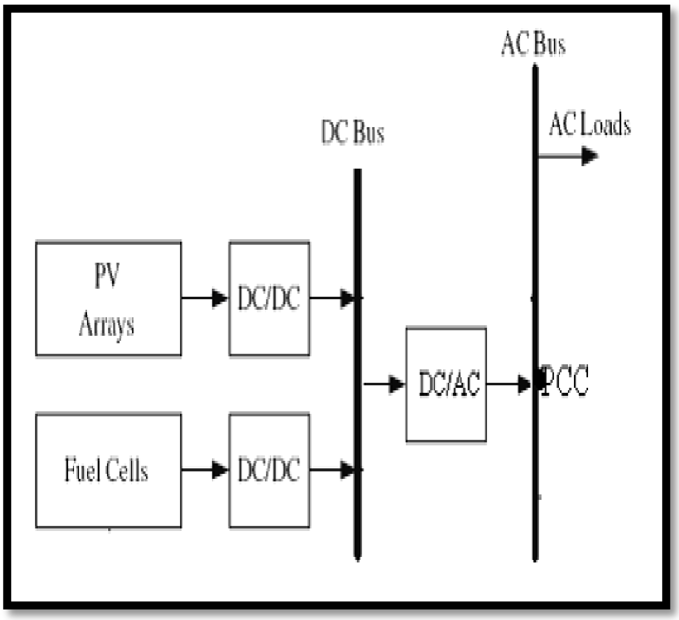

Fig-2.1-Grid connected PV-FC Hybrid system

Solar cell

There are several types of solar cells. However, more than 90 % of the solar cells currently made worldwide consist of wafer-based silicon cells. They are either cut from a single crystal rod or from a block composed of many crystals and are correspondingly called mono-crystalline or multi-crystalline silicon solar cells. Wafer-based silicon solar cells are approximately 200 µm thick. Another important family of solar cells is based on thin-films, which are approximately 1-2 µm thick and therefore require significantly less active, semiconducting material. Thin-film solar cells can be manufactured at lower cost in large production quantities; hence their market share will likely increase in the future. However, they indicate lower efficiencies than wafer-based silicon solar cells, which mean that more exposure surface and material for the installation is required for a similar performance. A number of solar cells electrically connected to each other and mounted in a single support structure or frame is called a ‘photovoltaic module’. Modules are designed to supply electricity at a certain voltage, such as a common 12 volt system. The current produced is directly dependent on the intensity of light reaching the module. Several modules can be wired together to form an array. Photovoltaic modules and arrays produce direct-current electricity. They can be connected in both series and parallel electrical arrangements to produce any required voltage and current combination.

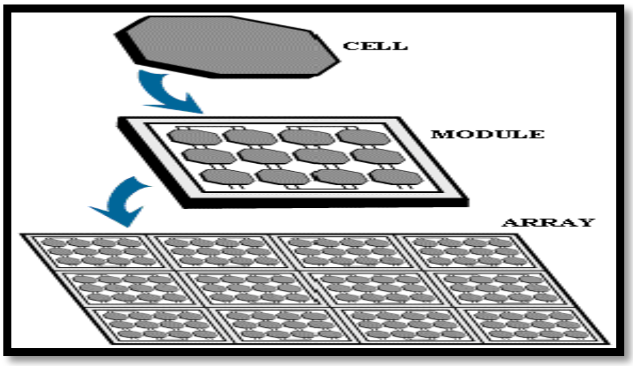

Fig-2.2 ELECTRICAL CONNECTION OF THE CELLS

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.

Series connection:

Figure-2.3 shows the series connection of three individual cells as an example and the resultant group of connected cells is commonly referred to as a series string. The current output of the string is equivalent to the current of a single cell, but the voltage output is increased, being an addition of the voltages from all the cells in the string (i.e. in this case, the voltage output is equal to 3Vcell).

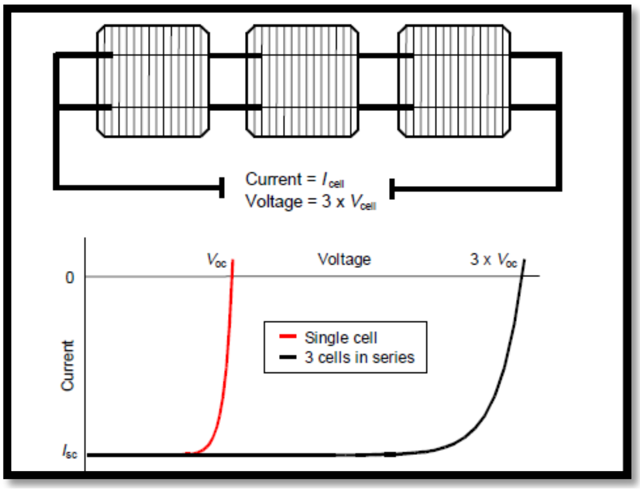

Fig-2.3 Series connection of cells, with resulting current–voltage characteristic

It is important to have well matched cells in the series string, particularly with respect to current. If one cell produces a significantly lower current than the other cells (under the same illumination conditions), then the string will operate at that lower current level and the remaining cells will not be operating at their maximum power points.

Parallel connection

Figure-2.4 shows the parallel connection of three individual cells as an example. In this case, the current from the cell group is equivalent to the addition of the current from each cell (in this case, 3 Icell), but the voltage remains equivalent to that of a single cell. As before, it is important to have the cells well matched in order to gain maximum output, but this time the voltage is the important parameter since all cells must be at the same operating voltage. If the voltage at the maximum power point is substantially different for one of the cells, then this will force all the cells to operate off their maximum power point, with the poorer cell being pushed towards its open-circuit voltage value and the better cells to voltages below the maximum power point voltage. In all cases, the power level will be reduced below the optimum.

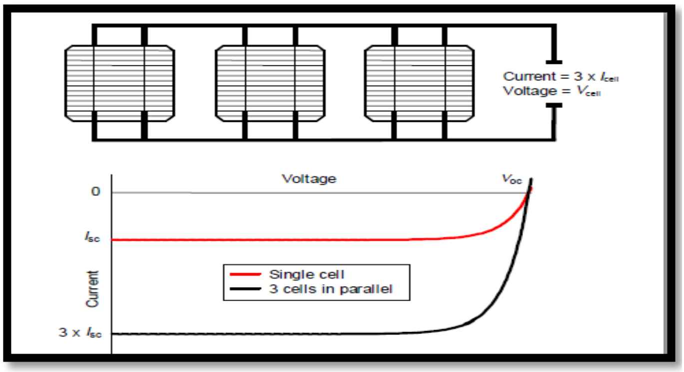

Fig-2.4 Parallel connection of cells, with resulting current–voltage characteristic

III. THE PHOTOVOLTAIC SYSTEM

A PV system consists of a number of interconnected components designed to accomplish a desired task, which may be to feed electricity into the main distribution grid, to pump water from a well, to power a small calculator or one of many more possible uses of solar-generated electricity. The design of the system depends on the task it must perform and the location and other site conditions under which it must operate. This section will consider the components of a PV system, variations in design according to the purpose of the system, system sizing and aspects of system operation and maintenance.

System design

There are two main system configurations – stand-alone and grid-connected. As its name implies, the stand-alone PV system operates independently of any other power supply and it usually supplies electricity to a dedicated load or loads. It may include a storage facility (e.g. battery bank) to allow electricity to be provided during the night or at times of poor sunlight levels. Stand-alone systems are also often referred to as autonomous systems since their operation is independent of other power sources. By contrast, the grid-connected PV system operates in parallel with the conventional electricity distribution system. It can be used to feed electricity into the grid distribution system or to power loads which can also be fed from the grid. It is also possible to add one or more alternative power supplies (e.g. diesel generator, wind turbine) to the system to meet some of the load requirements. These systems are then known as ‘hybrid’ systems. Hybrid systems can be used in both stand-alone and grid-connected applications but are more common in the former because, provided the power supplies have been chosen to be complementary, they allow reduction of the storage requirement without increased loss of load probability. Figures below illustrate the schematic diagrams of the three main system types.

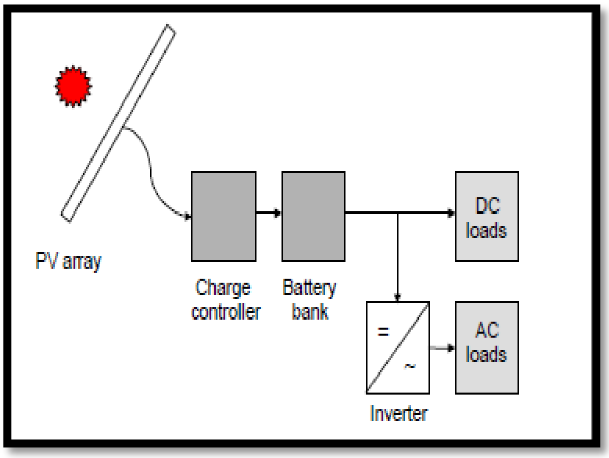

Fig-2.5 Schematic diagram of a stand-alone photovoltaic system

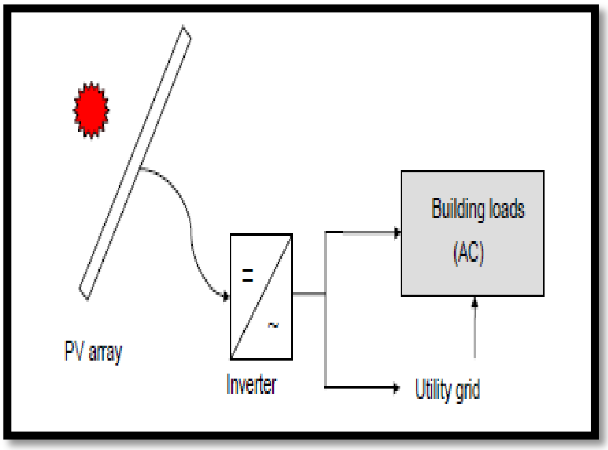

Fig-2.6 Schematic diagram of grid-connected photovoltaic system

IV. FUEL CELL

A fuel cell consists of a negatively charged electrode (anode), a positively charged electrode (cathode) and an electrolyte membrane. Hydrogen is oxidized at the anode and oxygen is reduced at the cathode. Protons are transported from the anode to the cathode through the electrolyte membrane, and the electrons are carried to the cathode over the external circuit. In nature, molecules cannot stay in an ionic state; therefore they immediately recombine with other molecules in order to return to the neutral state. Hydrogen protons in fuel cells stay in the ionic state by travelling from molecule to molecule through the use of special materials. The protons travel through a polymer membrane made of persulfonic acid groups with a Teflon backbone. The

electrons are attracted to conductive materials and travel to the load when needed. On the cathode, oxygen reacts with protons and electrons, forming water and producing heat. Both the anode and cathode contain a catalyst to speed up the electrochemical processes, as shown in figure 3.7.
A typical PEM fuel cell (proton exchange membrane fuel cell) has the following reactions:
Anode:

$$H_2(g) \rightarrow 2H^+(aq) + 2e^-$$

Cathode:

$$\frac{1}{2}O_2(g) + 2H^+(aq) + 2e^- \rightarrow H_2O(l)$$

Overall:

$$H_2(g) + \frac{1}{2}O_2(g) \rightarrow H_2O(l) \text{ + electric energy + waste heat}$$

Reactants are transported by diffusion and/or convection to the catalyzed electrode surfaces where the electrochemical reactions take place. The water and waste heat generated by the fuel cell must be continuously removed and may present critical issues for PEM fuel cells.

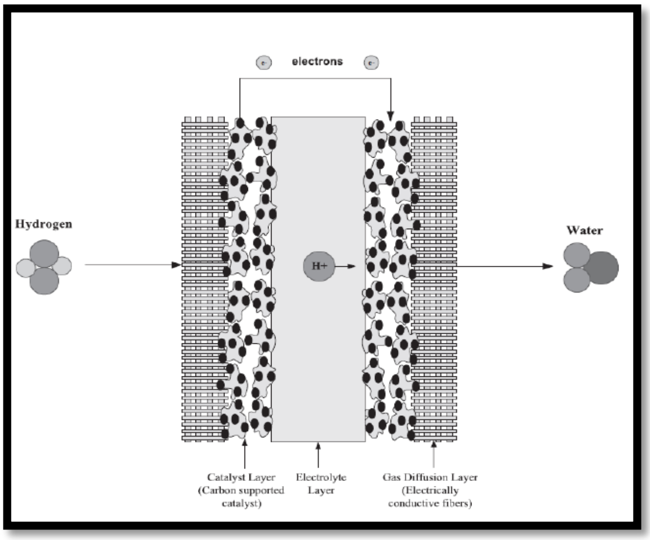

Fig 3.7-A single PEM fuel cell configuration

Some advantages of the fuel cell systems are as follows: -

- Fuel cells have the potential for a high operating efficiency
- There are many types of fuel sources, and methods of supplying fuel to a fuel cell
- Fuel cells have a highly scalable design
- Fuel cells produce no pollutants
- Fuel cells are low maintenance because they have no moving parts
- Fuel cells do not need to be recharged, and they provide power instantly when supplied with fuel.

Some limitations common to all fuel cell systems are as follows:

- Fuel cells are currently costly due to the need for materials with specific properties. There is an issue with finding low-cost replacements. This includes the need for platinum and Nafion material.
- Fuel reformation technology can be costly and heavy and needs power in order to run.
- If another fuel besides hydrogen is fed into the fuel cell, the performance gradually decreases over time due to catalyst degradation and electrolyte poisoning.

V. POWER MANAGEMENT

Power Management

Power management is a feature of some electrical appliances, especially copiers, computers and computer peripherals such as monitors and printers, that turns off the power or switches the system to a low-power state when inactive. In computing this is known as PC power management and is built around a standard called ACPI. This supersedes APM. All recent (consumer) computers have ACPI support.

Motivation:

PC power management for computer systems is desired for many reasons, particularly:

- Reduce overall energy consumption
- Prolong battery life for portable and embedded systems
- Reduce cooling requirements
- Reduce noise.
- Reduce operating costs for energy and cooling.

Lower power consumption also means lower heat dissipation, which increases system stability, and less energy use, which saves money and reduces the impact on the environment.

Processor level techniques:

The power management for microprocessors can be done over the whole processor, or in specific areas. With dynamic voltage scaling and dynamic frequency scaling, the CPU core voltage, clock rate, or both, can be altered to decrease power consumption at the price of potentially lower performance. This is sometimes done in real time to optimize the power-performance trade-off.
Additionally, processors can selectively power off internal circuitry (power gating). For example:

- Newer Intel Core processors support ultra-fine power control over the functional units within the processors.
- AMD Cool core technology gets more efficient performance by dynamically activating or turning off parts of the processor.[3]
- Intel VRT technology split the chip into a 3.3V I/O section and a 2.9V core section. The lower core voltage reduces power consumption.

Power Management System helps to:

Avoid Black-outs

In case of a lack of power, Load Shedding secures the electrical power to critical loads by switching off non-critical loads according to dynamic priority tables.

Reduce Energy Costs / Peak Shaving

When all on-site power generation is maximized and the power demand still tends to exceed the contracted maximum electricity import, the system will automatically shed some of the low priority loads.

Enhanced Operator Support

At sites where electricity is produced by several generators, the demands with respect to control activities by operators are much higher. Advanced functions such as intelligent alarm filtering, consistency analysis, operator guidance, and a well organized single-window interface support the operator and prevent incorrect interventions.

Achieve Stable Operation

The Power Control function shares the active and reactive power between the different generators and tie-lines in such a way that the working points of the machines are as far as possible away from the border of the individual PQ-capability diagrams so that the plant can withstand bigger disturbances.

Optimize Network Design

Because the set points for the generators, turbines and transformers are calculated in such a way that no component will be overloaded and the electrical network can be used up to its limits, over-dimensioning of the network is no longer needed.

Minimize Cabling and Engineering

All the signals and information which are available in protection/control relays, governor/excitation controllers and other microprocessor based equipment can be easily transmitted to the Industrial PMS via serial communication links. This avoids marshalling cubicles, interposing relays, cable ducts, spaghetti wiring, cabling engineering and provides extra functionality such as parameter setting/reading, stored events, disturbance data analysis and a single window to all electrical related data.

VI. SYSTEM DESCRIPTION

4.2.1Structure of Grid-Connected Hybrid Power 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 the PEMFC are modelled 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. 2. 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}.

PV Array Model

The mathematical model [3], [4] can be expressed as

$$I = I_{\text{ph}} - I_{\text{sat}} \left\{ \exp\left[\frac{q}{AKT}(V + IR_s) \right] - 1 \right\}. \qquad (1)$$

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 $\mathrm{G_a}$
(2)

$$I_{\text{ph}}(G_a) = I_{\text{sc}} \frac{G_a}{G_{\text{as}}}. \qquad (2)$$

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

$$I_{\text{sc}}(T) = I_{scs}[1 + \Delta I_{\text{sc}}(T - T_s)]. \qquad (3)$$

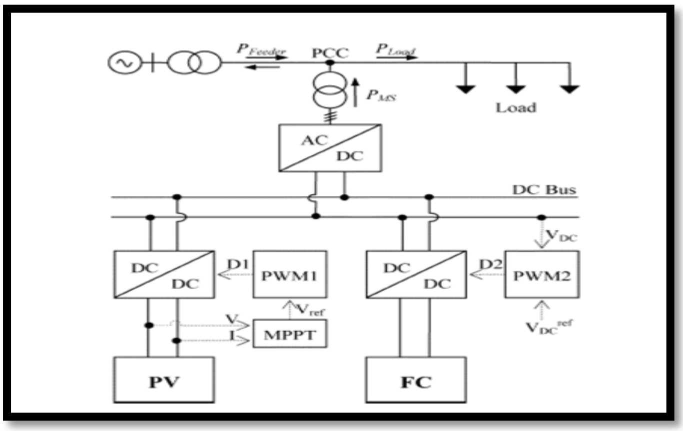

Fig 3.1-PV-FC base grid connected system

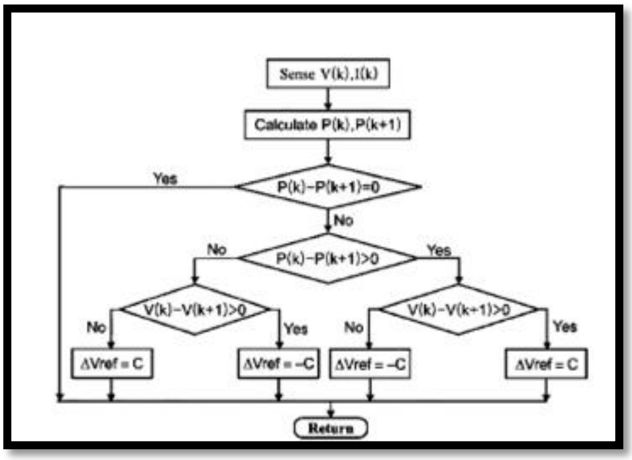

Fig 3.2-P & O algorithm

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

$$I_{\rm sat}(G_a,T)=\frac{I_{\rm ph}(G_a,T)}{e^{\left(\frac{V_{\rm oc}(T)}{V_{\rm t}(T)}\right)}-1}. \qquad (5)$$

PEMFC Model

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:

$$V_{\rm out}=E_{\rm Nerst}-V_{\rm act}-V_{\rm ohm}-V_{\rm conc} \qquad (6)$$

Where $E_{\rm Nerst}$ is the "thermodynamic potential" of Nearest, which represents the reversible (or open-circuit) voltage of the fuel cell.

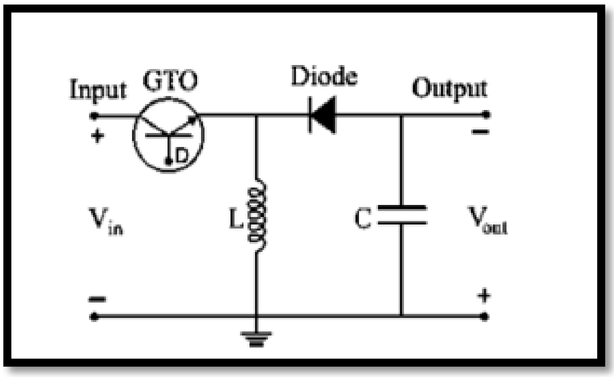

Fig 3.3-Buck-Boost topology

Activation voltage drop $V_{\rm act}$ is given in the Table equation as

$$V_{\rm act}=T[a+bln(I)] \qquad (7)$$

Where are the constant terms in the Table equation (in volts per Kelvin)

The overall Ohmic voltage drop $V_{\rm ohm}$ can be expressed as

$$V_{\rm ohm}=IR_{\rm ohm}. \qquad (8)$$

The Ohmic resistance $R_{\rm ohm}$ of PEMFC consists of the resistance of the polymer membrane and electrodes, and the resistances of the electrodes.

The concentration voltage drop $V_{\rm conc}$ is expressed as

$$V_{\rm conc}=-\frac{RT}{zF}ln\left(1-\frac{I}{I_{\rm limit}}\right). \qquad (9)$$

MPPT Control

Many MPPT algorithms have been proposed in the literature, such as incremental conductance (INC), constant voltage (CV), and perturbation and observation (P&O). The two algorithms often used to achieve maximum power point tracking are the P&O and INC methods. The INC method offers good performance under rapidly changing atmospheric conditions. However, four sensors are required to perform the computations. If the sensors require more conversion time, then the MPPT process will take longer to track the maximum power point. During tracking time, the PV output is less than its maximum power. This means that the longer the conversion time is, the larger amount of power loss will be. On the contrary, if the execution speed of the P&O method increases, then the system loss will decrease. Moreover, this method only requires two sensors, which results in a reduction of hardware requirements and cost. Therefore, the P&O method is used to control the MPPT process. In order to achieve maximum power, two different applied control methods that are often chosen are voltage-feedback control and power-feedback control. Voltage-feedback control uses the solar-array terminal voltage to control and keep the array operating near its maximum power point by regulating the array's voltage and matching the voltage of the array to a desired voltage. The drawback of the voltage-feedback control is its neglect of the effect of irradiation and cell temperature. Therefore, the power-feedback control is used to achieve maximum power. The P&O MPPT algorithm with a power-feedback control is shown in Fig. 2. 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 $\Delta V_{\rm ref}\cdot$. In order to implement the MPPT algorithm, a buck-boost dc/dc converter is used as depicted in Fig. 3. The parameters L and C in the buck-boost converter must satisfy the following conditions [11]:

$$L>\frac{(1-D)^2R}{2f} \quad ; \quad C>\frac{D}{Rf(\Delta V/V_{\rm out})}. \qquad (10)$$

The buck-boost converter consists of one switching device (GTO) that enables it to turn on and off depending on the applied gate signal D. The gate signal for the GTO can be obtained by comparing the saw tooth waveform with the control voltage.

The change of the reference voltage $\Delta V_{\rm ref}$ obtained by MPPT algorithm becomes the input of the pulse width modulation (PWM). The PWM generates a gate signal to control the buck-boost converter and, thus, maximum power is tracked and delivered to the ac side via a dc/ac inverter.

VII. MODELLING AND SIMULATION

CONTROL OF THE HYBRID SYSTEM

The control modes in the micro grid include unit power control, feeder flow control, and mixed control mode. The two control modes were first proposed by Lasserter [12]. 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 micro grid, 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 Pfeeder. 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 [13]–[16]. In this thesis, 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.

OPERATING STRATEGY OF THE HYBRID SYSTEM

As mentioned before, the purpose of the operating algorithm is to determine the control mode of the hybrid source and the reference value for each control mode so that the PV is able to work at maximum output power and the constraints are fulfilled. Once the constraints $(P_{FC}^{low}, P_{FC}^{up}, \text{and } P_{F}^{max})$ are known, the control mode of the hybrid source (UPC mode and FFC mode) depends on load variations and the PV output. The control mode is decided by the algorithm shown in Fig. 5.9, Subsection B. In the UPC mode, the reference output power of the hybrid source P_{MS}^{ref} depends on the PV output and the constraints of the FC output.

Simulation & Results of Grid Connected Hybrid Power System

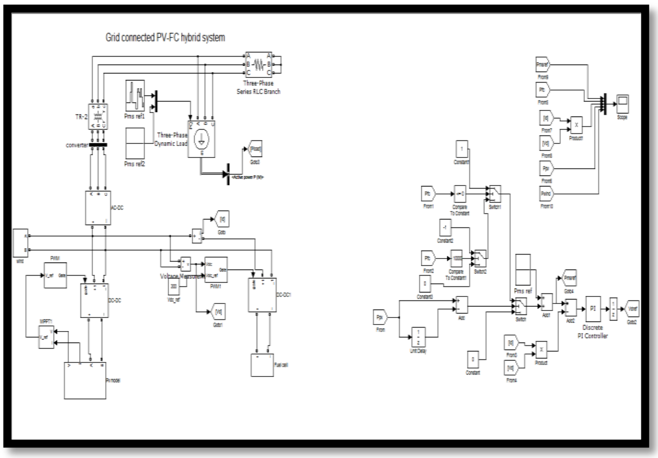

Fig 4.1-Grid Connected Hybrid PV-FC System

A. Simulation Results in the Case without Hysteresis

A simulation was carried out by using the system model shown in Fig. 4.1 to verify the operating strategies. The system parameters are shown in Table 5.1. In order to verify the operating strategy, the load demand and PV output were time varied in terms of step. According to the load demand and the change of PV output P_{PV} and P_{Load} , and the operating mode were determined by the proposed operating algorithm. Fig.4.1 shows the simulation results of the system operating strategy. The changes of and are shown in Fig. 4.1 (Δ line), respectively. Based on P_{PV} and the constraints of P_{FC} shown in Table 5.1, the reference value of the hybrid source output is determined as depicted in Fig.4.1 (o line). From 0 s to 10 s, the PV operates at standard test conditions to generate constant power and, thus, is constant. From 10 s to 20 s, changes step by step and, thus, P_{MS}^{ref} is defined as the algorithm shown in Fig.5.10. The PEMFC output P_{FC} , as shown in Fig. 4.1 (0, line), changes according to the change of and. Fig.4.2 shows the system operating mode. The UPC mode and FFC mode correspond to values 0 and 1, respectively.

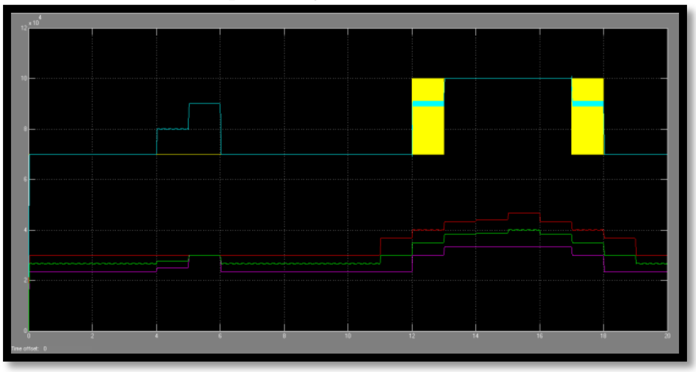

Fig.4.2- Simulation result without hysteresis. (a) Operating strategy of the hybrid source

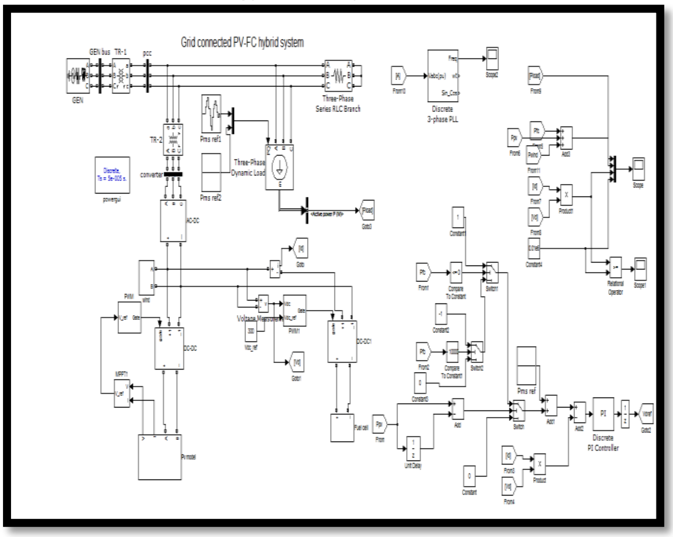

Fig4.3- Grid connected operating strategy of the whole system

B. Improving Operation Performance by Using Hysteresis

Fig. 4.3 shows the simulation results when hysteresis was included with the control scheme shown in Fig. 4.3. From 12 s to 13 s and from 17 s to 18 s, the variations of FC output and feeder flow are eliminated and, thus, the system works more stably compared to a case without hysteresis (Fig.5.13). Fig.4.6 shows the frequency variations when load changes or when the hybrid source reference power changes (at 12 s and 18 s). The parameter C was chosen at 0.03 MW and, thus, the frequency variations did not reach over its limit (% 0.3 Hz).

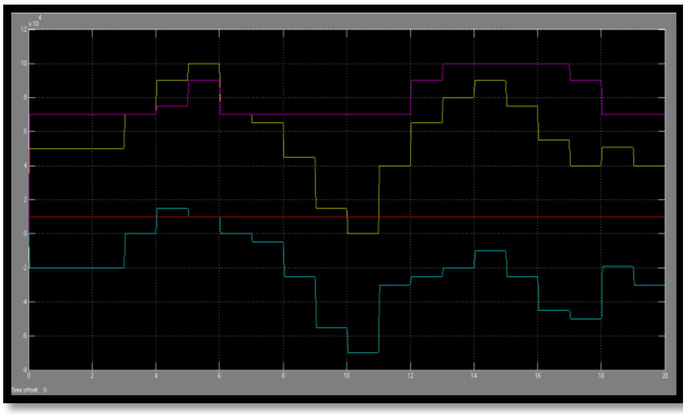

Fig 4.4-Simulation result without hysteresis (b) Operating strategy of the whole system

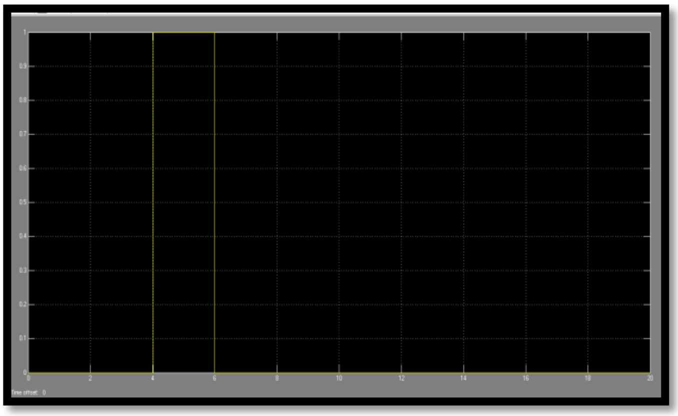

Fig 4.5 Simulation result without hysteresis (c) Change of operating modes

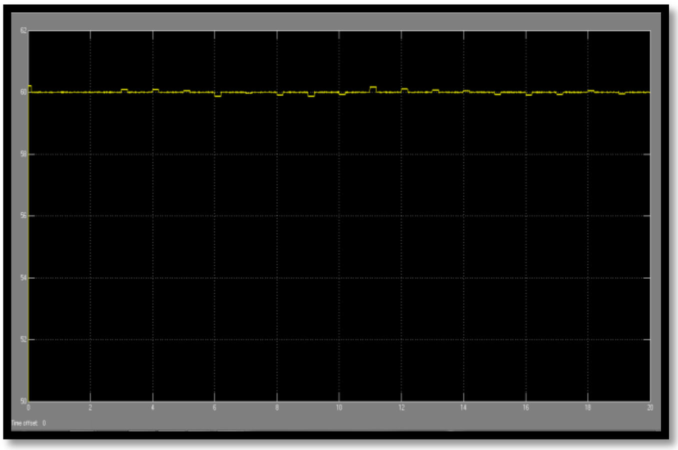

Fig.4.6 improving operation performance by using hysteresis:- (d) Frequency variations occur in the system

VIII. CONCLUSION

From the detail analysis of Photovoltaic system and Fuel Cell based hybrid system we can say that continuous power generation is obtain for customer and pubic. The hybrid connection of Solar PV system and FC system is easy and simple to design, operate. There is battery storage is also available for this kind of PV-FC base Hybrid system. This thesis has presented an available method to operate a hybrid grid-connected system. The hybrid system, composed of a PV array and PEMFC, was considered. The operating strategy of the system is based on the UPC mode and FFC mode. The purposes of the proposed operating strategy presented in this paper are to determine the control mode, to minimize the number of mode changes, to operate PV at the maximum power point, and to operate the FC output in its high-efficiency performance band. The main operating strategy, shown in Fig.5.10, is to specify the control mode; the algorithm shown in Fig.5.9 is to determine P_{MS}^{ref} in the UPC mode. With the operating algorithm, PV always operates at maximum output power, PEMFC operates within the high-efficiency range $(P_{FC}^{low} \div P_{FC}^{up})$, and feeder power flow is always less than its maximum value (P_{Feeder}^{max}).

The change of the operating mode depends on the current load demand, the PV output, and the constraints of PEMFC and feeder power. With the proposed operating algorithm, the system works flexibly, exploiting maximum solar energy; PEMFC works within a high-efficiency band and, hence, improves the performance of the system's operation.

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