Power Management of PV, BESS and Fuel Cell based Hybrid Power System

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Abstract - *The Photovoltaic (PV) solar energy systems are widely used as an important alternative energy source. To overcome the problem of intermittent power generation, PV power systems may be integrated with other power sources. Fuel cells are an attractive option because of high efficiency, modularity and fuel flexibility; however, one main week point is their slow dynamics. On the other hand, current technology batteries by themselves are usually insufficient to provide the long-term energy that the increasing loads require. Hybrid systems composed of fuel cells and batteries can be integrated with PV power systems to provide uninterrupted high-quality power. The goal of this study is to design an effective power management system for a PV/fuel cell/battery hybrid power system so that the combination can be used as a reliable power source. In this paper, the structure of the hybrid power system is described, and control strategies for power management of the hybrid power system are discussed. The proposed hybrid power system is then verified by numerical simulation.*

Key Words: photovoltaic cells, fuel cells, battery, hybrid power systems, power management.

1.INTRODUCTION

Renewable energy sources (solar, wind, tidal, etc.) are attracting more attention as alternative energy sources as conventional fossil-fuel energy sources are diminishing and world-wide environmental concerns about global warming and acid deposition increase. Among them, photovoltaic (PV) solar energy systems are widely used as an important option in small-size applications and are the most promising candidate for research and development for large-scale use because the fabrication of less costly photovoltaic cells becomes a reality. PV energy systems find various applications for the household appliances, for data communications and telecommunications systems, for the soldiers in the remote missions, for solar cars, and even for electric aircrafts [1]-[3]. From an operational viewpoint, a photovoltaic panel may experience large variations of its output power under variable weather conditions, which may result in control problems. One method to overcome these problems is to integrate the PV power system with other power sources; for example, diesel generators [4], superconductive magnetic energy storage (SMES) systems [5], battery energy storage systems [6]-[8], and fuel cell systems [9]-[10]. The diesel backup for PV power systems is able to make a continuous 24-hour power supply possible, but its severe drawbacks are that its efficiency decreases significantly at low levels of power output, and that diesel power generation is environmentally detrimental as well. The SMES technology is many years from commercialization, and significant potential health risks are associated with this technology because of strong magnetic fields. Fuel cells are a very attractive option to be used with intermittent sources of generation like the photovoltaic because of high efficiency, modularity and fuel flexibility. However, one main week point of the fuel cell is its very slow dynamics, which is actually limited by the slow dynamics in the fuel supply system that contains pumps, valves, or reformers. A rapid increase in the load power would result in a significant drop in the fuel cell output voltage, which would deteriorate power quality or even sometimes cause shutdown of the system at low temperature. The fuel cell system would have to be oversized to meet the peak power requirements. To increase the response speed and peak power capacity of the fuel cell power supply, auxiliary energy storage and corresponding power conditioning devices are needed. On the other hand, although secondary batteries are usually used in renewable energy systems to store energy when the input power is sufficient or the load is light and to provide energy in the case of no input power or a heavy load, current technology batteries by themselves are insufficient to provide the long term power (energy) that the increasing loads require. It is therefore worthwhile to integrate hybrid systems composed of fuel cells and batteries, which combine the high energy density of fuel cells and the high power density of batteries [11], with PV power systems through appropriate power converters and controls to obtain uninterrupted high-quality power. Fuel cells can be integrated into a PV system in two ways: as an independent power source, or as part of a long-term energy storage system for seasonal coordination through being fueled by hydrogen from a dedicated electrolyzer [12]–[13]. This paper discusses the independent power source case. In this case, the power provided by different sources of energy can be actively controlled and the control of these power subsystems is an issue. Active hybrid power systems require a much more complex control scheme that must ensure efficient and robust power transfer from the sources without risks of their rapidly degraded reliability due to prolonged over-current and/or under-voltage conditions. Therefore, rather than achieving a single voltage/current regulation goal at the output, the control system must regulate these power converters to balance the power flow of these energy sources so as to satisfy the load requirements while ensuring the various limitations of electrochemical components such as the battery overcharge limit, the fuel cell current limit, etc. The objective of this study is to design an effective power management system for a PV/fuel cell/battery hybrid power system so that the combination can be used as a reliable power source. In the following, the structure of the hybrid power system is first described, and control strategies for power management of the hybrid power system are discussed. The proposed hybrid power system is then verified by simulation.

2. MODELLING OF HYBRID POWER SYSTEM

Due to fluctuation and interruption in power generated from renewable sources like wind, solar and hydro energy, considering a form of energy storage to backup power fluctuation is very important. Therefore, short-term and/or long-term energy storage, such as batteries or super-capacitors and/or hydrogen storage tanks, must be used to achieve a reliable and safe operation and to maintain the required power supply during power fluctuation, failure or high power peak conditions. To achieve this, system components should be selected carefully and the control system must ensure that HPS components are well managed and monitored properly. This chapter will cover a brief description of the important hybrid system components used in this work:

(1) PV System.
(2) Fuel cell System.
(3) Batteries (or super-capacitor).
(4) Power management system.

A. PV System

A photovoltaic panel is an assembly of PV cells which are semi-conductor materials generating electricity from electro-magnetic radiation. When the source of radiation is the Sun, the PV cells are called solar cells. Most of the commercial solar panels are produced from silicon based solar cells. According to the quality of the cell, the energy conversion efficiency of the devices from solar power into direct current can be in the range of 5% to 20%. Because of the low energy conversion efficiencies and high cost of the solar panels, practical use of these devices are mostly limited to electricity generation in rural and remote areas, to telecommunication stations and to spacecrafts.

In the following sub-sections, a mathematical model of solar panels will be introduced. The model will be able to predict the output parameters of the PV panel such as power production, cell temperature and efficiency for a given set of meteorological data. In addition, it will be possible to measure the different commercial panel performances in generating electricity by changing the input data provided by producers. The equivalent electrical circuit of a PV cell is given in Figure 1. It is a one diode model which is also known as the 5 parameter circuit. The cell can be modeled by other equivalent circuits as well; such as 7 parameters but the one diode model is the most commonly used circuit in the literature and the solution of the circuit is not as complicated as is the case in other models. The parameters in the circuit are; ID, IL, ISH, RSH, RS, I and V.

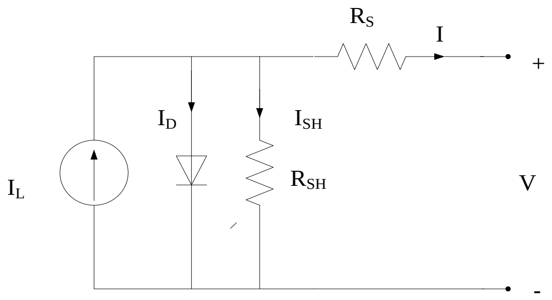

Fig -1: Equivalent circuit of a solar cell.

B. Fuel Cell System

A fuel cell is an electrochemical device that converts the chemical energy of the fuel (hydrogen) into electrical energy. It is centered on a chemical reaction between the fuel and the oxidant (generally oxygen) to produce electricity where water and heat are byproducts. This conversion of the fuel into energy takes place without combustion. Generally, efficiency of the fuel cells ranges from 40-60% and can be improved to 80-90% in cogeneration applications. The waste heat produced by the lower temperature cells is undesirable since it cannot be used for any application and thus limits the efficiency of the system. The higher temperature fuel cells have higher efficiency since the heat produced can be used for heating purposes.

The structure and the functioning of a fuel cell is similar to that of a battery except that the fuel can be continuously fed into the cell. The cell consists of two electrodes, anode (negative electrode) and cathode (positive electrode) separated by an electrolyte. Fuel is fed into the anode where electrochemical oxidation takes place and the oxidant is fed into the cathode where electrochemical reduction takes place to produce electric current and water is the primary product of the cell reaction. Figure 2.1 shows the flows of reactants in a simplified fuel cell.

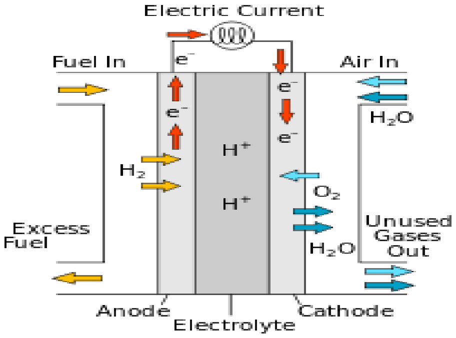

Fig.-2. Schematic of an individual fuel cell.

The hydrogen which enters the anode side is broken into hydrogen ions and electrons with the help of the catalyst. In case of lower temperature cells like the PEMFC and the PAFC, the hydrogen ions move through the electrolyte and the electrons flow through the external circuit. The oxygen which enters through the cathode side combines with these hydrogen ions and electrons to form water as shown in the above figure. As this water is removed, more ions are passed through the electrolyte to continue the reaction which results in further power production. In the SOFC, it is not the hydrogen ions which move through the electrolyte, but the oxygen radicals. In case of MCFC, carbon dioxide combines with the oxygen and electrons to form carbonate ions, which are transmitted through the electrolyte. Fuel cells are classified based on the type of electrolyte used. A solid polymer membrane electrolyte is fitted between two platinum catalyzed porous electrodes for PEM fuel cells. MCFCs have a liquid lithium-potassium or lithium-sodium based electrolyte while SOFCs employ a solid yittra-stablized zirconia ceramic electrolyte. The catalyst used for SOFC and MCFC are perovsikites and nickel, respectively, the cost of which is comparatively lower than that used for PEMFC.

C. Battery Energy Storage System

The battery energy storage system (BESS) comprises mainly of batteries, control and power conditioning system (C-PCS) and rest of plant. The rest of the plant is designed to provide good protection for batteries and C-PCS. The battery and C-PCS technologies are the major BESS components and each of these technologies is rapidly developing.

The batteries are made of stacked cells where-in chemical energy is converted to electrical energy and vice versa. The desired battery voltage as well as current levels are obtained by electrically connecting the cells in series and parallel. The batteries are rated in terms of their energy and power capacities. Foremost of the battery types, the power and energy capacities are not independent and are fixed during the battery design. Some of the other important features of a battery are efficiency, life span (stated in terms of number of cycles), operating temperature, depth of discharge (batteries are generally not discharged completely and depth of discharge refers to the extent to which they are discharged), self-discharge (some batteries cannot retain their electrical capacity when stored in a shelf and self-discharge represents the rate of discharge) and energy density. Currently, significant development is going on in the battery technology. Different types of batteries are being developed of which some are available commercially while some are still in the experimental stage. The batteries used in power system applications so far are deep cycle batteries (similar to the ones used in Electric vehicles) with energy capacity ranging from 17 to 40MWh and having efficiencies of about70–80%. Of the various battery technologies, some seem to be more suitable (have been used) for power system applications.

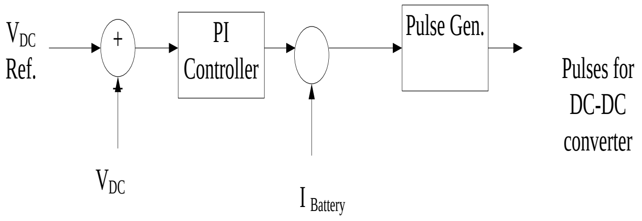

Fig. 3 Control strategy for DC-DC converter

3. POWER MANAGEMENT STARTEGY

As the hybrid power system is using PV, Fuel cell and battery as the power sources or sinks at different interval of time, so there are needs to share the power within these sources/sinks effectively. PV system output power is weather dependent, sometime PV system produces more power than the requirement and this excess power should be stored in the BESS which can be later used in with demand is more than the requirement. To maintain the power according to the load classical PI controller is used for power management among the different parts of the HPS. A central controller is used for fuel cell system, BESS and PV system for DC-DC conversion as well as for DC-AC conversion.

As the output of PV system, BESS and fuel cell system is DC, so it has to be converted in to suitable AC form with AC converter. First of all the three phase AC voltage and current are measured and converted into RMS values and compared with the reference voltage i.e. 1 pu. The error is then goes to the PI controller and again this is converted back in to three phase quantities. This signal is fed to the pulse generator which produces pulses for the inverter circuit.

4. SIMULATION RESULTS

In this section, two main scenarios will be explored to validate the hybrid system performance i.e. different solar irradiance and variable load conditions. The FC/PV HPS individual components are modelled using MATLAB Simulink. The system components have been grouped together to make the hybrid system.

There are two cases are considered, these are:

A. Variable Solar Irradiance

B. Step load change

For analyzing the validity of the HPS the system is subjected to different levels of solar irradiance. For the time interval 0-2 second the solar irradiance level is 1000 W/m2. From time interval between 2-6 second the solar irradiance level is reduced to 800W/m2 shown in the figure 4. As the irradiance level is decreased the output current and the output power of the PV system also decreased. For the simplicity only one time change in the solar irradiance is done otherwise the other waveforms will be overcrowded and cannot be clearly visible.

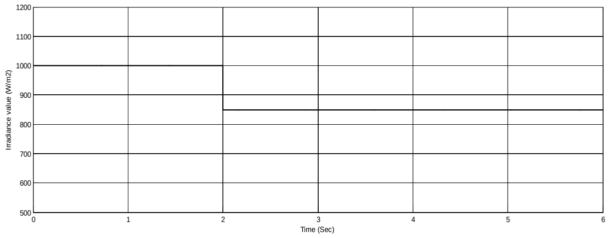

Fig. 4. Solar Irradiance level

Figure 5 shows the solar irradiance versus MPPT voltage waveform. From the figure it is clearly understood that the irradiance level decides the MPPT voltage. As the irradiance level decreased the MPPT voltage also reduces. Red line shows the PV MPPT voltage and blue line showing the solar irradiance level.

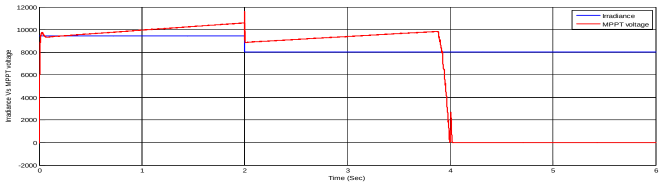

Fig. 5. Solar Irradiance level Vs PV MPPT voltage

For compensating the shortfall in the PV system power BESS reacts according to the requirement.

For these purpose BESS controllers gives the command to the converter circuit and further it supply power to the demand. If the BESS state of charge (SOC) less than the minimum value then BESS does not comes in to action. In the figure 5.4 BESS current waveform is shown. From the figure it is found that when the PV system output decreases, BESS power increased to compensate this shortfall.

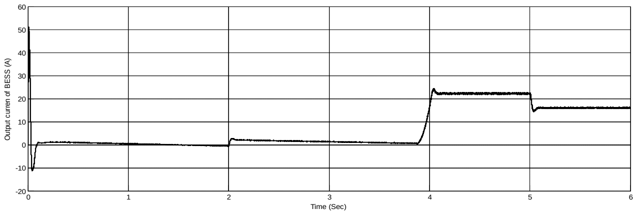

Fig. 6 Output current of the BESS

For the second case, there is change in load is made at the time 4 sec. initially the system is connected to the 10 KW resistive load. There is a step increase of additional 3 KW load is made at time 4 sec. this additional load I s removed at time 5 sec. Figure 7 shoes the waveform of the power drawn by the load.

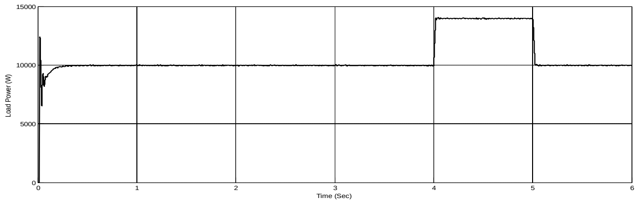

Fig.7.Power drawn by the load

When the load is increased the HPS system start supplying more current to meet the requirement. In the previous case it is described that shortfall in the PV system is compensated by the BESS. Here also when the load increases, this additional requirement is fulfilled by the BESS if the PV system and fuel cell system both are not capable of meeting the demand.

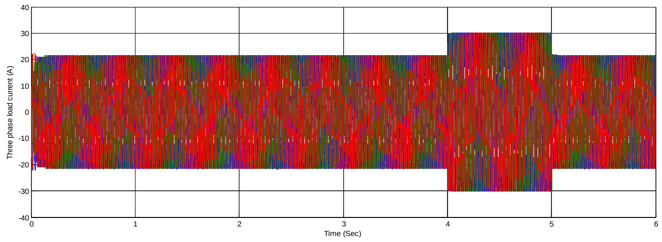

Fig. 8.Three phase current drawn by the load.

Figure 8 shows the waveform of three phase current drawn by the load. As predicted, the current increases as the load increases.

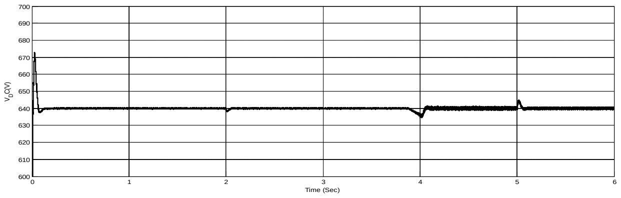

Fig. 9.V_{DC} of the boost converter

The voltage across the load should be constant whether there is change in load or change in solar irradiance level. The HPS satisfied this condition and work properly under these two perturbances.

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4. CONCLUSIONS

In this paper, off-grid power systems are modeled and system parameters are analyzed using a MATLAB/Simulink. The paper is focused on the effects of system components and on the total performance of the system. The photovoltaic Panels, BESS and the fuel cell system are modeled individually using MATLAB 7.12.0. The system is subjected with the two types of perturbances, i.e. change in load and change in solar irradiance level.

The power management technique based upon classical PI controller is used for sharing the power according to the load and environmental conditions. The study shows how energy stored in the can be used as a key system performance indicator, provided that no system constraints are violated. The performance of the system can be significantly affected by the small variations made on the system elements.

BESS is the only energy storage for a Stand-Alone Power System. The system is based on electricity-to-chemical and chemical-to electricity conversion which is an inefficient way of handling the extra energy.

Assembling PV panels, surface slope reduces the amount of this conversion and expected to increase the system performance and thus reduce the size of the equipments used. increasing the number of electrolyzer cells adds additional initial cost to the system but also increases the system efficiency and life time of the whole electrolyzer stack.

Adding a BESS plays an important role on the system performance and efficiency as well as the size of other components in the system. Increasing the number of batteries used also increases the system efficiency and decreases the other component sizes. On the other hand, the cost of the battery pack increases with a high rate while cost of other equipments decreases with a lesser rate.

Auxiliary equipment brings extra load on the system but they are essential for steady and continuous operation of a stand-alone power system. If grid electricity is not used for auxiliary equipment, a battery pack or a fuel cell stack working continuously should provide energy to these equipment. Since the control panel and similar equipment should work continuously.

REFERENCES

[1] B. Lindemark, G. Oberg, “Solar power for radio base station (RBS) sites applications including system dimensioning, cell planning and operation”, Proceedings of 23rd International Telecommunications Energy Conference, pp. 587 – 590, 14-18 Oct. 2001.

[2] L. McCarthy, J. Pieper, A. Rues, C. H. Wu, “Performance monitoring in UMR's solar car”, IEEE Instrumentation & Measurement Magazine, Vol. 3, No. 3, pp. 19-23, Sept. 2000.

[3] H. J. Wenger, C. Jennings, J. J. Iannucci, “Carrisa Plains PV power plant performance”, Proceedings of IEEE Photovoltaic Specialists Conference, vol.2, pp. 844-849, May 1990.

[4] T. M., “Autonomous Photovoltaic-Diesel Power System Design”, Proceedings of IEEE Photovoltaic Specialists Conference, Las Vegas, Nevada, October 1985, pp. 280-284.

[5] K. Tam, P. Kumar and M. Foreman, “Enhancing the Utilization of Photovoltaic Power Generation by Superconductive Magnetic Energy Storage”, IEEE Transactions on Energy Conversion, Vol. 4, No. 3, September 1989, pp. 314-321.

[6] Chaurey and S. Dembi, “Battery Storage for PV Power Systems: An Overview”, Renewable Energy, Vol. 2, No. 3, pp. 227-235, 1992.

[7] B.H. Chowdhury and S. Rahman, “Analysis of Interrelationships between Photovoltaic Power and Battery Storage for Electric Utility Load Management”,

IEEE Transactions on Power Systems, Vol. 3, No. 3, August 1988, pp. 900-907.

[8] K.C. Kalaitzakis and G.J. Vachtsevanos, “On the Control and Stability of Grid Connected Photovoltaic Sources”, IEEE Transactions on Energy Conversion, Vol. 2, No. 4, December 1987, pp. 556-562.

[9] S. Rahman and K. Tam, “A Feasibility Study of Photovoltaic-Fuel Cell Hybrid Energy System”, Transactions on Energy Conversion, Vol. 3, No. 1, March 1988, pp. 50-55.

[10] K. Tam and S. Rahman, “System Performance Improvement Provided by a Power Conditioning Subsystem for Central Station PhotovoltaicFuel Cell Power Plant”, IEEE Transactions on Energy Conversion, Vol. 3, No. 1, March 1988, pp. 64-70.

[11] Z. Jiang, L. Gao, and R. Dougal, “Flexible Multiobjective Control of Power Converter in Active Hybrid Fuel Cell/Battery Power Sources”, IEEE Transactions on Power Electronics, Vol. 20, No. 1, pp. 244-253, Jan. 2005.

[12] K. Agbossou, M. Kolhe, J Hamelin, T. K. Bose, “Performance of a stand-alone renewable energy system based on energy storage as hydrogen”, IEEE Transactions on Energy Conversion, Vol. 19, No. 3, pp. 633 - 640, Sept. 2004.

[13] W. Knaupp, E. Mundschau, “Photovoltaic-hydrogen energy systems for stratospheric platforms”, Proceedings of 3rd World Conference on Photovoltaic Energy Conversion, Vol. 3, pp. 2143 – 2147, May 2003.

[14] R. C. Neville, Solar Energy Conversion: The Solar Cell, Elsevier Scientific, New York, 1978.

[15] O. Wasynczuck, “Dynamic Behavior of a Class of Photovoltaic Power Systems”, IEEE Trans. Power Apparatus and Systems, Vol. PAS-102, No. 9, pp. 3031-3037, 1983.

[16] K. Hussein, I. Muta, T. Hoshino, and M. Osakada, “Maximum Photovoltaic Power Tracking: An Algorithm for Rapidly Changing Atmospheric Conditions”, IEE Proc. - Generation, Transmission, Distribution, Vol. 142, No.1, pp. 59-64, January, 1995.

[17] T. Noguchi, S. Togashi, R. Nakamoto, “Short-Current Pulse-Based Maximum-Power-Point Tracking Method for Multiple Photovoltaicand-Converter Module System”, IEEE Trans. on Industrial Electronics, vol. 49, pp. 217-223, Feb. 2002.

[18] J. H. R. Enslin, M. S. Wolf, D. B. Snyman and W. Swiegers, “Integrated Photovoltaic Maximum Power Point Tracking Converter”, IEEE Trans. on Industrial Electronics, vol. 44, pp. 769-773, Dec. 1997.

[19] M. Veerachary, T. Senjyu, K. Uezato, “Neural-network-based maximum-power-point tracking of coupled-inductor interleaved-boostconverter-supplied PV system using fuzzy controller”, IEEE Trans. on Industrial Electronics, Vol. 50, No. 4, pp. 749 –758, Aug. 2003.

[20] M. Veerachary, T. Senjyu, K. Uezato, “Feedforward maximum power point tracking of PV systems using fuzzy controller”, IEEE Transactions on Aerospace and Electronic Systems, Vol. 38, No. 3, pp. 969 –981, July 2002.

[21] T. Lovett, A Monti, E. Santi, R. Dougal, “A multilanguage environment for interactive simulation and development of controls for power electronics”, Proceedings of IEEE 32nd Annual Power Electronics Specialists Conference, Vol. 3, pp. 1725 –1729, 2001.