POWER MANAGEMENT OF A STAND-ALONE PHOTOVOLTAIC/FUEL CELL HYBRID ENERGY SYSTEM

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Abstract
This paper intends a hybrid photovoltaic (PV)/fuel cell (FC) hybrid energy system for stand-alone applications. Photovoltaic is the principal energysource of the system, and a Fuel cell is used as a long-term storage system and backup. A complete power management strategy is planned for the anticipated system to accomplish power flows among the different renewable energy sources and the storage unit in the system. A model for the hybrid system has been established using MATLAB/Simulink. The hybrid system performance under diverse scenarios has been confirmed by carrying out simulation studies using a load demand profile and weather data.

Index Terms: fuel cell (FC), alternative energy, hybrid system, photovoltaic (PV), electrolyzer, stand-alone, power management, alternative energy system.

I. INTRODUCTION
The ever growing energy consumption, the rising cost and the exhaustible nature of fossil fuel, and the deteriorating global environment have created augmented interest in renewable and/or fuel cell (FC)-based energy sources power generation systems. Solar power generation is one of the most promising renewable power generation technologies. The development of PV power generation systems has surpassed the most expectant estimation. Fuel cells also display great latent to be green power sources of the future due to several merits (such as zero or low emission of pollutant gases, flexible modular structure and high efficiency) and the speedy progress in FC technologies. However, each of the aforesaid technologies has its own shortcomings. For example, solar power is highly dependent on climatic conditions while Fuel cells need hydrogen-rich fuel. Nonetheless, as diverse alternative energy sources can balance each other to some degree, multisource hybrid alternative energy systems have unlimited potential to offer advanced quality and more reliable power to clients than a system based on a single resource. Due to this, hybrid energy systems have caught international research attention.

Many alternative energy sources including PV, wind, diesel system, FC, micro turbine and gas turbine can be used to construct a hybrid energy system. However, the foremost renewable energy source used and reported is Photovoltaic. Due to the erratic nature of solar energy, stand-alone PV system usually needs other generation sources or energy storage devices to form a hybrid system. The storage device can be superconducting magnetic energy storage (SMES), battery bank, FC electrolyzer system or a super capacitor bank.

In this paper, a stand-alone hybrid renewable energy system comprising of PV, FC and electrolyzer is projected. PV is the prime energy source of the system to take complete benefit of renewable energy, and the FC electrolyzer combination is used as a long-term storage system and a backup unit. The particulars of the system configuration and the features of the major system components are also deliberated in the paper. A complete power management strategy is planned for the system to synchronize the power flows among the different power sources. Simulation studies have been carried out to validate the system performance under different situations using practical load profile and real weather data. The paper is systematized as follows. The system configuration is conferred in Section II. Section III gives the system component characteristics. Section IV confers the inclusive power management strategy for the hybrid system and Section V gives the simulation results. Conclusion of the paper is given in Section VI.

II. SYSTEM CONFIGURATION
System configuration of the proposed hybrid energy can be considered as a complete eco-friendly power generation system because the chief energy source and storage system are all environment friendly. When there is additional solar generation available, the electrolyzer is activated to produce hydrogen, which is then delivered to the hydrogen storage tanks. If the H2 storage tanks become full, the excess power will be diverted to the dump load. When there is a shortage in PV power generation, the Fuel cell stack will begin to produce power using hydrogen from the reservoir tanks. Different energy sources are connected to the AC bus
through appropriate power electronic interfacing circuits. The hybrid system is designed to supply power to five homes in a rural area. A typical hourly residential load demand for rural homes is used. The total hourly average load demand is shown in Figure 1.

![Hourly average demand of five typical homes in a rural area](image)

**III. SYSTEM COMPONENT CHARACTERISTICS**

To design an overall power management strategy for the system and to examine the system performance, dynamic models for the main components in the proposed hybrid energy system have been developed using MATLAB/Simulink.

**A. Photovoltaic**

PV effect is a simple physical process through which solar energy is converted directly into electrical energy. The physics of a solar cell, is similar to the p-n junction diode. In a PV array higher the irradiance, the higher are the short-circuit current (Isc) and the open-circuit voltage (Voc). As a result, the larger will be the output PV power. Temperature plays avital role in the PV performance. It is noted that lower the temperature, the greater is the maximum power and higher the open circuit voltage.

**B. Fuel Cell**

The PEMFC model is operated under continuous channel pressure with uncontrolled input fuel flow into the Fuel cell. The FC will adjust the input fuel flow according to its load current to maintain the channel pressure constant. The characteristic curve can be divided into three areas. The voltage drop across the Fuel cell related with low currents is because of the activation loss inside the Fuel cell; the voltage drop in the middle of the curve is due to the ohmic loss in the FC stack; and as a result of the concentration loss, the output voltage at the end of the curve will drop suddenly as the load current rises.

**C. Electrolyzer**

An electrolyzer is a device that yields hydrogen and oxygen from water. In divergence to the electro chemical reaction occurring in an FC to produce electricity, an electrolyzer converts electrical energy into chemical energy stored in hydrogen. For a given electrolyzer, within its rating range, the higher the dc voltage applied, the greater is the load current. So, by applying a higher dc voltage, more H2 can be generated.

**IV. OVERALL POWER MANAGEMENT STRATEGY**

A total control scheme for power management among different resources in a multisource energy system is needed. The block diagram of the overall control scheme for the proposed hybrid alternative energy system is shown in figure 2. The Photovoltaic power generation unit, controlled by a maximum power point tracking (MPPT) controller, are the primary energy sources of the system. The power difference between the generation sources and the load demand is calculated as

\[ P_{net} = P_{PV} - P_{load} - P_{sc} \]

Where \( P_{PV} \) is the power produced by the PV energy system, \( P_{load} \) is the load demand, and \( P_{sc} \) is the self-consumed power of various components in the hybrid system, for example, the power needed for running the control unit, the gas compressor and the cooling systems. The central control strategy is that, at any given time, any extra PV-generated power (\( P_{net} > 0 \)) is delivered to the electrolyzer to produce hydrogen that is delivered to the hydrogen storage tanks. Therefore, the power balance equation can be written as

\[ P_{PV} = P_{load} + P_{elec} + P_{comp} \]

where \( P_{elec} \) is the power consumed by the electrolyzer to generate H2 and \( P_{comp} \) is the power consumed by the gas compressor.

When there is a shortage in power generation (\( P_{net} < 0 \)), the fuel cell stack initiates to produce energy for the load using hydrogen from the storage tanks. Therefore, the power balance equation can be written as

\[ P_{PV} + P_{FC} = P_{load} \]

where \( P_{FC} \) is the power generated by the FC stack.
V. SIMULATION RESULTS
The component models can be used to develop a model for the proposed PV/FC hybrid energy system using MATLAB/Simulink. In order to authenticate the system performance under different conditions, simulation studies have been carried out using real weather data (air temperature and solar irradiance) and practical load demand data. Simulation studies are carried out for power management during a typical winter and summer day. The load demand is kept the same for the two cases. Results for the winter and summer scenarios in simulink are discussed below.

A. Winter Scenario
Weather Data: The air temperature and hourly solar irradiance data collected on the same winter day are shown in Figure 3 and Figure 4 respectively.

When $P_{\text{net}} < 0$, the PV-generated power is not sufficient to supply the load demand. In this condition, the Fuel cell turns on to supply the power shortage. Figure 6 shows the actual power delivered by the FC stack.

B. Summer Scenario
Weather Data: The solar irradiance and air temperature data at the same place on the same day are shown in Figures 7 and 8, respectively.

The output power from the PV array in the hybrid energy system over the 24 h simulation period is shown in Figure 9.

When $P_{net} > 0$, there is excess power available for H2 generation. The available power is used by the electrolyzer to generate H2 through the electrolyzer controller. Figure 10 shows the H2 generation rate over the simulation period. The corresponding DC voltage applied to the electrolyzer is shown in Figure 11.

When $P_{net} < 0$, the PV generated power is not sufficient to supply the load demand. Under this condition, the fuel cell turns on to supply the power shortage. Figure 12 shows the power supplied by the FC. The corresponding H2 consumption rate is given in Figure 13.
VI. CONCLUSION
In this paper, a stand-alone PV/FC hybrid alternative energy system is proposed. The system configuration is proposed; the characteristics of the main components in the system, explicitly, the Photovoltaic, Fuel cell, and electrolyzer are given; and the overall control and power management scheme for the projected hybrid system is presented. The PV generation systems are the main power generation devices, and the electrolyzer acts as a storage device using any surplus power available to produce Hydrogen. The Fuel cell system serves as backup generation and supplies power to the system when there is power scarcity. The simulation model of the hybrid energy system has been developed using MATLAB. Simulation studies have been carried out to prove the system performance under different circumstances using typical load profile. The winter and summer scenario simulation results, show the efficacy of the overall power management strategy and the power flows among the different energy sources and the load demand is balanced successfully.

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REFERENCES