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Control Strategy of Solar Photovoltaic-Fuel Cell-Super Capacitor-Battery Hybrid System

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ABSTRACT

This paper presents the integration of photovoltaic (PV), fuel cell (FC) and energy storage systems for reliable power generation. The PV is the primary energy source, fuel cell is the auxiliary power source whereas battery and ultra-capacitor both are considered for their different power density to supply transient and steady load respectively. In this system FC is used as main power source and power from PV whenever available is harvested completely with storage system compensating for power fluctuations. This topology has high efficiency, modularity and fuel flexibility. The sources in this hybrid system complement each other very well against environmental variations and load variations. Of the many storage systems the use of ultra-capacitor gives advantage of absorbing and contributing to power transients quickly and efficiently.To increase the reliability of the system source Fuel cell has been chosen to keep the battery fully charged. The battery sources are connected to DC bus by DC-DC converters. In this work, Fuel cell is chosen to work for a limited period. This will avoid the over sizing of the Fuel cell and limit the operational cost of the system. In this paper, the structure of the hybrid power system is described. The proposed hybrid power system is then verified by numerical simulation.

Keywords : Photovoltaic cells, fuel cells, battery, super capacitor, MPPT, hybrid system, four leg voltage source converter

I. INTRODUCTION

As the conventional energy sources are getting diminished the need for alternate power sources is increasing drastically. Of the renewable sources, PV systems have many advantages as they are portable in nature, give clean power and suitable for different areas of applications from communication systems to solar cars. Though the fabrication cost is bit high at present it will gradually reduce with research and large scale use.

PV systems experience large variations of power fluctuations due to variable weather conditions thus the need to integrate with other power sources is imperative; for example battery energy storage, diesel generators and fuel cells. Diesel generators can give back up for limited periods and battery storage cannot meet all the load fluctuations. PV system being a insolation dependent source it has high degree of output power fluctuations. A controlled source is required which can match deficient power of PV and supply additional power to give rated power. So fuel cells present with an attractive option for integration with PV systems. Fuel cells also have added advantages of higher efficiency, modularity and fuel flexibility. Their only short coming is in the slow dynamics of fuel supply system, any sudden variations in the load will have direct effect on the terminal voltage of the fuel cells which can cause shutdown of the system. So to maintain the system in healthy state of operation PV, fuel cell and secondary storage have to be integrated with suitable power conditioning methods. Ultra capacitors are very effective in the use as storage devices as they provide high power density along with high energy density of fuel cells. They can quickly absorb or contribute power at a DC bus, giving a constant voltage without any fluctuations.

Fuel cells can be integrated with PV in either as independent power source or as a part of long term energy storage with dedicated electrolyzer. Here the independent operation is considered in which power from both sources is actively controlled to meet the load demands. The objective of the study is to design an effective power management system of PV/fuel cell/ultra capacitor. The structure and control strategies for the proposed system are discussed and then verified the results by numerical simulation.

In this project hybrid photovoltaic-fuel cell-battery-super capacitor system has been chosen for the application of standalone DC load isolated from the utility grid. It can be a critical load located in remote areas, telecom load, ATM, hospital, military establishment etc. Battery and super capacitor both as the storage device make the system able to supply all type of loading condition. Whereas photovoltaic and fuel cell, being the main sources try to keep the storage devices charged to desired level. In this study, a new control strategy has been proposed for fuel cell system. Fuel cell is only used to charge battery when battery state of charge reaches below its specified minimum state of charge limit, which will reduce fuel usage by reducing fuel cell running period, thus reducing system operational cost.

II. METHODS AND MATERIAL

A. System Representation

The proposed hybrid Energy system considering photovoltaic-fuel cell-battery-super capacitor is shown in Fig.1. The whole system is used to supply a variable DC load. In this paper, photovoltaic and fuel cell are used as the primary and auxiliary sources respectively while battery and super capacitor are the energy storing elements. Photovoltaic arrays are interfaced with the load by means of buck converter including maximum power point tracking to always extract maximum available solar power. Battery is the main energy storing device which is used to always charge the super capacitor to its maximum voltage. It also supplies long term energy when photovoltaic is not available. Super capacitor is controlled by a cascaded voltage and current control loop to supply the sudden load change and DC bus voltage stabilization. Both battery and super capacitor are using bidirectional DC/DC converter for their controlling. The main advantage of hybrid system lies in control of fuel cell, which is connected to the DC bus by means of boost converter. Here fuel cell only uses to charge the battery up to its maximum state of charge limit when Battery reaches its minimum State of charge level.

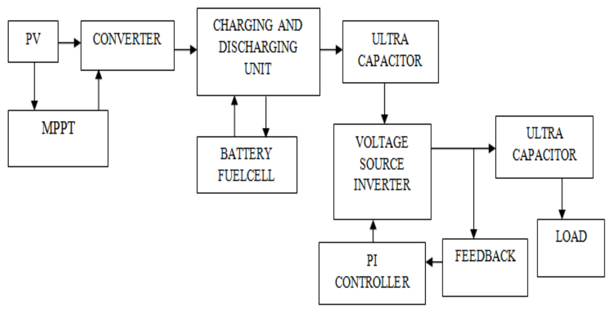

Figure 1. PV-FC-battery-SC hybrid system

The Fig. 2 illustrates the circuit schematic of the PV power subsystem. The PV panel powers the load and charges the battery through a boost converter which acts as a maximum power point tracker. A diode D1 is used to prevent the current from flowing back to the PV panel since the reverse current might damage the panel. The boost converter is driven by a PWM generator and is controlled by a digital controller.

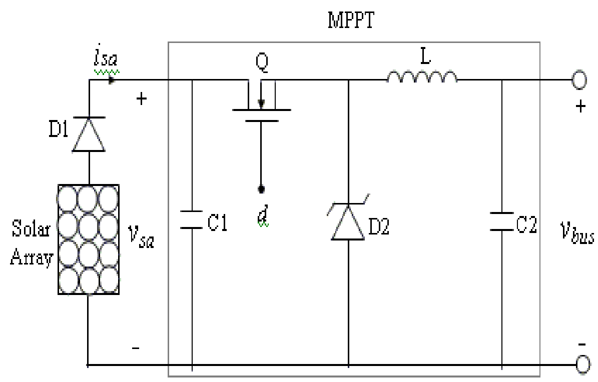

Figure 2. Circuit schematic of the photovoltaic power subsystem

A boost converter, as shown in Fig. 3, is selected to adapt the low DC voltage output from the fuel cell stack to the regulated bus voltage. The power stage of the fuel cell converter consists of a main switch S1, a Schottkey diode D1, a high frequency inductor L1, and a filtering capacitor C1. A diode D0 is used to prevent the current from flowing back to the fuel cell stack since the reverse current might damage the stack. The boost converter is driven by a PWM generator. Due to the low current operation, MOSFET switches are chosen for the boost converter. Switch S2 is a shutdown device for security purpose in case that there is a short-circuit fault in the circuit or a device failure.

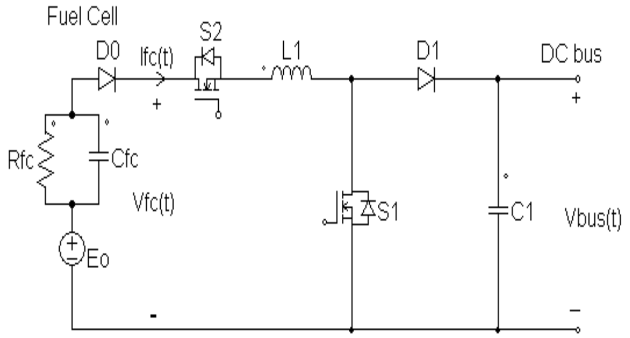

Figure 3. Circuit schematic of the fuel cell power subsystem

The battery is directly connected to the voltage bus. The power may flow through the battery in both directions. The charging current is regulated by controlling the bus voltage. This is achieved eventually by regulating the PV source and the fuel cell source.

B. Control Objectives

To make the system more reliable and efficient for various load condition, operational objectives have been decided. The energy exchange between D C bus and various sources can be established by considering following control parameters:

- ❖ Maximum power point tracking of PV power due to the intermittent nature of solar irradiance. This is the main control parameter.
- ❖ Load sharing among all the energy sources in energy management strategy.
- ❖ Charging-discharging cycle of battery. Battery is allowed to discharge up to a certain limit and then it gets charged by FC.
- ❖ Operation of SC near to its fully charged voltage being fast response auxiliary source.
- ❖ DC link voltage stabilization with safe operation of SC by limiting its charging and discharging current limit.

Based on the above objectives, the hybrid energy system has been sized and controlled to meet the load demand and charge the energy storing elements. The system has been designed in MATLAB SIMULINK and validated with the changing load condition to ensure the system reliability.

III. RESULTS AND DISCUSSION

Proposed Energy Management Strategy

The Energy Management strategy for the hybrid power system has been described by the control schemes. The control scheme is shown by block for each controller in the system. Each of the controllers has been discussed below.

A. Controller for PV

PV is the most intermittent type of source. Its output varies with varying irradiance and temperature. PV has been modeled by its circuit based model. Fig.4 describes the model of PV controller. It has two operational modes: Maximum Power point tracking and DC bus voltage control. The PV controller always works in MPPT mode if any one of the energy storage element is not at their fully charged state. If SC measured voltage (Vsc) is less than maximum SC voltage (Vscmax) or Battery measured SoC (BatSoc) in less that Battery maximum SoC limit (BatSoCmax), PV will operate in MPPT mode.

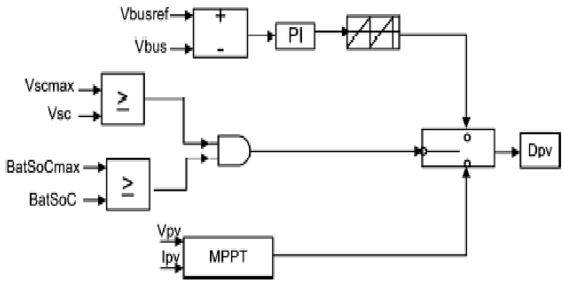

Fig. 4. Modeling of PV controller

In this paper, incremental conductance method is applied to extract maximum power from photovoltaic which operates by sensing the PV voltage (Vpv) and PV current (Ipv). The MPPT controller always regulates photovoltaic power to its maximum power (Pmpp). If more power is available it will always go to charge SC or battery. If both of the storage elements are at their maximum limit then PV converter will only control DC bus voltage. As more number of photovoltaic panel is connected in series DC/DC buck converter is used to control photovoltaic current. In this configuration 9 modules in 3 strings (each string with 3 modules in series) are connected to the DC bus.

B. Controller for SC

SC has been chosen to deliver or absorb transient power during sudden load changes due to fast charging/discharging cycle, good efficiency and long lifetime. In literature, many different models for SC have been proposed. It is composed of three ideal circuit elements: equivalent series resistance (ESR), a parallel resistor (Rp) which is modeled for the leakage current found in all capacitors and an ideal Capacitor (Csc). SCs are connected to DC link by means of a two quadrant DC-DC Converter. This converter is driven by the complementary pulses applied to two switches S2 and S3. This converter is operating in three modes: off, charging mode and discharging mode. The SC current can be positive or negative depending on its charging or discharging state. In this paper, at the time of discharging, SC current is considered to be positive and at the time of charging, it is negative.

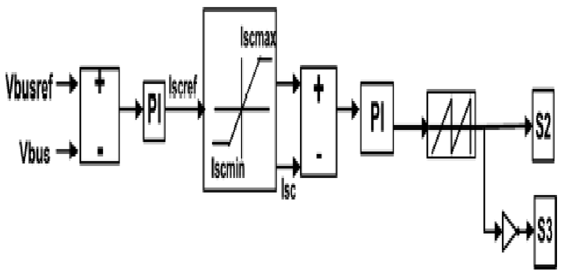

Fig. 5. Modeling of SC Controller

Fig.5 depicts the control scheme of the SC converter. Here, SC converter is controlled by two cascaded PI controllers consists of outer voltage control by means of inner current control. DC bus voltage (Vbus) is sensed and compared with the DC bus voltage reference (Vbusref) to produce the error. This error is minimized by the PI controller and SC current reference (Iscref) is produced. This Iscref must be limited to maximum allowable charging discharging currents [Iscmax, Iscmin] by means of SC current regulation function. In this study, current limits have been calculated by means of Equ. (1) and (2). It is compared with the actual SC current (Isc) and again the error is tuned and producing the complimentary pulses to drive the switches S2and S3.

$$Iscmin=-Iscrated\times(1, (Vscmax-Vsc)/\Delta v) \quad (1)$$

$$Iscmax=Iscrated\times(1,(Vsc-Vscmin)/\Delta v) \quad (2)$$

Where, Iscmin and Iscmax are SC discharging and charging current limits respectively.

C. Controller for Battery

The Battery bank serves as the primary and long term energy storage option in this hybrid system. It helps to smoothen out the fluctuating PV power by storing the excess PV power and by discharging when PV is not available. In this paper, the main objective of the battery is to keep the SC always charged to its maximum voltage (Vscmax). Since battery is having slower dynamics compared to SC due to its lower energy density, it is supplying the steady state load and SC supplies the transient load.

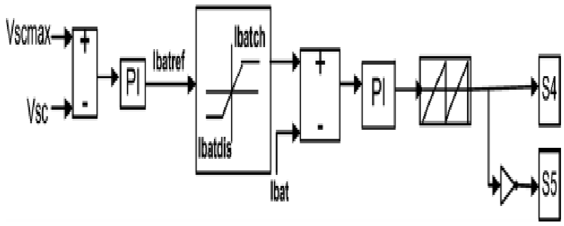

Fig. 6. Modeling of battery controller

Battery is also driven by bidirectional DC/DC converter like SC converter. As shown in Fig.6, it senses SC voltage (Vsc) and it is compared with the SC voltage reference (Vscref). This error is tuned by the PI controller and produce Battery current reference (Ibatref). This reference value can be positive or negative depending on the charging or discharging state of the SC. For the safety reason, Battery charging and discharging current rating [Ibatch,Ibatdis] is limited by battery current regulation function. The battery current (Ibat) will track this reference value and generate complementary pulses S4 and S5 for battery converter. These current ratings have been decided by battery charging rate.

D. Controller for FC

FC gives direct current at low voltage. Therefore DC/DC boost converter is connected to FC. Due to higher running cost of FC, a new control strategy has been proposed with FC to save fuel. Simultaneous operation of all energy sources will cause high system running cost. So a new control strategy has been employed by controlling the FC running period.

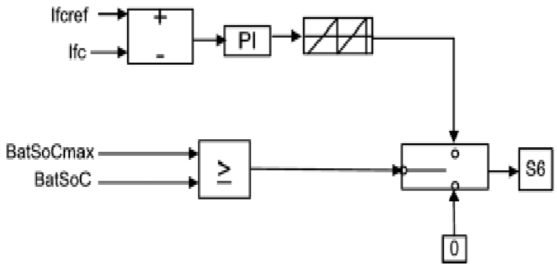

Figure 7. Modeling of FC controller

Fig.7 shows that a relay decides the ON and OFF state of FC and if Battery SoC (BatSoC) is lower than minimum allowable SoC limit of Battery (BatSoCmin), FC current (Ifc) will be regulated to its reference value (Ifcref) and if it is more than maximum SoC limit of Battery (BatSoCmax), FC current will be zero. These control parameters can be chosen depending on system requirement and load demand. A current based MPPT technique is applied here to maintain the FC current to its maximum value (Ifcmax).

IV. CONCLUSION

This work presents an optimal energy management control strategy of photovoltaic - fuel cell – battery - super capacitor hybrid system using proton exchange membrane fuel cell as auxiliary power source which will operate only for a small period. In fuel cell, fuel cost is much higher compare to other sources running cost, it contributes a large amount in system cost value. Only by reducing the use, the size and the annualized cost of fuel cell system can be reduced. This criterion has been considered in the proposed energy management strategy. The simulation results show the reliability of power supply and reduced fuel usage. This control strategy can be extended to any type of DC load pattern. The simulation results shows that classical proportional integral controller based control strategy for hybrid system not only supplies the load, but also keep battery and super capacitor almost fully charged and reduces fuel cell usage by reducing fuel cell running period.

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