Vol. 5, Issue. 8, 2018, ISSN 2349-0780

Control of Solar Photovoltaic – Fuel Cell – Super Capacitor – Battery Hybrid System

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Abstract : This paper presents a hybrid system comprise of photovoltaic (PV), Battery, Ultra capacitor (UC), Fuel Cell (FC) to meet isolated DC load demand. The PV is the primary energy source , fuel cell is the auxiliary power source whereas battery and super capacitor both are considered for their different power density to supply transient and steady load respectively. Fuel cells are an attractive option because of high efficiency, modularity and fuel flexibility; however, one main weak point is their slow dynamics. 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 full charged. The battery sources are connected to DC bus by DC – DC converters. A power flow control strategy adapts their variable DC voltage to bus voltage by means of these converters. In this work, Fuel cells 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 hybrid power system is described, and control strategies for power management of the hybrid power systems are discussed. The proposed hybrid power system is then verified by numerical simulation. The whole energy management principle has been validated in MATLAB/SIMUNIK with variable load demand and solar radiation profile.

Index Terms: Battery, fuel cells, Four leg voltage source converter, MPPT, Photovoltaic cells, Hybrid system, Ultra capacitor, ,.

I.INTRODUCTION

At present the power demand is mainly met by the energy from conventional fossil fuels which will be depleted after few years. There is the necessity to conserve the fossil fuel resources for further uses because of increasing energy demand. Due to increased green house gas emissions from the power plants and industries that make use of fossil fuels, the climatic conditions are worsened. This necessitates the use of renewable or alternative energy sources to meet the increasing power demand which are known to cause less pollution. Photovoltaic (PV) cells are semiconductor p-n junction devices produce DC power directly using energy from sunlight. The PV power system operates without noise and requires no maintenance as compared to other renewable energy resources. Since the solar irradiation on earth is intermittent, hybridizing PV systems with other source is necessary to provide continuous and reliable supply of electricity. Fuel cells (FC) supply constant DC power by converting chemical energy to electrical energy. Wind energy has complementary profiles with solar energy but it can be effectively extracted only in the regions where enough wind is available and its installation cost is high. Battery as a storage device is less reliable if used with the solar energy systems. Hence the fuel cell is the alternative source for backup when the standalone residential loads are considered. As long as the fuel (hydrogen and oxygen) is available, fuel cells keeps generating DC electricity with an efficiency of about 60%.

A stand alone system consisting of fuel cells the major energy source and super capacitor as the storage device. The DC-DC converters are not used at the source side in this proposed system. The voltage and phase angle control strategy is used to control the inverter operation.

The super capacitor bank can successfully compensate for load and source side variations and transients as it has a high power density. The load tracking was done using sensors and fuel rate control within the fuel cell model. In this project, the photovoltaic array and fuel cell system were hybridized along with the super capacitor to provide continuous power supply. The comparison made between the different types of fuel cells shows that the proton exchange membrane fule cell (PEMFC) is appropriate for standalone applications and power levels considered. A complex control structure of the same hybrid system is proposed in which additional power was stored in ultra capacitor and hydrogen electrolyzer and excess power is given to variable dump load.

Many researchers have compared the maximum power point tracking (MPPT) techniques for photovoltaic systems and found that incremental conductance algorithm is accurate and efficient. The inverter output voltage consists of harmonics. The filters are necessary to achieve a sinusoidal output voltage. In a standalone system when the load power suddenly changes, the voltage at the source falls and frequency will be distributed. Hence a control strategy ha to be developed to regulate voltage and frequency of the system so as to maintain the system stable and safe. The different techniques are reported to manage the power in a hybrid system. In this work, the hybrid system uses PV array and fuel cell along with super capacitor bank to supply or absorb load transients. In this isolated hybrid system, the super capacitor bank is directly connected to DC bus. This work aims to develop simpler control strategies for power management as compared to the existing literatures. The control system comprises of MPPT controller of PV system, controller for fuel cell system for power management and inverter controller to regulate voltage and frequency. Many researchers have focused their study on control of hybrid system of photovoltaic-super capacitor-battery based hybrid energy system to supply hybrid vehicles type load. They have implemented flatness based control strategy and classical PI controller based control to study photovoltaic-fuel cell- super capacitor hybrid energy system respectively.

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 establishments etc.

Battery and super capacitor both as the storage device make the system able to supply all type of loading conditions. Whereas photovoltaic and fuel cell, being the main sources try to keep the storage devices 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. 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 cells are used as the primary and auxiliary sources respectively while battery and super capacitor are 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 DC bus voltage stabilization. Both battery and

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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.

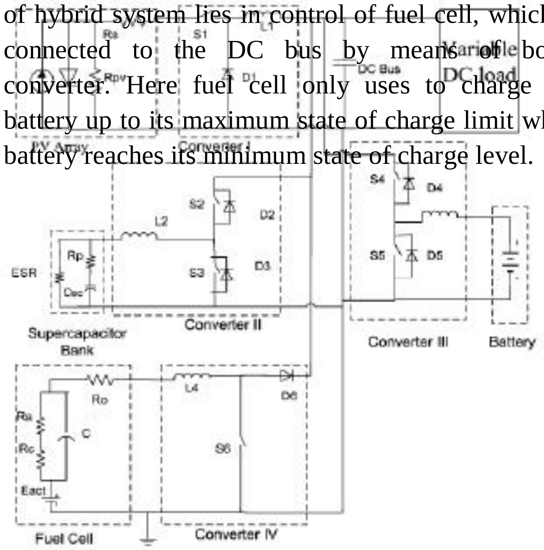

Fig.1. Structure of PV-FC-Battery-SC-hybrid system

III.CONTROL OBJECTIVES

To make the system more reliable and efficient for various load condition, operational objectives have been decided. The energy exchange between DC bus and various sources can be established by considering following 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-dicharging cycle of battery. Battery is allowed to discharge upto 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 SIMUKINK and validated with the changing load condition to ensure the system reliability.

IV.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 the system. Each of the controllers has been discussed below.

A. Controller of Photovoltaic

Photovoltaic is the most intermittent type of source. Its output varies with varying irradiance and temperature. Photovoltaic has been modeled by its circuit based model. Fig.2 describes the model of photovoltaic controller. It has two operational modes : Maximum power point tracking , DC bus voltage control. The photovoltaic controllers always works in maximum power point tracking mode if any one of the energy storage element is not at their fully charged state. If super capacitor measured voltage (Vsc) is less than maximum super capacitor voltage (Vscmax) or battery Measured state of charge (BatSoc) in less that battery maximum state of charge limit (BatSoCmax), photovoltaic will operate in maximum power point tracking mode. In this paper, incremental conductance method is applied to extract.Maximum power from photovoltaic which operates by sensing the photovoltaic voltage (Vpv) and photovoltaic 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 super capacitor or battery.

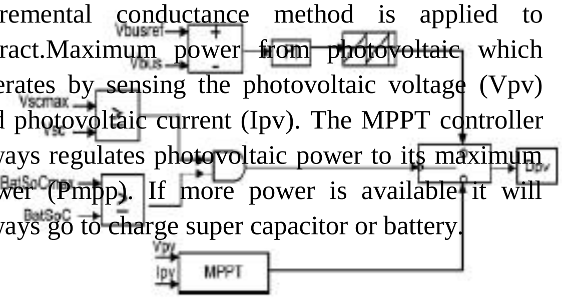

Fig.2. Modeling of photovoltaic controller

If both of the storage elements are at their maximum limit then photovoltaic 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 of super capacitor

Super capacitor 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 super capacitor have been proposed. It is composed of three ideal circuit elements : equivalent series resistance (ESR), a parallel resistor (Rp) which I modeled for the leakage current found in all capacitors and an ideal capacitor (Csc). Super capacitors 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 super capacitor current can be positive or negative depending on its charging or discharging state. In this paper, at the time of discharging, super capacitor current is considered to be positive and at the time of charging, it is negative.

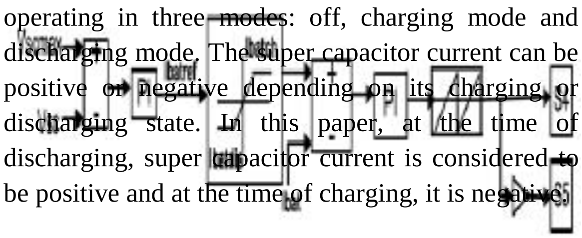

Fig.3.Modelleing of super capacitor controller.

Fig.3 depicts the control schemes of the super capacitor converter. Here, super capacitor converter us controlled by two cascaded proportional integral 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 proportional integral controller and super capacitor current reference (Iscref) is produced. This iscref must be limited to maximum allowable charging discharging currents [iscmax,iscmin] by means of super capacitor current regulation function. In this study, current limits have been calculated by means of Equ. (1) and (2). It is compared with the actual super capacitor current)isc) and again the error is tuned and producing tht complimentary pulses to drive the switches S2 and S3.

Iscmin=iscratedx(1,(vscmax-vsc)/ v)(1)

Iscmax=iscratedx(1,(vsc-vscmin)/ v)(2)

Where, iscmin and iscmax are super capacitor discharging and changing current limits respectively.

C.Control 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 photovoltaic power by storing the excess photovoltaic power and by discharging when photovoltaic is not available. In this paper, the main objective of the battery is to keep the super capacitor always charged to its maximum voltage (Vscmax). Since battery is having slower dynamics compared to super capacitor due to its lower energy density, it is supplying the steady state load and super capacitor supplies the transient load.

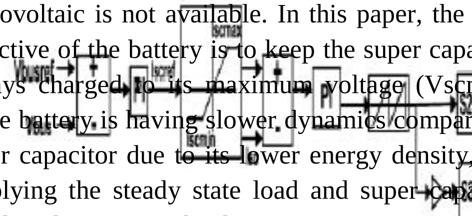

Fig.4. Modeling of battery controller

Battery is also driven by bidirectional DC/DC converter like super capacitor converter. As shown in Fig.4, it senses super capacitor voltage (Vsc) and it is compared with the super capacitor 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. Tha battery current (ibat) will track this reference value and generate complimentary pulses S4 and S5 for battery converter. These current rating have been decided by battery charging rate.

D. Controller of fuel cell

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

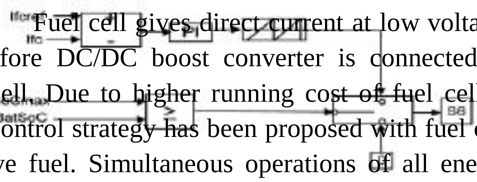

Fig.5. Modeling of fuel cell controller

Fig.5. shows that a relay decides the ON and OFF state of fuel cell and if battery state of charge (BatsSoc) is lower than minimum allowable state of charge limit of battery (BatSoCmin), fuel cell current (ifc) will be regulated to its reference value (ifref) and if it is more than the maximum state of charge limit of battery (batSoCmax), fuel cell current will be zero. These control parameter scan be chosen depending on system requirement and load demand. A current based maximum power point tracking technique is applied here to maintain the fuel cell current to its maximum value (ifcmax).

V. 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 a auxiliary power source which will operate only for a small period. In fuel cell, fuel cost is much higher compared 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 result 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 perio**d.**

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