Load Sharing In A Hybrid Power System With Renewable Energy Sources

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Abstract- In this paper PV, PEM fuel cell and battery are hybridized together to share the load in a power system. The PV converts solar energy directly into electrical power. The hybrid system draws maximum power from the PV panel with the help of MPPT algorithm. The fuel cell converts hydrogen directly into electrical energy plus heat energy through electro-chemical reaction. The fuel cell is used to overcome the intermittent output of PV. A 48V Li-ion battery, storage device is used to fulfill the temporary peak demand which the PV and fuel cell can't meet. The battery increases the response of the system. The output power from the sources are fed to the three phase induction motor through inverter. The output voltage become constant with the help of the PI controller.

Keywords- Hybrid, Fuel cell, Photovoltaic, Battery, MPPT, PI controller, Inverter.

I. INTRODUCTION

Depletion of conventional energy sources and the environmental pollution created by them become great problem to the world. Abundance of renewable energy have motivated immense interest towards alternative energy sources [1]. Solar (photovoltaic) energy is a major renewable energy source at the forefront of stand-alone and distributed power systems. Photovoltaic (PV) power systems are, however, dependent on climatic conditions making them an intermittent power source. Their output varies with the amount of solar radiation available and ambient temperature. Therefore, the generated power depends on the time of year, time of day and the amount of clouds. A stand-alone PV-based power system needs, therefore to be hybridized with either other complementary energy sources or-storages to ensure a reliable power supply.

Use of fuel cells (FC) in combination with a PV generator may ensure an uninterruptible power supply as long as the fuel cell power can meet the power deficit. Fuel cells show a particular promise as they can operate on hydrogen with zero emissions, have a relative high efficiency (30-60%), and have a limited number of moving parts with a flexible modular structure [1],[7]. The fuel cell can either be supplied with hydrogen from purchased gas containers or be produced from water in an electrolyzer which is supplied with surplus power from the PV system. In fuel cells, the power and energy is decoupled, which is opposite to when secondary batteries are used as energy storage. In this paper the case with fuel cell supplied from a hydrogen container is considered.

One problem with the fuel cell is its relative slow dynamics caused by the time constant of the hydrogen and gas supply systems that can be in the order of several seconds [8]. If a fuel cell was connected to a step increase in load, it would provide tin he current, but the voltage could instantaneously drop off the V-I curve and the fuel cell would take several seconds until it begins feeding the required power. In the mean time the fuel cell may be starved of fuel which is not good for the electro catalyst shortening its life [9]. Therefore, the fuel cell should be operated under controlled dynamic regimes, ensuring an optimum performance and durability of the fuel cell.

Batteries respond faster than a fuel cell for a fast step increase or decrease in power demand. Thus using these energy storage(s) together with fuel cells improves performance and fuel cell life by absorbing faster load changes and reventing fuel starvation of the fuel cell. Adding this storages will enable the hybrid system to follow fast changing loads while allowing the fuel cell to respond at a slower rate. In addition, by sizing the battery to supply the peaking load in surplus of what can be met by the fuel cell and PV, the fuel cell can be sized only for the base (average) load. This avoids over sizing of the fuel cell as long as the battery swing can cover the deficit peaking load duration increasing the peak power capability of the system[10].

The hybrid power system proposed in this paper can be an option for remote applications away from utility AC mains. One such application is remote telecommunication systems. Most of the hybrid power systems in use today for remote applications have a diesel genset as an important component. Using fuel cells instead of the traditional diesel generator as back up for reliability of power availability has advantages. In addition to being environmental friendly, fuel cells require much less maintenance as opposed to diesel engines which would require regular maintenance which is very expensive at a remote site.

II. PROPOSED HYBRID POWER SYSTEM

The generator is coupled to the DC bus via boost based DC/DC converter. The PV generator uses MPPT for maximum possible power output for given temperature, irradiance and loading condition. This helps us to use the solar energy to the maximum level. The main disadvantage of the PV is that it is not possible to get the power at night time. Therefore it should be hybridized with other sources which should be environment friendly.

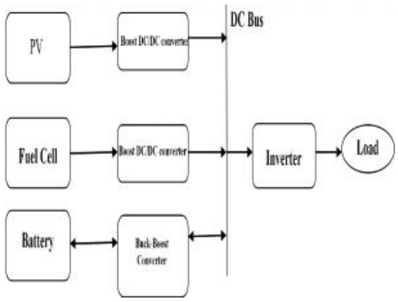

Fig. 1. Architecture of proposed hybrid power system

The PEM Fuel cell has been considered as a promising kind of source during the last 15years because of it's low working temperature, excellent load following capability, compactness, easy and safe operational mode. The PEM fuel cell is boosted to the DC bus level via dc-dc boost converter. The response of both the PV and FC are very slow, to increase the system response to meet the sudden increase in load lithium ion battery is used. The battery is connected to the dc bus via buck-boost converter. At the time of charging it acts as buck converter and at the time of discharging it acts as boost converter.

III. MAXIMUM POWER POINT OPERATION OF PV PANEL

The variations of the output current and output power of a PV panel as functions of the output voltage for a given light level are shown in Fig. 2. The I-V characteristic of a PV panel is given by

$$I = Isc - Isat\,[\exp(\alpha V) - 1] \ldots\ldots\ldots\ldots\ldots\ldots (1)$$

where α = q/(AKT). The parameters *α* and *Isat* can be determined from manufacturer's data. As the light level varies, the maximum power and the operating point for maximum power vary. One has to operate the PV panel at Q in order to get the maximum power from the PV panel and this makes the control difficult. There are several methods available for maximum power point tracking (MPPT) and most of them use microprocessors or DSPs [3], [4]. A simple method for tracking the maximum power point (MPP) has recently been proposed [2]. The MPP tracking is done by measuring the short-circuit current Isc and adjusting the actual load current to be equal to a desired fraction Ko (≈ 0.9) of Isc. The MPPT is integrated into the buck converter that is used to step down the PV panel voltage to a lower dc level.

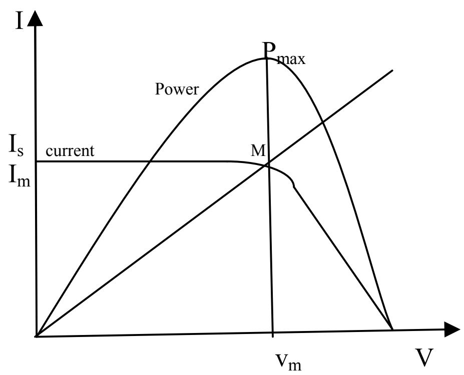

Fig. 2 Characteristics of a PV panel

IV. PEM FUEL CELL AS A POWER SOURCE

The fuel cell can supply electrical power continuously as long as hydrogen is supplied. Thus it can supply power to critical loads or supplement other renewable power sources. The volt-ampere characteristic of a single fuel cell is shown in Fig. 3. The fuel cell has three operating regions, namely, activation polarization, ohmic polarization, and concentration polarization.

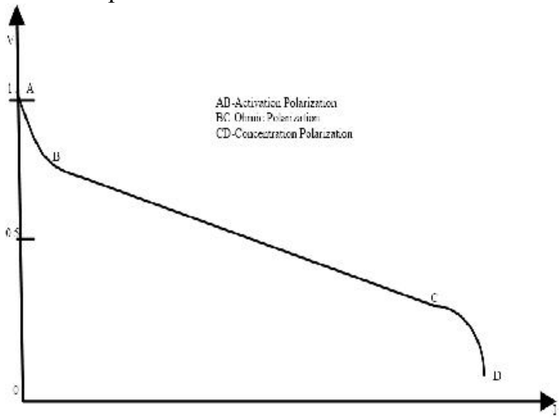

Fig. 3 V-I characteristic of a unit fuel cell

The activation polarization can be considered as the no load region where there is a large voltage drop for a small increase in the output current. In the ohmic polarization region where the fuel cell will normally concentration polarization can be considered as the overload region which is encountered when the output current is very high. In a commercial fuel-cell module, the fuel-cell electronics prevents the fuel cell from operating in the concentration (over load) region. A commercial fuel cell module comprises of several unit cells connected in series to provide a high dc voltage. The PEM fuel cell is normally operated in the ohmic polarization region to supply a desired amount of power. It has a shunt characteristic which allows a higher output current (power) at a slightly reduced output voltage. The reduction in the output voltage is not a problem since it can be stepped up to a desired level using a boost converter. A simple circuit model for the PEM fuel cell is available [8] and it can be used for the design of fuel cell based converters.

V. LOAD SHARING IN THE HYBRID POWER SYSTEM

The block diagram of the hybrid power system with the PV panel, the PEM fuel cell and the battery is shown in fig. 1. The main objective of the hybrid power system is to share the load, maximum from the PV panel and the rest is from the fuel cell and battery.

The PV converts sunlight directly into electrical energy. The control of the PV panel is such at any light condition it should draw the maximum power. This can be achieved by the maximum power point tracking algorithm (MPPT).The PV panel is connected in series and parallel combination of the solar cell to give a constant output voltage. The output voltage from the PV panel is stepped up to the lower voltage through the boost converter consists of transistor, diode and inductor. The ripple in the output voltage is reduced by using the filter capacitor C_f. The current I_{PV} supplied by the PV panel is measured by the voltage drop across the resister connected before the converter components. The feedback loop from the MPPT control the output power of the PV panel. The output voltage is given by

$$V_{mp}=1/\alpha \ln [(I_{sc}- I_{pv}+ I_{sat}) /_{sat}] \ldots\ldots\ldots\ldots\ldots\ldots(2)$$

$$P_{max} = V_{mp} \times I_{pv}$$
$$= V_{mp} \times K_0 I_{sc}$$
$$K_0 = 0.92$$

$$P_{pv\,max} = 0.92\, I_{sc} / \ln [(I_{sc} - I_{pv} + I_{sat}) / I_{sat} \ldots\ldots(3)$$

If the total power demand on the hybrid power system is P_0, then the fuel cell has to supply

$$(P_0 - P_{pvmax}- P_b) / n_f$$

Where n_f is the efficiency of the fuel cell converter. The fuel cell converts hydrogen directly into electrical energy plus heat energy. The flow rate regulator in the fuel cell is used to control the flow of hydrogen. The output voltage of the fuel cell stack is given by

$$E_{fc}= \{1.229 + (T-298)(-44.43/zf) + (RT/zf) \ln(P_{H2}P_{O2})\},\ T\le 100^0 C$$

$$= \{1.229 + (T-298)(-44.43/zf) + (RT/zf)\ln(P_{H2}P_{O2}^{0.5}/P_{H2O})\},\ T>100^0 C \ldots\ldots\ldots(4)$$

The output voltage of the combined power system is maintained at desired level by using the feedback loop which adjusts the duty cycle of the fuel cell converter transistor. The boost converter of the fuel cell is used to step up the voltage V_0 of the dc bus. The output voltage of the hybrid system is maintained at the desired level of $V_{0\,ref}$ by using the PI controller which adjust the duty cycle of the fuel cell converter.

The battery is used to increase response of the hybrid power system during sudden increase in the load. The feedback loop from the output voltage and reference voltage of dc bus is used give a desired duty cycle to the buck-boost converter of the battery.

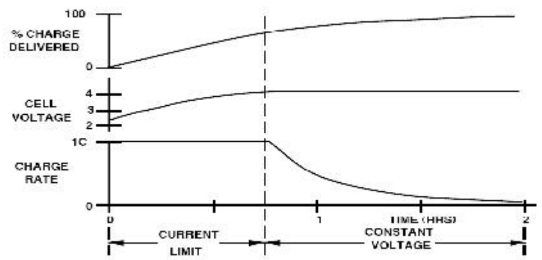

Fig. 4 Typical C-V charge profile

When the load is minimum the converter acts as buck converter and charges the battery. At the same time when the load is increased to the maximum level the voltage in the dc bus reduced. By adjusting the duty cycle the converter act as a boost converter and it supplies the required voltage level to the dc bus. Thus the output voltage will be adjusted.

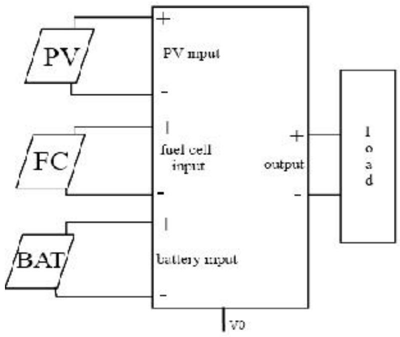

Fig. 5 Proposed Hybrid System

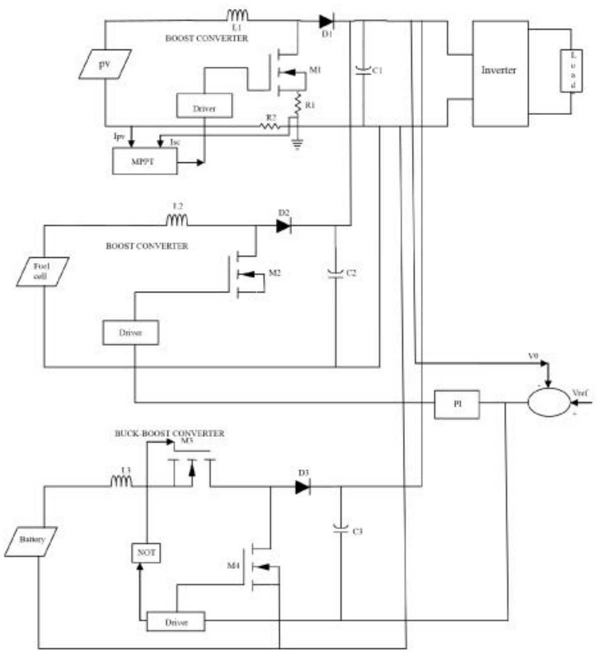

Fig. 6 Block diagram of a Hybrid Power System

VI. DESIGN OF CONVERTER COMPONENTS

The hybrid system uses a two boost converter, a buck-boost converter and a PI controller. The boost converter for the fuel cell is designed for continuous inductor current without any constraints. At t=0s, the DC/DC converter applies $100V_{dc}$ to the load. The boost converter for the PV panel has to be designed by taking MPPT function into the account. The amplitude of the pulse generator is 5 and the time delay is 1µs and the pulse width is 50% of the period. The current through the transistor is given by

$$I=V_0/R_{eq}(1-e^{(-R_{eq}t)/L}) \ldots\ldots\ldots\ldots\ldots\ldots(5)$$

Where V_0 is the output voltage of the converter and R_{eq} is the total resistance in the shorting path. The maximum value of the buck inductor is given by

$$L_{max} = R_{eq}\, t_d /(1-I_{max}\, R_{eq}/V_0) \ldots\ldots\ldots\ldots(6)$$

As far as PI controller, the selection of the time constant can be choosen to be in the order of 1ms to 10ms.

VII. RESULTS

The hybrid system described in the section is formed by the PV panel, the fuel cell stack and the battery. The PV panel is formed by the parallel/series combination of the solar cell to give a nominal voltage of 230A and a current of 25V. A 6KW PEM fuel cell [9] is used in conjunction with the PV panel. The nominal voltage of the fuel cell stack is 45V and the output current is around 133A. The battery used in the system is the Lithium-ion battery. The nominal voltage is 42V and the rated capacity is 11Ah. The fully charged voltage is 48.8875V and the nominal discharge current is 4.7826A. The converters are built using MOSFET with a switching frequency of 25KHZ. The output voltage of the hybrid system is chosen as 100V. The complete hybrid power system is simulated using the circuit models for the PV panel, the PEM fuel cell and the battery. The short circuit current of the PV panel depends upon the amount of sunlight and it can be chosen to give the maximum power output the MPPT algorithm described in section [2] is used in simulation. The load sharing was verified for different loading condition. The output results are obtained by keeping an output voltage of 100V.

Case 1: Three phase induction motor load-8KW

P_{PV} = 7.2 KW
P_{FC} = 1.85 KW
P_{BATT} = 0.4 KW
I_{PV} = 243 A
I_{FC} = 30.12 A
I_{BATT} = 0.03 A
I_{LOAD} = 7.2 A

Case 2: Three phase induction motor load-10KW

P_{PV} = 6.9 KW
P_{FC} = 4.01 KW
P_{BATT} = 0.5 KW
I_{PV} = 232 A
I_{FC} = 33.65 A
I_{BATT} = 0.0249 A
I_{LOAD} = 7.9 A

The load used for the system is the three phase induction motor. The output 100Vdc is converted into ac by the inverter circuit. The resistance of the IGBT is 0.0001Ω. The carrier frequency of the gate pulse of the inverter circuit is 900Hz and the sampling time is 5.14µs and the frequency of the output voltage is 60Hz. Fig. 7 shows a output current of a PV panel. At first current reaches to a maximum level. With the help of MPPT it reached to a saturated value. Fig. 8 shows a output of the fuel cell, due to flow rate regulator it reached saturated level. Fig. 9 shows the saturated output current of a battery. The stator and rotor current of the 3-phase load current is shown in Fig. 10.

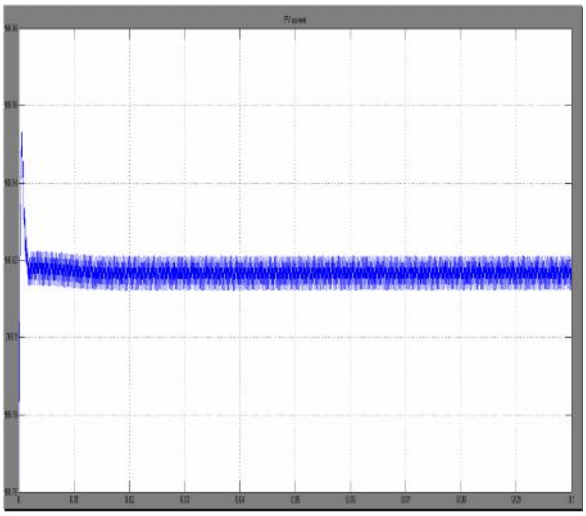

Fig. 7 PV output current

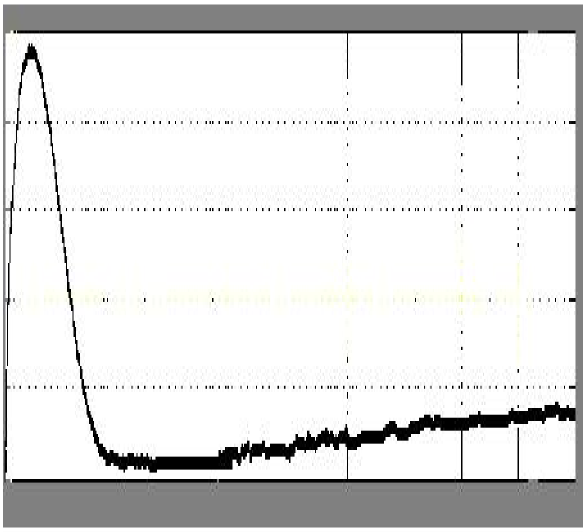

Fig. 8 Fuel Cell output current

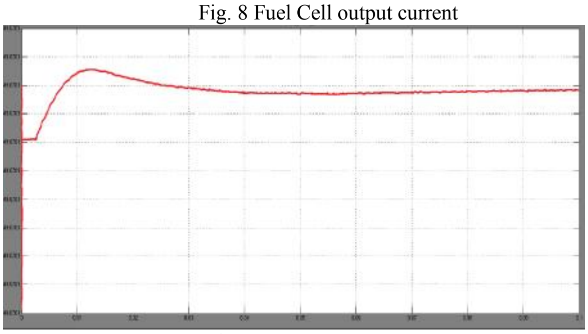

Fig. 9 Battery output current

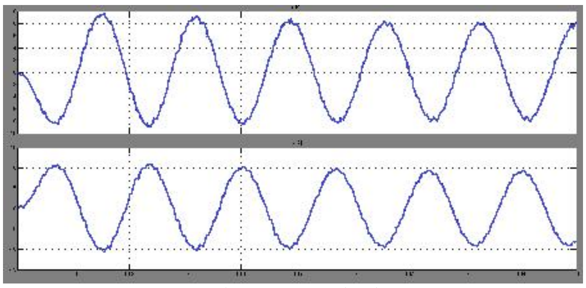

Fig. 10 Output load current

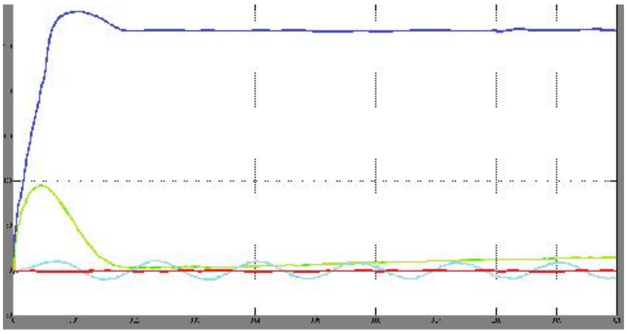

Fig. 11 Experimental results

Fig. 11 shows the load current shared by the PV, Fuel cell and Battery.

VIII. CONCLUSION

The hybrid power system with a set of a PV panel, a PEM fuel cell and a battery is described. A simple MPPT algorithm is used for tracking the maximum power from the PV panel and the remaining power for satisfying the demanded load is supplied by the fuel cell and battery. The Charging and Discharging of the battery depend upon the load condition, at light load battery charges and at the peak load condition it discharge the power to the hybrid system. This action is controlled by the PI controller. The load sharing in the hybrid system was verified from the simulation results. The simulation results are shown. Thus an effective load sharing is done by the "eco-friendly" sources.

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