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Power Management in a Standalone Solar/ Fuel cell/ Battery Hybrid Power system

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Abstract: - This paper explains the design of a standalone Solar/ Fuel cell/ Battery hybrid power system which involves the design of individual systems along with the power management circuit. The variation of solar insolation according to the time and the Maximum Power Point Tracking's (MPPT) Perturb and Observe (P&O) algorithm is considered in the design of solar system. Similarly, the control of fuel flow rate according to the load and a DC- DC converter is considered in the design of the fuel cell system. A battery charger is designed to protect the battery from the over and under charging from source and load respectively. All these power sources are controlled by the power management circuit, controlling the relays of each subsystem according to the load demand.

Keywords: - DC-DC converter, Maximum Power Point Tracking (MPPT), P&O algorithm, power management circuit, Relay, load demand.

I. INTRODUCTION

Energy crisis is increasing by the day because of tremendous increase in the energy consumption which is also leading to decay of fossil fuels and global warming. To avoid this, we need to go for an alternative energy sources like solar, wind, fuel cell, tidal etc. But each renewable energy source has its own drawbacks. For instance, solar panel has low efficiency and its power output depends on climatic conditions like insolation and temperature. Similarly, fuel cell needs pure hydrogen and its reaction kinetics on the cathode side is slow [1]. To avoid these drawbacks, instead of enhancing the energy production, we can share the load in between these power sources according to their availability [2]. So, hybrid system is the most desired and emerging solution in Renewable Energy sector to overcome the respective disadvantages of individual systems. Hybrid power system has advantages like, batteries are not deeply discharged, reserve capacity in batteries can be used for peak power demand to support inrush current to start air-conditioners etc. Since solar insolation in a day is not constant, to operate the solar panel at its maximum power point, P&O algorithm, which is most efficient MPPT technique used. P&O algorithm works by perturbing the voltage or current of the panel by comparing the power at that instant with the power of previous instant [3][4]. The power management between power sources can be done by using high power Relays and these relays ensure that if there is any source with over load or under load, then it will compensate the load by switching on the other energy source [2]. This paper explains the design aspects of a solar/ fuel cell/ battery hybrid power system for a 1kW load and a real time solar insolation by using MATLAB/ Simulink.

II. SOLAR/ FUEL CELL/ BATTERY HYBRID POWER SYSTEM

The standalone hybrid power system consists of three energy sources (solar/fuel cell/battery) which are controlled by the power management circuit. The block diagram schematic of the hybrid power system is as shown in Fig. 1.

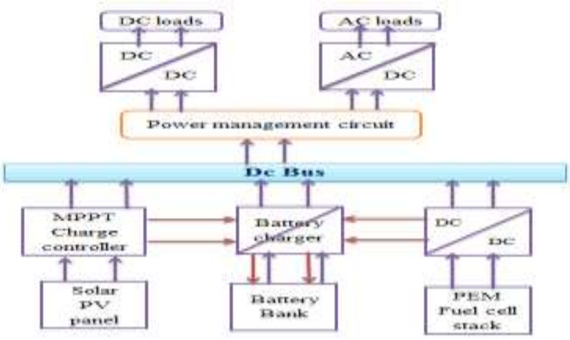

Fig.1. **Block diagram of solar/ fuel cell/ battery hybrid power system**

A. PV System Design

Solar cell is an important and basic segment of the solar system which produces the Direct Current from sun light. The equivalent circuit of the solar cell is as shown in (Fig. 2) [5].

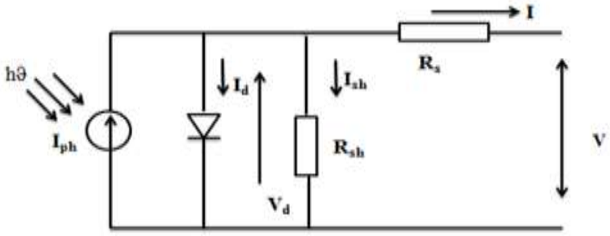

Fig.2. **Solar cell equivalent circuit**

Parameters that need to model a solar cell are the light generaed current(I_{ph}), Saturation current(I_0), series and shunt resistances(R_s, R_{sh}). The output current of the solar cell is expressed by the following equations;

$$I = I_{ph}-I_d-V/R_{sh} \quad (1)$$

$$V_d = V+IR_s \quad (2)$$

$$I_d = I_0 \{\exp(qV_d/nKT)-1\} \quad (3)$$

Where K= Boltzmann Constant = $1.38\text{x}10^{-23}$ J/K
T= operating temparature (^{0}K)
q= elementry charge= $1.602\text{x}10^{-19}$C

From the above equations, solar cell can be designed in the Simulink and required voltage and current can be produced by connecting them in series and parallel combinations. The flow chart of the P&O algorithm is as shown in Fig. 3;

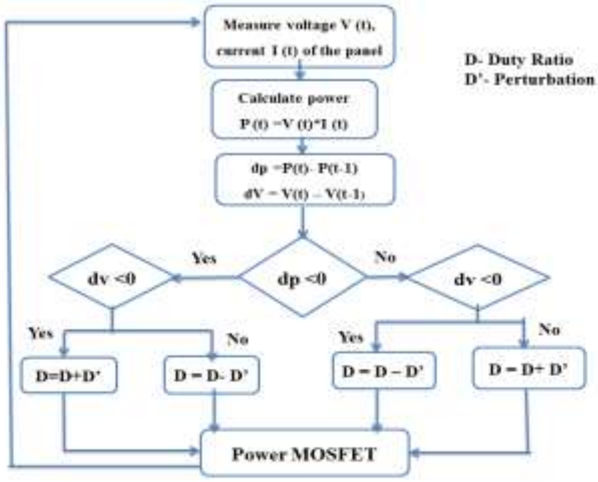

Fig.3. **P&O algorithm flow chart**

According to the duty ratio generated by MPPT, the DC-DC converter will change the voltage level and hence system will operate at its maximum power point (V_m, I_m). The schematic of the solar system Simulink model is as shown in Fig. 4.

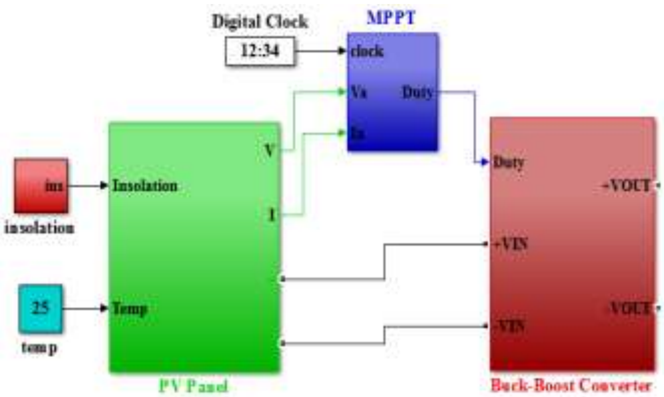

Fig.4. **Solar PV system Simulink mode**

B. Fuel Cell System Design

Fuel cell is an electrochemical energy conversion device which converts the chemical energy of hydrogen and oxygen to electricity and water. Among all the types of fuel cells, Proton Exchange Membrane (PEM) fuel cell is a very good alternative energy source because it has a short startup time and low temperature operability which is important in hybrid power system application. The basic operation of the PEM fuel cell is explained by Fig. 5[6].

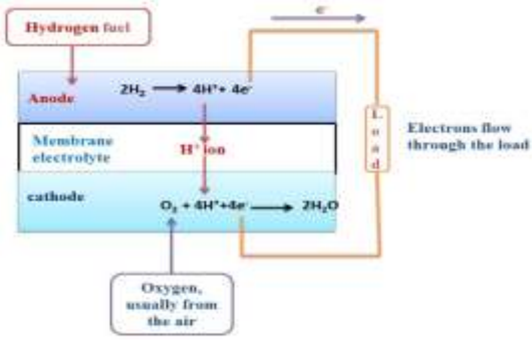

***Fig. 5*. Operation of a PEM fuel cell**

At the anode, hydrogen gets ionised and releases the electrons by creating protons (H+ ion) which are then transferred to the cathode via a proton exchange membrane. The electrons produced are passed through an external circuit and are collected at the cathode by oxygen to form water. The equations governing the operation of a PEM Fuel Cell are [6]:

At the anode;

$$2H_2 \rightarrow 4H^+ + 4e^- \quad (3)$$

At the cathode;

$$O_2 + 4H^+ + 4e^- \rightarrow 2H_2O \quad (4)$$

The design of the PEM fuel cell system in the MATLAB/ Simulink involves the design of a PEM fuel cell stack, a flow rate selector for selecting the fuel input according to the load and a DC-DC converter for changing the voltage level [7].

C. Battery System Design

The power coming from the solar PV system is not continuous and the startup time of fuel cell system is still high to provide instantaneous power. So, in order to supply power during these intermittent conditions, a storage system is needed wherein a battery bank can be a very good option. However, during charging and discharging conditions, the battery has to be protected from over voltage and under voltage which can be done by a controller. Since power flows from higher voltage level to lower voltage level, we need to increase the voltage level of the power coming from the source by using a boost converter to charge the battery. In the circuit, two switches are used to connect or disconnect the source and load respectively from the battery at the times of charging and discharging. A controller is designed to compare the voltage of the battery with its maximum and minimum voltage limits, based on which it will switch on the corresponding switch.

D. Power Management Circuit

The load can be shared among the power sources by controlling the respective relays of each subsystem. The status of each power source according to the output of relay is as shown in Table.1.

Table.1. Status of each subsystem and its relay

Relay Name	Relay Output	Status of power source
R1	0	Solar PV system OFF
	1	Solar PV system ON
R2	0	Battery system OFF
	1	Battery system ON
R3	0	Fuel Cell system OFF
	1	Fuel Cell system ON

The relays of the controlling circuit will operate according to the following algorithm as shown in Fig. 6

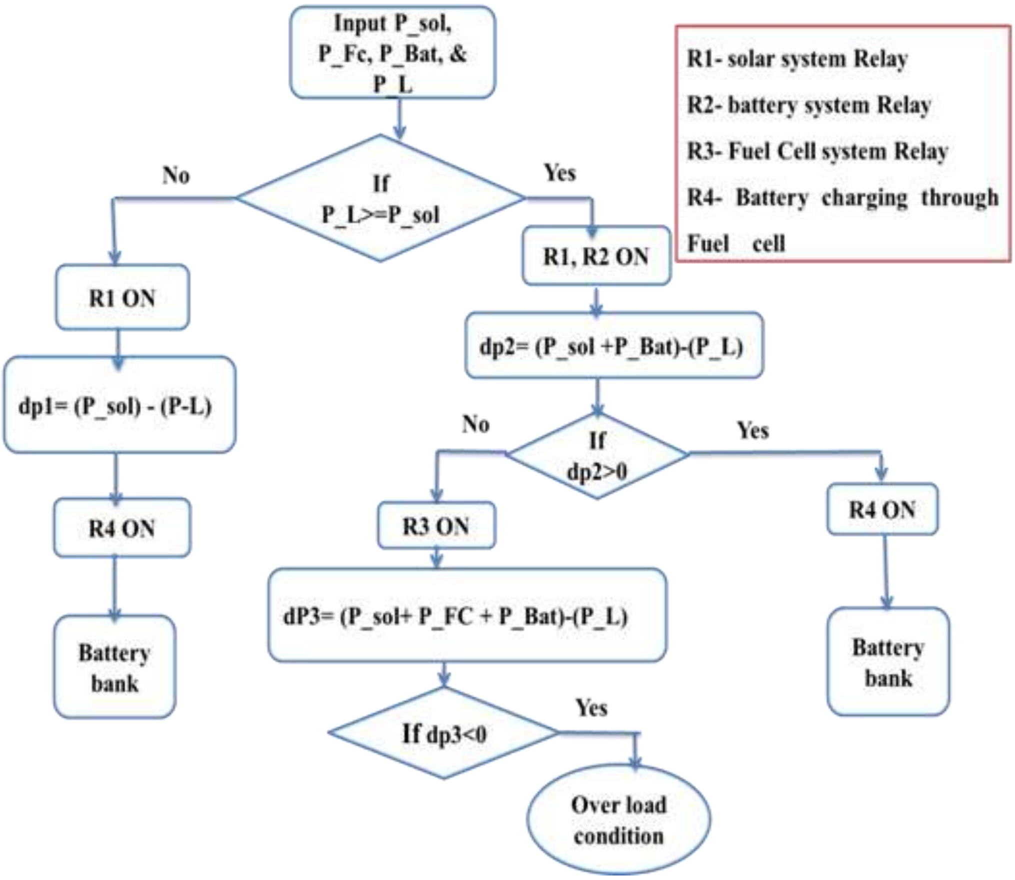

***Fig. 6*. Power Management Algorithm**

The load sharing is done by activating the respective relay of individual subsystem. For instance, if the solar system alone able to supply power to the load, then, the fuel cell system charges the battery by activating the respective relay.

III. SIMULATION RESULTS

A 1 kW hybrid power system is designed in the MATLAB/ Simulink by combining a 1 kW solar PV, 1 kW fuel cell and a 48V 100Ah lead acid battery Simulink models. A PID controller is designed according to the battery specifications (full charge voltage= 58.8V, current drawn by the load=12A) for protecting the battery. For testing the hybrid system, a 1 kW load pattern and a real time solar insolation pattern available from weather monitoring station in CSIR-CSIO is taken. This pattern is considered for a day and it is normalized to 24 seconds for simulation purpose. The insolation is attined its maximum insolation of 1000W/ m^2 during afternoon time. The insolation pattern considered in and the output of the solar PV system while supplying the load are as shown in Fig.7.a and Fig.7.b.

For observing the change in voltage and current, fuel input to the PEM stack is changed which leads the voltage to be reduced and current to be increased. The voltage and current of the stack are as shown in Fig.8. Similarly, when the solar PV system is not able to meet the load, then Battery system will supply the load. As the time progresses, the voltage of the battery will decrease as the load is drawing current continuously. The current drawn and voltage of the battery are as shown in Fig.9. For a 1kW load pattern the load sharing between the power sources and status of each relays are as shown in Fig.10.

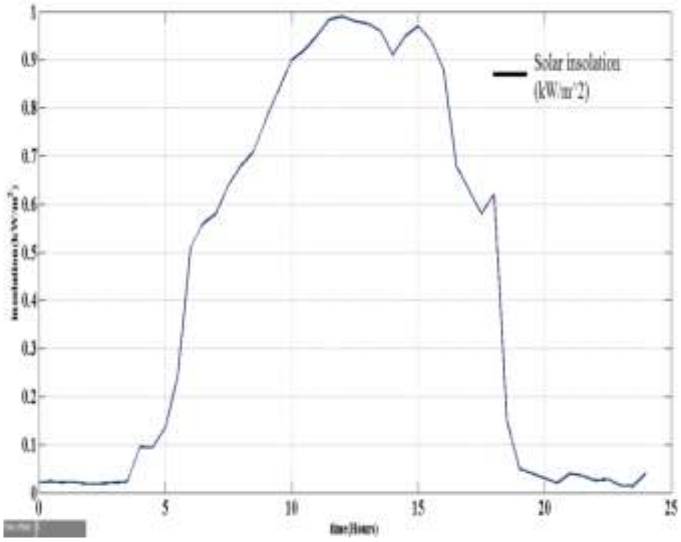

Fig.7. **a. Solar insolation (kW/m^2,**

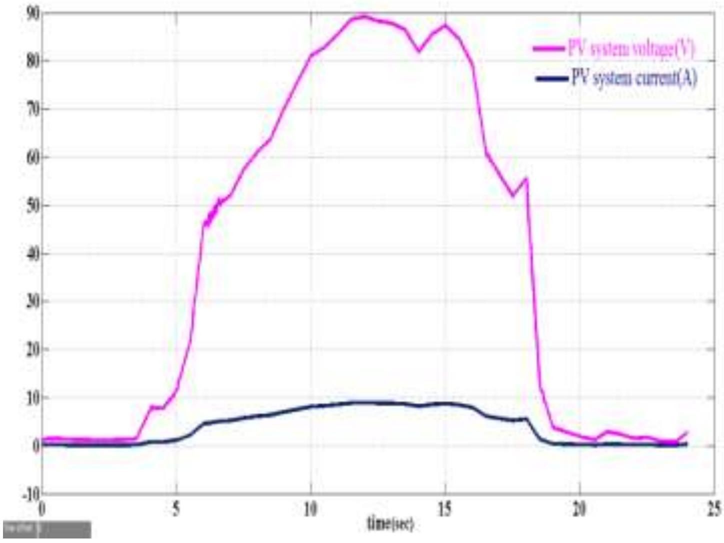

Fig.7.b. **Solar PV system output voltage, current curves**

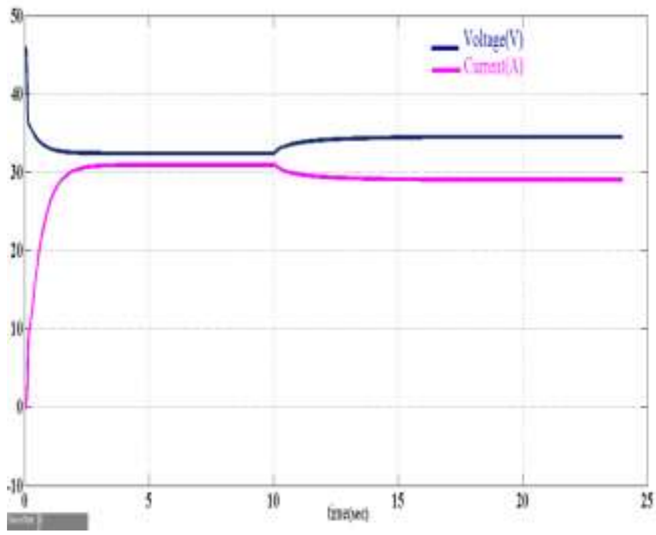

Fig.8. **PEM Fuel cell stack output voltage, current curves**

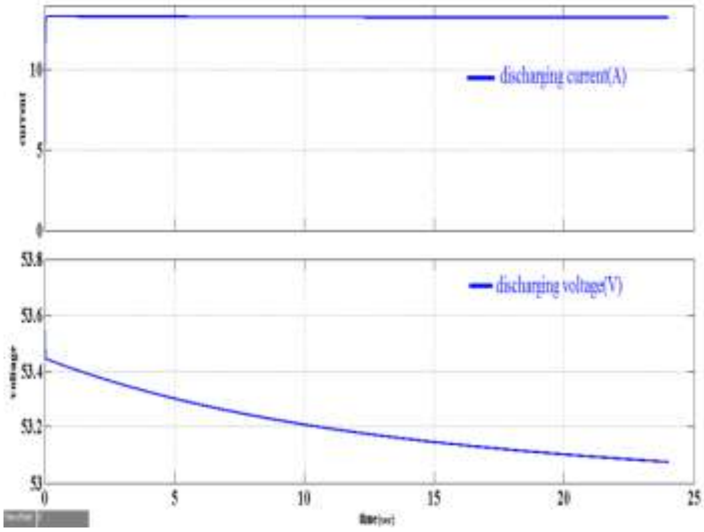

Fig.9. **Battery discharging voltage, current curves**

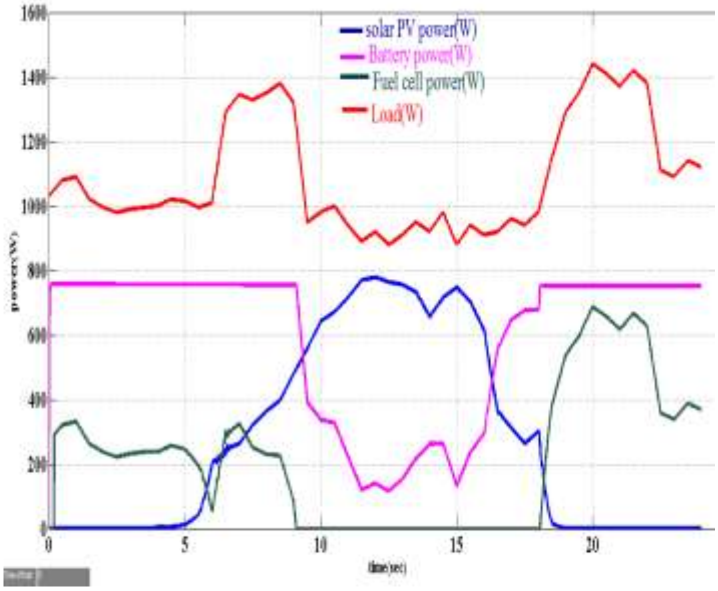

***Fig. 10.a*. Load sharing between the sources according to the load**

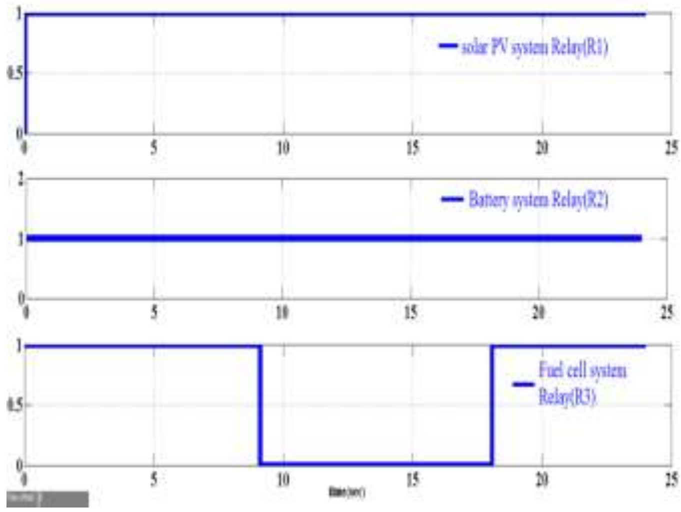

Fig.10.b. **Status of each sub system Relay**

III. CONCLUSION

Since the fuel cell dynamics is slow, the battery is supplying the power as a secondary source. This simulation is useful for testing the solar/ fuel cell/ battery hybrid power system in real time and it will give the performance of a solar PV system for the real time solar insolation. From the simulation, we can conclude that battery is responding quickly for the sudden variations in load and fuel cell is used to supply the load slowly with steady state.

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