Hybrid PV Solar, PEM Fuel Cell and Battery with Active Power Management for Electric Vehicles.

Premananda Pany

Abstract: ***Hybridization of Different electrical sources helps to enhance the overall performance of electric vehicles. Due to the advantages of hybridization of power sources, in this work three energy sources such as Fuel cell (FC), Battery and solar have been considered to supply power adequately to electric vehicles. This paper focuses on power management of these three energy sources during vehicle driving. Because of their different characteristic, power sharing at different time and condition is different and the proposed control strategy demonstrates the active power sharing of the three energy sources. The feasibility of the proposed system is verified through computer simulation using matlab/simulink software. The demonstration of simulation results shows the performance of electric drive system is more satisfactory over the entire drive operation, fulfilling the power management rules and load requirement.***

Keywords: Solar PV cells, Fuel Cell, Battery, Power management, EV.

I. INTRODUCTION

With growing demand for electric vehicle(EVs)s on road, different types of electric cars are being designed by different manufacturers .on the available electric vehicles some of them are only Battery Based EVs (BBEV) and some are hybrid electric vehicle (HEV) consist of renewable sources and energy storage system (ESS). The hybrid power sources which might be a combination of Photo voltaic/ battery or, FC/ battery or arrangement of PV solar/FC/battery presents more advantages such as clean energy, environmental-friendly with high power quality. By considering fuel cell as alternative energy source, among the various FC, proton exchange membrane fuel cell (PEMFC) has high prospective to use as a primary energy source in vehicles due to effectively zero CO_2 and other harmful emissions, high efficiency and can be operated fairly at low temperature [1]. But the possibility of increasing reliability as well as the efficiency can be achieved by combining FC with PV system for better solution [2]. However, fuel cell systems have the drawback of sluggish dynamic behavior. In dynamic system, abrupt increase in load demand leads to drop in stack output voltage of FC, worsening the power quality and occasionally might cause serious problems in the system [3]-[4]. Therefore, to overcome this problem an energy storage system of adequate energy is required which makes the system more stable and efficient. Now a day Li-ion batteries are widely being utilized in application requires high-power [5]-[6]. At present work, a Li-ion battery module has been used as an energy storage device constitutes hybrid power source fed electric drive for application in EVs.

As this hybrid system consists of battery to store the excess energy and PV solar energy and integrated with FC to supply the load depending on driving conditions, an appropriate effective control system is required. Since most advance electric vehicles like FC EV have more supportive energy sources as part of propulsion system, it is feasible and essential to use most suitable control technology to optimize the fuel economically [7]-[8]. In this hybrid system, an active power sharing control scheme is implemented and simulation results are presented in section IV.

II. SYSTEM CONFIGURATION AND DYNAMIC MODELING OF PV, BATTERY AND FC SYSTEM

Dynamic equations of photo voltaic system, lithium ion battery and PEM fuel cell are required to study their behavior in steady state and transient state which are ultimately used in simulation models. Each components of the hybrid electric drive system has been mathematically modeled and are presented in this section which is described below. Fig.1 shows the hybrid source fed DC drive propulsion system for electric vehicle application.

PEM Fuel Cell

As discussed in previous section, Electrical power can be generated from PEM Fuel Cell through chemical reactions which use hydrogen as oxidant. It has great potential to use in low power to high power application [9]. In this study the PEMFC has been designed and considered for electric vehicle application. The driving equations of the fuel cell stack are given below. The fuel cell output voltage is a function of reactant pressure, temperature and of course stacks current.

$$E_{FC} = E_{oc} - N\frac{RT}{2\alpha f}\ln\left(\frac{I_{FC}}{I_e}\right) - N.I_{FC}R_{FC} \qquad (1)$$

$$I_e = \frac{K_b F\left(PH_2 + PO_2\right)}{Rh}e^{-(\tau G/RT)} \qquad (2)$$

where E_{oc} represents open circuit voltage, N → number of cells, K_b is universal gas constant I_e is the exchange current, I_{FC} is the FC current, T is the operating temperature and R_{FC} is the internal resistance of fuel cell. R =8.314 kJ/kmol, Faraday's constant, F = 96 485 C/mol. Whereas PH_2 and PO_2 denotes partial pressures of hydrogen and oxygen respectively [10].

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* Correspondence Author
Premananda Pany*, Electrical & Electronics Engineering Department, Sharda University, Greater Noida, India. Email: pnpany@gmail.com

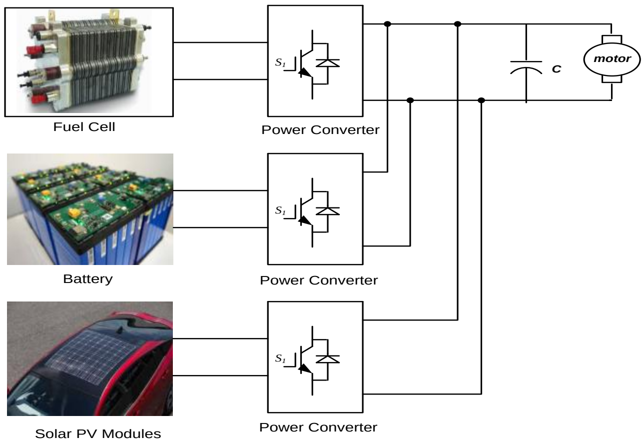

Fig.1. Hybrid Power Source (PEMFC/Bat/PV solar) fed DC drive system.

EQUIVALENT CIRCUIT OF PHOTO VOLTAIC SOLAR CELL MODULE

In this study the dynamic model of Photo voltaic system has been considered which contributes a significant amount of power to the hybrid system. .the mathematical equation of PV current is derived from its electrical circuit model and it is represented as follows [11].

$$I_{PV} = I_{SC} - I_0 \left[e^{\left\langle \frac{q(V - R_S I)}{N K_b T_a} \right\rangle} - 1 \right] - \frac{V - R_S I}{R_{sh}} \quad (3)$$

In the above equation I_{PV} and V are output current and voltage of solar cell respectively. The so called dark saturation current is represented as I_0, which depends on the temperature of solar cell, $q \rightarrow$ electric charge (1.6×10^{-19} C) and factor, $K_b \rightarrow$ Boltzmann constant (1.38×10^{-23}J/K). T_a is the absolute temperature of the PV cells, R_S *is* the series and R_{sh} is shunt resistances of PV cell respectively. Resistance R_S is due to links and semiconductor material of PV cell. The shunt resistance R_{sh} is associated with the presence of impurities around the boundaries of the solar cell which provides short-circuit of the junctions. To improve the overall efficiency it is desired to minimize the effect of resistances R_s and R_{sh}. I_{SC} is the photo voltaic current which depends on solar radiation, photo cell temperature and can be represented as

$$I_{SC} = [\lambda_{SC}(T_C - T_r) + I_{SC}]H \quad (4)$$

Here λ_{SC} is the temperature coefficient of the solar cell's short circuit current, Tr is reference temperature of the cell, I_{sc} is the cell's short-circuit current at minimum temperature and H is solar irradiation (kW/m^2). In addition, with the variation in the cell temperature, the saturation current I_0 will also vary [12].

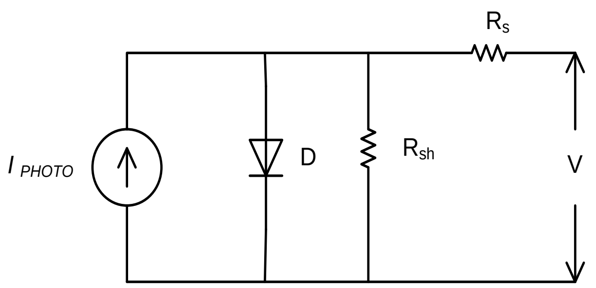

Fig.2 Electrical equivalent circuit of Photo Voltaic Cell.

Many solar cells are connected together to form a PV panel and these cells can be connected in series, parallel to meet the power requirement. By considering the above mentioned condition the V-I characteristic of PV panel can be obtained.

Lithium Ion Battery

A 48V, 50Ah Lithium Ion battery bank has been used in this hybrid system. It is little more expensive than lead acid battery, NiCd, NiMH but they have more specific energy density, recyclability. Lithium ion battery also plays vital role in this hybrid source fed dc drive, therefore its modeling is required. Battery parameters affect the value of every element of the battery equivalent circuit. The profile of battery terminal voltage depends on the nature of the load current, thus it has to supply same current. The scenario can be well observed along with battery SOC which is the indication of remaining charge left with respect to the battery maximum capacity at a given temperature.

DC–DC Converters

In this hybrid system each energy source supplies different power to the load as per the load demand. Hence, pulse-width modulated (PWM) based control method is employed for dc–dc converters used in this work to supply the power required at common DC bus which is directly connected with the load. The output voltage of PV panel and FC is always less than load voltage; therefore dc-dc boost type unidirectional converts are used for controlled power transfer. As battery needs charging and discharging during driving cycle, a buck-boost dc-dc converter is used and facilitates both the operation.

III. ENERGY MANAGEMENT CONTROL STRATEGY

Energy management in such multiple source based hybrid power source particularly when used in vehicular application is a challenging task. The power demand always varies as the driving condition changes frequently. With appropriate control strategy the power flow from PEMFC, Solar PV cells and batteries can be controlled to minimize hydrogen consumption during driving while with regard to all the component operational limitations. The maximum power can be generated from solar panels in sunny day hours and minimum in the dark situation. To meet the load demand at any time all the three power sources can be utilized efficiently. The following equation is implemented to obtain the desired power at the load side. The percentage of power sharing among these sources varies based on the load demand, climatic condition, battery health condition, battery SOC, and availability of hydrogen fuel for PEMFC.

$$V_0.I_0 = V_{PV}.I_{PV} + V_{FC}.I_{FC} + V_{Bat}.I_{Bat} = P_{DC} \quad (5)$$

$$I_O = I_{Load} = \frac{k_x}{\sum_{x=1}^{3} k_x}.I_{Ref} \quad (6)$$

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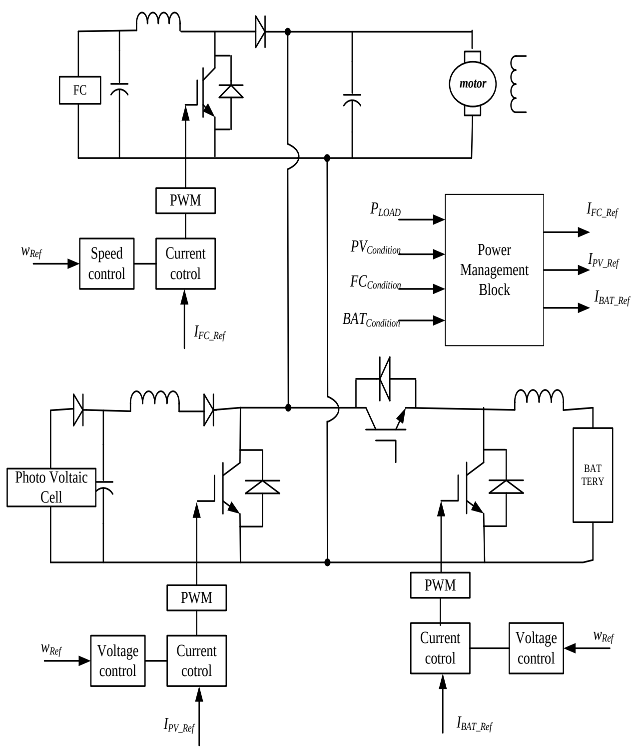

Fig.3. schematic of hybrid power source, power converters and their control methodology,

TABLE-1

SI.No	Specifications	Rating
1.	**Specifications of Solar PV panel**	
	Rated output Power, P_o	1kW
	Rated Operational temperature	40^0C
	Open circuit voltage, V_{out}	120V
	Rated output current, I_o	9.2A
2	**specifications of Fuel cell stacks**	
	fuel cell Type	PEMFC
	Rated Power	2 kW
	Operating temperature	55^0C
	Rated voltage	70 V
	Rated current	66 A
	No of cells	84
3	**Specifications of Battery bank**	
	Battery Type	Li-Ion
	Rated Voltage	48
	Rating in Ah	80Ah
	Open circuit voltage	56V

IV. SYSTEM SIMULATION RESULT AND DESCRIPTION

This section presents the simulation result in view of power sharing of each source of the hybrid power system driving a dc motor load. Table-1contains the values of the system parameters used in the simulation study. The main focus of the control strategy is power sharing among the three power sources such as PEMFC, PV and battery. The DC bus voltage is regulated based on load demand and power management component decides the power sharing percentage among the three energy sources based on their health condition. Fig.4 shows the power sharing among the FC, Bat and PV to supply a load demand of 1650W. it is evident that the controller performs satisfactorily and smoothly exchanges the power between the different sources. Fig. 5 indicates the motor speed (120 rad/sec) tracks the reference speed at almost zero steady state error. The motor velocity is set at 120 rad/sec. Fig. 6 shows the motor torque at a load current of 10 A. Fig.7 shows the battery SOC which degrades while delivering power to load along with other power sources, initial battery SOC was set at 88% and it discharges to little more than 87.95 during this 6 seconds of simulation. Fig. 8 indicates the battery current; it varies as per its energy contribution to the hybrid system. Fig 9 and Fig 10 indicates the FC current and voltage respectively. These simulation results demonstrate the performance more satisfactorily over the entire cycle of operation satisfying load requirement.

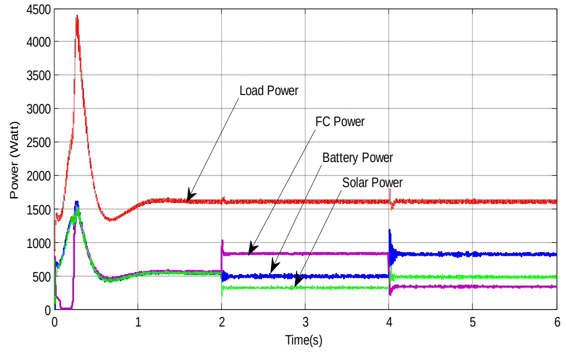

Fig. 4. Power Shared by PV, FC and Bat with neet power demand.

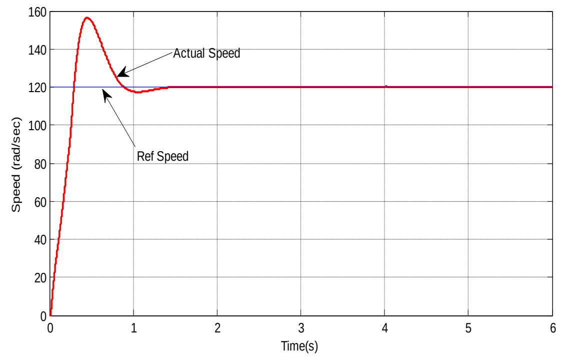

Fig.5 . Speed Response of the motor and the reference speed.

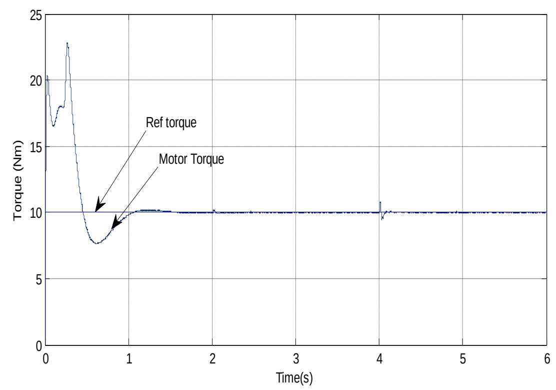

Fig.6. Nature of torque during the drive.

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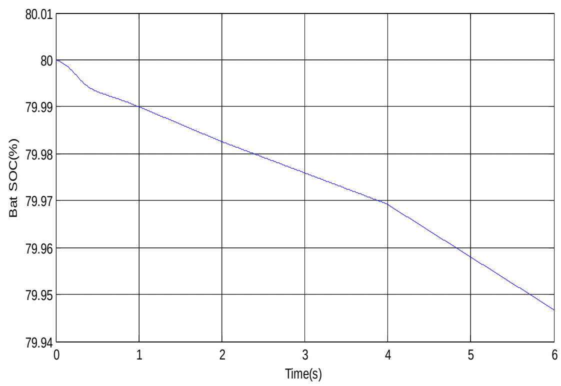

Fig.7. Battery state of charge (SOC).

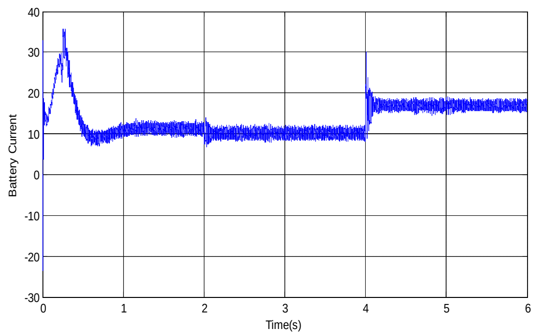

Fig.8.Battery Current characteristic.

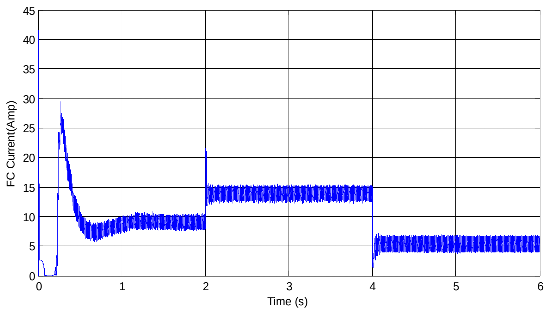

Fig.9. Fuel Cell Current characteristic.

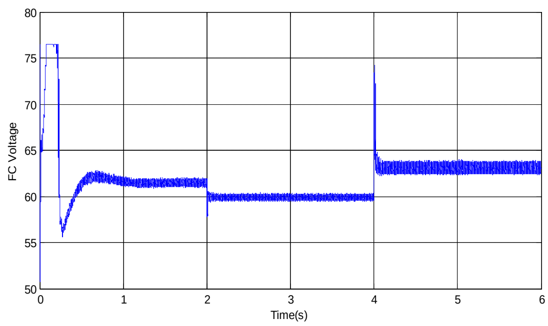

Fig. 10. FC Voltage characteristic.

V. Conclusion

The feasibility of power management in hybrid source comprising PV solar, FC and battery in application with electric vehicle is presented in this paper. Very satisfactory controller performance has been observed in smooth driving of the drive with the proposed power sharing technique. The power sharing of PV as per the light intensity in sunny and dark situation has been carried out effectively. Power management block observes the health condition of the energy sources and the climatic condition, thus supplying the load power requirement by loading the sources equally as well as unequally depending on the situation.

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AUTHORS PROFILE

Ph.D in Electrical Engineering with specialization Power electronics & drives from MNNIT, Allahabad. Currently working as Associate Professor in EEE Department at Sharda University. Have 17 years of experience in the field of Teaching, Research & Industry. Published research papers in the area of Power Electronics, Electric vehicle in various international journals and conferences.

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