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Modeling of a Photovoltaic-Fuel Cell Battery for Hybrid Electric Vehicle

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Abstract:
The development towards electric vehicle is growing enormously due to global warming phenomenon. So in order to reduce the global warming, electric vehicle is moving towards Renewable Energy Sources (RES) such as Solar and fuel cell, Hence this work modeled and analysed the achievability of hybrid PV-FC source for EV. This system comprises PV system, FC and a Boost converter unit and is modeled using MATLAB Simulink environment. From the results, it is concluded that this system can effectively work in different situations and exhibits better fuel economy.

***Keywords**: Fuel cell, Hybrid Electric Vehicle, Fuzzy Logic Controller, PV system.*

INTRODUCTION

The ever growing restrictions over pollution and its the concerns over depletion of natural sources have created a greater interest towards (EVs. It exhibits high efficiency with lower emission [1]., A hydrogen FC is a pollutant-free cell which could be a favorable source to EVs along quick refueling technology[2] . Next, Proton exchange membrane FC (PEMFC) exhibits higher efficiency, faster response rate and also has good low-temperature response. This quality has made this more suitable for EVs [3-5]. PV is considered as one of the most important RES because of its readily available nature. Thus the combination of FC with PV panels can reduce daily hydrogen consumption nearly about 40% in EVs [6]. As a result integrating HEV with PV and FC exhibits higher energy and efficiency[7]. Therefore, this type of vehicle will eradicate global warming in near future and protects environment[8].

Chowdhury (2017). studied the HEV's powertrain which comprises a FC, battery and PV panel [9]. This work mainly focused on the performances of each component in the system not on the energy management of the system. Sharaf (2011) formulated a structure fro hybrid PV-FC diesel-battery powered EV [10]. Mokrani (2014) designed an integrated PV-FC-battery module for 3 kW EV traction unit [11].

However, there will be some unsolved problems in modeling of EVs while implementing in in the real world EV applications [12-15]. Therefore, the main objectives of this work is to develop a detailed model of a PVFCHEV system. This confirms the feasibility of PVFCHEV in a trustworthy manner. Finally, the model has been evaluated under different conditions such as varying power demand, under variance in PV power and under different states of the battery.

II. SYSTEM DESCRIPTION

Figure 1 describes the outline of the proposed PVFCHEV system. It comprises PV array, a PEMFC, Boost converter and a lithium battery. The

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PV array is associated to a MPPT to attain maximum output power.

The PEMFC acts as a power source and a flow rate regulator regulates its flow rate and hence the FC power can be adjusted. The Li-ion battery incorporated in the system exhibits higher power density and hence the dynamic response is fast. So that it can easily compensate the transient output power.

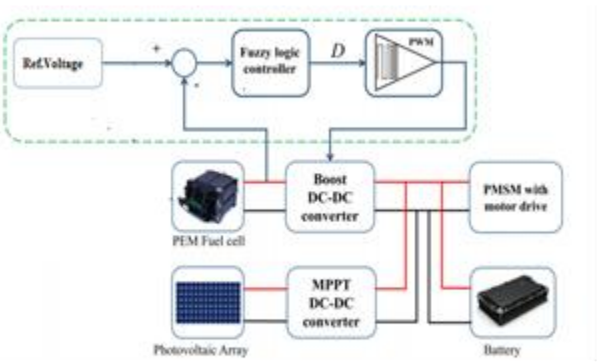

Figure 1. Outline of the proposed PVFCHEV system

PV array and MPPT converter

PV ARRAY MODELING

The basic building block of PV arrays is the solar cell. The PV cell 's equivalent circuit is represented in Figure 2.

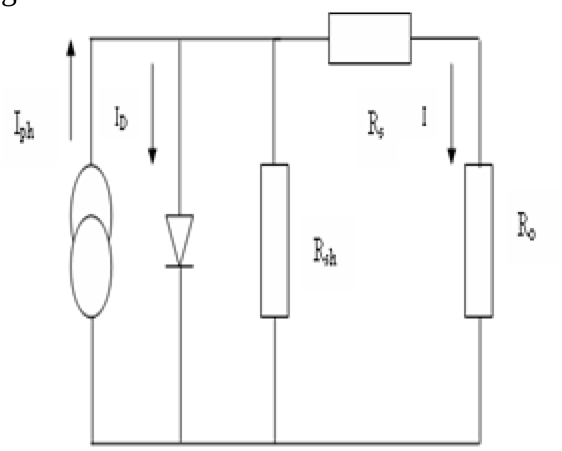

Figure 2. Equivalent circuit of a PV cell

Thus the mathematical model of a PV array can be expressed as

$$Ipv = n_{pa} I_{pho} - n_{pa} I_s \left[exp\left(\frac{q}{KTA}\right) * \left({}^{Vpv}/_{n_{ser}}\right) - 1 \right]$$

(1)

where

I_{pho} - Photo Current

Ipv - PV array 's output current

Vpv - PV array 's output voltage

n_{ser} - number of cells in series

n_{pa} - number of cells in parallel

q - Charge

K - Boltzmann's constant [8.62 x 10-5 eV/K]

A - Ideality factor.

T - Cell temperature (K)

In this model, the value of I_s varies with temperature and the I_{pho} depends on the radiation and cell temperature of the sun.

FC and Boost converter

The voltage of the FC stack VFC is:

$$V_{FC} = E_{OC} - NA\ In\left(\frac{i_{FC}}{i_0}\right)\frac{1}{\frac{sT_d}{3}+1} - Ri_{FC}$$

where

EOC - open circuit voltage,

iFC – FC current

N - number of cells,

Td - reaction time,

R - internal resistance.

Then EOC can be defined as $E_{OC} = K_C E_n$

EOC =KCEn ð5Þ

where

KC - voltage constant

Boost converter

Figure 3 depicts the arrangement of the Boost converter. During the 'ON' time, Switch remains closed and current across the inductor raises. During 'OFF' condition, Switch remains open and the inductor current flows across the diode and load.

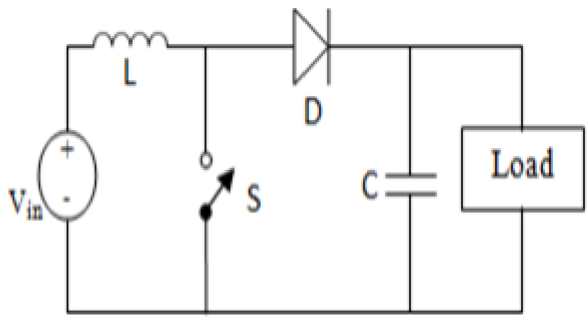

Figure 3. Boost converter

The boost converter is controlled using a fuzzy controller.

Design of FLC

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Fuzzy logic controllers (FLCs) are intelligent control systems that are characterized by a set of linguistic statements based on expert knowledge or experience. Thus the flowchart representation of fuzzy logic controller is represented in Figure 4a.

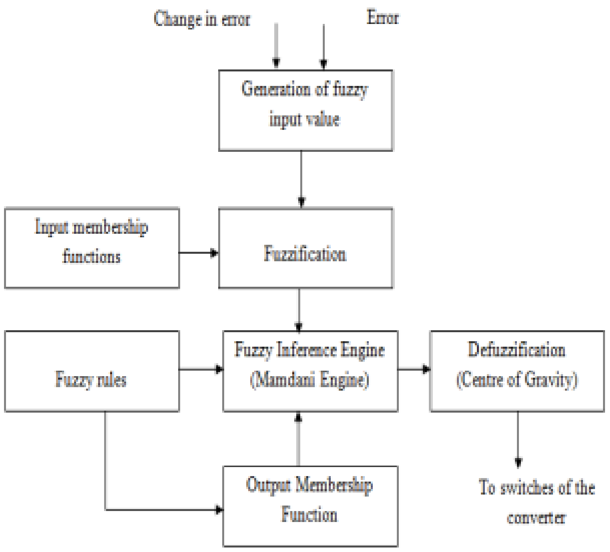

Figure 4a. Flowchart representation of FLC

Thus the proposed FC comprises 7 linguistic variables (NB, NM, NS, ZE, PS, PM, PB) for each input and output variables. Triangular membership function is adopted and the same is depicted in Figure 4b, c and d.

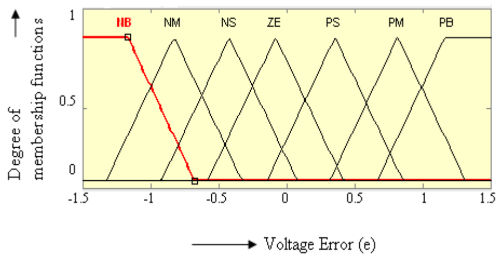

Figure 4b. Membership function (*Error)*

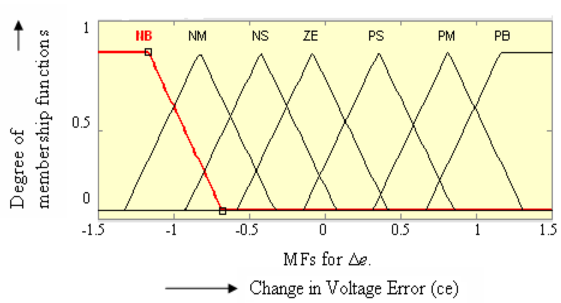

Figure 4c. Membership function (Change in error*)*

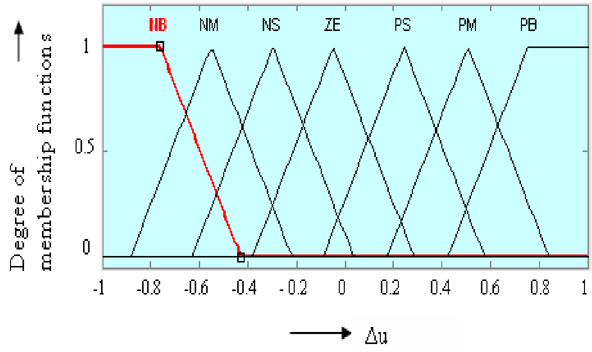

Figure 4d. Membership function (Output)

The output from the FLC controls the PWM of the converter circuit.

Battery

A Li-ion battery is utilized and it comprises 12 series connected modules which are of 12 V / 0.8 Ah (totally 144 V/9.6 Ah).

III. RESULTS AND DISCUSSION

Thus the performance of proposed system is investigated using MATLAB simulation. Table 1 and table 2 depict the specifications of PV array and PEMFC used in this simulation..

Table 1. Specifications of the PV array

Parameter	Value	Unit
Series-connected modules	2	Piece
Cells per module	72	Piece
Maximum current at MPP	5.84	A
Maximum voltage at MPP	42.8	V
Short circuit current (Isc)	6.2	A
Open circuit voltage (Voc)	50.93	V
Maximum power per module	250	W

Table 2. Specifications of PEMFC

Parameter	Value	Unit
Number of cells	65	Piece

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Nominal voltage	45	V
Nominal power	4.2	kW
Peak power	6	kW
Fuel supply pressure	1.5	bar
Operating temperature	65	^{0}C
Nominal stack efficiency	55	%

Figure 5 shows the output voltage and current of PV system and the figure 6 depicts the output voltage and current of the FC.

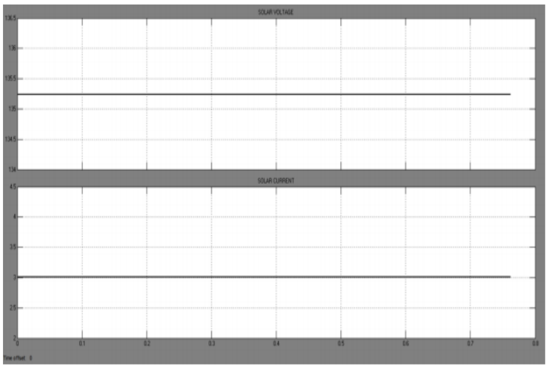

Figure 5. Output voltage and current of PV system

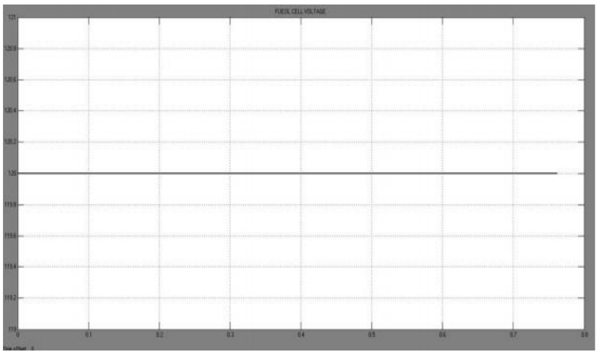

Figure 6. Output voltage FC system

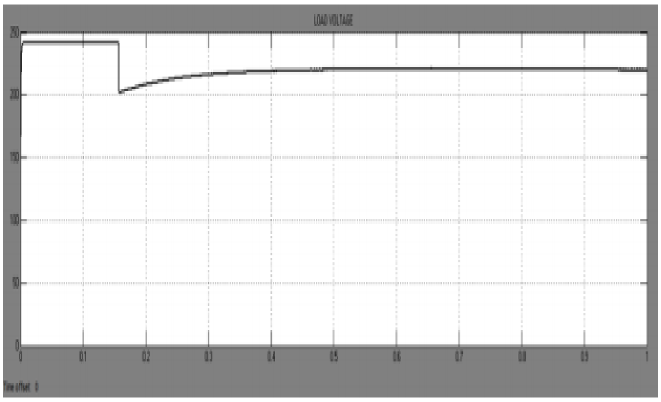

Figure7. Output voltage across the load

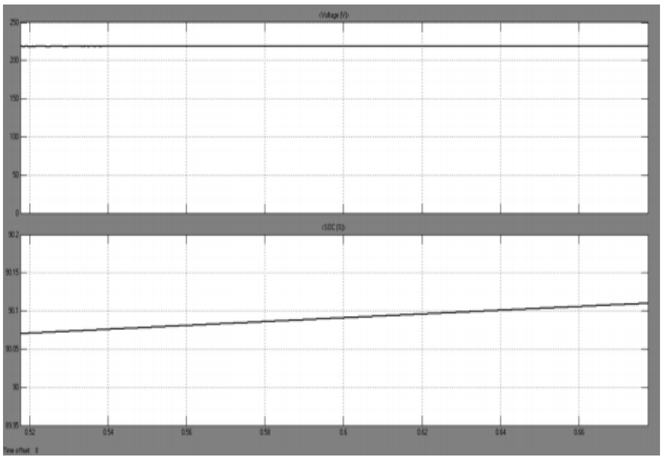

Figure 8. Battery voltage and SOC

Figure 7 and 8 depicts the output voltage across the load and battery voltage and its SOC.

The FC generates more power than the demand power to recover the battery SOC at beginning. When the SOC of the battery reaches about 45%, the FC stops its excessive generation.

IV. CONCLUSION

This article studied about the feasibility of PV-FC based HEV. It aimed in the equal distribution of power over the power sources rationally and also maximized the utilization of solar energy. From the results it is concluded that it regulates power distribution equally under all conditions. Furthermore, it exhibits a better fuel economy. In this context, this work can facilitate the design of experiment apparatuses in future.

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