Design and Implementation of Automated Solar/Fuel Cell Power Controller for Hybrid Electric Vehicle

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Abstract
With an ever increasing demand for energy for transportation and alarmingly high levels of pollution caused due to excessive consumption of fossil fuels, the Research & Development in Electric/Hybrid Electric Vehicles is being carried out at an accelerated pace. The success of any of the above approaches will depend on the capabilities of the batteries i.e., power density, cost, maintenance and life span etc. This paper proposes a novel, flexible strategy for Multi Objective Control of Power Controller (MOPC) for a Hybrid Electric Vehicle (HEV). Here a new control strategy has been implemented with three different configurations like Constant Fuel Cell Current Mode, Constant Battery Current mode and Constant Battery Voltage Mode. Based on the load demand on the vehicle, control strategy is automatically selected for propulsion or charging purposes, by using computer and interfacing circuits.

Keywords
hybrid electric vehicle, power controller, solar cells, fuel cells, system control

1. INTRODUCTION

The dream of having commercially viable Electric Vehicle (EV) and Hybrid Electric Vehicle (HEV) is fast becoming a reality. A Hybrid Electric Vehicle is an automobile that has two or more major sources of propulsion [Jiang et al., 2005]. Most hybrid vehicles currently available to consumers have both conventional gasoline and electric motors connected in series/parallel to power the vehicle either independently or both in tandem based on the requirement. Although solar powered electric vehicles, which are equipped with batteries that are charged by the sunlight, have longer ranges, they are still dependent on batteries, which have size and weight constraints. To meet the public acceptance, a vehicle must adhere to specific conditions: be able to drive a minimum of 300 miles (482 km) after each re-fuelling, fill-up promptly and drive fast enough to keep up with the traffic. An electric vehicle cannot go more than 100 miles (161 km) between subsequent re-charging, is difficult to re -charge in some instances and so far has not been able to drive beyond 60 mpg as yet. Fuel cells of reasonable size may provide the necessary energy, but not the peak power demanded by vehicles. The simplest hybrid configuration results by connecting both the fuel cell and the battery directly to the power bus. Hybrid systems composed of high energy density fuel cells with high power density batteries eliminate the drawbacks of Electric Vehicles. The battery can condition the power output from the fuel cell to provide a voltage range that is acceptable to the equipment since battery operated devices are generally designed to accommodate the source characteristics of a battery. This passive hybrid has a number of disadvantages. Firstly, since the power is passively distributed between the fuel cell and the battery, depending on the characteristics of each component, the maximum output current of the hybrid system might be limited by the current capacity of the fuel cell. Secondly, it is necessary to match the nominal voltage of the fuel cell stack to that of the battery, which eliminates the flexibility in the system design. As an alternative to the passive hybrid, a dc/dc power converter could be placed between the fuel cell and the battery, which would greatly augment the peak output power at the same time, reducing the system weight and volume. The active fuel cell/battery/converter hybrids could be configured in two different ways depending on the position of each component. In both configurations, the power shared by the components could then be actively controlled. However, control of the power converter in such systems becomes very complicated, which actually is a multi objective control issue. Rather than being controlled to serve as a sole voltage or current regulator, the power converter is required to balance the power flow between the fuel cell and the battery to satisfy the load power requirements while ensuring the operation within any limitations of the electrochemical components such as battery over-charge /over-discharge, fuel cell current limit, etc [Minami, 2011].

2. THE PROPOSED MODEL

Block diagram of the proposed model is shown in Figure 1. The Major blocks involved in implementation of the drive and its control are (1) Control strategy block which gives the status of battery and fuel cell current, (2) D.C/D.C converter with Pulse width modulator, (3) Energy storage system composed of batteries, (4) Personal computer [Jiang et al., 2005].

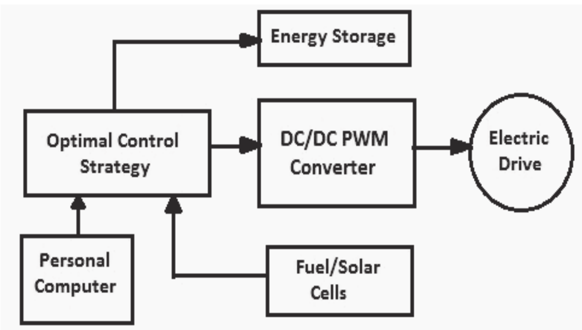

Fig.1 Block diagram of the proposed model

2.1 Multi objective power controller

D.C-D.C converter with Pulse width modulation technique as shown in Figure 2 is used for controlling the power fed to Electric Drive. A Pulse Width Modulator is a device that may be used as an efficient D.C motor speed controller. One additional advantage of Pulse Width Modulation is that the pulses reach the full supply voltage and will produce more torque in the motor thus enabling it to overcome the internal motor resistances more easily. The DC voltage is converted to a square-wave signal, alternating between fully ON

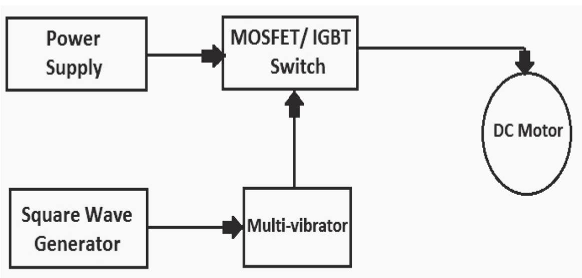

Fig. 2 Block diagram of multi-objective power controller

(nearly 12 V) and fully OFF (zero), giving the motor a series of power "kicks". If the switching frequency is high enough, the motor runs at a steady speed due to its flywheel momentum. By adjusting the duty cycle of the signal (modulating the width of the pulse, hence the 'PWM') i.e., the time fraction it is "ON", the average power can be varied, and hence the motor speed [Stewart et al., 2002]. The pulses generated are as shown in the Figure 3 .If the potentiometer is adjusted to give a high reference voltage (horizontal line), the saw tooth never reaches it, so output is zero. With a lower reference, the comparator is always on, giving full power.

An oscillator is used to generate a triangle or saw tooth waveform as shown in Figure 3. At low frequencies the motor speed tends to be jerky, at high frequencies the motor's inductance becomes significant and power is lost. Frequencies of 30-200 Hz are commonly used. A potentiometer is used to set a steady reference voltage (Ref Line). A comparator then compares the saw tooth voltage with the reference voltage when the saw tooth voltage rises above the reference voltage; a power switch (MOSFET/IGBT) is switched on. As it falls below the reference, it is switched off. This gives a square wave output to the D.C motor. The necessary input electrical power is being supplied either by using solar panel or Fuel cell stack [Djekic et al., 1998].

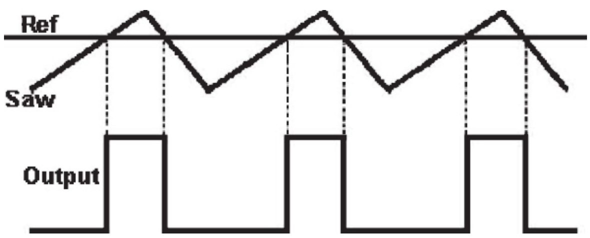

Fig. 3 Waveforms generated

2.2 Square wave generator

Square wave generator as shown in Figure 4 is used for functioning of the Mono stable Multi vibrator. Square wave outputs are generated when the op-amp is forced to operate in the saturated region. That is, the output of the op-amp is forced to swing repetitively between positive saturation $+V_{sat}$ and negative saturation $-V_{sat}$, resulting in square wave output. Design aspects of Multivibrator is described in equations (1)-(7)

$$V_1 = (R_1 / R_1+R_2)\,(-V_{SAT}) \qquad (1)$$

With output at $+V_{SAT}$, voltage V_1 at the non inverting input is

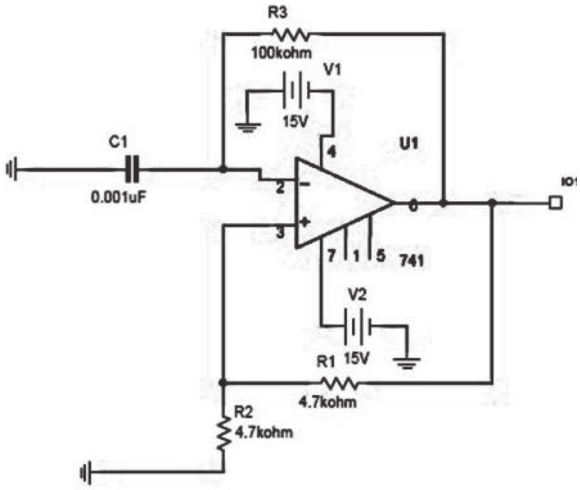

Fig. 4 Square wave generator

$V_1 = (R_1 / R_1 + R_2) (+V_{SAT})$ (2)

The time period T of the output waveform is given by

$T = 2RC \ln ((2R_1 + R_2) / R_2)$ (3)

In practice, each inverting and non- inverting terminal needs a series resistance RS to prevent excessive differential current flow because the inputs of the op-amp are subjected to large differential voltages. The resistance RS used should be 100 k ohm or higher. Circuit for a mono stable multi vibrator is as shown in Figure 5.

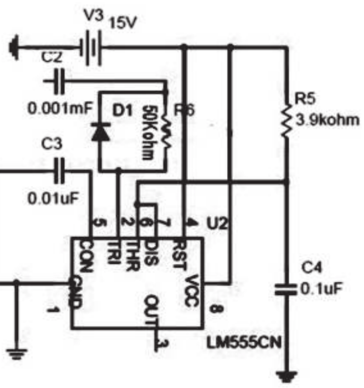

Fig. 5 Mono stable multi vibrator

2.3 Mono stable multi vibrator

A monostable multivibrator produces a single pulse whose width can be controlled, since the pulse duration depends upon the circuit elements viz. resistance and capacitance. By varying the time constant RC, it is possible to have any desired pulse width, as required by practical considerations .often in practice a decoupling capacitor (10 micro farad) is used between $+V_{CC}$ (pin 8) and ground (pin 1) to eliminate unwanted voltage spikes in the output voltage waveform. Sometimes, to prevent any possibility of mis-triggering the monostable multivibrator on positive pulse edges, a wave shaping circuit consisting of R, C_2, and diode D is connected between the trigger input pin 2 and V_{CC} pin 8. The values of R and C_2 should be selected so that the time constant RC_2 is smaller than the output pulse width tp. Consider the charging of the capacitor. Since the capacitor voltage V_c increases exponentially. The following equations are used for designing the width of the pulses [Jarvis et al., 2003].

$V_c = V (1- e^{-t/RC})$, (4)

Where V = maximum charging voltage.
When the capacitor voltage has reached the value 2/3 V_{cc}, We have

$V_c = 2/3 V_{cc}$. Also $V = V_{cc}$ (5)

Therefore $2/3\ V_{cc} = V_{cc}\ (1-e^{-t/RC})$ (6)

Therefore $t = -RClog_e(1/3) = -RC\ (-1.0986)$ (7)

The pulse width Ton =1.1 RC

3. SOFTWARE & HARD WARE IMPLEMENTATION OF THE PROJECT

In NI Multisim, by "Mounting" a circuit, we can simulate its operation with the various parameters measured directly by virtual instruments that can be connected at any point. Zenar based solar engine, Fuel cell charger and PWM controller are modelled and tested [Trentini and Pieper, 1998] and responses are shown from Figures (6-10) respectively. The output of the D.C/D.C converter is shown in Figure 11. (Note XSC in the diagram refers to The Tektronix Oscillo-

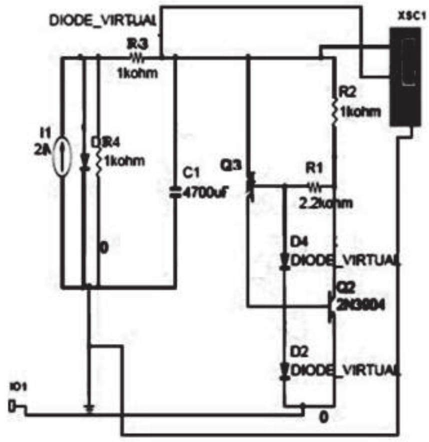

Fig. 6 Simulation of solar charger

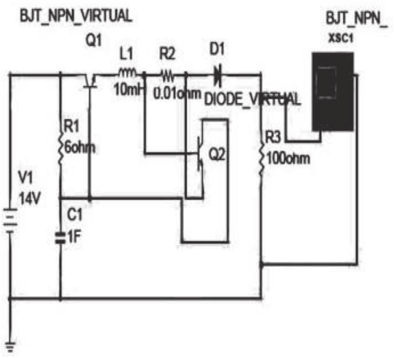

Fig. 7 Simulation of fuel cell

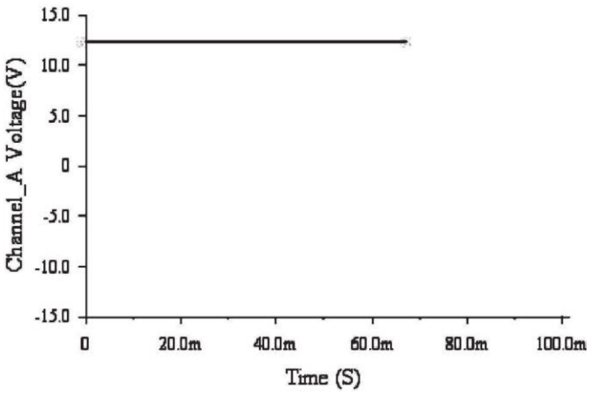

Fig. 8 Output solar charger

scope XSC, as shown on the screen of Multisim Window and VIRTUAL refers to Virtual Devices) [Rao et al., 2009].

The motor's armature is represented in Figure 9.

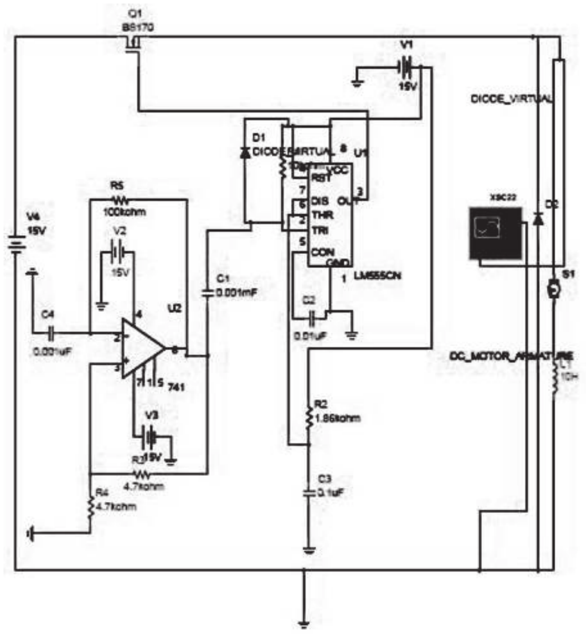

Fig. 9 Simulation of PWM controller

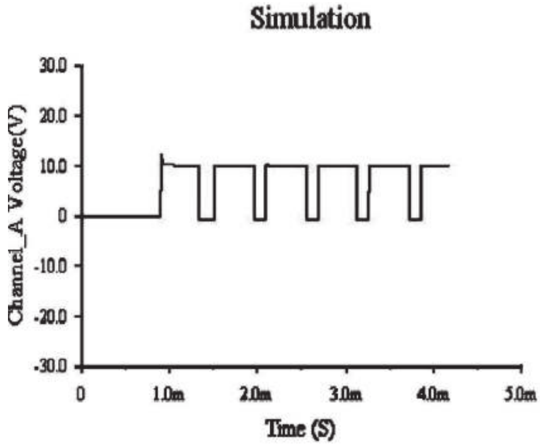

Fig. 10 Voltage output of D.C to D.C converter

Fig. 11 Fabricated model of solar charger

The link between base of Q_2 and other branch from R_2 to emitter of Q_2 is not connected.

The charging system for hybrid electric vehicle requires different sources like solar/fuel cells to charge the batteries. The solar battery charger circuit (Figure 6), electronic model for fuel cell (Figure 7) are fabricated and shown in Figures 11 and 13 respectively. For the implementation of the proposed strategy and to control the charging time of batteries, we must execute a 'C' program using an interfacing circuit shown in Figure 14. In this prototype, a set of two Nickel-Metal Hydride (Ni-MH) (12 V/2 A) batteries were selected for propelling HEV system [Gao et al., 2002]. Algorithm as shown in Figure 12 was realized for implementing the required strategy to control the Hybrid Electric Vehicle [Martha et al., 2006].

4. RESULTS AND CONCLUSIONS

The circuit is assembled and connected to a parallel port of a PC. On executing the application, using a simple C program we get three options to select the mode of operation i.e. Battery Mode or Electric Mode or Hybrid Mode. Also the charging and discharging of the batteries can be monitored and modified using this program, thus simplifying the entire process of control and operation of the Hybrid Electric Vehicle and rendering it user-friendly. As such, similar control strategies can be extended and implemented in a

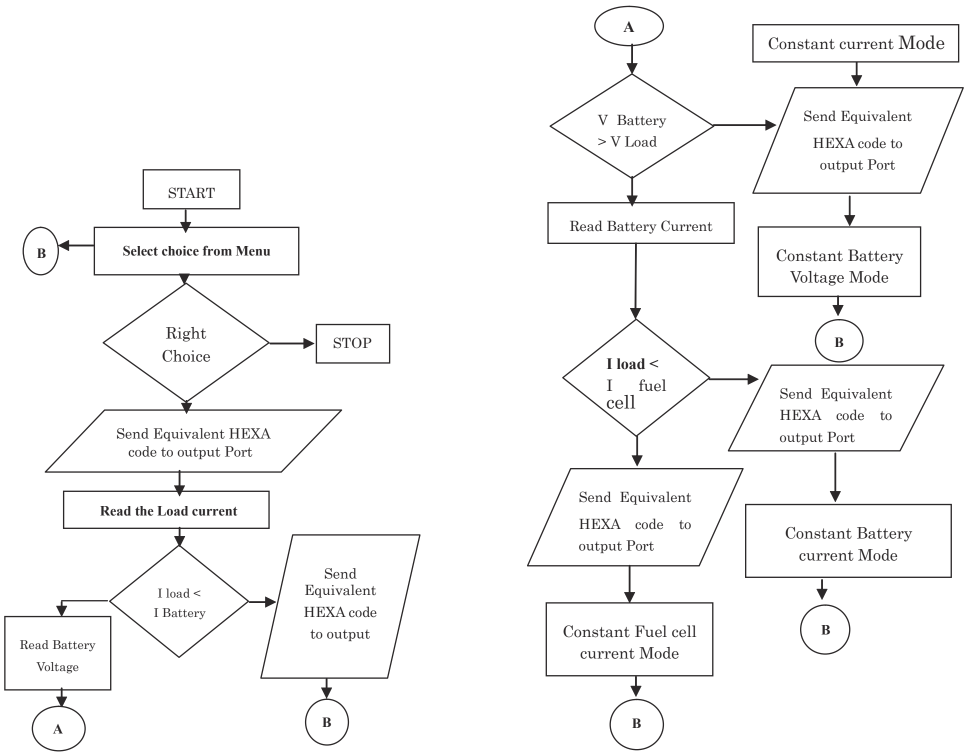

Fig. 12 Flow Chart Depicting the Control Strategy

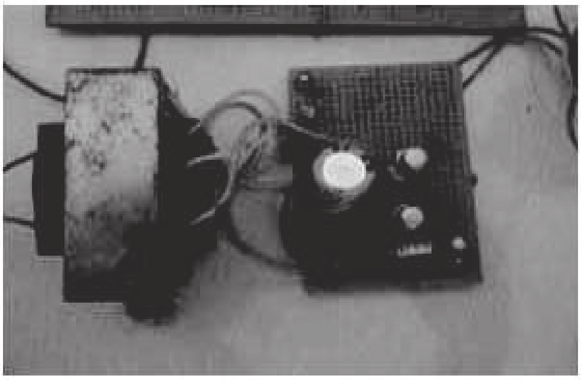

Fig. 13 Fabricated model of Fuel-cell charger

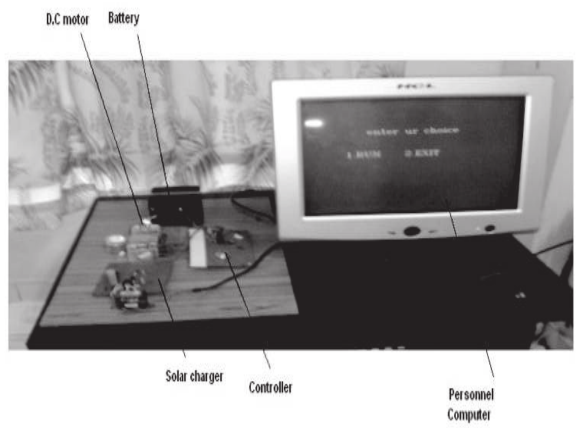

Fig. 14 Complete hardware model of the hybrid power controller

Table 1 Theoretical and Practical results of PWM converter

S.no	Theoritical	Practical
o/p	V_0 = 15 V	V_0 = 14 V
R	1.21 K ohm	1.21 K ohm
C	0.1 micro farad	0.1 micro farad
Ton	1.1 RC = 1.1 * 1.21k * 0.1u = 0.133lms	0.008 ms

fully developed vehicle to enhance its performance and reduce the battery related failures due to poor maintenance as we cannot control the parameters of charging/discharging otherwise.

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