Intelligent controller based power management system in hybrid energy fed electric vehicle

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Abstract
Nowadays, more than one power source is needed to fulfill the power demand for electric vehicles. The multiple sources enhance reliability regarding the cruising range and decrease the charging cost. However, the inclusion of multi-sources generally gives rise to issues in the controller unit, such as slow response due to the immediate changes in load and power conversion complexity while switching the sources. This paper presents a novel intelligent control scheme based on fuzzy logic to mitigate this issue. The proposed controller includes a solar panel, a fuel cell, and a battery as input source. In this work, to examine the instantaneous reference currents from the sources and to manage power for the electric vehicle motor, a permanent magnet synchronous machine (PMSM) is considered. The proposed controller performs real-time power management, Maximum Power Point Tracking (MPPT) for the PV system, and load calculations based on vehicle dynamics.

Keywords: DC-DC converter, fuel cell, intelligent controller, battery storage system, electric vehicles, MPPT, solar photovoltaics

Introduction
The world population exhibits tremendous vehicle growth, leading to heavy pollution, an insufficiency of fossil fuels, fuel price hikes and drastically affecting the environment. National Oceanic and Atmospheric Administration (NOAA) releases global warming statistics every year. Internal combustion engine vehicles are the prime reason for polluting nature and threatening the living organisms on the earth. Switching transportation to Electric Vehicles (EVs) is the prominent solution to save the planet and make the globe healthy. The EV market contributes to economic growth and many government schemes in the country and subsidies help move users towards the EV side every government tries to increase the charging infrastructure to meet the charging requirement and to make more EV users. Even though electric vehicle transportation was started in 1827, it has yet to be successful due to the unavailability of battery technologies. These technological include rise to battery electric vehicles (BEV) which is mostly practiced in the transportation industry for the past two decades. It has account of battery-stacks as an energy source to the vehicle similar to traditional Internal Combustion (IC) engine-based vehicle. These BEVs are equipped with Battery Management Module (BMM) which maintains state-of-charge of battery-stacks. This continuous dependence on charging system can be solved by solar-based BEVs. Moreover, the power transformation set-up specific to solar-panel to BMM has marked the new phase of BEVs [1, 2].

Fuel Cell Electric Vehicles (FCEVs) are increasing rapidly due to some advantages over BEVs, such as hydrogen filling time period much shorter than charging the battery, the ability to run without any grid dependency and almost zero pollution [3]. Hence, the combination of BEVs and FCEVs enables efficient EVs because of their features and reliability [4, 5]. The solar, battery and fuel cell-fed EVs are most suitable for school or university campuses, which need one hydrogen station to fill the gas and the utility of solar energy is possible because of school working time during the day. The incorporation of these sources is ready to give power. However, the respective quantity of power needs to reach the load through a power management scheme.

The Power Management Strategy (PMS) integrates these three sources with a proper
controller and power electronic converters and it adjusts the power from available input sources to load. The benefits of the PMS include increasing system efficiency, increasing the utility of present power from sources, energy conservation and reliability improvement. The control technique activates the PMS function throughout the EV operation, which can be set by the user as any code or program and needs some predetermined knowledge about the power production range from various sources and the load demand. The PMS technique implemented in EVs involves some favourable and unfavourable factors for researchers as far as the control methodology is concerned. Battery-fed energy distribution is carried out through direct torque control using a lookup table and gets better efficiency from two standard driving cycles. Vehicle propulsion is achieved by two sets of batteries and motors for the front and back wheels. Control methodology creates complexity due to two inverters controlling the induction motor load and this EV system depends on the grid for charging the battery. The energy management process is executed using a robust optimization method, where the authors considered uncertainty in the cost function and compared the work with other optimization methods. Input sources for this methodology are battery, ultra-capacitor and fuel cell, but it does not involve the practical drive cycle and there is no hardware implementation. Vector-based power management control is performed using a single stage of hybrid battery and supercapacitor sources. During testing, the 110 kW motor for power is split up in the testing laboratory by the two inverters as a power modulator for a traditional DC-DC converter, where vehicle dynamics and drive cycles are not involved. The principle behind power management control is simultaneous perturbation approximation. The operation of an EV is simulated for two dissimilar scenarios with battery and fuel-cell-fed EVs for heavy vehicles, but simulation results describe the load power as around 6.8 kW. The emerging control methodology of PMS in EVs is known as the multi-objective algorithm (MOA), which controls the firing angle of the power modulator connected between the source and EV motor. The reinforcement learning and model predictive control methodologies are employed in MOA to control the 75 kW motor load with multiple drive cycles. Equivalent consumption of the dynamic factor control scheme controls the battery and two motor-generator pairs for PMS operation and this work has been tested with four different drive cycles in simulation but no hardware implementation. Because of fuel cell and battery, the system needs to control the temperature and PMS operation is possible with the aid of a thermal management system, as the authors proved using an equivalent consumption methodology for the controller.

Proposed Methodology

The proposed EV includes three significant energies: solar, hydrogen and chemical, to produce mechanical energy to propel the entire EV system. More power density, less noise, better speed regulation, and steady output torque are the reasons for PMSM in EV applications. The power modulator is needed for smooth operation. Therefore, the power sources are connected with DC-DC converters and the inverter is linked to PMSM. Two unidirectional DC-DC converters are for solar PV panel and fuel cell and one bidirectional DC-DC converter is for battery. All four converters have connected their respective switches: a solar switch, fuel cell switch, battery charging or discharging switch and load switch, to a common DC bus. An MPPT controller is included to fetch maximum power through the solar panel and an intelligent controller controls the solar-fed DC-DC converter for MPPT operation. This intelligent controller controls all converters and maintains the same voltage at the DC-DC converters output. Collected inside the university campus are captured as Google images. The power management technique using the three different sources for the real-time school bus through an intelligent control method is shown in Fig. 1.

A fuel cell is the prime power source in the FCEVs. The hydrogen input determines the fuel cell output power and this hydrogen is a liquefied as well as highly compressed. At 50 atmospheric pressure, liquid hydrogen produces 2.36 kW-hr per liter. The storage of hydrogen must be safe because of its highly inflammable, but nowadays, hydrogen-based EVs are growing rapidly with full safety precautions for the passengers as well as the vehicle. The proposed EV has an 80 kW of fuel cell with 280V and 288A. A fuel cell model is in Fig. 1. A voltage source is connected in series to the internal resistor and this structure is again in series with the parallel resistor capacitor connection.
The dynamic equations governing the vehicle motion are discussed in the chapter and a school bus has been considered as an electric vehicle for the proposed work. The basic principle behind accelerating the vehicle is the second law of Newton, which states that any movement of the body depends on the total force influenced by the body. To move the vehicle forward, some positive forces need to overmatch the negative forces like wind, gravity, road obstacles and wheel resistance. Vehicle movement starts only if it overcomes the following resistive force acting on the bus. The DC-DC converter connects every source in parallel to the DC bus and the DC-DC converters output should be 465 V, even if there are changes in the input voltages of the sources and load. The input resistance or impedance of the sources connected with converters is different and the output of the DC-DC converters voltages is different when connected to the load. Hence, a fuzzy controller is designed to keep the constant voltage at the output of all DC-DC converters by regulating the duty cycle of the converters. The Vehicle Specifications and Weight calculations for proposed vehicle are shown in Table 1 and Table 2.

### Table 1: Vehicle specifications

<table>
<thead>
<tr>
<th>Vehicle name</th>
<th>SML ISUZU Swaraj Mazda T 3500 WV-26</th>
</tr>
</thead>
<tbody>
<tr>
<td>Type</td>
<td>Bus</td>
</tr>
<tr>
<td>Number of seats</td>
<td>38 + D</td>
</tr>
<tr>
<td>Weight</td>
<td>3950 kg</td>
</tr>
<tr>
<td>Engine</td>
<td>P = 75 kW @ 2800 rpm with BS-IV SLT4</td>
</tr>
<tr>
<td>Length</td>
<td>30.5 feet</td>
</tr>
<tr>
<td>Width</td>
<td>7.5 feet</td>
</tr>
</tbody>
</table>

Batteries operate by converting chemical energy into electrical energy through electrochemical discharge reactions. Batteries are composed of one or more cells, each containing a positive electrode, negative electrode, separator, and electrolyte. Cells can be divided into two major classes: primary and secondary. Primary cells are not rechargeable and must be replaced once the reactants are depleted. Secondary cells are rechargeable and require a DC charging source to restore reactants to their fully charged state. The maximum power available from a battery depends on its internal construction. The battery chosen for this project is a 12 V Sealed Lead Acid battery with 6 cells and 35Ah, which is manufactured by Battery Mart. The battery has an approximate battery life of over 100,000 operating hours and 450A max discharge surge current and minimum charge current of 1 Amp. The battery’s dimension is 7.65” x 5.25” x 7.18” and weighing 29 pounds, which was a good size in comparison to other batteries found while doing research.

### Table 2: Weight calculations for proposed vehicle

<table>
<thead>
<tr>
<th>Weight of engine and fuel tank</th>
<th>700 kg</th>
</tr>
</thead>
<tbody>
<tr>
<td>Kerb without engine/fuel tank</td>
<td>3250 kg</td>
</tr>
<tr>
<td>Passengers weight</td>
<td>1000 kg</td>
</tr>
<tr>
<td>8 solar panels and battery</td>
<td>404 kg</td>
</tr>
<tr>
<td>Fuel cell</td>
<td>56 kg</td>
</tr>
<tr>
<td>Hydrogen tank</td>
<td>100 kg</td>
</tr>
<tr>
<td>Motor</td>
<td>140 kg</td>
</tr>
<tr>
<td>Other weight</td>
<td>50 kg</td>
</tr>
<tr>
<td>Total</td>
<td>5000 kg</td>
</tr>
</tbody>
</table>

Hydrogen and electricity are often considered as complementary energy carriers for the future. Hydrogen has some unique properties, which in conjunction with electricity make it an ideal energy carrier or fuel \(^{11, 21}\). Just as electricity hydrogen can be produced from any energy source, including the renewable energy sources. Hydrogen can be produced from electricity and can be converted into electricity at relatively high efficiencies. Some processes for hydrogen production directly from solar energy are also being developed, such as photo-electro-chemical conversion or biological photo production. Raw material for hydrogen production is water, which is available in abundance. Hydrogen is a completely renewable fuel, since the product of hydrogen utilization (Either through combustion or through chemical electrical conversion) is pure water or water vapour. Hydrogen is a very good fuel for internal combustion engines. Hydrogen powered internal combustion engines are on average about 20% more efficient than comparable gasoline engines.

### Results and Discussion

The power modulators used in this power management operation of the EV are the boost converter, bidirectional converter and voltage source inverter. The intelligent controller receives the solar, battery and fuel cell input voltages and exhibits the duty cycle to each and every DC-DC converter to set the 465 V exactly at the output terminal of the DC-DC converter. As per the solar data, the total solar panel delivers a minimum of 40 V to a maximum of 400 V. Variations in current and voltage from the solar panel are sensed by the controller. The bidirectional converter is in buck mode (540 V to 465 V) when the DC bus is powered by the battery and boost mode (465 V to 540 V) battery absorbs power from the DC bus. The fuel cell voltage is 280 V, which gives input to the boost converter to make 465 V as the output of the boost converter. The controller senses the power (current and voltage) variation in each and every instant and it is capable of setting 465 V in the DC-DC converters output instantaneously due to the adjustment of duty cycles. The DC bus is 465 V because all converters are commonly connected to the DC bus using three switches. The control pulse for different modes is shown in Fig. 2.
Induction motors are sized for maximum loads and are operated at a constant full speed, because they are supplied with power from AC line at a fixed sinusoidal voltage and fixed frequency. They are being preferred to their DC motors counterparts because of their low cost maintenance with superior speed-torque characteristic. Electronic control of power is now increasingly applied to induction motor control as a result of the development in the world of electronics over decades which have made possible a lot of techniques to meet the ever increasing demand. Inverters are types of electronic control device that convert direct current (DC) input voltage to alternating current (AC) output voltage of desired voltage and frequency. Inverters have no moving parts and hence they are used in a wide range of applications, from small switching power supplies in computer and electronics, industrial controls to large utility as High-Voltage Direct Current application that transport bulk power. The management of power using intelligent controller is shown in Fig 3.

The proposed work compares the different sources used, control methods, implementation of different drive cycles, vehicle dynamics design, type of motor, MPPT controller, experimental validation of the system, comparative study and self-charging aspects. The prototype working model of Intelligent Controller-Based Power Management System in Hybrid Energy Fed Electric Vehicle is shown in fig. 4. By using novel intelligent controller, we can reduce the losses occur due to hybrid sources and losses in conversion of sources. And also it increases the efficiency of the system by using the novel intelligent controller. Through this novel intelligent controller, we can use required amount of energy to the load from the sources and also according to the energy requirement battery gets charged as well as motor starts rotating to propel the vehicle wheels through solar.
Fig 4: Proto type working model

Conclusion
The proposed controller is fast in response, accurate in operation and less complex in structure. The intelligent control topology resolved the issues while employing instantaneous reference current-based power management. The controller algorithm effectively operated for multiple input powers to the PMSM motor as per the priority effective control mechanism during different load conditions. The intelligent control-based management of power for EVs is commended brilliantly in all possible modes, from available input power to required load power. The control strategy maintained the SoC level in the safe operating region (20% - 80%), and it can also improve battery health. The proposed method can be extended for future work with the thermal management of EVs using artificial intelligence (AI).

References