Energy-Efficient Battery Charging In Hybrid Electric Vehicles with Solar Panels

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Abstract -- The problem of pollution in our country due to transportation is increasing day by day. As most of the transportation is based on petrol and diesel. Hybrid and electric vehicles are increasingly popular, to reduce the fuel consumption and harmful pollutants. An electric vehicle usually uses a battery which has been charged by external electrical power supply. All recent electric vehicles present a drive on AC power supplied motor. An inverter set is required to be connected with the battery through which AC power is converted to DC power. During this conversion many losses take place and also the maintenance cost of the AC System is very high. The proposed topology has the most feasible solar/electric power generation system mounted on the vehicle to charge the battery during all durations. This paper analyzes the problem of transferring the energy generated by an on-board solar cell system to the main battery pack of an electric vehicle and proposes an optimized solution based on the interaction with the BMS.

Index Terms- battery charging; cell balancing; hybrid electric vehicle; photovoltaic panels.

I. INTRODUCTION

The idea of an electric vehicle is not new and has a history of more than 100 years. Since more than a decade ago, the searching for developments of Zero-Emission Vehicles (ZEV), Electric Vehicles (EV), and Hybrid Electric Vehicles (HEV) has taken a new impulse. These technologies can be observed in the consecutive auto shows around the world in the shape of conceptual designs. An incipient presence in the market is appreciated in the last years, basically with hybrid technology combining two or more energy systems. In accordance with the use of new and clean energy sources, photovoltaic solar energy plays an essential role in the implementation of clean energies as main electricity source for EVs. A zero-emission solar vehicle is powered by photovoltaic solar energy by means of solar panels, with storage of electric energy in batteries, and the traction is obtained by an electric motor, this is the basic idea. Nevertheless, solar energy for vehicle applications is not an obvious issue because several critical
Points must be care-fully analyzed, e.g.

a) The efficiency and costs of photo-voltaic panels,
b) How to maximize the solar radiation, and
c) The energy management and control

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At present there are numerous solar vehicle projects around the world for multiple purposes. From the applied research point of view, interesting contributions have been presented in the last two years, e.g., in a photovoltaic powered zero-emission electric vehicle is presented in the context of an educational project. In a solar and wind powered HEV, with an internal combustion engine was proposed, and initially tested in a commercial product. A hybrid energy system for an EV is proposed in, including solar panel, battery and super-capacitor, jointly with the system configuration and control strategy analysis. A project involving battery powered electric vehicles charged

Currently, the most typical rechargeable batteries in hybrid and fully electric vehicles are lithium-ion (Li-ion) cells, which are characterized by a greater specific energy with respect to other common battery cells of different chemistry. In addition, a Li-ion cell is not affected by the memory effect and it has a slow loss of charge when not in use.

To obtain the voltage and the capacity required by a specific application. The management of a battery pack is performed through a Battery Management System (BMS), which can be implemented in many ways. This system is mainly devoted to
(i) Constantly monitoring the state-of-charge (SOC) of the various battery cells.
(ii) Equalizing the SOC of all the cells.
(iii) Regulating the charging current.

II. DESIGN OF THE SOLAR VEHICLE

An experimental solar vehicle prototype was built in the context of an interdisciplinary project called “Pampa Solar” for promoting the use of clean energies in multipurpose vehicles. This is a vehicle with a hybrid system based on photovoltaic solar energy as main electricity source, and complemented by the contribution of human energy. One of the most important points in the construction of the vehicle is closely related to the chassis design, with the purpose of achieving a structural optimized work, and expressed in the lowest possible energy consumption for the vehicle’s movement. The design was conceived from a point of view of a high-efficiency, lightweight and stable transport, with reduced costs, and zero emission, in its operation and in the obtaining of the energy.

2.1. General Description

The solar vehicle was made with a structure of three wheels, in the shape of an inverted tricycle, for only one rider in recumbent position. The high-efficiency electric traction is achieved by a 48V – 2kW brushless in-wheel motor. Besides, it has an accommodation for the battery behind the seat, and a rear-mounted structure for accommodating electronics and controllers.

2.2. Energy Contributions

The solar vehicle combines the use of electric energy from three different sources:

a) Photovoltaic solar energy,

b) Energy obtained through human contribution, and

c) Batteries.

Depicts the energy systems that constitute the base of the solar vehicle, jointly with the accumulator of these energies. The photovoltaic solar energy is obtained from five photovoltaic solar panels that supply the battery through the panel’s Maximum Power Point Tracker (MPPT), operating in buck mode

The batteries constitute the storage system of the electric energy and contribution when the electric motor requirements have a power request greater than the input. The battery pack has an intelligent charge-discharge system called Battery Management System (BMS) that monitors the voltage of each cell, protecting it against overloads and charge imbalances, thus ensuring the capacity of the entire pack at different temperatures and its working life.

2.3. Battery Choosing

The correct dimensions of the battery establish the autonomy degree of the solar vehicle. The goal is to search for a suitable relation among weight, volume, lifetime, cost, energy density, and environmental impact. At the same time, these factors must be expressed in the lowest possible weight and volume of the vehicle. In our case an exhaustive analysis of alternatives and existing technologies on the market was made for determining a convenient relation among the aforementioned parameters.

III. CHARACTERISTICS

a) Solar panel specifications

Solar cells are solid state semiconductor devices which convert light energy directly into electrical energy. A solar cell contains a low voltage typically about 0.45 volts per cell; cells are connected in series to increase voltage. The generated current depends on the solar irradiance, temperature and load current. The typical equivalent circuit of PV cell.

i) Energy during driving time(Edt)

The energy produced during a running period of a vehicle is calculated by the following expression.

Edt = ŋpv*Apv*esun *[(SEsun - SEPT)/ SEsun]*[(BAct - BAdt)/BAct] ------(1)

ii) Energy during Parking Time (Ept)

The energy produced captured during the parking period of vehicle is calculated by the following expression.

Ept = ELDT +ŋpv*Apv*esun *[(SEsun - SEPT)/ SEsun]*[(BAct - BAdt)/BAct] ------(2)

Where,

ŋpv – PV Panel efficiency

Apv- PV Surface Area

esun – Average energy enough by solar panel captured.

SEsun – Solar energy captured during a sun at (7 AM to 6 PM)

SEPT – Solar energy during a parking time.

BAct - Battery Charging time.

BAdt - Battery Discharging time.

ELDT - Energy loss during driving time.

During sunless conditions, battery will be charged with the help of electric power supply (230V, AC). It can be stepped down and can be rectified into DC with the help of Diode Rectifier.

Ebat = Ŋac*[(BAct - BAdt)/BAct] ------(3)

Ebat – Energy stored in battery due to power supply

Ŋac – Power supply efficiency

Total power = Driving time + Parking time

E=Edt+Ept ----- (4)

Ipv – PV Current in Amps.

Vpv – PV Voltage in Volts.

ID - Diode current in Amps.

IRP – Parallel Resistance current in Amps.

IRS – Series Resistance current in Amps.

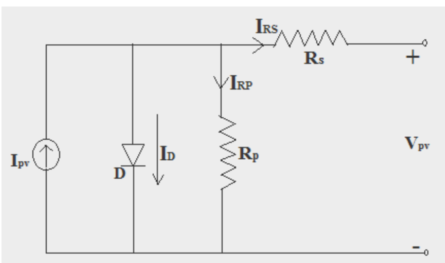

Fig.1. Equivalent Circuit of PV Cell

The Solar Module mounted on the top of vehicle is used to charge the batteries via charge controller. The upper frame of this solar module is converted with thick glass to avoid breakage of the solar panel. After that the electric supply are stepped down with the help of step down transformer and rectified with the help of diode rectifier and connected to the lead-acid batteries. the current and the voltage waveform of 230Watts Solar Module.

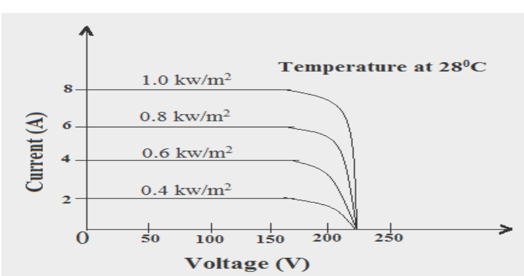

Fig.2. V-I Curve of the 230 watts Solar Module

b) Charge controller and battery specifications

Charge controller limits the rate at which electric current is added to or drawn from the electric batteries. The prime purpose of using the charge controller is to prevent against overcharging and deep charging of a battery. In the SEPHV design we will be taking a depth of discharge to be 85%.Temperature correction is needed because at low temperature battery efficiency decreases.

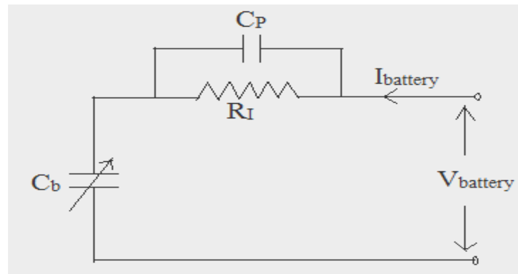

Fig. 3. Equivalent Circuit of Battery

CP – Polarization Capacitor in Farad

Cb – Variable battery Capacitor in Farad

RI – Internal Resistor in Ohms

Vbattery – Battery Voltage in volts

Ibattery – Battery Current in Amps

The correct dimensions of battery establish the Solar/Electric Powered Hybrid Vehicle. The goal is to search for a suitable relation among weight, volume, life time, cost, energy density and environmental impact.

These factors must be expressed in the lowest possible weight and volume of the SEPHV. For the 24V/150AH battery bank, 24V/12A solar charge controller is an ideal choice. Charge controller is connected between the solar modules and the batteries. In represents equivalent circuit of battery model. It includes the internal Resistor and Polarization capacitor (Cp)

IV. RELATED WORK

(i). Battery Cell Balancing

The individual cells in a battery pack typically have somewhat different capacities and they may be at different SOC levels. This phenomenon may limit the energy that can be taken from and returned to the battery since the discharging phase must stop when the cell with the lowest capacity is empty, even though other cells have an SOC 6= 0.

Although charging Li-ion batteries is generally based on a standard protocol, the Constant Current - Constant Voltage (CC-CV) mode , methods for cell balancing differ depending
on the battery management policy. These methods can be divided into two main classes: passive and active. Passive balancing relies on the principle that the energy of the cells with the highest voltage is "wasted" through a power resistor connected in series with a control MOSFET transistor.

(ii). Vehicles with solar panels
In general, comprehensive analysis of conversion efficiency, from solar energy to battery charge, is provided in. In the patent by Ward, a low-voltage solar panel on a hybrid vehicle directly charges battery cells, individually or in series, but with no power optimization through Maximum Power Point Tracking (MPPT) techniques.

This paper proposes an active balancing approach that uses solar power from PV modules installed on the vehicle. The battery pack is charged with the PV energy following an algorithm (described later), which balances the cells voltage that is, the SOC of the cell strings belonging to the battery pack. In the case of partial shading of one of the solar submodules, the related MPPT device is still able to maximize the power transfer and to provide a contribution to the total current; in the case of complete shading of one sub-module.

A. Operating mode analysis
The following paragraphs show the capability of the system to transfer energy efficiently in different operating modes of the car. We analyze three main different scenarios, which are based on the current requested for the traction (I motor) and auxiliary systems (Iaux), other than on the current provided by the PV cells (I solar).

1) Car Stopped, Auxiliary Systems Turned Off: In this configuration, typical of long-stay parking, no charge is applied to the battery pack, but the solar cells can provide energy.
Without solar contribution, the state of charge of each module stays the same, or decreases moderately due to leakage.

$Imotor = 0; Iaux = 0; Isolar > 0$ (1)

2) Car Stopped, Auxiliary Systems Turned On: This configuration is typical, for example, of a parked car with an antitheft system powered with a converter attached to the main car battery.

$Imotor = 0; Iaux > 0; Isolar > 0$ (2)

In this case, two situations are possible, depending on the proportion between the energy amount requested by the loads and the one available from the solar source. In the former case,
$Isolar \geq Iaux$ (3)

Therefore the solar energy contribution will partly feed the auxiliary load, and will partly charge one of the battery modules. By periodically switching the connected battery module, it will be possible to slowly fill up the battery pack. In the latter case we have

$Isolar < Iaux$ (4)
3) Car Moving: This last configuration, is characterized by

$Imotor > 0; Iaux \geq 0; Isolar > 0; Imotor + Iaux > Isolar$ (5)

B. System Management Strategies
Although the battery pack has a high nominal voltage, e.g., 120V, a lower voltage is needed for charging the cells. The boost converter SPV1020 adopted here provides an output voltage in the range between 0 and 40V and, therefore, it can be connected to the strings, one at a time. This technique requires special care to avoid creating a high unbalancing of the various strings during charging. This can be achieved by transferring to each string, alternately, the energy generated by the solar cells, starting from the string with the lowest SOC. Hence, the charge of each string will increase each time by a certain percentage until the SOC is equal to 100%.

V. ENVIRONMENTAL IMPACT

Renewable source of energy provides solution to many problems. Solar energy can contribute to the sustainable development of human activities. One of the main advantages of the use of solar energy is the reduction of the green houses gases emitted by the use of the fossil fuel in the conventional power plants. Due to the increase in the CO_2 concentration in the environment. This is the high time to shift from non-conventional sources to conventional sources. The pollution level and the diseases increased by the use of the hazardous sources that we are using for fulfilling our daily needs. The sun is the best source of energy if we capture the sun energy we can get up-to 1000 times the present requirement. The cost of the conventional fuels are also going up and scarcity of the fuels is also there, therefore government and also the private sector needs to invest and take interest on the solar energy.

VI. CONCLUSION

In this paper we addressed the problem of transferring the energy generated by an on-board solar cell system to the main battery pack of an electric vehicle. Three alternatives were presented and one was selected due to the improved efficiency thanks to the reduced number of conversion steps required. For this solution, based on the interaction with the BMS devices, we performed additional analyses and presented an algorithm for balancing the SOC of the battery cells during the charging phase. The analysis and results of the simulations performed in realistic conditions demonstrate that the proposed architecture is suitable for extending the driving range of electrical or hybrid vehicles, by maximizing efficiency and by guaranteeing a good battery cells balancing. By the latter improvement, it is also reasonable to expect an extended battery life

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