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Smart Charging of PHEVs Based on Efficient Battery Back-up Architecture

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Abstract: *The Upcoming researches in the field of plug-in hybrid electric vehicles (PHEVs) and the growing global awareness for a pollution free environment will lead to an increasing demand in PHEVs in the near future. A smart charging system is proposed such that the overall power of PHEVs does not drain under any condition until the lifetime of the vehicle battery. The power needed to charge the plug-in hybrid comes from two sub-batteries. The three way interaction between the PHEV and the two sub-batteries ensures optimal usage of available power. The system designed to achieve the desired objective consists of DC/DC boost converter, DC/DC buck converter, and the two sub-batteries.*

Keywords: *Plug-in hybrid electric vehicle, boost converter, buck converter, sub-battery back-up.*

I. Introduction

Compared to conventional vehicles, PHEV reduce air pollution locally and also the dependence on petroleum. PHEVs reduce green house gas emission and contribute to global warming. The most recent research was the use of photo voltaic system to charge the PHEVs [1]. But it has the disadvantage of high cost and it completely depends on the change in weather conditions. Hence, it's time to develop a smart charging technique where sub-battery architecture is used to charge the PHEVs. The reasons to choose a sub-battery back-up are:

- The required power comes from a cyclic distribution of power between the main battery and the two sub-batteries, so that power does not drain until the battery life-time.
- The sub-battery back-up is also within the electric vehicle by which there is no dependence on other external energy resources.

A review of literature suggests that research on PHEV charging is being carried out around the world with keen interest. In reference [1], the author proposed a PV (Photo Voltaic) integrated system to charge the PHEV where the system mostly depends on solar energy.

In reference [2], full charging of battery pack can take 4-8 hours and even a quick charge to 80% capacity can take 30 minutes. Thus our proposed system avoids the need to charge the PHEV externally.

In most of the cases AC charging is employed, because AC system has been used for years and there are well developed standards and technologies. DC charging on the other hand increases the overall efficiency by reducing the number of power conversion stages and also offers the advantage of fast charging [3]-[5]. As shown in Fig. 1 PHEVs are directly connected to the DC link by employing a DC/Dc buck converter. The proposed architecture is an effective solution for charging PHEVs using a sub-battery back-up.

An Intelligent Energy Management System (IEMS) is proposed in [6]. The IEMs allocates power to the vehicle battery chargers through real time monitoring, to ensure optimal usage of available power, charging time and grid stability. However, control and architecture of the power electronic interface needed to implement the IEMS is not discussed.

The concept of DC Bus Signaling (DBS) has been employed to supply power to the DC loads. DBS induces DC bus voltage level changes to realize the communication between different source/storage interface converters [7],[8]. Though DBS is a novel idea it has great impacts on the DC bus voltage level.

This paper overcomes these disadvantages and validates the practical feasibility of the proposed control strategy through experimental results using a laboratory prototype. Based on the power levels of the two sub-batteries, the operation of the proposed architecture can be categorized into two modes, when P1 (power in battery 1) is greater than P2 (power in battery 2) and when P2 is greater than P1.

II. Significance Of The Proposed System

It is predicted that there will be one million plug-in hybrid electric vehicles on the road by the year 2015 [9], [10]. This indicates the need for a smart charging technique. PHEVs are greatly suited for urban areas and it is said to improve the local air quality.

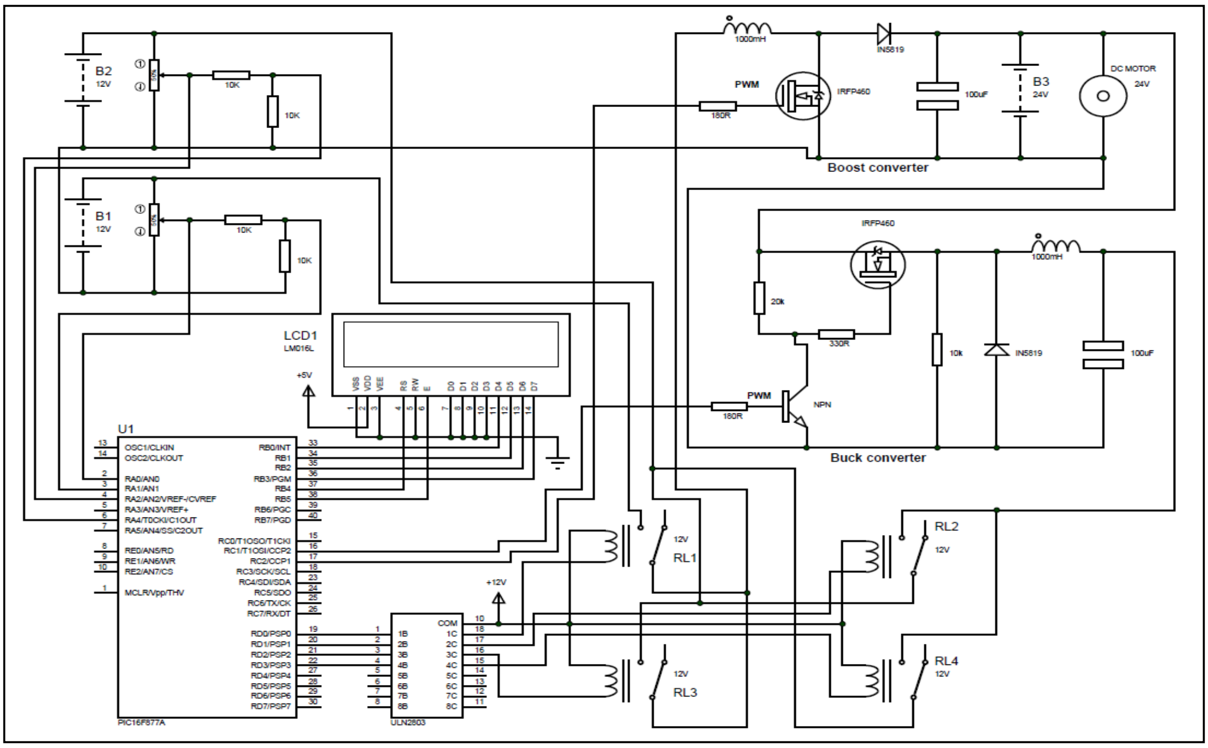

Fig 1: Detailed block diagram showing the controller and converter circuit

The goal of the proposed architecture is: to charge the PHEVs using minimum energy from the utility with a kind of demand side management to improve the energy efficiency. Smart charging techniques like the one proposed in this paper will be required to avoid major expense to upgrade the transformers and other substation equipment [11]-[12].

III. Architecture Description

Fig.1 shows a detailed block diagram of the proposed charging system architecture. This architecture is a laboratory prototype. The main components of the charging system are, the two sub-batteries (B1 and B2), the main battery B3, boost converter, buck converter, LCD terminal and the controller. The block diagram in Fig. 1 and the following control description is based on charging requirements of a single PHEV.

In our proposed system we have used three batteries to operate the boost and buck converters. The two batteries (B1 and B2) are connected to the input side of the boost converter and another battery B3 which is the main battery is connected to the boost converter output side.

If the two batteries (B1 and B2) powers are full, the microcontroller will give the priority to any one battery to distribute the input power to the boost converter. Suppose B1 power is full and B2 power is low means the lower power battery is charged by the buck converter and the charge full battery distributes the input power to the boost converter.

Thus the boost converter is stepped up to the input voltage and its output is given to the main battery and the buck converter input. The buck converter is stepped down to the input voltage and the converter output is directly connected to the low power battery for charging purpose.

The controller monitors and controls the power flow in the system. As shown in Fig. 1, the controller operation is based on the four inputs- current and voltage of B1, current and voltage of B2. The controller generates PWM (Pulse Width Modulation) signals at 20 kHz to facilitate the switching of the inverter switches. PWM signals at high switching frequency ensures a sinusoidal voltage at the inverter output.

Four relays RL1, RL2, RL3, and RL4 are used. RL1 and RL3 are used for selection of boost converter when the power needs to be boosted for any one of the batteries B1 or B2. RL2 and RL4 are used for selection of buck converter, when the power needs to be stepped down.

Fig. 2 represents the picture representing the proposed idea. Here the battery pack consists of the main battery and the sub-batteries. The cyclic exchange of power between these three batteries ensures that the power does not drain until the life time of the batteries. The plug-in facility is an optional one, where it can or cannot be used depending upon the wish of the car owner.

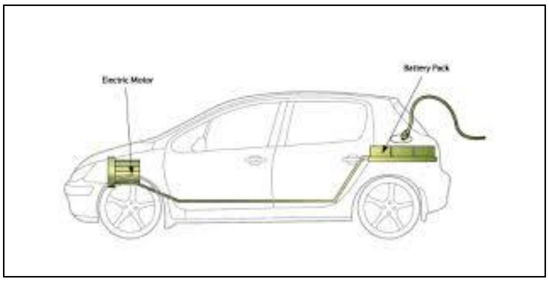

Fig. 2. Picture representing the proposed idea.

IV. Component Description

For the purpose of laboratory prototype we have used three small range lead-acid batteries for exhibiting the proposed idea. The different components used in fig.1 are explained in this section.

4.1. Boost Converter

The key principle that drives the boost converter in Fig. 1 is the tendency of an inductor to resist changes in current by creating and destroying a magnetic field. Here we have used a MOSFET (Metal Oxide Semi-conductor Field Effect Transistor) operated boost converter circuit.

When the switch is closed, current flows through the inductor in clockwise direction and the inductor stores some energy by generating a magnetic field. Polarity of the left side of the inductor is positive now.

When the switch is opened, current will be reduced as the impedance is higher. The magnetic field previously created will be destroyed to maintain the current flow towards the load. Thus the polarity will be reversed (means the left side of the inductor will be negative now).

As a result the two sources will be in series causing a higher voltage to charge the capacitor through the diode. Thus the output voltage is always higher than the input voltage for a boost converter.

4.2. Buck Converter

A buck converter is a voltage step down and a current step up converter. In Fig. 1 when the switch is closed, the current will begin to increase and the inductor will produce an opposing voltage across its terminals in response to the changing current. This voltage drop counteracts the voltage of the source and therefore reduces the net current across the load. Overtime, the rate of change of current decreases, increasing the voltage at the load. During this time, the inductor is storing energy in the form of magnetic field.

If the switch is opened while the current is still changing, then there will always be a voltage drop across the inductor. Thus the net voltage at the load will always be less than the input voltage source for a buck converter.

4.3. Controller

In the micro controller family, PIC16F877A is more widely used device in the recent times. The reasons for its wide usage are its large memory capacity and its adequate input/output ports. It has an internal analog to digital converter which is used to detect the voltages of B1 and B2 and convert them to digital values. The five ports of the controller are, Port A, Port B, Port C, Port D and Port E.

Here Port A is interfaced with the internal analog to digital converter. Port B is interfaced with the LCD (Liquid Crystal Display) Port C is used to generate PWM (Pulse Width Modulation) signals that operate the switches of the boost and buck converters. Pulse Width Modulation is a powerful technique for controlling analog circuits with a processor’s digital outputs. Port D is interfaced with the four relays using ULN2003A.
The micro controller is programmed using CCS (Code Composer Studio).

4.4. Relay

A Relay is an electrically operated switch. Relays are used where it is necessary to control a circuit by a signal (with complete electrical isolation between control and controller circuits), or where several circuits must be controlled by one signal. Here the four relays used are RL1, RL2, RL3 and RL4.

4.5. LCD (Liquid Crystal Display)

LCD screen is an electronic display module and is used in wide range of applications. LCDs are economical, easily programmable, have no limitation of displaying special and even custom characters, animations and so on. To indicate the voltage of the main battery here the LCD is interfaced with the micro controller.

4.6. Batteries

The architecture is designed with three lead acid batteries. The range of the two sub-batteries (B1 and B2) is 12 V 1.2 Ah batteries and the range of the main battery (B3) is 24 V 2.4 Ah batteries. These three batteries work simultaneously such that their power range is maintained throughout the battery life time.

The lead-acid batteries are rechargeable batteries. Despite having a very low energy-o-weight ratio and a low energy-to volume ratio, its ability to supply high surge current means the cells has a large power-to-weight ratio. These features, along with their low cost make it attractive for use in motor vehicles to provide the high current required by automobile starter motors.

4.7. ULN2003A

AnULN2003A is a high voltage, high current Darlington transistor array. It consists of seven NPN Darlington pairs that feature high voltage outputs with common cathode fly back diodes for switching inductive loads. The drivers can be paralleled for high current capability, even stacking one chip on top of another, both electrically and physically has been done.

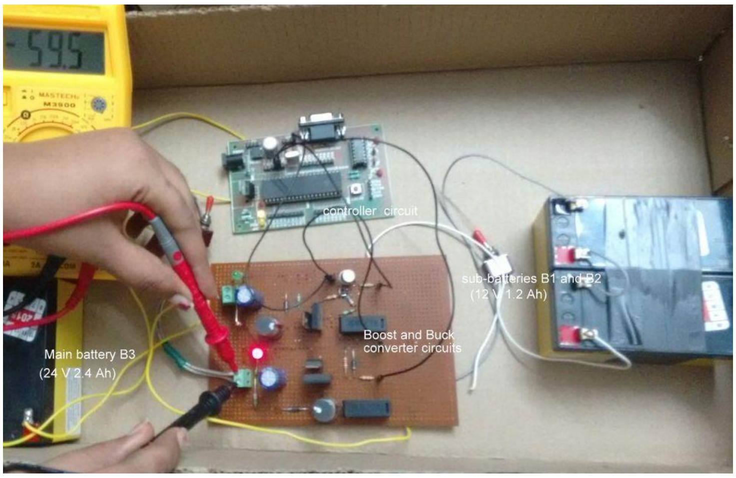

Fig. 3. Experimental setup

V. Operating Modes

Fig.3 shows the experimental set-up of the system. The components include micro-controller circuit, boost and buck converter circuit, two sub-batteries B1 an B2, and the main battery B3. In the place of PHEVs 24 V 2.4 Ah battery is used. Initially the micro controller checks for the voltage and current of B1 and B2. Since both B1 and B2 are said to have equal voltage and current of 12 V 1,2 Ah, the micro controller gives priority to any one of the battery. The two modes by which the set-up works is described below.

5.1. Mode 1:

When the power of B1 is greater than the power of B2, then the relays RL1 and RL4 switches ON and RL2 and RL3 switches OFF, by which the power of B1 is delivered to the boost converter circuit. The incoming 12 Vis boosted up to nearly 59 V which is shown in Fig. 3. Thus this boosted voltage is given to the battery B3 which is the main battery of PHEV.B3 gets boosted-up until its requirement of 24 V. The excess voltage is then given to the buck converter, where its output is again fed to the battery B1where the voltage drop has been taken place. The stepped down voltage charges B1 until its requirement of 12 V.

5.2. Mode 2:

When the power of battery B2 is greater than the power of battery B1, then the relays RL2 and RL3 switches ON and RL1 and RL4 switches OO by which the power of B2 is delivered to the boost converter circuit. The process repeats again where the incoming 12 V is boosted up to be given to the battery B3 and the voltage is given to buck converter and then to B2 where the voltage drain has taken place. Here again the stepped down voltage charges B2 until its requirement of 12 V.

Thus the process takes place in a cyclic manner such that the power requirement of all the three batteries is maintained. Finally the results of the proposed idea were validated experimentally using a laboratory prototype as shown in Fig.3.

VI. Simulation Results

The results were also tested using the Proteus Design Suite Version 8.0 simulation software. Simulation till the boost converter circuit has been completed separately and the simulation of buck converter circuit is under process.

The circuit of Fig. 1 with only boost converter is implemented in Fig. 4. Here a virtual terminal is used to show the input power to the boost converter. The output voltage is indicated using a voltmeter and a LED indicates that the power has been boosted-up by which it turns Yellow.

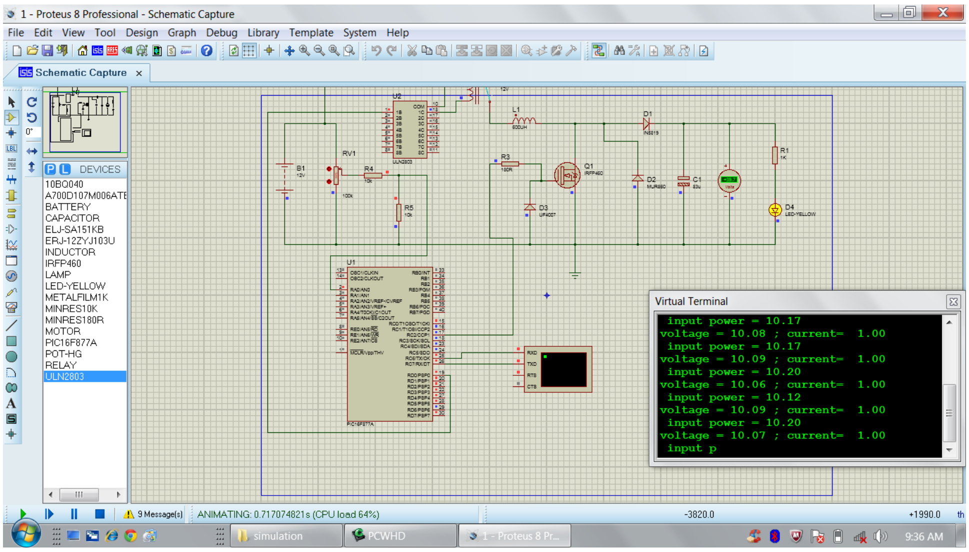

Fig. 4. Simulation result when power is less than 11 W.

6.1. Case 1:

The voltage and current of the sub-battery (B1) is sensed using a controller and is known using a virtual terminal. When the input power is less than 11 W, the voltage gets boosted-up to nearly 39 V which is shown using the voltmeter. When there is increase in the voltage, the LED glows which is indicated using the LED turning Yellow as shown in Fig. 4.

6.2. Case 2:

When input power is greater than 11 W, voltage drain takes place and it is viewed using the voltmeter. Simultaneously the LED turns OFF slowly as the voltage drop takes place. This result is shown in Fig. 5.

Thus using simulation tool, the boost converter circuit to indicate the increase in the voltage of the sub-battery (B1) is verified.

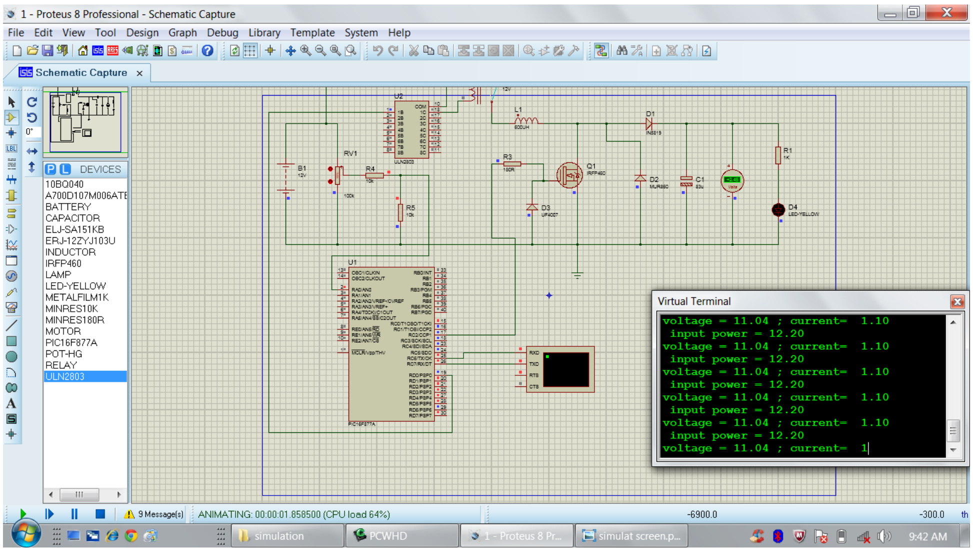

Fig. 5. Simulation result when power is greater than 11 W

VII. Conclusion

This paper presents a charging system architecture by using a combination of sub-battery back-up and smart charging technique. A unique control strategy based on DC link voltage sensing, which decides the direction of power flow is presented and the various modes of operation have been described. The practical feasibility and effectiveness of the proposed control strategy has been validated by experimental results from a laboratory prototype. Similarly the simulation results till the boost converter circuit have been carried out separately and for the buck converter circuit is under process. Smart charging techniques like the one proposed in this paper will avoid the need to depend on external charging techniques to charge the PHEVs.

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