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Fast Charging of Batteries Utilized in Electrical Vehicle

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***Abstract*: The scarcity of fossil fuel and increasing pollution leads the use of electrical vehicles (EV) and hybrid electrical vehicle instead of conventional internal combustion(IC) engine vehicle. The scope of this paper is to design and develop an electrical vehicle fast charge controller using battery management system (BMS) with Cuk Converter that is powered by an electric motor which gets its supply from rechargeable batteries. This paper will focus on, main battery (lithium ion) and auxiliary battery (lead acid) parts of battery storage, aimed to fast charging of electrical vehicle. An electrical vehicle requires an on board charger (OBC) to charge the main as well as auxiliary battery. The objective of this paper is to design a charger to charge both the battery fast and to reduce the charging stress on main battery by employing an auxiliary battery in Battery Management System. Due to such BMS to enhance battery lifetime, to avoid prolonged charging and to reduce overall cost of battery management system. These proposed topologies are simulated in MATLAB software and some results are show the performance of the system.**

***Keywords*: Bi-directional DC-DC converter, Buck Boost converter, Battery, Isolated converter, Fast charging, Cuk converter**

1. Introduction

Rapidly increasing air pollution, fossil fuels consumption in the world, concerns relevant to security and price of energy and increasing global warming are combined to indicate that an acceptable solution is required to replace the internal combustion- engine (ICE) vehicles. Therefore, the research institutes and car manufacturers are encouraging to improve recent technologies and deploy of new technologies concepts such as EVs, plug-in hybrid vehicles (P``HV), and fuel cell vehicles in order to address these problems surrounding the ICE vehicles. However, this type of cars as an immature technology suffers from some problems such as short driving range and high cost. To solve these problems, Energy storage system (ESS) acts an important role. Performance of ESS from weight, volume, and cost and life cycle aspects should be improved to make EVs competitive with conventional vehicles. Battery as a common energy storage device is the most important element to improve EVs operation which represents an expensive component in the system. According to today's technologies, batteries that can supply an EV to run an acceptable driving range comparing with ICE, are very expensive. Another option to improve EVs operation is Hybrid energy storage system (HESS). HESS combines two or more energy storage devices such as battery, Ultra capacitor (UC) and fuel cells. In the HESS topologies which battery is utilized, battery only provides average power (energy) while other sources handle peak power during acceleration and regenerative braking; therefore, batteries have an outstanding role. Over the last years, different types of batteries such as lead acid, nickel-cadmium (Ni-Cd), nickel-metal hybrid (Ni-MH), and Lithium- ion (Li-ion) are employed in EVs applications. The well improved structure of this kind of battery which can be considered as maintenance free is known as Valve Regulated Lead Acid (VRLA) battery. Lead-acid battery has relatively good response time and their efficiency is in the range of 95% to 99%. Higher weight and volume which lead to low energy density compared to other types are the main disadvantage of lead-acid batteries. Ni-Cd batteries are utilized when long life time, high discharge rate, and cost are important factors for designers. However, low energy density and environmental issues are disadvantages of Ni-Cd batteries. Ni-MH battery is able to work in high voltage and has higher energy density but their life time is lower than other batteries.

Recent advancements in Li-ion battery technologies lead to improved power and energy density. Also they have an outstanding capability for long lifetime. Because of these advantages, Li-ion battery is a preferred choice for utilizing in ESSs. In EVs that high power and energy density is required for acceptable mileage, several battery cells should be connected in series and parallel. Employing a bidirectional converter for providing a specific voltage level to drive the system and managing power flow is necessary. Several bi-directional DC-DC converters for energy management in EVs are reported in literature. They can be categorized into basic topologies such as Half-bridge converter, Cuk converter, and SEPIC/Luo converter and derived topologies such as cascaded half-bridge converter and interleaved half-bridge converter. In this regard battery charger is categorized to on-board and off board. On-board charger has weight, volume, and cost constrains, hence this type is not used in high power. To solve this problem, in the on-board charger is integrated with the drive system. In other hand, one of the significant issues regarding EVs, is prolonging the lifetime of batteries, causing lower expenses for the customer due to later necessity of battery pack exchanging.

2. Principle of operation and control

In this paper a topology with the capability of utilizing two types of batteries alongside each other in charging and discharging modes is proposed. One of these batteries perform as the main battery of the EV and the other one will act as an auxiliary battery which can be used for fast charging, battery exchanging and acceleration. As shown in Fig.1 The proposed structure consists of two batteries, a relay for connection and disconnection of the auxiliary battery and a Cuk converter as an interface between the main battery and the auxiliary battery. This structure is capable of performing in different scenarios like: charging both batteries at the same time, discharging the main battery in the drive system and discharging the auxiliary battery in the main battery and the drive system. The key point of using two kind of batteries is that fast charging stresses are relegated to the auxiliary battery to have more desirable charge process for the main battery. Another advantage of this structure is ability of replacing a discharged auxiliary battery with a fully charged one, which will significantly decrease the dwell time of EV drivers in charging stations. Li-ion batteries are less weighted, more efficient and environmentally-friendly, which make them a preferred choice for the main battery of proposed structure. Although Li-ion batteries have many benefits, they are more expensive and fast charging strategies decrease their life time, hence employing them as auxiliary battery will not be economic. Lead-acid batteries have less energy density than Li-ion batteries but capability of charging/discharging in high rating current and being economically cost efficient make them a desired option for the auxiliary battery. Due to structural differences between main battery and auxiliary battery, employing a DC-DC converter between them for power sharing is essential. There are many different types of converters available, however a converter with characteristics like low voltage ripple and continues input and output current should be utilized. These attributes enhance battery lifetime and durability.

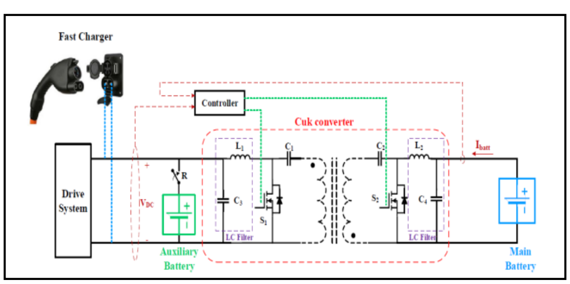

Fig. 1. System topology

Buck, Boost and Buck-Boost converters have discontinuous current in input, output or even both of them. Cuk converter satisfies the required characteristics, so it will be a suitable choice for this purpose. In this paper an isolated bidirectional Cuk converter for charging and discharging the batteries is presented. Isolation and voltage polarity adjustment are the major benefits of using a high frequency transformer. Size of this transformer will not be a concern in this application cause high switching frequency will reduce the transformer size significantly.

The operation of proposed topology is categorized into three main scenarios. Each scenario will be discussed completely below.

- *Scenario 1:* In this scenario auxiliary battery's relay is closed and batteries are charging in fast charging station. Fig. 2 shows the current flow direction and relay status in scenario 1. In this scenario switch S1 is being controlled, while switch S2 is off and power is flowing through its parallel diode. A current controller will provide constant current charging for the main battery and prevents harsh current changes in case of any variations in the fast charger output current. This will help the expensive battery charging to be more efficient which will enhance battery lifetime.

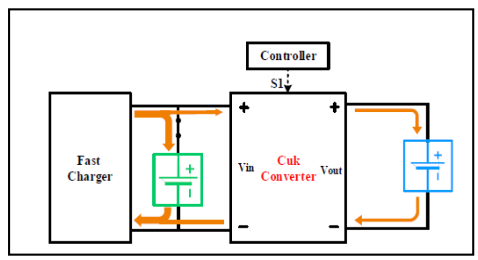

Fig. 2. Scenario 1

- *Scenario 2:* In this scenario the EV has started working and the fast charger is no longer connected. Auxiliary battery is the main energy source of the EV. The priority of the auxiliary battery is providing required energy of the drive system while excess power can charge Li-ion battery. The controller will ensure constant current charging mode of Li-ion battery (similar to scenario#1). This scenario continues until lead-acid battery reaches its Depth of Discharge (DOD) limit. Fig. 3 shows the current flow direction and relay status in scenario 2.

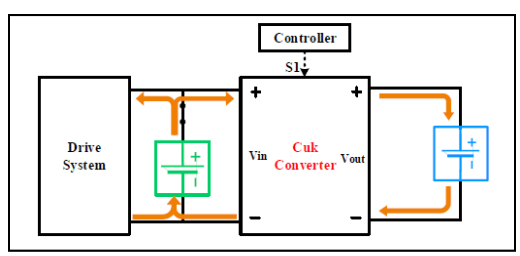

Fig. 3. Scenario 2

- *Scenario 3:* In this scenario the lead-acid battery is not available or it has reached its DOD limit so the auxiliary battery's relay is opened. The Li-ion battery is the main ESS and it supplies the drive system. Role of the controller in this scenario is different from the last scenarios. The controller which is shown in Fig.4 tries to stabilize DC link voltage at a constant value regardless of Li-ion battery voltage changes. Constant DC bus voltage helps inverter of the drive system to work smoothly and efficiently. Fig. 4 shows the current flow in scenario 3.

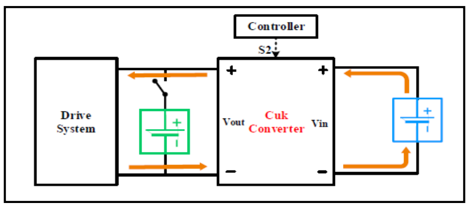

Fig. 4. Scenario 3

3. Simulation results and graph

In order to verify the proposed structure in different scenarios, the structure is simulated with MATLAB/Simulink Software and results are presented in this section.

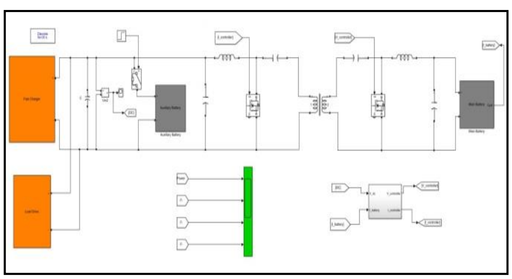

Fig. 5. Simulation block diagram

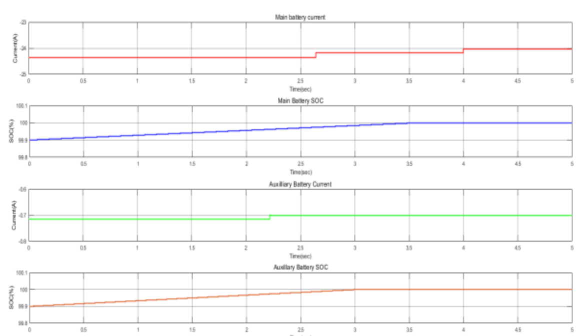

Fig. 6. Simulation result in scenario 1

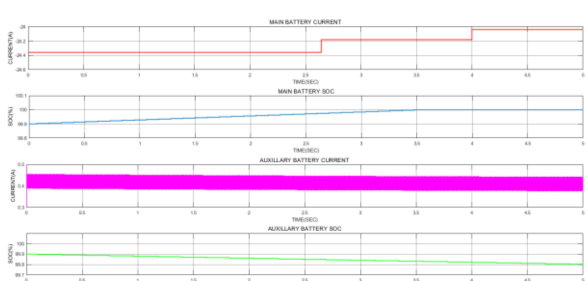

Fig. 7. Simulation result in scenario 2

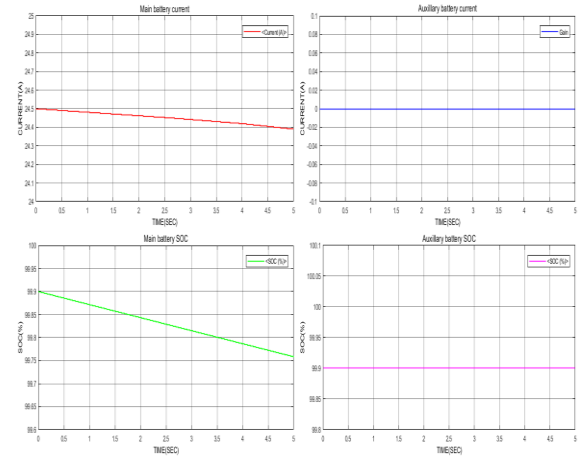

Fig. 8. Simulation result in scenario 2

4. Result

By testing all the parameters simulated in MATLAB /Simulink software and considering all the specification we get the result that the minimum time is required to charging the battery.

Table 1
Comparison between EV available in market and project topology

Specification	Hero Electric Flash LA	Benling Falcon	Proposed project
Range	50km/charge	75 km/charge	150-170km/charge
Motor power	250W	250W	300W
Charging time	8-10Hr	6-8Hr	3-4Hr for both batteries
Max speed	25kmph	25kmph	35kmph
Battery type	Lead acid	Lithium ion	Lead acid and lithium ion
Battery capacity	48V 20Ah	48V 24Ah	48V 24Ah 48V 20Ah
Efficiency	Good	Good	Excellent

Aimed to fast charging of electrical vehicles is success using battery management system (BMS) with the help of Cuk converter. The initial investment is quite high due to high price of battery and other electronics components but running cost is extremely low due to no requirement of any conventional type of fuel. The economic and eco-friendly energy used in the electric vehicle is makes it more superior.

5. Conclusion

In this project, a BMS including two different battery types and an isolated bidirectional Cuk converter for EVs was proposed. Li-ion battery is dominant type of battery in EVs due to its advantages, while other types like lead-acid can be employed in this application. Here, reducing fast charging stresses on the main battery was achieved by utilizing a lead acid battery as an auxiliary battery. An isolated Cuk converter was utilized to manage contribution of the batteries and enhance battery lifetime by achieving low voltage ripple and continues current. Three possible scenarios were considered to evaluate the performance of the proposed topology and control algorithm. The results confirm that the proposed converter is able to handle different functions in various conditions, desirably.

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