Experimental study and analysis of Modular Multilevel Converter with Controlling system for Electric Vehicle Application

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Abstract

Electric vehicles system (EVs) are in high demand today due to rising fuel prices and environmental pollution concerns. Since the backbone of EVs is an energy storage system, careful and efficient control of the energy storage system in terms of power, current and temperature is essential. Typical AC current harmonics introduced by the operation of the Modular Multilevel Converter (MMC)-EV will accelerate battery degradation and are detrimental to battery lifetime. This work addresses this problem by introducing a converter topology that allows better utilization of battery cells and improves the efficiency of the energy conversion system. A power conversion system for plug-in hybrid electric vehicles based on a "back-to-back" modular multilevel converter is proposed to solve the problem that conventional MMC-EVs.

Keywords-Modular Multilevel Converter (MMC), Battery Management System, Electric Vehicle.

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1. Introduction

This paper proposes a detailed energy conversion system and control methods to integrate the motor drive, AC and DC load functions of the MMC into EV. The methods for state of charge (SOC) balancing of the MMC were verified in discharge mode, while for AC or DC charging operation, it was not included. In terms of topology, the proposed MMC battery system could be directly connected to the various AC or DC power supplies without any additional hardware on board other than the internal latch switch. Balancing SOCs in MMC in offload mode was demonstrated. Therefore, this paper will mainly focus on the detailed SOC balancing methods in dc and ac charging modes with the specific operating principles presented.Furthermore, to meet the diverse demands of electric vehicles, a new inverter must be selected or even designed for each application. This process prolongs the total development time and increases the cost. With a modularized and scalable design, however, transmission systems for a wide range of applications, from small personal vehicles to large commercial vehicles, can be built more easily using different numbers of identical sub-modules. By properly controlling the submodules, efficiency can also be optimized under all conditions. In previous research, modular multilevel converter (MMC) and cascaded H-bridges were adopted as modular drivetrain solutions for electric vehicles.

In a submodule, some studies directly use a battery cell (or several cells in parallel) to get rid of the equalization circuit, but hundreds of submodules must be cascaded to reach the required voltage. Thus, control is extremely complicated and the overall efficiency is affected. Others use higher voltage battery cells to reduce the number of sub-modules, but a balancing circuit is still needed for balancing. The dilemma caused by the low voltage of the battery cells can be solved by adding a DC/DC converter in each sub-module to increase the voltage. Power electronic transformer (PET) structures can be one of the ideal converters due to their high power density, high efficiency and flexibility. Battery cell capacity is determined by several factors, including cell impedance, temperature, age, and charge. Consequently, the capacities of the cells present in a battery vary among themselves, even if they are of the same specification (Lu et al., 2013). In high voltage applications, the package voltage is the sum of the voltages of the individual cells of a string connected in series. With the same current drawn from the cells connected in series, an imbalance in the SOCs of the cells is observed due to the variation in capacities between neighboring cells. SOC mismatch increases over long periods of use when some cells are overloaded or discharged excessively than others. This can result in a battery failure and interrupt system operation (Lu et al., 2013).

Therefore, a cell balancing mechanism against the battery maintenance system (BMS) is required to keep the battery charge and discharge rates within desirable operational limits. Multi-level modular converters (MMC) have attracted great interest from power system designers due to their ability to operate over a wide switching frequency range with low power losses (Zhao, Li, Jiang, Lu, and Yuan, 2015).). Additionally, MMCs do not rely on capacitors, inductors or transformers for power sharing, meaning a compact design. Thus, the modularity of MMCs can be leveraged for use in mobile power systems consisting of many power cells. The output of each phase leg is connected to an H-bridge MMC that performs the DC to AC conversion. The converter switches are operated based on a high frequency precedence based charge/discharge procedure. As each power cell is connected to an MMC half-bridge, the controller is configured with a Pulse Width Modulation (PWM) switching scheme to discharge high SOC cells more than low SOC cells and vice versa for charging.

2. Literature review

De Wang et al. (2019), the application of multilevel modular converter (MMC) in electric vehicle (EV) systems has been studied as an emerging research topic in recent years, due to its many advantages such as high modularity, failure tolerance capability, high-quality output and the ability to integrate motor drive, onboard charger and cell equalization functions. **Rahul Jaiswal et al. (2019),** this paper presents a comparative analysis of a modular multilevel converter using a multicar modulation technique. Total harmonic distortion (THD) analysis was performed using phase-array pulse-width modulation (PD-PWM) and phase-opposition-array pulse-width modulation (POD-PWM) techniques at variable modulation and index of fixed switching frequency.

Di Wang et al. (2020), the multilevel modular converter (MMC) for electric vehicle applications has been studied in recent years, due to its advantages such as high modularity, fault tolerance capability and multi-function capability (drive motor, equalizer cell and on-board charger) integration. However, during MMC operation, certain AC harmonics will be introduced into the battery cell current, reducing battery life. **Nan Lee et al. (2020),** this paper proposes a multifunctional modular multilevel conversion system for an electric vehicle, which can provide only the engine drive function as well as AC and DC battery charging functions. To better illustrate the proposed system, operational principles and control strategies are thoroughly investigated, including state-of-charge (SOC) balance control strategies in conduction mode, DC or AC charging in charging mode.

Xingxing Chen et al. (2020), insulated gate bipolar transistor (IGBT) open-circuit faults adversely affect the reliable operation of modular multilevel V-converters (MMCs). Existing literature does not provide an efficient diagnosis algorithm for MMCs when multiple IGBT open-circuit faults appear simultaneously on one arm. This paper presents a diagnostic strategy for dealing with this condition.

3. Methodology

The submodule (SM) consists of a half-bridge circuit with battery and filter capacitor connected in parallel. A fuse is added to protect the batteries and switches from damage in the event of a failure. Due to the implementation of PWM switching, ripple currents will be imposed on the batteries. Basically, dc/dc interface converters are added to smooth out these wavy components. With more suppression devices installed, the space remaining for the batteries is further reduced, which will decrease the autonomy. It is encouraged to find that wavy components may not appear to have measurable impacts on the aging progress of lithium-ion batteries, due to the intrinsic double-layer capacitor on the surface of their electrodes.

The topology uses energy storage to distribute electricity, including batteries. Batteries can be designed to charge or discharge depending on requirements. If the inverter is expected to transfer power to the motor (assuming it is connected to the charging end of the inverter), the batteries will be active in output mode. Once the connected car's charge arrives, it resets the switch output, the batteries drain and is discharged. The described topology will be an integrated component of electric vehicles and will integrate batteries in each SM.

4. Experimental studies

The experimental setup consisted of various components such as Step-down Transformer, Bridge Type Rectifier, Blacking rectifier, Microcontroller PIC 18F452, Multilevel inverter, Rectifier for linear coil, Linear coil, Linear coil with magnetic field, Resistance, Capacitor, Filter, ON/OFF switch, Two way switch and Gear head DC motor, is shown in Table 1. Figure 4 shows the power analyzer results of the current harmonic (19.88%) of the use of the MMC without the filter during the OFF position of the two-way switch, thus the filter is not connected to the electrical vehicle system circuits. In Figure 5 the power analyzer results of the current harmonic (9.88%) using the MMC were shown with the filter ON position of the two way switch, thus the filter is the connected circuit of the electrical vehicle system.

5. Components

Table 1 Detail of Components with Specifications

Sl. No.	Components	Specifications
1	Step-down Transformer	48 VA
2	Bridge Type Rectifier	IN4007, 3Amp
3	Blacking rectifier	5408, 3 Amp
4	Microcontroller. PIC 18F452	28 pin activated, 500 mA
5	Multilevel inverter	Two stage, SP1, SP2, By Thyristor (T1-T8)
6	Rectifier for linear coil	IN4007, 3Amp.
7	Linear coil	100 henry, 120 henry.
8	Linear coil with magnetic field	Two step
9	Resistance	1 watt, 100 kΩ
10	Capacitor	1000uF, 60 VDC
11	Filter	4700 µF
12	ON/OFF switch	5 Amp X 2
13	Two way switch	5 Amp., F/R
14	Gear head DC motor	1 Amp. X 2, 48VDC
15	LED Chamber	500 mamp. X 2, 48VDC (Maximum)

16	Regulator , LM7805	5 Amp
17	PV Cells	12VDC X 4 Units, 22 Watts
18	Connection Wire	1 mm
19	Selector switch	4 Points
20	MMC Power Consumption	250 mamp., 12VDC

6. Experimental Setup

Figure 1 Experimental Setup

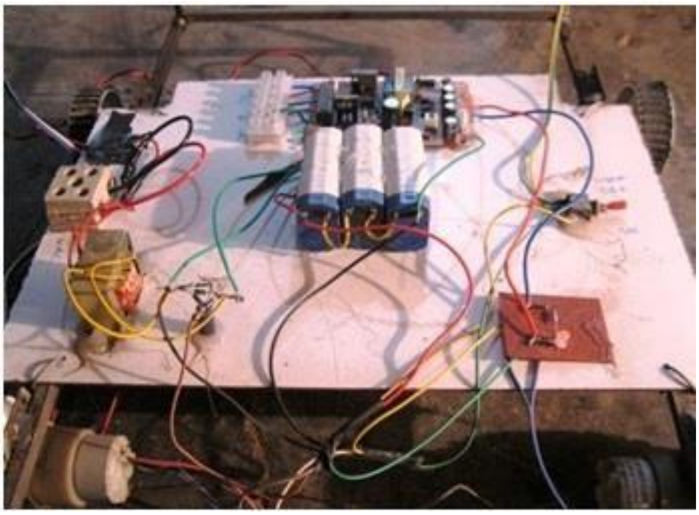

Figure 2 Control panel of Experimental Setup

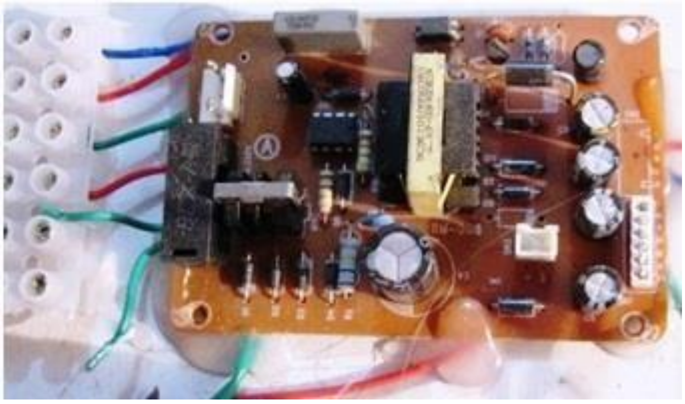

Figure 3 Modular Multilevel Converter of Experimental Setup

7. Results and Discussion

Figure 4 shows the THDF of current harmonic (19.88%) using of MMC without filter as tested by Power Analyzer during experimental process. Figure 5 shows the THDF of current harmonic (9.88%) using of MMC with filter as tested by Power Analyzer during experimental process.

Figure 4 Power Analyzer Results of current harmonic (19.88%) using of MMC without filter

Figure 5 Power Analyzer Results of current harmonic (9.88%) using of MMC with filter

8. Conclusions

An improved MMC control system for EV application is proposed in this paper. In this paper, a modular multilevel topology with embedded battery was presented for BEVs. The modular structured multilevel inverter is very attractive in battery vehicle applications. The proposed method can reduce the current harmonics by using filters and reduce the negative effect of harmonics on battery lifetime to improve its performance and a lower THD value of the output motor current can be found. A large number of submodules increases the number of output voltage levels and strongly reduces the THD of motor currents. MMC is therefore a suitable candidate for eliminating battery balancing circuits from electric vehicles, as the new concept incorporates battery cells directly into the energy converter.

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