RECHARGEABLE BATTERY SYSTEM FOR SMALL SCALE ELECTRIC VEHICLE

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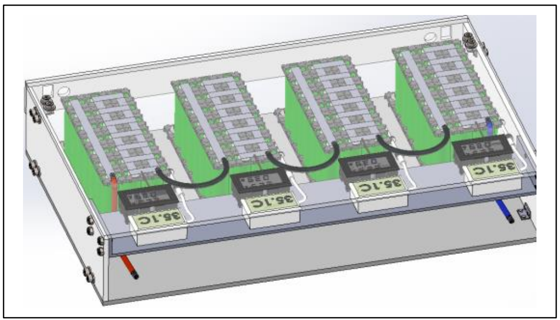
GRAPHICAL ABSTRACT



ABSTRACT

Popularity of electric vehicle (EV) is growing very rapidly in recent times due to favourable emission regulations and its improved practicality in terms of the battery technology. Because of that, studying the rechargeable battery technologies becomes increasingly crucial. Therefore, this paper describes the work carried out to design a rechargeable battery system that integrate parameters monitoring system. The battery system was designed to be implemented in a small-scale EV that uses 10 kW electric motor. Lithium-ion battery was used in the system due to its relatively high energy capacity and charging cycles. For the monitoring system, three sensors where used; voltage sensor, current sensor and thermocouple, to measure the voltage, current and temperature, respectively. As a result, the battery's performance and conditions can be monitored during operation.

KEYWORDS

Lithium-ion battery; voltage sensor; cylindrical battery cell; thermocouple

INTRODUCTION

An Electric Vehicle (EV) is a motor vehicle that use an electrical motor, instead of one that burns gasoline and other combustibles to generate power. Consequently, cars are considered a feasible alternative to traditional automobiles, because they may help meet environmental issues including pollution, global warming, and natural resource depletion. While the notion of electrical vehicles has been around for quite some time, this decade has seen an increasing carbon footprint and varied environmental repercussions of fuel-based vehicles, such as the effect on the ozone layer, draw in fresh interest in the concept. The cost of power for charging a car is far cheaper than gas prices.

In an EV powertrain, battery is a crucial component that is responsible to store electricity to power the motor. The battery, ideally, should have high power density so that it can store high amount of electricity with a minimum weight. Not only that, it also must have high rechargeable cycles, which means that it can be recharged as many times as possible. To increase the lifespan of the battery, its parameters must be monitored and controlled properly, hence certain parameters monitoring system is required. The crucial parameters to be measured are voltage, current and temperature. Measuring voltage and current is useful to determine the battery's state of charge (SOC) which defines how much capacity of electricity is available. Not only that, it can also be used to estimate the battery's health, thus the remaining lifespan of the battery can be approximated [1,2]. Battery temperature, on the other hand, is critical to ensure that the battery can be operated optimally while at the same time avoiding the risks of damaging it due to thermal runaway [3]. Therefore, in this paper, a rechargeable battery system that includes parameters monitoring system is designed. The integrated battery system serves as the foundation for further studies on optimizing its lifespan and performance can be done in the future.

METHODOLOGY

The main objective for this paper is to design a rechargeable battery system with parameters monitoring. The system is designed for application with a 48 V 10 kW electric motor which is a typical output power for a small-scale EV. The battery's parameters to be measured by the monitoring system are voltage, current and temperature, which means that voltage sensor, current sensor and thermocouple are required to be integrated with the battery.

The designing process starts by identifying the battery material that is most suitable for powering a 48 V electric motor with a rated power of 10 kW. Thus, five typical materials of battery are considered, and these materials are lead-acid, nickel-metal hydride, lithium-ion, lithium-titanite and alkaline. The materials are evaluated in terms of energy capacity and rechargeable cycles. In terms of energy capacity, lithium-ion is the best with up to 160 Wh/kg, followed by alkaline (up to 110 Wh/kg), lithium titanite (up to 100 Wh/kg), nickel-metal hydride (up to 100 Wh/kg) and lastly lead-acid (35 Wh/kg). For rechargeable cycles, lithium titanite is the best up to 3000 cycles, followed by nickel-metal hydride at about 2000 cycles, then lithium-ion, lead acid and last alkaline, at around 1000 cycles, 200 cycles and less than 100 cycles, respectively. The complete data of the battery materials is provided in Table 1 [1-5].

Next, the physical designs of the battery cell are compared and evaluated to determine the most suitable design to be used in the battery system. There are three typical physical designs of the battery cell available widely in the market; cylindrical cell, pouch cell and prismatic cell. In terms of cost, cylindrical cell is the cheapest and it can be purchased easily due to its wide availability. Nevertheless, it has low individual energy capacity, and this means that its number has to be increased if big capacity battery is to be designed. Comparatively, prismatic cell and pouch cell are larger with bigger capacity, but they are also more costly. The difference between them is that the former uses hard casing, while the latter uses soft casing. Table 2 shows the comparison between these physical designs of the battery. Based on this comparison, two types of battery; prismatic cell and cylindrical cell are chosen for the CAD modelling.

Table 1: Evaluated battery's materials

Materials	Cell voltage (V)	Energy capacity (Wh/kg)	Rechargeable cycles (-)
Lead-acid	2.0	35	200
Nickel-metal hydride	1.2	100	2000
Lithium-ion	3.8	160	1000
Lithium-titanite	2.5	100	3000
Alkaline	1.5	110	< 100

Table 2: Evaluated battery's physical designs

Cylindrical cell	Pouch cell	Prismatic cell
Low energy capacity per cell	High energy capacity per cell	High energy capacity per cell
Cheap per cell	Costly per cell	Costly per cell
Small size	Moderate size	Moderate size
Hard casing	Soft casing	Hard casing

Based on the two battery types, CAD model of the cells' arrangement is developed. In the CAD model, the arrangement must be designed properly so that the desired capacity in terms of voltage and current can be achieved. For example, if the battery system is expected to power the motor for a maximum power operation (20 kW) in one hour, then the system must provide 48 V and 208 Ah. In this study, the target is set lower than that, due to safety and cost constraint. Thus, the actual target set here is 48 V and between 70 Ah to 100 Ah. With such target, the battery can be used to power the motor for 5 kW in 30 minutes to one hour. If the motor is still to be run at its maximum output power, then the battery is capable of doing that for less than half an hour. Thus, the final target of the battery system (or battery pack) is set at 48 V and 70 Ah to 100 Ah, representing about 5 kWh power capacity. Summary of the design methodology conducted in this research is presented in the following Figure 1.

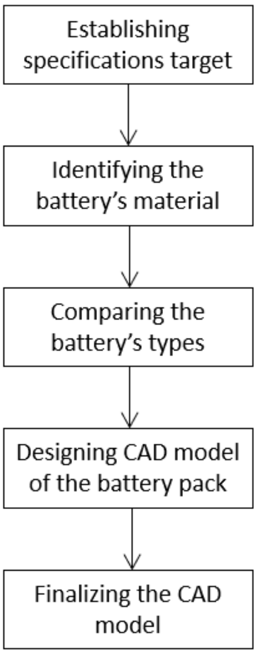


Figure 1: The proposed rechargeable battery system

RESULTS AND DISCUSSIONS

Based on comparison of the data provided in Table 1, lithium-ion battery is selected since it is the best compromised material that has high voltage cell, reasonably high energy capacity, high voltage and acceptable rechargeable cycles as well as cost and availability. In terms of physical design, cylindrical cell is chosen, mainly because their price, weight and availability. Between the cells, prismatic cell and pouch cell have higher energy capacity, but they are relatively more expensive and bigger. The cylindrical cell, on the contrary, is much more compact, lighter and cheaper, but it provides much lower energy capacity than the prismatic one. Due to that, it is necessary to buy quite a big number of the cell, and arrange them accordingly so that the desired voltage (48V) and current capacity (100 Ah) can be realized.

Once the type of cell is decided, the schematic diagram of the cells' arrangement is established. The objective of the arrangement is to demonstrate the cells can be organized to achieve the aforementioned voltage and current capacity, and how many cells are required to be purchased. Based on survey online, one cylindrical cell normally has 4.2 charging voltage and 10 Ah current capacity. Based on these, the 3 cells must be arranged in series so that the voltage can be multiplied to 12.6 V to suit 12 V. Next, the 7 cells must be organized in parallel for each the three serial arrangements, so that the current can be multiplied to 70 Ah. So now, a battery pack of 12.6 V and 70 Ah is complete. Finally, four units of the same battery packs are arranged in series so that the voltage can be multiplied further to at least 48 V (in this case, it is 50.4 V). Now, the battery pack that is capable of providing 48 V and 70 Ah has been successfully arranged. Figure 2 shows the schematic diagram of the cells' arrangement in the battery pack.

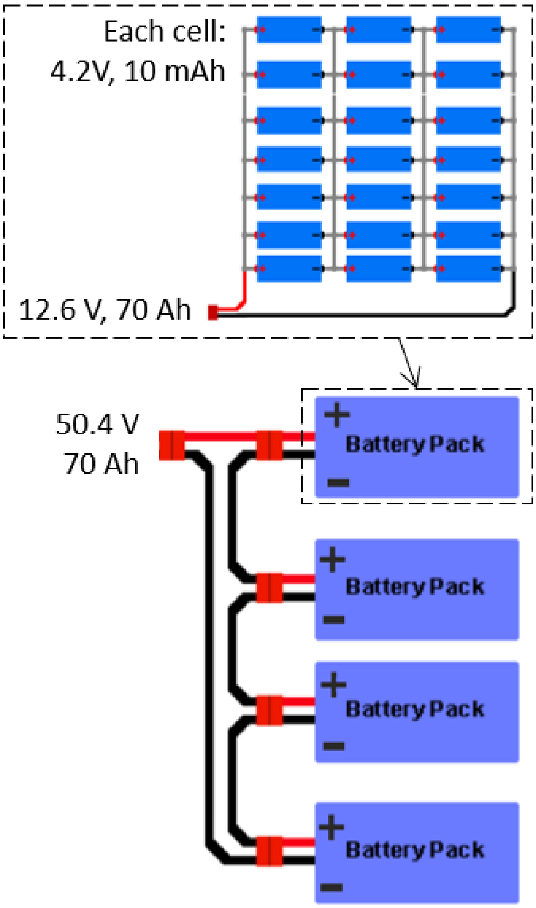


Figure 2: Schematic diagram of the cells' arrangement

From the schematic diagram, the preliminary CAD model of the battery pack is produced as shown in Figure 3. Here, the CAD model follows the actual physical parameters of the cylindrical cells available in the market. In total, 84 cells (type 18650) are required for the 48 V battery pack, which contains four smaller packs of 12 V and 70 Ah battery. In the smaller battery pack, 21 cylindrical cells are used. In terms of the overall size, the width of the complete 48 V battery pack is 0.4 m, while its length and height are 0.254 m and 0.079 m, respectively. Subsequently, based on the preliminary CAD model, the complete CAD model of the battery system; consisting the battery pack, the wiring and its monitoring system, is developed. The complete CAD model is depicted in Figure 4, where it consists voltage sensor with display and thermocouple for each of the smaller battery pack (12 V).

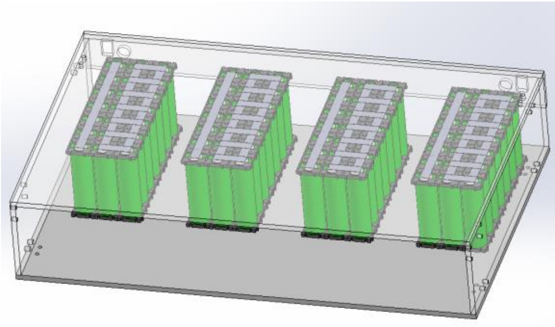


Figure 3: Preliminary CAD model of the battery pack

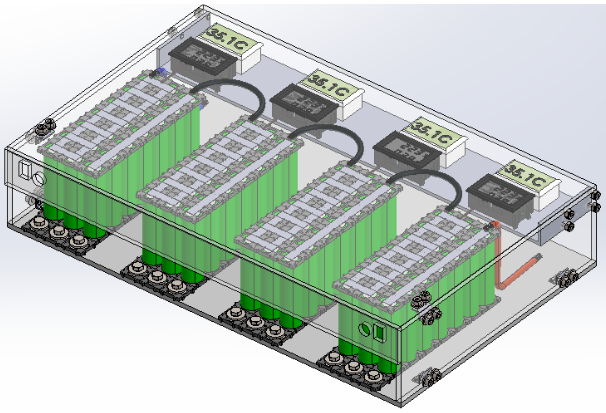


Figure 4: Complete CAD model of the battery system

For the casing, transparent acrylic plates are used and they are fixed together using L-shape acrylic bracket. The material is chosen so that the battery physical conditions during operation can be observed clearly. At the side of the casing, several holes are provided for cooling down the battery, which in the future, an active cooling system with a dedicated fan can be installed.

The designed rechargeable battery system here is capable of 48 V and 70 Ah (3.36 kW), which although still in the targeted range, it is significantly below 5 kWh. At the moment, with the battery, the motor can be safely operated in a continuous one hour for up to 3 kW output power, which is slightly lower than the desired 5 kWh, and much lower than the maximum motor's output power of 10 kW. This means that there are some risks if the battery is to be used for operating the motor at 5 kW to 10 kW for an hour. For preliminary testing to prove the battery workability, such capacity is still acceptable. But for a more extensive testing of the powertrain, further capacity increase is crucial.

So, to improve this in the future, another twelve cylindrical cells have to be added to each of the 12 V battery pack, which can increase the current capacity to at least 110 Ah. This can be translated into 48 more cells for the entire 48 V battery pack. As a result, the power capacity is improved to 5.28 kW and now it will be much safer to operate up to 5 kW power for one hour. Nevertheless, for 10 kW power, more cells have to be purchased and added into the battery systems. This means increase cost and size.

In terms of the monitoring system, two sensors, namely, voltage sensor and thermocouple are used in each of the 12 V battery module. The current sensor is connected at the positive terminal of the 48 V battery system which is not shown in the figure. Voltage sensor is included in each 12 V battery module to make sure that the voltage of each module can be monitored separately. This is crucial in case if the voltage drop for each module is not the same. The thermocouple is also integrated in each of the module, for the same reason to monitor the thermal characteristics of each module independently. Based on the literature [1-5], the most likely location on the battery that will exhibit the highest temperature is in the region close to its negative terminal. Hence, the thermocouple is attached close to this location so that the most critical battery temperature can be measured and monitored.

The complete components and specifications of the rechargeable 48 V battery system with parameters monitoring is provided in Tables 3. In total, 84 lithium-ion cells type 18650 are used, with four thermocouples with temperature display and four voltage sensors with display.

Table 3: Components used in the 48 V battery system

Components	Quantity	Descriptions
Lithium-ion cyclindrical cell type 18650	84	Charging voltage of 4.2 V, current of 10 Ah
Thermocouple with display	4	One attached at the negative terminal of each 12 V battery module
Voltage sensor with display	4	One attached at each of the 12 V battery module

Conclusion

In conclusion, the objective of the paper, which is to design an integrated battery system for application with a 48 V 10 kW electric motor has been achieved. The battery system uses cylindrical lithium-ion cells due to its favourable characteristics in terms of cost, voltage, recharging cycles and energy capacity. The battery system also includes parameters monitoring system which allows users to monitor its voltage and temperature during operation.

However, the integrated battery system has lower amperage at 70 Ah, which makes it less suitable for extensive testing with the designated motor. Additional cells must be included in the battery system. Thus, the amperage can be increased to 110 Ah, allowing 5.28 kWh of electricity to be stored. This makes the battery systems more suitable for extensive application with the designated motor.

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