Optimization of Battery Endurance By Using Thermal Regulation System

Abdullah Alazzawi
Department of Electrical and Electronics Engineering
Karabuk University
Karabuk, Turkey
adnab2@gmail.com

***Abstract*—Thermal runaway is one of the most prevalent problems that is related to batteries. The problem of unwanted thermal runaway and the unexpected decrement temperatures that happens both directly or indirectly by internal and external influences poses a risk to the efficiency and the lifespan of batteries. The medium for using batteries differs from place to place, each medium has its different temperature conditions. So the problem's solution that is being discussed in this paper is being shortly showed as enhancing battery endurance via balancing the voltage ratios in each cell, tracking and monitoring battery temperatures while taking into account the variation of mediums that the battery will be used in. The temperature degrees are being elevated and reduced by employing an Arduino microcontroller that works passively with the fluid pump so it can indirectly manage the temperature of batteries. This management of temperature degrees improves the efficiency of batteries and prevents their structure from being damaged.**

Keywords—battery, battery thermal management, battery cooling system, electric vehicles, thermal runaway

I. INTRODUCTION

Recently, there has been a change in the global energy system, as it gradually began to abandon energy sources that may cause problems to the ecosystem. Therefore, a greater trend has been made to use sustainable electric energy [1]. Batteries are an essential part of this sustainable energy system. Batteries are used in both small and large industries and we see remarkable progress in this field, especially in the electric vehicles sector, and from here comes our main topic (batteries). One of the most prominent problems with batteries is thermal runaway [2]. The abnormal temperature change may cause damage to some components of the battery and leading the insulating materials that are replaced between cathode and anode to lose their properties causing a rupture or leakage even in worse cases causing an explosion. Batteries are energy storage components that convert chemical energy into electrical energy.

Most large projects do not operate with a single battery, but rather depend on more than one battery, especially if we look at the field of electric vehicles, we see that electric vehicles battery system is composed of multiple cells which are designed in series and parallel combinations that form a battery pack to produce a desired rate of energy. At the point when the battery is associated with a load for supplying the demand of energy the battery gradually gets empty then comes the need of recharging the battery, so we need a recharge process.

The process of discharging and recharging generates heat, this temperature changing happens by utilizing what we call joule heating. The abnormal increment in temperature may cause physical damage to the battery structure or even in worse cases leading to battery explosion [3]. And it may lead to the release of high amounts of toxic and flammable gas [4]. Preventing such problems is our priority in this research. So our aim in this study is to ensure that we get accurate voltage and current values by maintaining a constant temperature.

There are several cooling techniques utilized in the battery system to maintain batteries temperature under control and to prevent the overheating of the battery [5]. In contrast to other cooling methods, the system we used in our study was chosen to be simple, efficient, reliable, and cheap in comparison with other cooling techniques.

We managed to automate a system that can regulate itself according to the temperature degree of the battery that it receives so whenever the level of temperature exceeds the usual levels that we defined before, the cooling system works on restoring the temperature to the optimum degrees to ensure that the system works at peak performance. We managed to simulate the system's temperature using Matlab while charging and discharging and also we made an observation on how the battery temperature changes while it is used with a cooling system and also without using a cooling system.

Air cooling systems are well known in the industrial field for its simplicity, low cost, and reliability, but it is not appropriate for being operated with batteries that run at a high ambient temperature or with a high discharging rate so in these cases air cooling systems are considered to be ineffective [6]. There are a lot of types of cooling techniques [7] which are used in battery thermal managing system, as it is depicted in Fig. 1.

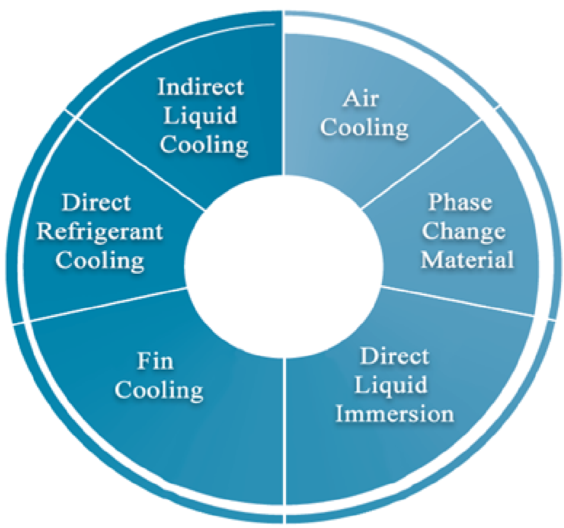

Fig. 1. Traditional battery thermal management cooling systems

II. Battery Managing System

A. Battery Thermal Runaway

The chemical reaction that takes place inside the battery to produce energy is the result of electrons being transferred from the anode to the electrode, this electronic discharge is being occurred with the help of the electrolyte, which is a chemical medium that allows electrons to pass through it so that the chemical potential works on balancing the two ends of the battery. The constant flow of electrons between the two processes of charging and discharging generates heat as a result of Joule's law: P=R*I^2 [8].

Some of the energy loss converts into heat and it happens by the current that flows through the internal resistance of the batteries. The temperature increment is limited by the amount of energy inside the battery.

B. Cooling System Hardware

Fig. 2 depicts the hardware design in which a 12V battery is used during this process to highlight the variance and disparity between the two battery packs behavior in a different graph while one of the batteries is being operated with a cooling system and the other one is not to make a comparison to inspect how efficient and effective the cooling system is.

As shown in the above design, a thermal sensor of the LM35 type was used. The temperatures that this sensor can measure range from -55 to 150 Celsius. This type of sensor has a structure similar to that of an ordinary transistor, and the working principle of this sensor is by converting the temperatures measured in the surrounding physical medium into an analog voltage. The relationship between the voltages and the temperature is directly proportional, so the higher the temperature, the greater the amount of voltage.

The cooling system used in this research is based on regulating the temperature by using fluids for cooling when needed.

As a result, when the sensor detects elevated temperatures, a signal is transmitted to the fluid pumps connected with the Arduino input ports, causing the coolant fluids to be pumped.

We have two major components in our system that need to be cooled down in case of abnormal increment in temperature degree and the two major components are the load and the battery, so we attached the fluid pump to each of them. So when the temperature of the battery reaches the set point, the cooling device inside the thermal system is activated, after activating it, the temperature of the battery will be reduced and it will allow the system to operate within its normal operating range.

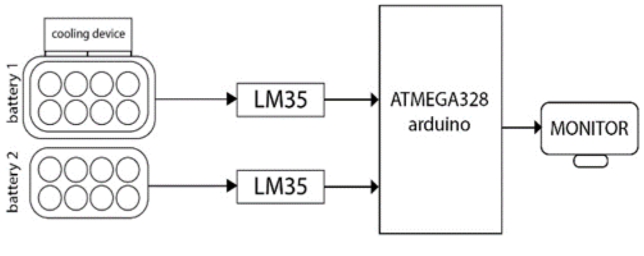

Fig. 2. Hardware Design

III. Methodology

The cooling system can produce higher thermal transfer at much lower mass flow levels. And as it is acknowledged that the fluid-cooled system is typically utilized where massive heat loads or large power densities must be dissipated because of its ability to transfer heat out of the battery while the air cooling technique needs a much high flow rate. Although air cooling has advantages such as weight, low cost, and ease of maintenance, it is not suitable for batteries operating under abusive operating conditions like high discharging level or high ambient temperature due to air's poor heat transfer characteristics. The most common disadvantage in the liquid cooling system is that it can supply small amounts of liquid in comparison to the almost infinite volume of air that can circulate into a cell. The fluid Cooling tube is in charge of transferring heat from the battery with heavy heat degrees to the fluid used in the temperature control system. The reliability of these parts is critical to the efficiency of the fluid system. The battery cooling mechanism depends on supplying the motor pump with a 12V DC source and it is used to give the ability to the pump to transfer liquid over the transmitting tube from the battery to the circumstance of the battery. We also wired the data transmitters to the microcontroller and the LM35 temperature sensor to the dc power supply. The cooling mechanism is regulated using Arduino software. As a result, the battery can operate within standard operating conditions in this battery cooling system. We also attached various loads at different times to observe the battery as it was discharging. The cooling system is utilized to maintain the temperature under control. Two pumps are being employed in the battery cooling device to move liquid through one side towards the other, while the second pump is being employed to drain liquid into the tank. And we used to keep tracking the battery's proper functioning by using the battery managing systems monitor so the all the temperature degrees, voltage values, and current values, and power level inside each battery cell inside the battery pack. By using the fluid motor pump that is considered an essential part of the battery control units we were able to regulate the liquid flow rate based on the battery cell's temperature value. The plate of metal which is connected to the top of the battery acts as a transmitter and as a rapid cooler for improving efficiency.

In our study, we employed a light bulb as a load and we chose it to be at a high watt rate so it can drain a good amount of energy out of the battery to observe how good is the fluid cooling system while it's working on cooling down the battery's temperature. The operating temperature of Li-ion battery should be kept between 20°C and 40°C. Operating at higher temperatures deteriorates the performance, lifespan and safety of Li-ion batteries and may endure thermal runaway under extreme conditions [9].

The time that light bulb we have chosen before being fully empty in:

Time = (7.5 AH/ The flow of current inside bulb /0.85) ^1.2)

And we divided the current over 0.85 because the duration of transforming direct current to alternative current power is approximately 85% efficient, so the amps ofthe light bulb should be divided by 0.85 to achieve the proper amp value from the battery.

Now with this formula, we can do the calculation of the discharging time of the load in connection with the battery.

There is no need to discharge the battery out. After discharging 50% of the charge, the battery will be reset to charge with the charging circuit. There are several techniques for calculating a battery's state of charge (SOC).

A. Coloumb counting technique

The coulomb counting technique, also known as ampere-hour testing and current integration, is the most commonly used method for determining SOC [10]. This system determines SOC values based on battery current readings that are numerically synchronized over the consumption time period and we can calculate its values by

$$\mathrm{SOC(t)} = \mathrm{SOC(t-1)} + \int_0^{t} \frac{1}{C_{bat}} dt \quad (1)$$

A working battery's releasable limit (Crelease) is the discharged limit until it is fully released. Similarly, the SOC is described as the level of the releasable limit in comparison to the battery rated value (Cr) provided by the manufacturer [10].

$$SOC = (Crelease/Cr) * 100\% \quad (2)$$

The maximum releasable limit (Cmax) of a fully charged battery is not always the same as the appraised limit. In general, Cmax differs from Cr to some degree for a newly used battery and decreases with use time. This calculation can be used to calculate a battery's SOH.

$$SOH = (Cmax/Cr) * 100\% \quad (3)$$

Where Crelease is the maximum amount of current that can be produced. The differentiation of the D (t) in a working cycle is achieved by utilizing a deliberate charging-discharging current (Ib) where D (t) can be determined by

$$\Delta D = \frac{\int_t^{t+1} I_b(t).D(t)}{C_r} 100\% \quad (4)$$

Where Ib denotes battery current, which is negative when discharging and positive when charging and for calculating D in means of time we should use the following equation

$$D(t) = D(t_0) + \Delta D \quad (5)$$

The working proficiency denoted as (n) is taken into account to increase measurement accuracy so D becomes,

$$D(t) = D(t_0) + \eta \Delta D \quad (6)$$

While (n) is equal to (nd) during releasing stage and is equal to (nc) during the charging stage the SOC can be communicated as

$$SOC(t) = SOH(t) - D(t) \quad (7)$$

As we noticing from fig [3, 4] when the battery runs at a higher temperature, the battery performs optimally. However, this comes at an expense, since the battery's performance and lifetime are reduced.

The requisite amount of current would not be produced if the device was run at a low temperature [11]. As a result, to avoid adverse temperature effects, a battery thermal management system (BTMS) is required to maintain the proper temperature range and minimize the temperature gradient of these batteries [12]. And we also notice that the area where the battery's life and power intersect is where the battery performs most effectively.

IV. RESULTS

As we explained before, the performance of the battery in the case of charging and discharging can be highly affected by the temperature. So we aimed to gain the optimum performance of the battery by using an efficient and low-cost technique that can do the voltage balancing between battery cells and the observation and controlling of the battery pack.

The simulation that we did on MATLAB / SIMULINK is depicted in Fig.6. In this simulation, we managed to employ a motor to work as a load, and the water flows via pipes from a powered pump, increasing the flow rate as the battery temperature rises.

From the Fig.7 we can inspect three parameters that are related and complementary to each other so they can do the operation of controlling the battery pack's temperature. Whenever we see incensement in the pump power values we can declare that the system is in needs to be cooled down so the battery can operate optimally.

Fig.8 shows the cooling device model used in our study. We used water as a cooling liquid for its ability to transfer heat through it. And we also used a pump to do the water transferring from the tank through the tubes to the battery pack. Additional modifications are to be considered to further decrease the temperature in order to increase the lifetime of batteries and decrease the disparity between different batteries in the pack [13].

In this study, a comparison to inspect what are the differences between battery that operates with cooling system and with one which operates separately, we also estimated the battery heat degree dependency. In the above figure, the orange line the represents the battery that operates while using a cooling system is showing better results when time moves over and the opposite situation happens while not using the cooling system. In this study, we used two 9W DC bulbs with equal ratings.

As the battery temperature exceeds thirty degrees Celsius, the cooling mechanism steps cool the battery pack down to the optimum degrees.

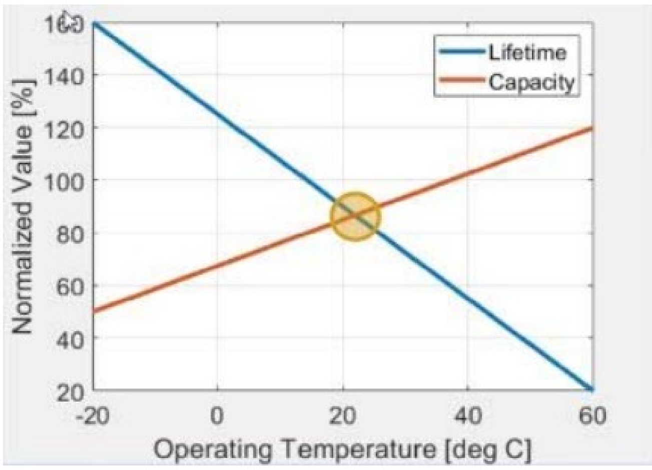

Fig. 3. Output characteristics of a battery

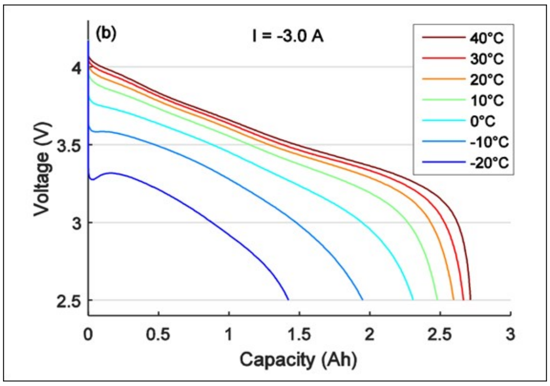

Fig. 4. Discharging the voltage of a Li-ion cell and temperature changing

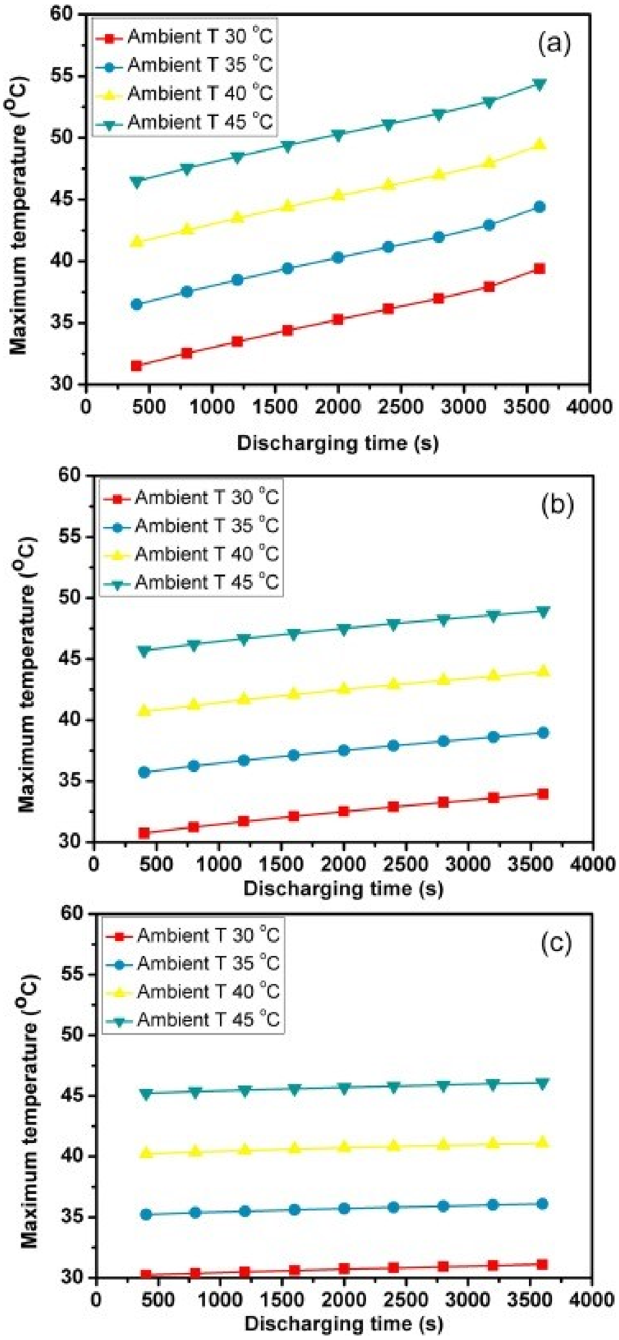

Fig. 5. The overall battery temperature varies in means of time at different ambient temperatures and the discharging rate of (a) 1 C, (b) 0.7 C, and (c) 0.4 C.

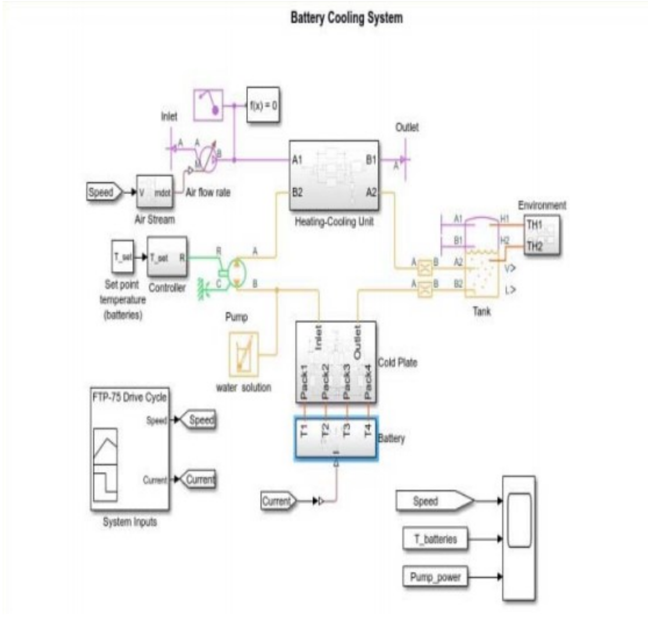

Fig. 6. The Matlab (Simulink) diagram of the Battery Management System

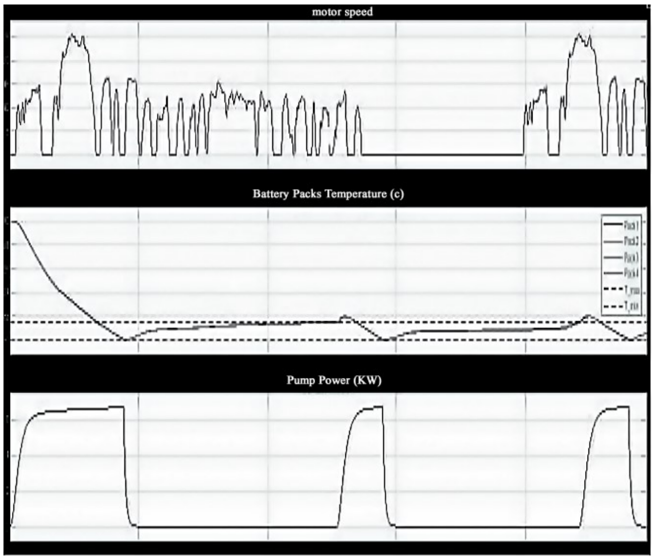

Fig. 7. Simulation Results

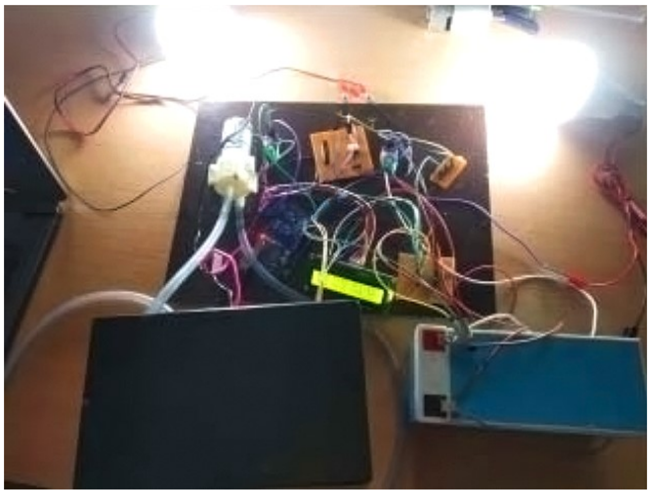

Fig. 8. The cooling device model

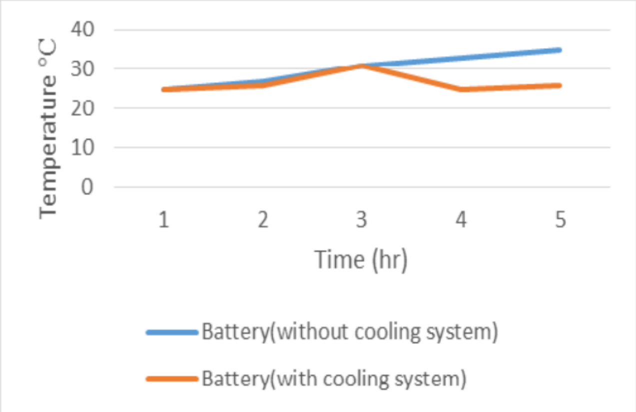

Fig. 9. Comparison between the battery characteristics while using the cooling system and while not using it

V. Conclusion

This study proposed a technique for modeling and improving the endurance of a battery by using a motor pump and cooling plates. We used the cooling plates as a heat reducer so the temperature of the battery pack can return to the optimum temperature degrees, thus the mechanism is used to release the unwanted heat generated by the battery. And we also observed the battery thermal behavior and we put it in a comparative study the alternative model solution changed the cooling layer structure even further. The cooling plates are designed to reduce the excess heat produced by the battery system during vehicle operation or in the process of charging or discharging. The regulation of the battery's temperature could be quite effective and inexpensive. Therefore, a liquid-cooled plate would circulate the liquid that is associated with the battery's outer structure in tubes. The cooling plates are circulated with the aid of the pump, which wants to limit heat transfer and preserve the temperature levels of the battery to the optimum thermal operation degrees.

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