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Research on Charging and Discharging of Lithium Ion Battery based on Temperature Controlled Technique

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***Abstract*—**With the development of technology and the growing problems of environmental protection and energy shortage, renewable and clean energy power generation is receiving more and more attention. However, due to the randomness and volatility of renewable energy, it has a certain impact on the power grid. Hence, efficient energy storage technology is urgently needed to solve this problem. Therefore, battery energy storage system (BESS) has become one of the hot topic for research. Currently most of the electric energy is being stored in battery storage system. The main tasks of this paper are as follows: firstly, introduce and analyze lithium ion battery storage system and its characteristics, especially the operating temperature ranges of the optimal charging and discharging curves. Secondly, analyze the charge and discharge curve of lithium ion battery in the range of minus 40 degrees Celsius to plus 40 degrees Celsius by simulating temperature dependence model in MATLAB. And through observation, it was found that Lithium Ion Battery has better charge-discharge properties during operation in the range of zero degrees to 40 degrees Celsius. Thirdly, a temperature controlled topological method is proposed to make the lithium ion battery to operate in three temperature ranges respectively: 10 to 20 degrees Celsius, 20 to 30 degrees Celsius and 30 to 40 degrees Celsius. Based on MATLAB and GUI, a program for comparing the charge and discharge performance of lithium-ion battery in different temperature ranges was developed. The conclusions of this paper were verified by the analysis of charging and discharging in these temperature ranges. Finally, an android application is designed to upload battery voltage, temperature and circuit control status in real time. In conclusion, this paper provides some technical support for charging and discharging application of lithium battery energy storage system

***Keywords*—** Battery Energy Storage System (BESS), lithium ion battery(Li-ion), temperature control circuit, charge, discharge, temperature ranges

I. INTRODUCTION

Lithium Ion battery charger system technology is currently being incorporated in urban industrial areas to maintain with these demands lot of work is on towards [1]. Batteries are extremely convenient energy devices which employed in our daily life, in energy storage, lighting, household appliances and portable electronic devices [2],[3].Temperature plays a significant role in lithium ion batteries and their performance; cycle lifetime and safety depend highly on the temperature range. So, its operating temperature needs to be well controlled for better performance.[4],[5].Operation at higher temperatures may cause catastrophic failures, thermal runaway and may ignite fire or explosion. Different operating temperatures will also cause the difference in behavior of its operation like due to high temperature the resistance may increase which cause the change in charging and discharging characteristics of the battery[6]. So, to overcome these issues special cooling systems and protections are used to control the temperature hence increase the safety and increase the efficiency of battery. LIB's usability can be increased if its operation temperature range is extended by using modern technology.

In this paper authors have presented a temperature controlled circuitry for the charging and discharging of lithium ion battery. It's a new technique which enables the lithium ion battery to charge and discharge in specific temperature range and by analyzing its performance in that specific temperature range authors have concluded that If we make the lithium ion battery to operate in the temperature range of 20 ^{o}C to 30 ^{o}C for both charging and discharging then we get the better battery performance. To develop this circuitry, I have used various components integrated together centrally controlled by Arduino Uno.

II. LITERATURE REVIEW/ METHODOLOGY

All the battery technologies, that is, lead, nickel, lithium, and sodium-can avail different and important functions to the network thus introducing a variety of application and financial benefits.

Until recently, BESS technology that was considered economically feasible was based on lead-acid battery technology. However, recent improvements in the valve regulated lead-acid (VRLA) batteries and other types of batteries contributed towards their emergence as important energy storage components in consumer system

A. Lead Acid Battery

This type of energy storing system is marginally economical, despite having substantial maintenance and space requirements. This BESS has a characteristically shorter life, which decreases significantly once the battery's charge reaches

30%. [7] This characteristic causes a reduction in energy density thus increasing capital costs linked with this BESS. This energy storing system is mainly used in uninterrupted power supply (UPS) and in renewable and distributed power system. The main strengths associated with this system is that it has long life span, and the technology is commercially available. The key limitations linked with this system are frequent maintenance, limited portability and it is expensive as compared to conventional options.[8]

The electrolyte between the rods contains aqueous ions of H+ and SO4-2. Further, conduction mechanism at the surface of the rod involves redox reaction, where charges are transferred from ions in the solution to the conducting electrons in the electrodes. Chemical reaction that takes place during its functioning are as follows;

$$Pb + SO_4^{-2} \rightarrow PbSO_4 + 2e^-$$

Further, charged sulfate and hydrogen ions diffuse towards the lead-oxide molecules on the surface of the anode. Lead atoms become ionized and bond with sulfate ions, thus releasing two water molecules. This reaction, is as follows;

$$PbO^2 + SO_4^{-2} + 4H^+ + 2e^- \rightarrow PbSO_4 + 2H_2O$$

The reactions above cause electrodes to be coated with lead sulfate and reduce the concentration of the acid electrolyte.[9]

Lead acid batteries are commonly used in cars as a starter. Lead acid batteries are effective in extreme conditions. Constant current charging for lead acid batteries is a set voltage of 2.40V/Cell at normal temperature of surroundings. This voltage is directly related to the temperature and it is set higher in cold environment and set to lower in warm environment.

Cold environment has some side effects for lead acid batteries like if the surrounding temperature is below 0oC and it causes the freezing of lead acid battery then it can cause permanent damage to lead acid battery. Special care must be taken in such areas and should keep the battery fully charged because in a discharge state the electrolyte in lead acid battery has characteristics resemble with water and it may freeze quicker as compared to the charged state. [10]

B. Vanadium Redox Flow Battery

Vanadium redox flow batteries (VRFB) are electricity storage system that has numerous potential applications within deregulated and decentralized energy networks.This system mainly comprises of two main elements; a) the cell stack, on which chemical energy is changed to electricity in a reversible reaction, and b) the tanks containing electrolyte where the energy is stored [11].

The vanadium redox flow battery uses vanadium on the positive and negative electrodes. One benefit of its design is that the battery's capacity does not decrease when the positive and negative electrolytes are mixed through the membrane. [20] [24] Further, the electrode reactions in the vanadium redox flow system are as follows;

Reactions taking place at the anode

$$VO^{2+}(\text{tetravalent}) + H_2O \leftrightharpoons VO_2^{+} + 2H^+ + e^-: E^0 = 1.00V$$

Reactions taking place at the cathode

$$V^{3+}(\text{trivalent}) + e^- \leftrightharpoons V^{2+}(\text{bivalent}): E^0 = -0.26V$$

Operating temperature has a deep effect on the electrochemical process of VRFB. During the electrochemical process of charging and discharging, Operating temperature affects the electrode kinetics and transport properties.[12] Additionally, the reaction rates of hydrogen and oxygen evolution and vanadium crossover also depends on the operating temperature. Temperature affects the performance of VRFB in such a way that its voltage performance is best in conditions where temperature is increased from 15°C to 55°C. Beyond or less than this temperature will affect the efficiency of VRFB. Average charge voltage of VRFB decreases with temperature while the discharge voltage increases. Increasing operating temperature reduces both the charge and discharge overpotentials and thus favors the voltage efficiency[13]

C. NiCad Battery

The abbreviation of nickel – cadmium batteries came from the chemical symbols of nickel (Ni) and cadmium (Cd). It is a rechargeable battery mostly used in computers, camcorders, versatile drills, and other small battery-fueled gadgets, having an effective and even power release.[14][15]

Nickel based batteries have a great market in worldwide. Ni-based battery cells typically comprise of a Nickel Oxyhydroxide (NiOOH) cathode, a separator between the terminals and a basic electrolyte – for the most part potassium hydroxide – though the anode comprises of various minerals, contingent upon the Ni-based battery cell compose.[16][17]

The voltage of Ni-based batteries is 1.2V/cell and the real sorts are NiCd, NiMH and NiFe battery cells

Like other batteries, nickel based batteries also get affected by the operating temperature range Permissible range for charging nickel based batteries is 0°C to 45°C and for discharging the range is -20 °C to 65°C.[18] It is highly recommended that if charging is required to be done below freezing point then charge current must be 0.1C. [19][20]

D. Analysis of Lithium ion battery temperature dependant model

From the analysis done by using MATLAB Simulink standard model for charging and discharging at different temperatures it is observed that the battery will perform well when it is made functional above 0 oC. During the temperature above 0 oC the charging and discharging cycles of lithium ion battery gives the graph which is more near to the graph of a standard battery B (Blue) as shown in the figure below where Battery A(Yellow) is being operated in the conditions where temperature does not go below 0 oC and beyond 40 oC, so its operating temperature is kept between 0 oC to 40 oC. While Battery C (Red) is being tested for the conditions where temperature does not increase from 0 oC and decrease from -40 oC i-e between 0 oC to -40 oC .The model has been run for 4000 seconds during which the battery gets discharge first and then gets charge.

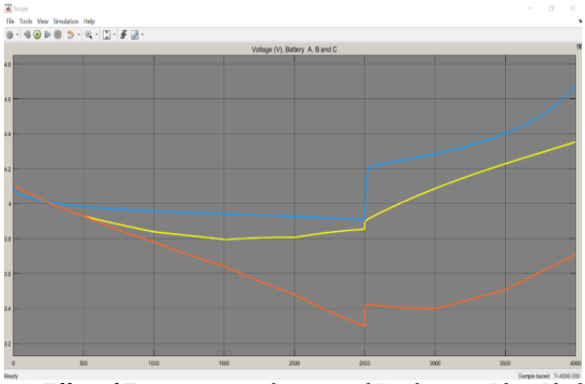

Figure 1: Effect of Temperature on charging and Discharging, Blue=Ideal State, Yellow= Battery A, Red = Battery

So considering this fact I decided to make a temperature control circuit which will control the temperature of battery to make it work in the specified temperature range and gives the output in the form of graph on MATLAB. Also, I divided the temperature ranges into three to observe the lithium ion battery Charging/Discharging best performance in specified temperature ranges which are 10-20 ^{o}C, 20-30 ^{o}C and 30-40 ^{o}C.

TABLE I. MBIENT TEMPERATURE, INTERNAL TEMPERATURE AND VOLTAGE COMPARISON OF BATTERY A.B AND C

Time	Battery A			Battery B	Battery C		
Seconds	Ambient Temp in ºC	Internal Temp in ºC	Voltage V	Voltage V	Ambient Temp in ºC	Internal Temp in ºC	Voltage V
0	0	18	4.18	4.2	0	18	4.19
500	5	12	3.95	4.0	-5	11	3.94
1000	10	9	3.86	3.9	-10	06	3.75
1500	20	10	3.78	3.88	-20	0	3.63
2000	30	14	3.79	3.85	-30	-8	3.42
2500	40	20	3.85	3.82	-40	-17	3.40
3000	40	28	4.15	4.25	-30	-24	3.42
3500	40	33	4.2	4.3	0	-21	3.49

III. METHODOLOGY

A. *Design Background*

From the analysis done by using MATLAB Simulink standard model for charging and discharging at different temperatures it is observed that the battery will perform well when it is made functional above 0 oC. During the temperature above 0 oC the charging and discharging cycles of lithium ion battery gives the graph which is more near to the graph of a standard battery so considering this fact It is decided to make a temperature control circuit which will control the temperature of battery to make it work in the specified temperature range and gives the output in the form of graph on MATLAB. Also, to observe the lithium ion battery Charging/Discharging best performance, temperature is divided into three ranges, which are 10-20 oC, 20-30 oC and 30-40 oC.

B. *Temperature Control Circuitry for Lithium Ion Battery.*

To control the temperature of lithium ion battery and to make it work in a specified temperature ranges following circuit is designed in Porteous software.

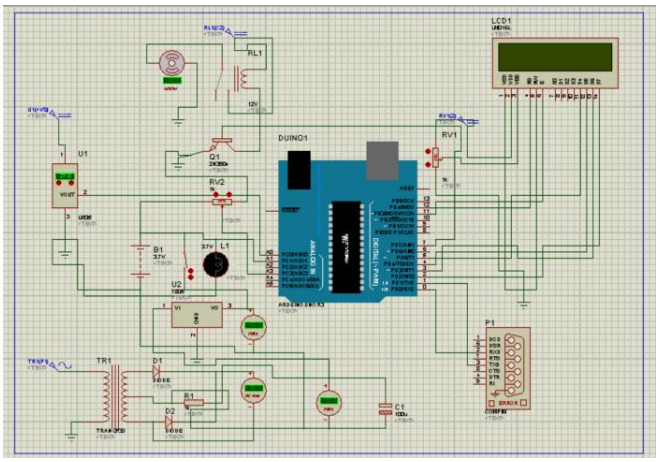

Figure 2: Proteous Model of Temperature Control Circuitry for Lithium Ion Battery

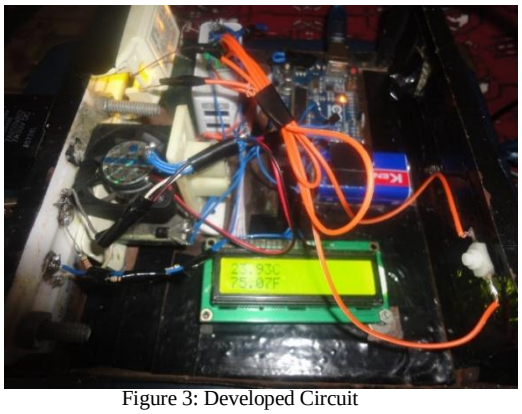

Figure 3: Developed Circuit

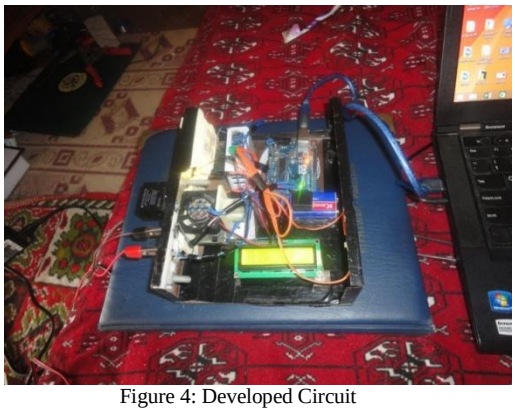

Figure 4: Developed Circuit

IV. RESULTS AND DISCUSSION.

For experimentation a rechargeable lithium ion battery of 3.7 V, 1050mAh is selected and placed it in circuit for charging and discharging analysis. A 4W LED is selected as load and

observed the process of charging and discharging on different temperature ranges which are as follows

Charging at:

- 10 to 20 ^{o}C
- 20 to 30 ^{o}C
- 30 to 40 ^{o}C

Discharging at:

- 10 to 20 ^{o}C
- 20 to 30 ^{o}C
- 30 to 40 ^{o}C

A. Charging Graphs

1. Between Range of 10-20 ^{o}C

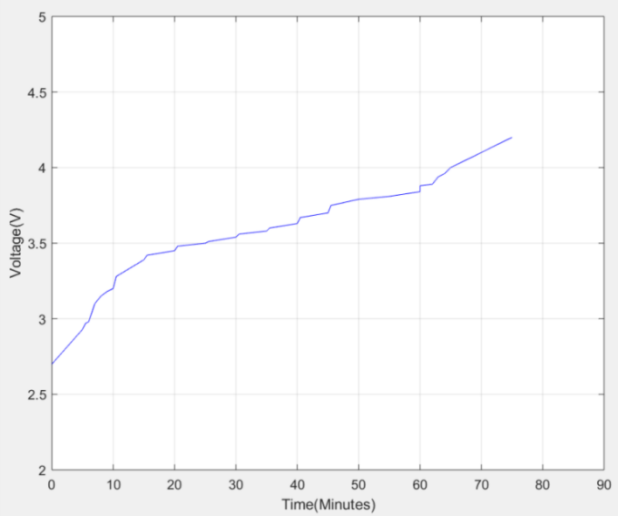

Figure 5: Graph of Charging Between temperature range of 10 to 20 ^{o}C.

2. Between Range of 20-30 ^{o}C

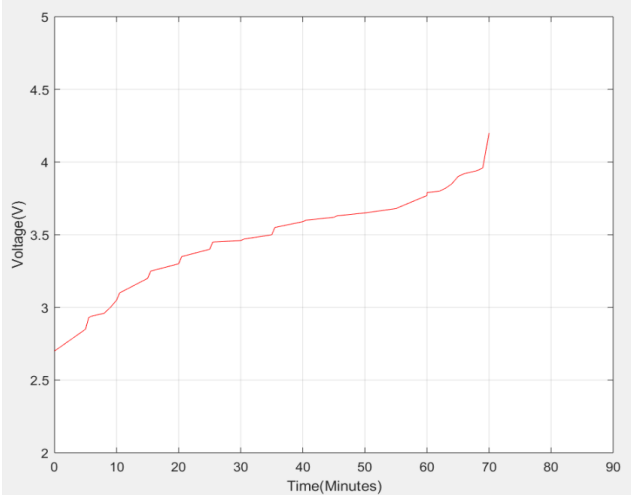

Figure 6: Graph of Charging Between temperature range of 20 to 30 ^{o}C

3. Between Range of 30-40 ^{o}C

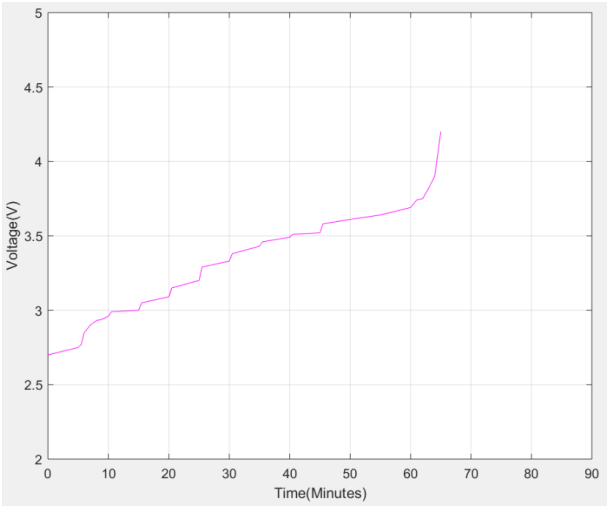

Figure 7: Graph of Charging Between temperature range of 30 to 40 ^{o}C

4. Comparison between three ranges:

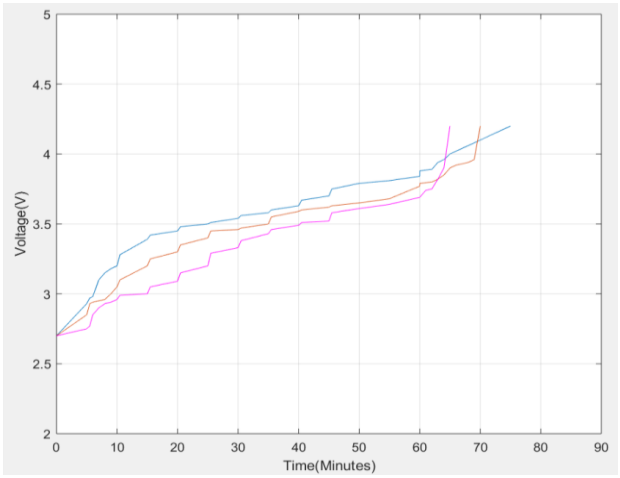

Figure 8: Comparison of All three temperature ranges

Following table shows the comparison of all three ranges.

TABLE II. COMPARISON OF THREE CHARGING CURVES

10-20 °C			20-30 °C			30-40 °C		
Time (minutes)	Voltage (V)	Temp °C	Time (minutes)	Voltage (V)	Temp °C	Time (minutes)	Voltage (V)	Temp °C
0	2.7	13	0	2.7	24	0	2.7	31
10	3.20	13	10	3.05	24	10	2.96	35
20	3.45	15	20	3.30	23	20	3.09	33
30	3.54	14	30	3.46	26	30	3.33	30
40	3.63	18	40	3.59	28	40	3.49	34
50	3.79	20	50	3.65	27	50	3.61	39
60	3.84	17	60	3.77	30	55	3.64	40
70	4.19	20	65	3.95	30	60	3.69	39
75	4.3	20	70	4.3	29	65	4.2	40

From above graph its observed that when the battery is being operated at elevated temperatures i-e between 30 to 40 ^{o}C it takes little less time to get charge as compared to the comparatively lower temperature and there is a sharp rise of voltage level near 100%SOC.Fast charging can be achieved on elevated temperatures but continuous operation on elevated temperatures is harmful for the life cycle of battery and it may harm the internal structure of battery also. While its observed from the above graphs that when battery is operated between 20-30 ^{o}C temperature range it achieves highest voltage point a little earlier as compared to 10-20 ^{o}C and also 20-30 ^{o}C is very close to room temperature. So, it can be said that battery may have longer life and faster charging at the temperature range of 20-30 ^{o}C.

B. Discharging Graphs

1. Between Range of 10-20 ^{o}C

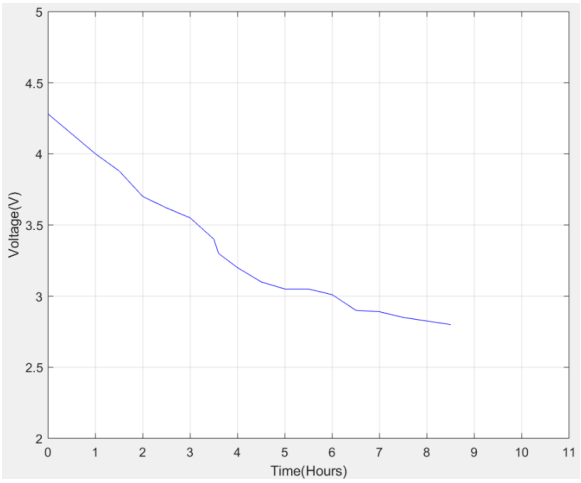

Figure 9: Graph of Discharging Between temperature range of 10 to 20 ^{o}C

2. Between Range of 20-30 ^{o}C

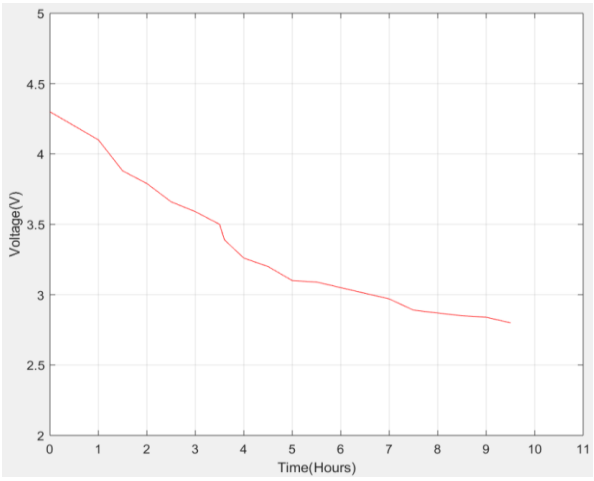

Figure 10: Graph of Discharging Between temperature range of 20 to 30 ^{o}C

3. Between Range of 30-40 ^{o}C

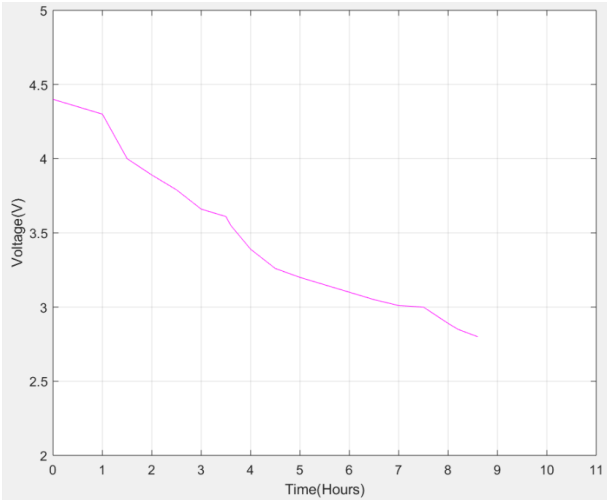

Figure 11: Graph of Discharging Between temperature range of 30 to 40 ^{o}C

4. Comparison between three ranges:

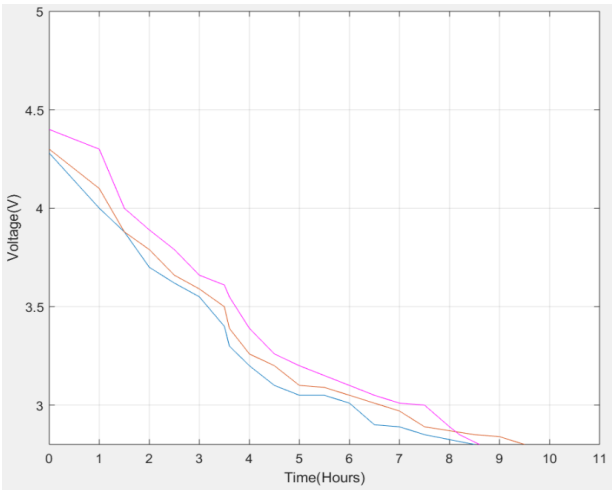

Figure 12: Comparison of all three discharging curves

From Above 4 figures it can be can seen that the discharging of lithium ion battery at three temperature ranges i-e 10-20 ^{o}C, 20-30 ^{o}C and 30-40 ^{o}C. and the 4th graph is the comparison graph of all these three temperature ranges graphs. According to the comparison of three discharging graphs at three different temperature ranges its analyzed that when battery is operating between 20-30 ^{o}C it gives the maximum discharging time as compared to the 10-20 ^{o}C and 30-40 ^{o}C. Infact during 30-40 ^{o}C it goes a sudden discharge at the extreme end. So, it can be said that if the battery temperature is maintained between 20-30 ^{o}C during discharging, maximum output can be obtained and it will also make the operating life of lithium ion battery longer. Following table shows the comparison of all three discharging curves.

TABLE III. COMPARISON OF ALL THREE DISCHARGING CURVES

10-20 ^{o}C			20-30 ^{o}C			30-40 ^{o}C		
Time (h)	Voltage (V)	Temp ^{o}C	Time (h)	Voltage (V)	Temp ^{o}C	Time (h)	Voltage (V)	Temp ^{o}C

0	4.28	15	0	4.3	22	0	4.4	31
1	4.0	12	1	4.1	23	1	4.3	33
2	3.70	10	2	3.79	25	2	3.89	35
3	3.55	15	3	3.59	27	3	3.66	36
4	3.20	19	4	3.36	29	4	3.39	38
5	3.05	20	5	3.10	30	5	3.20	40
6	3.01	16	6	3.05	28	6	3.10	39
7	2.89	18	7	2.97	26	7	3.01	36
8	2.85	17	8	2.88	23	8	2.89	36
8.5	2.80	20	9	2.84	21	8.5	2.75	35
-	-	-	9.5	2.80	24	-	-	-

CONCLUSION

This work used to investigat efficiency of charging and discharging for battery level with temperature range. The circuit developed, makes the battery to operate between the temperature range of 10 to 40 ^{o}C. And after analyzing the charging/discharging performance of a lithium ion battery in these temperature ranges authors have come to a conclusion that as far as charging is concern the battery will be charged quickly at the elevated temperatures but continuous operation at elevated temperatures is not feasible for the battery life and it may harm the battery so after graphic analysis for battery charging, 20-30 ^{o}C is found to be the best suitable temperature range and for discharging, the battery can be operated between 10-20 ^{o}C it also gives good results in this temperature range but it may give better results if its been operated between 20-30 ^{o}C range. By keeping the operational range of lithium ion battery in these temperature ranges, performance and life of Lithium ion battery can be enhanced.

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