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Design and Implementation of Li - ion Battery Charger

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Abstract: This paper presents a lithium-ion battery charger based on microcontroller that primarily works on constant current, constant voltage (CC/CV) type of charging algorithm. Lithium-ion batteries outperform conventional battery technology in terms of longevity and power density, providing longer battery life in a lighter container. But in order to make the best use out of this battery, there is a huge requirement of such a charger that is specifically designed to observe the battery's charging status and provide a charge, as soon as necessary, in order to maintain the battery, keeping it healthy and energized. The following prototype can be applicable in electric vehicles etc. It completely eliminates the monitoring part for the users towards the battery and allow them to multitask or else focus on different activities.

***Index Terms* - Lithium–ion battery, Atmega2560 Controller, CC/CV, ACS712 current sensor.**

I. INTRODUCTION

Lithium-ion batteries are widely used in various applications due to its high energy density, low self-discharge rate, and long cycle life. To avoid overcharging, which can result in thermal runaway, shorter battery life, and even safety risks, charging a lithium-ion battery requires careful monitoring of the charging voltage and current. A microcontroller-based lithium-ion battery charger can be utilized to overcome these difficulties. The components of this kind of charger are a microcontroller unit (MCU), power management circuitry, and battery management circuitry. The MCU, which serves as the charger's central processing unit, is in charge of keeping track of the voltage and current of the battery and adjusting the charging voltage and current as necessary. The MCU also regulates the charging procedure, choosing the charging mode (constant voltage or constant current), keeping track of the battery's and the charging circuitry's temperature, and determining when the charging cycle has finished [1], [2].

The AC to DC input power is converted by the power management circuitry into the proper voltage and current for charging the battery. Different power conversion topologies, such as a rectifier or linear regulator, can be used to do this. Protection measures like overvoltage and overcurrent protection are also included in the power management circuitry. During the charging process, the battery management circuitry is in charge of keeping track of the battery's condition. The temperature of the battery can be measured, the charge level can be determined, and any flaws or irregularities in the battery can be found. Additionally, the battery management circuitry can balance and equalize the battery cells to ensure even charging and avoid overcharging specific cells [4], [12]-[17].

Overall, a microcontroller-based lithium-ion battery charger is a popular option for a variety of applications because it offers a versatile and dependable solution for charging lithium-ion batteries. The charging procedure may be carefully controlled and tailored to fit various battery chemistries and charging profiles using a microcontroller, which also offers safety features to safeguard the battery and the charging circuitry [1], [7].

II. HISTORY OF BATTERY CHARGER

The history of lithium-ion battery chargers dates back to the early 1970s when noble prize winner Michael Stanley Whittingham came up with the concept of rechargeable lithium-ion batteries for the first time. During the late 1990s, a Japanese chemist Akira Yoshino patented the very first rechargeable lithium-ion battery on his name which became extensively popular in cellular phones and other portable electronic devices. With his provided technology, Sony started manufacturing and selling the commercial rechargeable lithium-ion batteries and its charger. With the start of the 2000s, the lithium-ion batteries were now used in a wide range of electronic devices causing the demand of more advanced battery chargers [8], [16]. Taking it as an opportunity the companies began developing lithium-ion battery chargers based on microcontrollers in order to gain more accurate control on the charging process of these batteries [3], [5], [6].

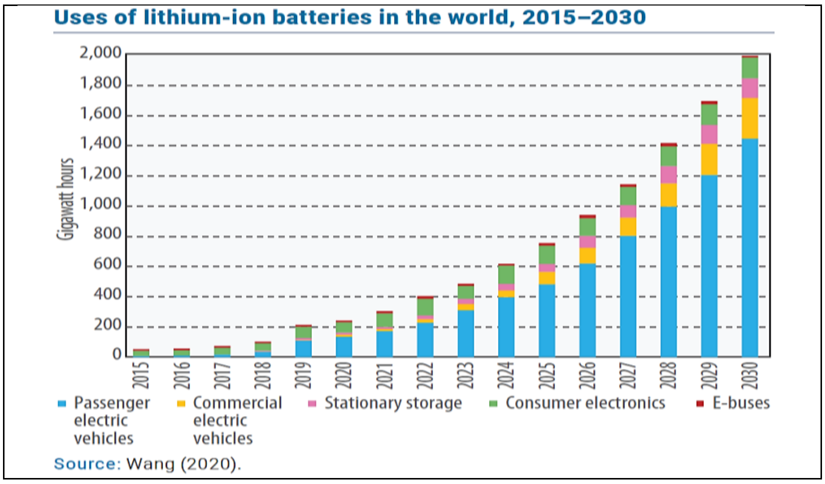


Figure 1 Uses of lithium-ion batteries in the world, 2015-2023

This was also the time when India was also welcoming this technology by setting up its first manufacturing plant of lithium-ion battery and its charger in Mohali, Punjab in 1998 [10], [15]. The biggest revolution in the industry came when Maxim Integrated introduced the MAX712 series of lithium-ion battery charger based on microcontroller in 2005. This charger was designed with programmable charging algorithm that could be customized to charge batteries even with different charging profiles [9], [11].

Overall, the development history of these battery chargers was driven by need to develop safe and efficient charging solutions for lithium-ion batteries. Fig.1 shows the uses of lithium-ion batteries in the world since 2015 and anticipated to 2030.

III. Architecture

The project's core is its primary charging unit Fig.2 showing architecture. Its purpose is to change the AC voltage values that are obtained from the network into DC voltage values. This transformation's block diagram is provided in Fig.3.

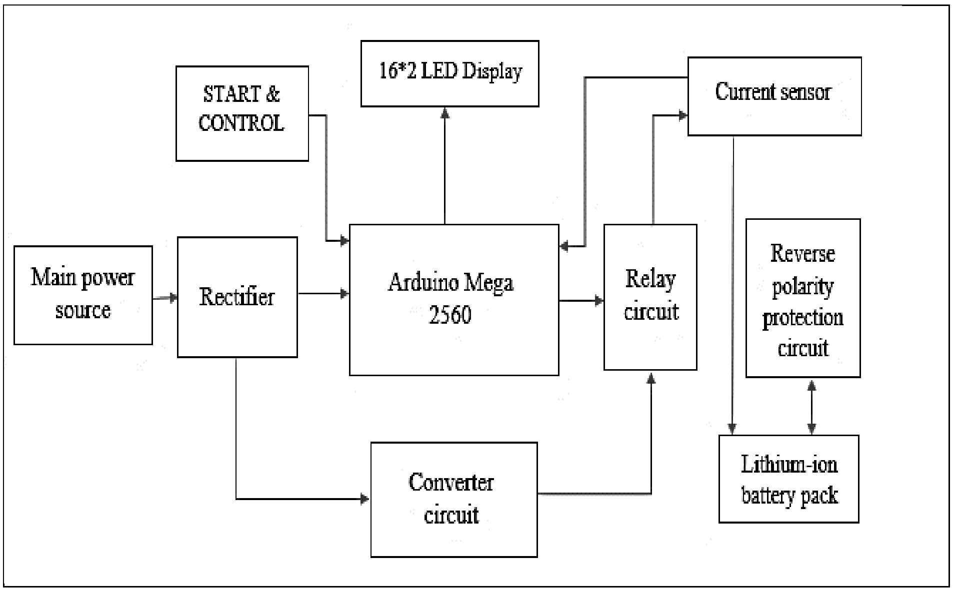


Figure 2 Architecture of Circuit

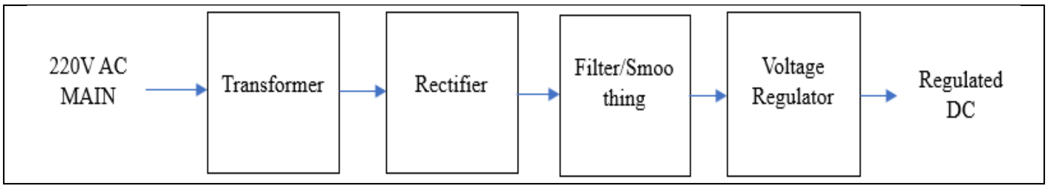


Figure 3 Block diagram of Charging process

Transformer: Low voltage AC is produced by transformers, which step down high voltage AC mains. Our voltage at this point is still AC.

Bridge rectifier: A bridge rectifier Fig.4 is a grouping of four diodes that produces an output voltage with the same polarity for either polarity of input voltage. AC is converted to DC using a rectifier; however, the DC output varies.

Filter capacitor: The DC is reduced from having a large range to a small ripple by smoothing the capacitors.

Regulator: By fixing the DC output voltage, the regulator removes the ripple.

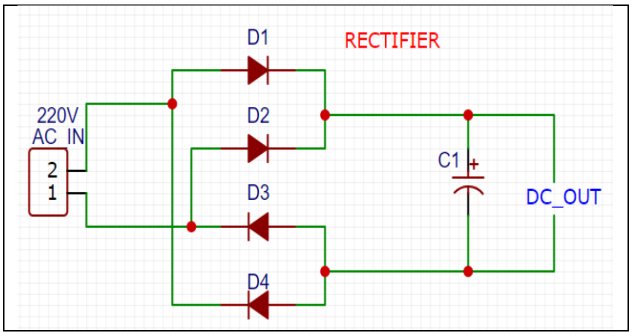


Figure 4 Bridge Rectifier

A. *Flow chart of operation*

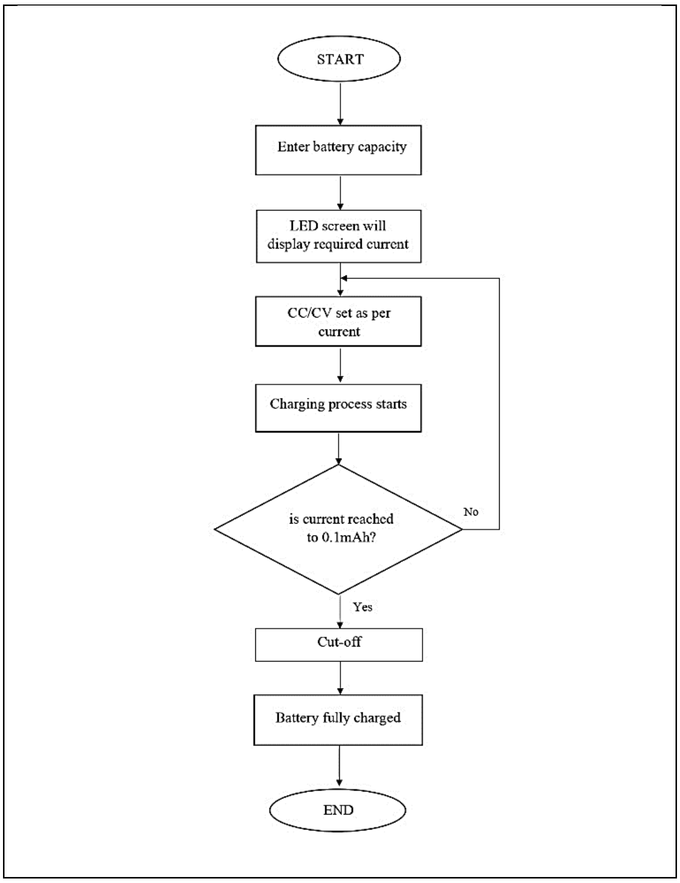


Figure 4 Flow Chart of Operation

B. *Charging Circuit*

Once the charger is turned on, we will be prompted for the battery capacity of the connected device. To increase the battery capacity displayed on the screen, press the INC button. It will increase by 100mAh on the display for each press. With this charger, batteries with capacities between 1000mAh and 5000mAh can be charged. Any additional increment will reset to 1000mAh once we reach 5000mAh. The LCD will display the previously configured 0.5C charging current for the CC/CV buck converter when we push the start button. The current sensor is then calibrated, and the stray magnetic field is then considered by Arduino. This may take five to fifteen seconds.

The charger begins examining the CC and CV modes. If the charging current is decreased by 20% from the initial current, CV mode will be displayed. The charging procedure itself is about to begin. Charging stops when the current reaches 0.1C, and we can remove the battery from the charger at that point.

The charger will detect over-current and stop charging if the charging current is set at higher than 0.7C on the buck converter. It must be lowered to less than 0.7C, ideally 0.5C. If the charging process is not finished within the allotted time, the timeout process will start and the charging will be stopped. We can alter the timeout setting in the code according to our requirements. Schematic diagram of charging circuit is realized in Fig.6.

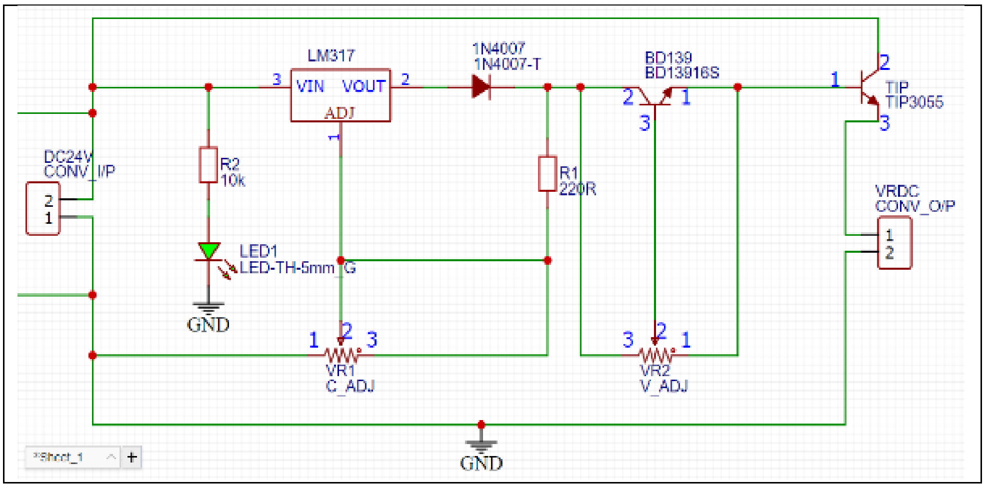


Figure 5 Schematic Diagram of Charging Circuit

C. *Arduino Mega 2560*

Table-1 specification of the microcontroller board is entirely based on the ATmega2560. It has sixteen analogue inputs, four hardware serial ports (UARTs), a sixteen MHz crystal oscillator, 54 digital input/output pins, of which 15 can be used as PWM outputs, ICSP header, USB port, and reset button. We can use a USB cable to connect it to a laptop or an AC-to-DC adapter to power it initially. Everything required to support the microcontroller is included. The majority of shields created for the Uno and previous boards, Demilune or Decimal, are compatible with the Mega 2560 board.

Table 1 Specifications of ATmega2560

Microcontroller	ATmega2560
Operating Voltage	5V
Input Voltage (Recommended)	7-12V
Input Voltage (Limit)	6-20V
Digital I/O Pins	54 (of which 15 provide PWM output)
Analog Input Pins	16
DC Current Per I/O Pin	20 mA
DC Current For 3.3v Pin	50 mA
Flash Memory	256 KB of which 8 KB used by bootloader
SRAM	8 KB
EEPROM	4 KB
Clock Speed	16 MHz
LED BUILTIN	13
Length	101.52 mm
Width	53.3 mm
Weight	37

The ATmega2560 has 4 KB of EEPROM (which can be read and written with the EEPROM library), 8 KB of SRAM, and 256 KB of flash memory for storing code, of which 8 KB is used for the bootloader.

D. *CC/CV converter*

The CC/CV power supply, which is really a converter, is in charge of controlling the voltage and current going to the lithium-ion battery. Similar to other voltage buck converters, this constant current/constant voltage converter also has the ability to limit current. Two control potentiometers, one for voltage and the other for current, are present in this circuit. The short circuit current won't go over 1A once the current limit is set to, say, 1A.

The output voltage and output current can both be changed using the two multiturn trim pots. The output voltage can be raised gradually by turning the voltage adjustment (V-ADJ) trim pot clockwise, and it can be lowered gradually by doing the opposite. Similar to this, turning the current adjustment (I-ADJ) trim pot clockwise raises the current limit while doing so anticlockwise lowers it. It is recommended to first adjust the voltage level before adjusting the current level.

E. *ACS712 current sensor*

To measure the circuit's charging current, we are using an ACS712 (ACS712-05B) 5A (AC/DC) current sensor module. The magnetic effect principle, which states that a conductor carrying current will create a magnetic field around it and that the strength of the magnetic field is directly inversely proportional to the current flow, underlies the operation of this current sensor.

The IC on the breakout board senses the magnetic field and produces a proportional analogue voltage between 0 and 5V. Since it is capable of measuring both AC and DC, the output voltage will be 2.5V in the absence of input current and will change to 5V or 0V if current is applied. The output of this sensor, however, rarely centers at 2.5V and strongly deviates from the actual current value because it is noisy and picks up stray magnetic fields from its surroundings.

As demonstrated, we can add a 0.47uF capacitor of any kind in parallel with the current SMD component to further improve accuracy.

F. LCD Display & I2C Module

The battery's current charge level and other essential charging-related details are shown on a "16*2" LCD display. In order to simplify the project's wiring, we are employing an I2C LCD adaptor module. Inter-Integrated Circuit (I2C; pronounced "eye-squared-C"), often known as I2C or IIC, is a synchronous, multi-master/multi-slave (controller/target), packet switched, single-ended serial communication bus. There are 8 I/O pins, 3 I2C bus address pins (A0, A1, A2), and SDA and SCL pins. A built-in potentiometer on the LCD controller board controls the LCD's contrast.

G. DC Relay

We are using a 12V relay which is activated by a low power NPN transistor. While turning the relay ON and OFF, a diode will stop excessive voltage back EMF. They enable the control of a high current flow circuit by a low current flow circuit.

H. PCB Designing

In our daily lives, electronics have an ever-green influence. To argue that electronics have become an integral part of our life would not be an exaggeration. Electronics design has advanced to a highly advanced level. Printed circuit boards are appropriately referred to as the brain, heart, and spine of any electronic gadget. Therefore, it is vitally essential that the PCB be created with the utmost care. Most of the equipment's limiting qualities in terms of noise immunity, quick pulses, high frequency, and low-level characteristics are determined by the PCB design.

- Circuit Diagram
- Layout
- Artwork
- Computer Aided Design

Easy EDA (Electric Design Automation) software was used for PCB design. And our college handled the fabrication portion. Positive development was a part of fabrication, and screen printing was used for printing.

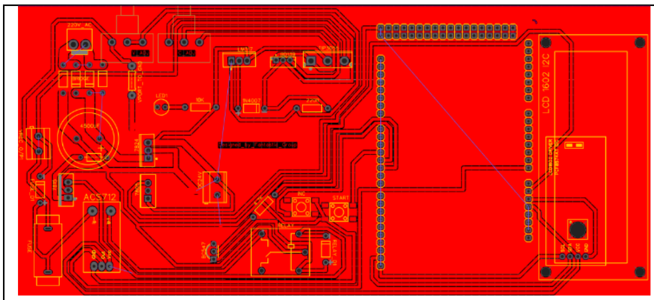
IV. METHODOLOGY

There are typically two steps to the charging of a lithium-ion battery: the constant current (CC) stage and the constant voltage (CV) stage.

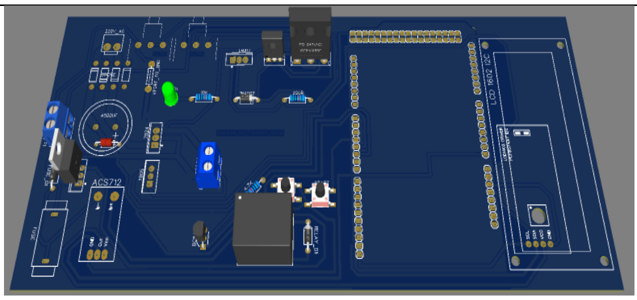
A. Constant Current (CC) Stage

A constant current is used by the charger to quickly charge the battery during the CC stage. Approximately 70–80% of the battery's capacity is charged during this stage. Where C is the battery's nominal capacity, the charging current is normally set to a value between 0.5C and 1C. For instance, the charging current would be set at 0.5A to 1A if the battery had a nominal capacity of 1000mAh.

As the battery charges during the CC stage, the voltage of the battery gradually rises. The charger adjusts the charging current as necessary to maintain the desired charging pace. The charging current is normally monitored using a current sensing circuit.



(a) PCB Layout



(b) 3D View

Figure 7 PCB Layout & 3D View

B. Constant Voltage (CV) Stage

The charger moves to the CV stage when the battery voltage reaches a certain level, typically approximately 4.2V per cell. In order to avoid overcharging the battery during the CV stage, the charger controls the charging current while maintaining a constant voltage across the battery terminals. As the battery gets closer to being fully charged, the charging current gradually decreases. The charger keeps charging the battery until the charging current falls below a predetermined level, usually between 0.05C and 0.1C. The charging voltage is normally restricted to 4.2V per cell in order to prevent overcharging. The battery manufacturer determines this voltage limit based on the electrochemical characteristics of the battery. If the battery is charged above this voltage threshold, it may suffer irreparable harm, such as thermal runaway and fire.

Overall, charging lithium-ion batteries with the CC/CV stage is a successful and efficient process. During the CC stage, it offers quick charging, and during the CV stage, it makes sure the battery is charged effectively and safely Fig. 8.

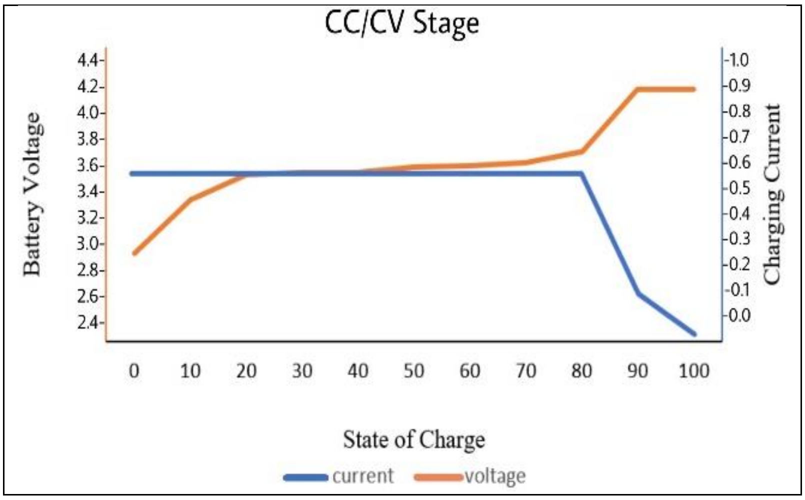


Figure 8 Charging Stages of Battery

V. Case Study

Outline: A CC/CV (constant current/constant voltage) lithium-ion battery charger is a widely used method to charge lithium-ion batteries. The charging process involves two stages: the constant current stage, in which the charger supplies a constant current to the battery until the battery voltage reaches a certain level, and the constant voltage stage, in which the charger supplies a constant voltage to the battery to complete the charging process.

Problem: A company required to charge a 3.7V - 4.2V lithium-ion battery with a capacity of 5000mAh in less than 2 - 3 hours. Also, the charger should be able to communicate with the microcontroller in order to monitor the charging process and provide feedback to the user.

Solution: In order to provide the desired solution for this problem, a CC/CV lithium-ion battery charger based on a microcontroller has been developed for the client. The charger consisted of a microcontroller, current sensors, protection circuit, variable power supply and a relay circuit. The microcontroller was programmed to control the charging process and communicate with the user. During the constant current stage, the microcontroller set the charging current to a predetermined value using pulse width modulation (PWM). The microcontroller monitored the current sensing circuit to ensure that the charging current remained constant until the battery voltage reached a predetermined level. Once the battery voltage reached the predetermined level, the microcontroller switched to the constant voltage stage. During this stage, the microcontroller regulated the charging voltage to a predetermined value using PWM.

The microcontroller communicates through a serial interface to provide feedback to the user. The user could monitor the charging process on the LCD display and the battery will auto-cut-off when the charging process was complete.

Results and Consequences: The CC/CV lithium-ion battery charger based on a microcontroller was successfully designed and implemented. The charger could charge a 3.7V lithium-ion battery with a capacity of 5000mAh in less than three hours. The charging process was monitored and controlled by the microcontroller, ensuring that the battery was charged safely and efficiently.

Summary: The CC/CV lithium-ion battery charger based on a microcontroller was an effective solution for our battery charging needs. The charger was able to charge the battery safely and efficiently while providing feedback to the user. The use of a microcontroller allowed for precise control of the charging process and improved communication with the user. All specifications were satisfied in the finished product.

VI. Result and Discussion

There are two sections in this paper. One is a segment for software, and the other is a section for hardware Fig.8. Proteus Software is used for all testing in the software segment, and it is put into practice. The individual testing of different modules is developed and the final setup was made arranging all devices in proper manner. After this final arrangement the whole system has been tested and all the three batteries have been charged successfully. Fig. 9 the final product shows:

- Facility of fast charging and slow charging as per the need.
- After charging, batteries automatically disconnect.
- Batteries should be connected in parallel to allow for safe battery removal without disturbing the others.
- Charging indication.
- protection from overheating and overcharging.
- Batteries with different charging profile can be charged.

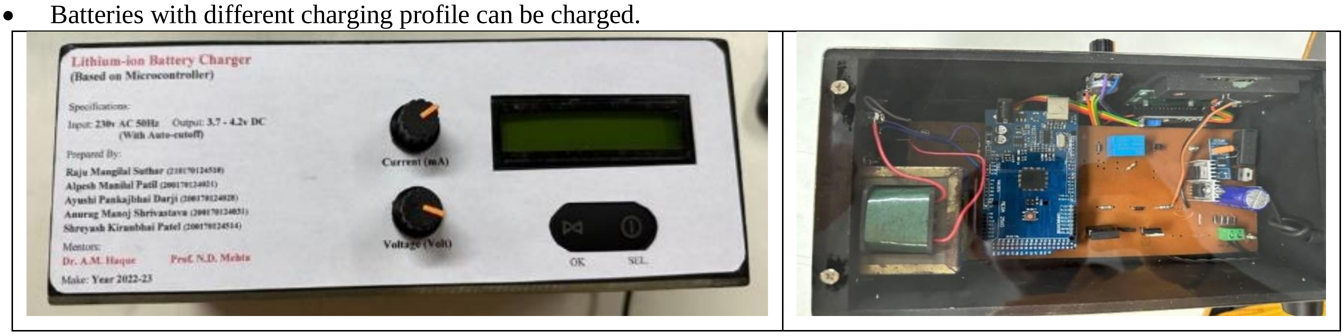


Figure 9 Final End Product (with nomenclature on translucent casing)

VII. Conclusions

Owing to its high energy density and 99% efficiency, lithium-ion batteries are used in a variety of sectors. But if they are not orated within an optimal operating range that is determined by parameters such as temperature, charging and discharging current and voltage, they are bound to fail and age quickly and this may even lead thermal breakdown.

Therefore, it is important to monitor these parameters and whenever the battery exceeds the prescribed limits, warning should be generated. This problem is solved using the prototype that monitors current using an ACS712 current sensor and voltage using the inbuilt ADC of the microcontroller. All of the indications are screened on LED display along with the real time readings. With a minor improvement in microcontroller basics and Arduino mega, we are able to monitor lithium-ion batteries and offer a real-time solution needed to anticipate energy from lithium-ion batteries in terms of efficiency and safety.

VIII. Acknowledgment

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References

[1] M. H. RASHID, Power Electronics Handbook, Florida: Academic Press, 2001.
[2] A. I. Pressman, Switching Power Supply Design, McGraw Hill, 1992.
[3] Festus, Ben & R., Amodu & N, Bassey & Ugwu, Uchenna. (2017). An Improved Microcontroller Based Lead Acid Battery Charger. 10.13140/RG.2.2.18869.37608.
[4] Guan-Chyun Hsieh, Liang-Rui Chen and Kuo-Shun Huang, "Fuzzy-controlled Li-ion battery charge system with active state-of-charge controller," in IEEE Transactions on Industrial Electronics, vol. 48, no. 3, pp. 585-593, June 2001, doi: 10.1109/41.925585.
[5] Chia-Hsiang Lin et al., "Fast charging technique for Li-Ion battery charger," 2008 15th IEEE International Conference on Electronics, Circuits and Systems, Saint Julian's, Malta, 2008, pp. 618-621, doi: 10.1109/ICECS.2008.4674929.
[6] Zhang, Shuo & Zhang, C. & Xiong, Rui & Zhou, Wei. (2014). Study on the Optimal Charging Strategy for Lithium-Ion Batteries Used in Electric Vehicles. Energies. 7. 6783-6797. 10.3390/en7106783.
[7] A. M. Rahimi, "A lithium-ion battery charger for charging up to eight cells," 2005 IEEE Vehicle Power and Propulsion Conference, Chicago, IL, USA, 2005, pp. 6 pp.-, doi: 10.1109/VPPC.2005.1554545.
[8] Hassan, Ahmed & Hassan, Haitham & Zeid, Magdy & Soliman, Moataz. (2012). Maximum power battery charging from PV system microcontroller based. 111-116. 10.1109/ICCTA.2012.6523555.
[9] M. Chen and G. A. Rincon-Mora, "Accurate, Compact, and Power-Efficient Li-Ion Battery Charger Circuit," in IEEE Transactions on Circuits and Systems II: Express Briefs, vol. 53, no. 11, pp. 1180-1184, Nov. 2006, doi: 10.1109/TCSII.2006.883220.
[10] B. Arabsalmanabadi, N. Tashakor, A. Javadi and K. Al-Haddad, "Charging Techniques in Lithium-Ion Battery Charger: Review and New Solution," IECON 2018 - 44th Annual Conference of the IEEE Industrial Electronics Society, Washington, DC, USA, 2018, pp. 5731-5738, doi: 10.1109/IECON.2018.8591173.
[11] V. L. Teofilo, L. V. Merritt and R. P. Hollandsworth, "Advanced lithium-ion battery charger," in IEEE Aerospace and Electronic Systems Magazine, vol. 12, no. 11, pp. 30-36, Nov. 1997, doi: 10.1109/62.636803.
[12] L. -R. Chen, R. C. Hsu and C. -S. Liu, "A Design of a Grey-Predicted Li-Ion Battery Charge System," in IEEE Transactions on Industrial Electronics, vol. 55, no. 10, pp. 3692-3701, Oct. 2008, doi: 10.1109/TIE.2008.928106.
[13] Kaifeng Huang, Yong Wang, Juqiang Feng, "Design of lithium-ion Battery management system for mine electric vehicle", https://www.researchgate.net/publication/349979975 IOP Conference Series Earth and Environmental Science · March 2021, DOI: 10.1088/1755-1315/680/1/012015
[14] Gao ZC, Chin CS, Chiew JHK, Jia JB, Zhang CZ. "Design and Implementation of Smart Lithium-ion Battery System with Real-time Fault Diagnosis Capability for Electric Vehicles", Newcastle University ePrints - eprint.ncl.ac.uk. Energies 2017, 10(10): 1503.
[**15**] Sabeur Jemmali, Bilal Manaï, Mahmoud Hamouda, "Pure hardware design and implementation on FPGA of an EKF based accelerated SoC estimator for a lithium-ion battery in electric vehicles", IET Power Electronics published by John Wiley & Sons Ltd on behalf of The Institution of Engineering and Technology, 2022. pp 1005-1015. DOI: 10.1049/pel2.12283
[16] https://images.app.goo.gl/7QFrzUtwGMgepYtT9
[17] https://books.google.co.in/books/about/Microcontroller_Based_Battery_Charger.html?id=84x8nQAACAAJ&redir_esc=y