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Design and Implementation of Modular Li-ion Battery Fast Chargers

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A B S T R A C T

In order to reduce our dependence on fossil fuel, electric vehicles (EVs) are the future of transportation, as the amount of greenhouse gases and global warming is at a record high and fossil fuels are depleting at an alarming rate.. Electric vehicles are now impracticable owing to the lengthy charging times that are required of them. Therefore, a fast charger is necessary for electric cars in order to satisfy the high range requirement and to minimize the amount of time that it takes for electric vehicles to charge, both of which will result in improved performance in comparison to EVs already on the market. When using a fast-charging station, the amount of electricity necessary to charge a car in a short amount of time is dependent upon the degree of charge that is already present in the battery. The work that is being suggested is on a rapid charger that is based on a transformer and can generate an output current of up to 200A. The suggested topology has been constructed, and simulations have been run on it using MATLAB Simulink and NI multisim. The performance parameters have been tallied. It has been determined that the hardware implementation of the topology is complete.

Keywords:LFP battery, BMS, Cell equalization, Charge and discharge control, Arduino

Abbreviations

BCR: Battery Current regulation
LI ion: lithium ion
DCCT: Direct Current CT

1. INTRODUCTION

In recent years, electric cars (EVs) have emerged as a possible alternative to internal combustion engine (ICE) vehicles. The goal of these EVs is to lessen the heavy dependence on petroleum as well as to comply with the increasingly stringent rules on emissions that have resulted from a significant environmental concern about global warming. These laws have been derived from the fact that there is a growing worry about global warming. [1]. Despite the fact that the number of EVs is still far from being equal to conventional ICE vehicles, recent advances in energy storage technologies and electronics engineering are boosting their growth in the automotive sector. Different companies are betting for full EVs stimulated by the last advancements in energy storage technologies and power electronics. For instance, Tesla Motors has recently presented Model S which is capable to cover a distance of 430 km with a full charge of the battery [2]. However, despite their main advantages, such as high energy efficiency, independence on fossil fuels and zero emissions, the main drawbacks of EVs are their high initial cost, relative short driving autonomy, life cycle of the batteries and slow charging. In order to simplify the notation, both PHEVs and pure EVs will be referred as EVs hereinafter.
Regarding the employed battery technology in EVs, the nickel-metal hydride (NiMH) batteries were the most widely used energy storage technology during the 1990s and 2000s due to their high power density and proven safety. These days, lithium-ion (Li-ion) batteries are considered the most promising battery technology for EVs as a result of its relatively higher specific energy and power density with respect to lead acid and NiMH. A higher specific energy density is generally traduced into higher autonomy, which is a highly appreciated characteristic in the automotive sector.

However, Li-ion batteries need to use a more complex battery management system (BMS) to provide different protections, such as overvoltage, under voltage, over temperature and overcurrent; in addition to voltage cell's equalization [3, 4].Several battery chargers can be found and they can be classified according to different criteria

The vast majority of on-board single-phase battery chargers include a cascading process comprising two phases [5]. The first step is made up of an AC/DC converter, which guarantees a power factor correction (PFC) of unity by absorbing a sine supply from the network that has minimal current harmonics. The second level is comprised of a DC/DC converter, which controls the current that is supplied to the battery in accordance with its state of charge (SoC) and matches the voltage differential that exists between the DC connection and the battery.

A diode rectifier followed by a boost converter is the most popular unidirectional AC/DC converter owing to its continuous input current, simple structure and grounded transistor [6]

The main drawback is that an important share of conduction losses is generated by the diode rectifier. For this reason, several bridgeless topologies have been proposed to avoid the use of a rectifier,

The diode rectifier of a unidirectional boost converter can be substituted by a synchronous rectifier to allow the bidirectional power flow capability .

A unidirectional buck converter is the kind of DC/DC converter that is most often used for the battery current regulation (BCR) stage. This type of converter is used to lower the voltage coming from the DC-link.

In order to cut down on the number of filtering components, an LC output filter is sometimes incorporated.

Other topologies include the use of a high-frequency switched transformer to provide galvanic isolation between the grid and the battery. High-frequency switched transformers are preferred to line-frequency transformers in terms of size and weight. The phase-shifted full-bridge DC/DC converter and the full-bridge series resonant converter are the two topologies that are used the most often. [7]

2. PROPOSED CHARGER TOPOLOGY

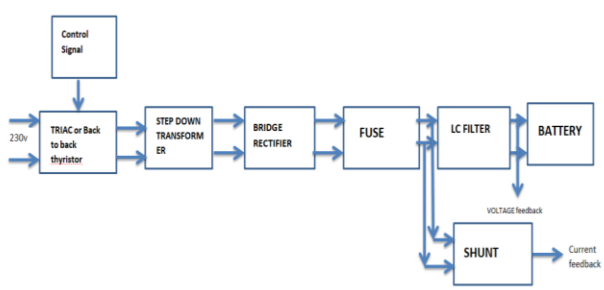


FIG. 1 – Block diagram of proposed topology

The proposed topology consists of a step down transformer to reduce the input AC current to 15 v from the 230 V supply which is been provided from the current grid . The bridge rectifier converts the AC into DC using power diodes as the high current will be present in the system. A LC filter is provided to remove the ripple to obtain a better output without any noise in the waveform. For the feedback circuit a current feedback is taken from the shunt in the circuit and a voltage feedback is obtained from the load voltage which is used for the analog gate circuit which consists of opamp which are used as a comparator to obtain the control signal for the TRIAC or the back to back thyristor. An actual charger has been simulated and examined in the lab with the aim of determining the system efficiency at a range of charging currents. The block diagram for the charger is shown below.

A.IRON CORE TRANSFORMER

The iron core toroidal transformer in a charger's major duty is to step down the mains AC voltage to 15V, which is the same as the battery bank voltage. A 15V battery bank typically requires 600W of charging power. The transformer, however, suffers power losses during the step-down operation, including magnetising loss in the core, eddy current loss, hysteresis loss, and resistive losses in the copper coil [8]. These losses will vary depending on the transformer's efficiency. If a 70 percent efficiency is anticipated, a power loss of roughly 200W must be included in. As a result, the total input power of a traditional charger should be considered to be in the range of 800W to 900W.As a result, you'll need an high rating iron core transformer with a high VA rating. This makes the charger size quite huge, which has a substantial impact on its portability. A typical charger, weighing around 10 kilograms, is seen in the diagram below. The transformer is responsible for about 95% of the total weight.

B.BRIDGE RECTIFIER

Alternating current (AC) is changed into direct current (DC) using a device called a bridge rectifier, which is a full wave rectifier (DC). This converter receives alternating current or alternating voltage from the mains as its input, and it produces direct current or direct voltage as its output. In power supplies, which are the devices that are in charge of providing electronic modules and equipment with the required DC voltage, bridge rectifiers are used the vast majority of the time. This is the location where one is most likely to find them. They are the ones that are constructed utilising generally four or more diodes or other kinds of solid-state controlled switches, and the output of these devices is a voltage that is effective DC. The suitable bridge rectifier is determined after taking into consideration the requisite load current. When choosing a rectifier power supply for an application involving an electronic circuit, a number of factors, including component ratings and specifications, breakdown voltage, temperature ranges, transient current rating, forward current rating, mounting requirements, and other considerations, are taken into account. The following graphic shows how the components of a bridge rectifier are connected to one another. The diodes labelled D1, D2, D3, and D4 together with a load resistor are the components that are required to construct this circuit (RL). Alternating current may be converted to direct current in an efficient way by utilising these diodes, which may be connected in a closed-loop arrangement. The most important advantage of using this specific architecture is that it does not need a transformer with a center-tapped winding. Both the size and the cost will end up being reduced as a direct consequence of this change.

The most significant benefit of using a bridge rectifier is that its output voltage is nearly twice as high as that of a full-wave rectifier with a center-tapped transformer. This is the primary reason why employing a bridge rectifier is preferable. This circuit, on the other hand, does not require for a center-tapped transformer, which gives it the appearance of a more economical rectifier. According to the schematic representation of the rectifier's circuit, a bridge rectifier is made up of many stages of electronic components. These components include a transformer, a diode bridge, filters, and regulators. In a broader sense, the combination of these building elements is known as a regulated DC power supply. Many different kinds of electronic devices can be powered by this kind of external power source.

The first stage of the circuit is comprised of a step-down transformer, which has the main purpose of lowering the amplitude of the voltage that is being fed into the circuit. A 230/12V transformer is required for the majority of electrical projects since it is necessary to change the standard 230V AC mains supply into 12V AC. The third stage is a diode-bridge rectifier, which, depending on the kind of bridge rectifier that is being used, may make use of four or more diodes in addition to the diodes already in use. It is important to take into account the Peak Inverse Voltage (PIV), forward current (If), voltage ratings, and any other pertinent data when selecting a diode or similar switching device to use in a rectifier. It is in charge of producing unidirectional current, also known as DC current, at the load by means of conducting a series of diodes for each half-cycle of the input signal. As a direct consequence of this, the electric current will flow in just one direction. Filtration is required in order to achieve pure DC due to the pulsating nature of the output of the diode bridge rectifiers. Filtration is essential in order to acquire pure DC. As can be seen in the graphic that follows, filtering is often achieved by connecting one or more capacitors across the load, which smooths the wave. This can be seen in action in the accompanying figure. One may consider this to be a standard approach to filtering. The value of this capacitor is also determined in part by the voltage that is produced by the device.

3. DESIGN AND SIMULATION

Creating a functional prototype of the proposed charger involved a few strategic steps. The abstract idea was implemented using PSIM software, where the preliminary testing and parameter adjustments were made. Then, once a stable model was created in PSIM, the next step was to design the hardware and improve it through necessary adjustments of component values, until the desired outcome was obtained.

LC Filter Design: A very short dead time between complimentary PWM signals was supplied to prevent short circuits. Both MOSFETs are turned off for this brief interval. As a result, there is some ripple in the output current and voltage. As a result, a small inductor must be utilized to lessen the current ripple. A modest capacitor bank should also be employed in parallel with the load to prevent voltage ripple. The filter's inductance and capacitance were calculated using the equation [9] below. The smaller the filter is, the higher the frequency of ripple. Since the halfbridge inverter's switching frequency was 20kHz in this study.

The battery pack comprises of 3 parallel cells and 4 series cells. Each cell has a nominal voltage of 3.2 and a nominal capacity of 120Ah. This accounts for the pack's overall voltage of 12V and capacity of 360Ah[10]

Table 1 - Battery specification

Parameter	Rating
Nominal Voltage	3.2V
Nominal Capacity	120Ah
Cycle Life	>2000 cycles
Working Voltage	2.5-3.65V
Internal Resistance	≤0.5mΩ
End of discharge Voltage	2.5V
Charge Method	2C CC/CV
Max.Continuous charge current	120A
Nominal Discharge Current	240A Maximum duration:3min
Max. Pulse Discharge Current	360A/10S
Dimensions(mm)	L174mm x W48mm x H170mm
Weight	2.9±0.1KGS

Table2 – PFC specification

Parameter	Rating
Rated power Po	3.2kW
Output voltage Vo	16V
Output current Io	200A
Inductor, L1	4000mH
Capacitor C1,	90000µF
Switching frequency f0	100kHz

The model is being simulated using the NI multisim software and MATLAB Simulink 2021A software and the results are shown below

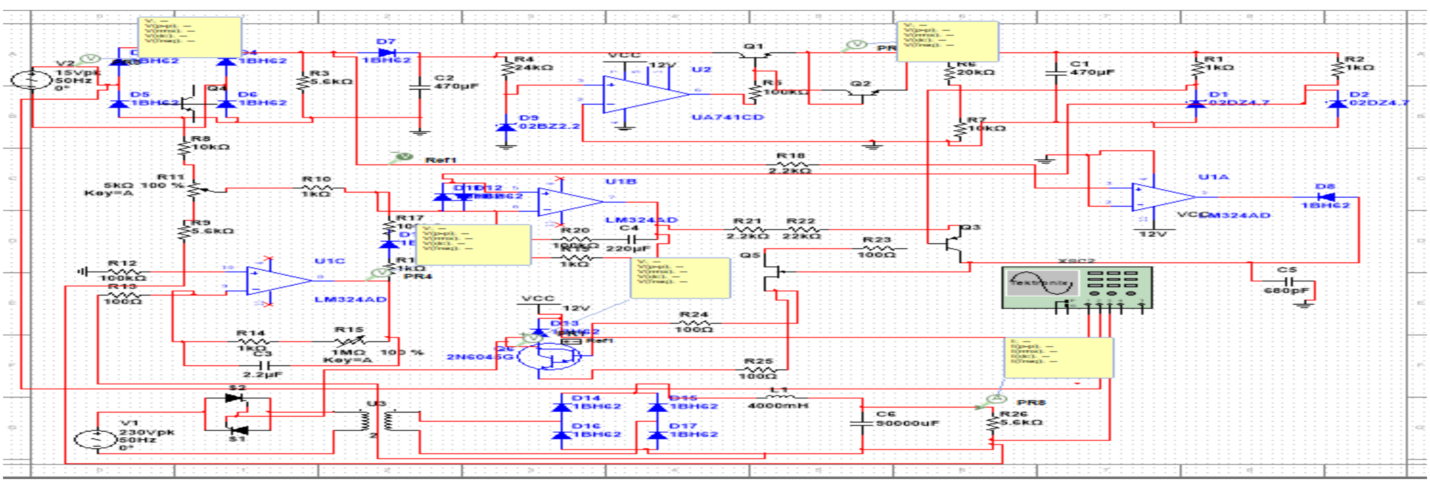


FIG. 2 -Control circuit simulation in NI multisim

In the figure 2 the simulation of the control circuit for the current and the voltage feedback are observed using the comparator opamp (operational amplefiers). The outputs of the comparator are given through a BJT and MOSFET and the voltage is supplied into a pulse transformer which provides the control gating pulses that are required to control the TRIAC which regulates the input voltage

charger circuit and the performance parameters have been noted and the current and the voltage have been noted

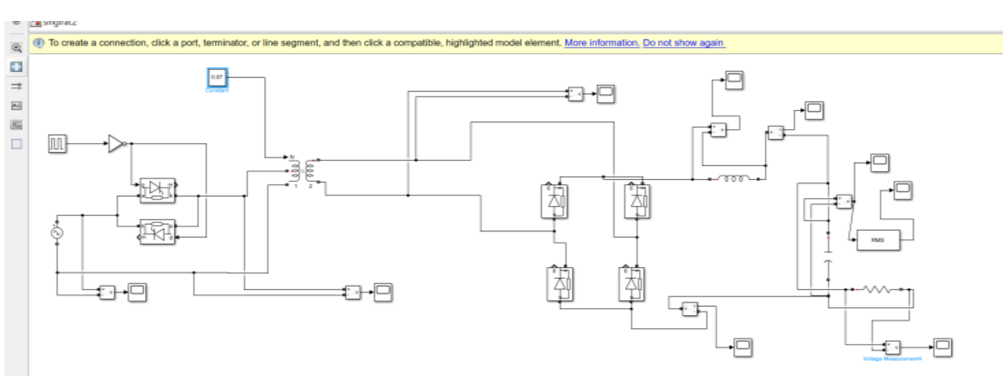


FIG. 3 –Simulink simulation of the charger

4. HARDWARE IMPLEMENTATION

An experimental setup was rigged up to observe the parameters such as the charging current and the charging voltage. The power was observed and a variable resistor is used to change the output current. The various outputcurrents and the corresponding voltages that provide the charging power is tabulated. The control circuit for the TRIAC triggering[11] has been designed using the comparator opampa shown in figure 5. The circuit consists of a rectifier which gives the dc voltage to the voltage regulator which produces the 12V constant output which is used for the voltage comparison.

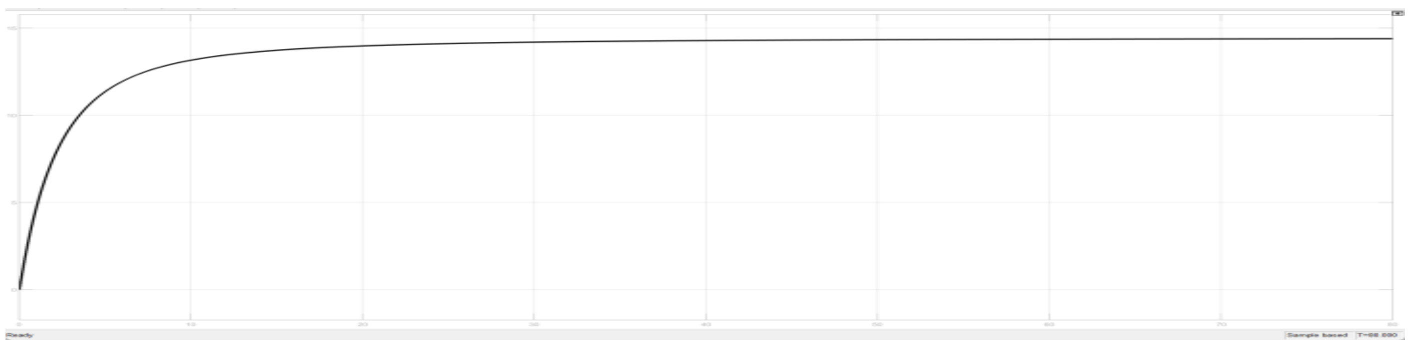


FIG. 4 –15V output voltage waveform

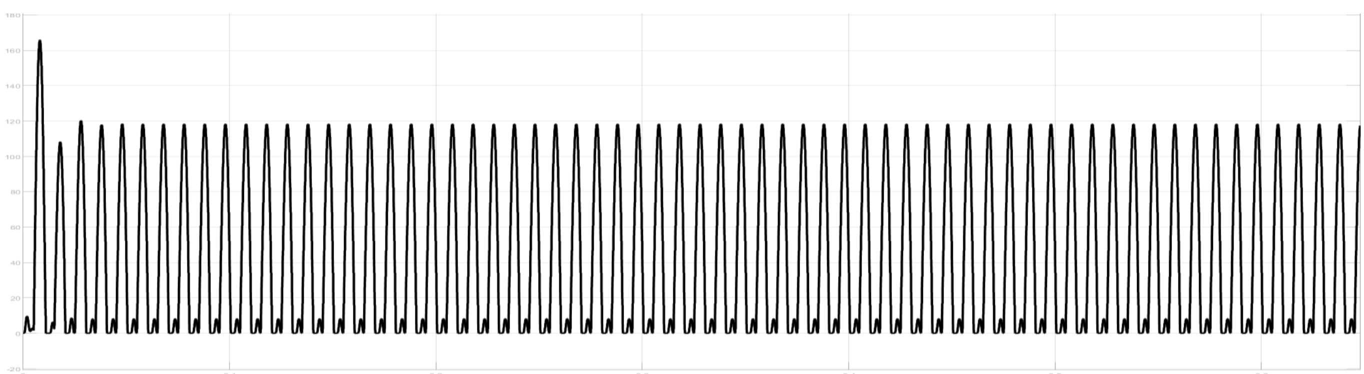


FIG. 5 –120A output current waveform

The MATLAB SIMULINK simulation of the suggested architecture without the feedback circuit is shown above in figure 3, and it illustrates how one may generate an output voltage of 12V and an output current of 120A. The SIMULINK model consists of the transformer, a bridge rectifier, and either a TRIAC or two back-to-back SCRs coupled for the gating pulses. Additionally, the model has a connected gating pulse connector. In order to get a filtered output from the simulation diagram, an LC filter consisting of a capacitor and an inductor is used. Figure 4 illustrates the output of the proposed topology, which is 16 volts, and Figure 5 illustrates the output current of the charger topology, which is 120 amps.

The block diagram for the hardware implementation of the comparator circuit is shown in figure 6

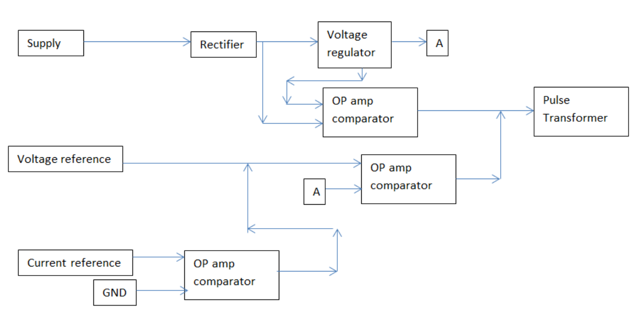


FIG. 6 –Block diagram of triggering circuit

The pulses are generated by the comparator1, which compares the rectified constant voltage to the ground and then compares the results. In order to determine what the outputs are, the comparator 2 will compare the reference voltage with the output from the voltage regulator and the. After being compared to ground, the current feedback is then used to generate pulses, which are then sent into the input of the voltage comparator. The comparators' outputs are connected to the mosfet's emitter, while the collector is connected to the mosfet. The output is sent to the pulse transformer, and the triggering pulses are sent to the TRIAC. The piece in question Figure 7 depicts the hardware implementation of the topology. It shows the 200A iron core transformer that is used to step down the input voltage and to increase the current in the circuit. The inductors and the capacitor that have been used for the filters are also depicted in the charger implementation. This image displays the control board that is based on the LM324 microcontroller. It contains a pulse transformer that supplies the pulse gate input for the TRIAC, which may assist in achieving the desired level of output power.

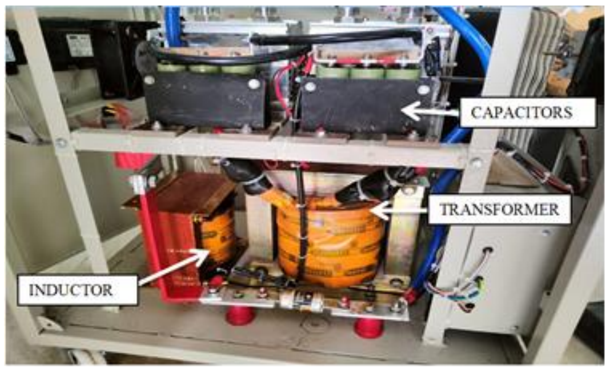
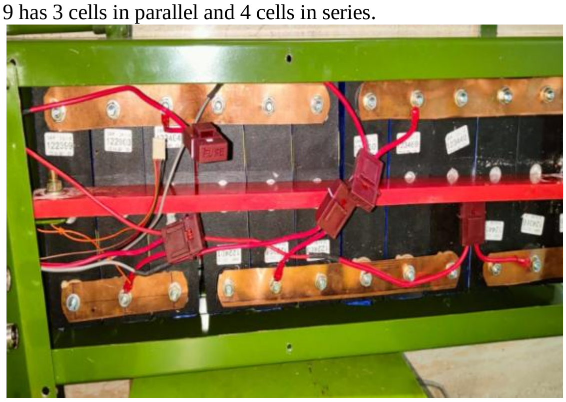


FIG. 7 – Hardware implementation

FIG. 8 –Individual LFP Cell

Figure 8 represents a Prismatic LFP (Lithium Iron Phosphate) cell with nominal voltage of 3.2V and Capacity of 120Ah. The battery pack shown in figure 9 has 3 cells in parallel and 4 cells in series.



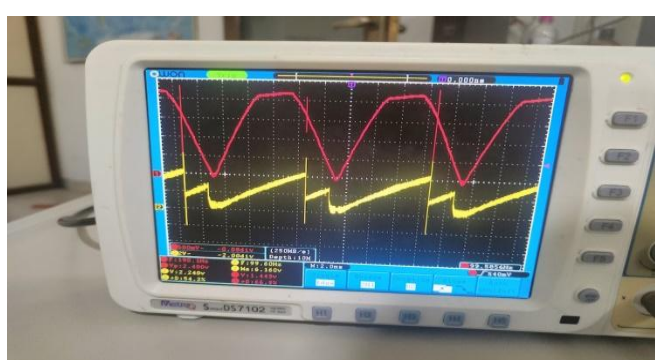


FIG. 9 –Battery pack with 3 cell in parallel and 4cell in series

FIG. 10 –TRIAC triggering

The pulsing current waveform can be seen in the picture above, and below it, a modification in the saw tooth waveform can be seen, both of which are used for the generation of the pulses that are given for the triggering of the TRIAC.

5. CONCLUSION

Through modelling, hardware implementation, and observation of output characteristics, this article suggests a high-speed fast charger for a 360A, 12.8V battery module. The charger has been tested, and it has a high charging rate. In the circuitry, an analogue triggering mechanism that makes use of TRIAC has been built, and also the pulses for both the TRIAC triggers are delivered depending on the current feedback. It was discovered that if there was a change in the current, the pulses, which are generated by the current feedback, would also change, which would then cause the TRIAC to be activated. As a result, the current is regulated so that it corresponds with the necessary load circumstances. A trickle charging control is also performed when the battery voltage is over 3.4V and a 1 M resistor is found to be delivering a trickle charging current of 3-4 A. This is done to prevent the battery from being overcharged and damaged as a result of the overcharging process. The charger control now includes the charging control that is included as portion of the battery management system. This technique of rapid charging is not only simple to adopt but also needs a lower level of maintenance. The analogue op-amp oriented triggering circuit is used in the suggested charger circuit, which results in improved current regulation.

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REFERENCES

[1] M. Ehsani, Y. Gao, and A. Emadi, Modern electric, hybrid electric, and fuel cell vehicles: fundamentals, theory, and design, 2nd ed., New York: CRC Press, 2020.

[2] J S. Kocaoğlu, N. S. Dağılgan and M. Furat, "Horizontal Rotating Charging Platform for Electric Vehicles," 2019 3rd International Symposium on Multidisciplinary Studies and Innovative Technologies (ISMSIT), 2019,

[3] G. S. Kumar, A. I. Selvi and K. Pandiyan, "Design and Analysis for Energy Storage Systems for Transport and Grid Applications using SMES devices with PWM-CSC," 2019 IEEE International Conference on Clean Energy and Energy Efficient Electronics Circuit for Sustainable Development

[4] A. Ahmad, M. S. Alam and R. Chabaan, "A Comprehensive Review of Wireless Charging Technologies for Electric Vehicles," in IEEE Transactions on Transportation Electrification,

[5] H. Wen, D. Jiao and J. -S. Lai, "Optimal Design Methodology for High Frequency GaN Based Step-up LLC Resonant Converter," 2019 IEEE 4th International Future Energy Electronics Conference (IFEEC), 2019,

[6] R. B. Beddingfield, S. Samanta, M. S. Nations, I. Wong, P. R. Ohodnicki and S. Bhattacharya, "Analysis and Design Considerations of a Contactless Magnetic Plug for Charging Electric Vehicles Directly From the Medium-Voltage DC Grid With Arc Flash Mitigation," in IEEE Journal of Emerging and Selected Topics in Industrial Electronics,

[7] "IEEE Standard for Technical Specifications of a DC Quick and Bidirectional Charger for Use with Electric Vehicles," in IEEE Std 2030.1.1-2021 (Revision of IEEE Std 2030.1.1-2015) , vol., no., pp.1-147, 18 Feb. 2022

[8] Electrical Engineering Portal. [Online]. Available: http://electricalengineering- portal.com/transformer-heat-copper-and-iron-losses, Accessed on: Sep. 3, 2015.

[9] Y. Li, S. -l. Liu and H. Gao, "A Simplified Output Voltage Ripple Calculation Method of Intrinsically Safe Buck Converter with LC Low Pass Filter," 2019 14th IEEE Conference on Industrial Electronics and Applications (ICIEA), 2019, pp. 1536-1539, doi: 10.1109/ICIEA.2019.8833828.

[10] S. Mittal, R. Khullar, G. Kapur and V. P. Pyara, "To propose a design parameter γ, resistor transfer parameter for UJT which shows resemblance with BJT," 2012 Students Conference on Engineering and Systems, 2012, pp. 1-5, doi: 10.1109/SCES.2012.6199031.

[11] M. A. Hannan, M. M. Hoque, A. Hussain, Y. Yusof and P. J. Ker, "State-of-the-Art and Energy Management System of Lithium-Ion Batteries in Electric Vehicle Applications: Issues and Recommendations," in IEEE Access, vol. 6, pp. 19362-19378, 2018, doi: 10.1109/ACCESS.2018.2817655