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Design of DC-DC Fast Charger for EV Scooter

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***Abstract*— Electric vehicles (EVs) are a new and promising way toward environmental change as the world struggles with climate change and pollution. India is also in the process of EV integration with the support from the FAME program and many states offering various subsidies. Nevertheless, there are still some challenges that need to be solved, such as the insufficient number of charging stations, relatively high costs of electric cars in the beginning, range anxiety, and further development of battery technologies.**

In response to these issues, this project proposes the design of a small-sized and energy-saving DC-DC fast charger for EV scooters. The aim is to resort charging times to a lower level and minimize the consumption of the electrical grid. We also use topcomp MOSFETs, a synchronous buck converter, and efficient PCB layout to introduce a charger that improves performance while built specifically to integrate into home charging stations. In our early-stage concept, there were a few problems such as low ratings of the components and issues with the PCB layout. Yet, by the virtue of refinements and enhanced hardware, the eventual design proves efficiency and reliability in the increasing complexity.

***Keywords*—Electric Vehicle(EV), DC-DC Converters, Inductor Design, PCB Design**

I. INTRODUCTION

The term "EV" refers to an electric car, or more broadly, an electric vehicle, which is a car equipped with one or more electrical engines and often powered by rechargeable batteries. When an EV car is charged by a renewable resource, it emits no direct exhaust fumes into the environment, thereby reducing air pollution and delaying global warming. The adoption of Adoption of these types of vehicles can aid in reducing greenhouse gas emissions and improving the quality of air in cities, particularly as concerns about global warming and environmental degradation increase. Using EVs can likely improve public health by reducing respiratory and cardiovascular diseases caused by harmful emissions from internal combustion engine vehicles. While the initial cost of an EV may be higher than that of a 'normal' car, research reveals significantly lower operating and maintenance costs over the course of ownership. y is cheaper than gasoline or diesel, electric motors call for less maintenance and contain fewer parts than internal combustion engines.

A. EV Adoption Policies Enacted in India

Several legislations and policies that the Indian government has placed have helped the establishment of the ecosystem of EVs. From these, one that has focused on affordable financing of EVs and stimulating the manufacturing and development of charging infrastructure is known as FAME, standing for Faster Adoption and Manufacturing of Hybrid and Electric Vehicles. Besides the FAME program, there are also subsidies and other incentives offered by several state governments for the usage of electrical vehicles. They could include techniques such as reduced customs tariffs on EV components, road tax and registration fees, and direct price subsidies to the purchase price of these vehicles. Thus, combating myths and allaying concerns about battery, charging portable, and range and enhancing the degree of awareness of the benefits of electric cars are already in action.

B. India's EV Growth

The government incentives, emerging awareness of environmental issues, advancements in mobility technology, and other issues have also made India sharpen the market for electric vehicles by January 2022. Indeed, as stated earlier, they constitute a very small market in car sales in India; however, as can be observed today, car sales in the electric vehicles segment per se have been on an ascending trend. Out of all the electric vehicles, electric two-wheelers have primarily dominated the market in India owing to the following factors: a low operating cost of the vehicle, being easy to afford compared to other EVs, and being suitable for traffic communications in urban areas. Most of the Indian manufacturers, including the startups in the mass market, have begun importing electric motorbikes and scooters.

C. Problem faced in India for EV adoption

- The lack of adequate charging infrastructure is regarded as one of the most significant challenges. It may even exist in large cities where charging stations are rather limited and absent in rural areas (the presence of a few methods). As a result, it is essential to have the norms and structures for recharging the EVs properly set up, as this is critical to their widespread use.
- When it comes to type and cost, electric vehicles are more costly initially than ordinary internal combustion engine automobiles. This is mostly because batteries are still one of the largest components of an EV's overall cost. However, the start-up cost of EVs may deter potential consumers due to their varying operating expenses, particularly in regions like India where affordability is a primary concern.
- Range anxiety, a term commonly used to describe the fear of seeing the battery deplete to a low value and experiencing restricted or no mobility distance, is a significant issue for customers. Customers often face difficulties in finding charging stations, particularly during extended journeys. The advancements in battery and charging system networks can alleviate this concern.
- Although battery technology is progressing rapidly today, concerns about energy density, charging time, and battery longevity remain problematic. Improvisations in these areas are necessary to extend the electric vehicle's travel ability, reduce charging time, and improve its overall dependability.

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II. LITERATURE REVIEW

[1] Four types of DC-DC converters are compared in the study: boost, buck, buck-boost, and non-inverting buck-boost converters. The non-inverting buck-boost converter reaches the highest efficiency of almost 95%, according to efficiency estimates.

[2] According to user attributes, previous charging session data is clustered, and probability density functions are defined for each cluster. Then, based on variables like arrival time, charging length, and average power, each charging session is forecast. A supervised classification procedure and clustering labels are used in the strategy to handle outliers. When compared to a benchmark, the methodology produced estimated energy with a seven-day forecast horizon and received a Skill Score of 0.37.

[3] To overcome partial shading issues, it suggests a technique that combines particle swarm optimization (PSO) with perturbation and observation (P&O) and a proportional integral (PI) controller. The study shows better power extraction performance when compared to traditional techniques like P&O. To obtain the intended MPP based on IV characteristics, a DC-DC boost converter is incorporated into the suggested system. The PSO + PI + P&O method's efficacy in optimizing PV module functioning under various conditions is demonstrated by the results. In the future, additional AI methods like genetic algorithms might be included for improved results.

[4] It contrasts several charging techniques, including Type I, Type II, Type III, CP-CV, and CL-CV, according to experimental parameters like temperature rise, charging efficiency, and time. The paper also describes several battery models that were utilized for analysis, such as the equivalent circuit model, the pseudo 2D (P2D) model, and the single particle model (SPM). The importance of empirical models for quicker reaction and prediction in battery management systems is also mentioned.

III. PROBLEM DESCRIPTION

Population growth raises pollution levels, which in turn raises demand for environmentally friendly electric vehicles. According to data from amrit.org, as of June 2023, there were 2.4 million electric cars (EVs) registered in India; yet, there are only 6,586 public charging stations in the country. The demand for EVs is rising, which puts a lot of strain on the public electrical system. The public electric distribution network is used to charge all electric vehicles with adapters, which places a significant load on the electrical grid. The government might need to produce more electricity in order to fulfill this rising demand, possibly turning to non-renewable resources like coal. There may be questions regarding whether EVs are actually more environmentally beneficial due to their dependency on non-renewable resources.

The ideal approach for utilizing the sun as a renewable resource is solar charging. Filter circuits are recommended in order to preserve a steady power supply and avoid any battery damage when charging with the boost converter. Furthermore, the boost converter's efficiency and performance can be greatly increased by adding a feedback mechanism.

A. Objective

- To create a small, DC-DC fast charger for EV scooters that can be used at home.
- To shorten the current AC wall socket's lengthy charging period.
- To raise the charger's power rating.
- To lessen the strain on the local distribution network's electric grid.

IV. METHODOLOGY

Primary Techniques for Charging Rechargeable Batteries:

- Constant Voltage-Constant Current
- Constant Voltage-Constant Power
- Variable Current Profile
- Boost charging
- Multistage constant current

Most manufacturers of Li-Ion battery packs recommend a constant current-constant voltage strategy. The widely used technique of Constant Current Constant Voltage (CCCV) charging ensures safe and effective battery charge. Fast charging times, effective power consumption, and overcharging protection are just a few of the features that make CC-CV charging ideal for a wide range of applications, such as renewable energy systems, consumer electronics, and electric cars. However, CC-CV has a few drawbacks, such as a slower charging speed and a lower level of health. When using CC-CV charging, the charging current doesn't change until the battery voltage hits a set point, which is usually the highest voltage that can be charged. Subsequently, the charger transitions to a constant voltage mode, in which the battery gets closer to full charge while the voltage stays constant.

Compared to CPCV, where the charging power is constant throughout the charging process, this steady decrease in charging current in the later phases of charging may lead to longer total charging periods. In contrast, CPCV charging keeps the power level steady throughout the charging cycle. This implies that, in contrast to CCCV, a quicker charging rate is achieved when the battery voltage rises, particularly in the later phases of charging when the battery voltage is getting close to its maximum level. It's important to keep in mind, though, that in order to ensure consistent power output during CPCV charging, more complex charging control algorithms and additional circuitry may be needed, which could raise system complexity and cost. Furthermore, not all battery chemistries and types may benefit from CPCV charging, and careful monitoring of battery voltage and temperature is required to avoid overcharging and overheating.

Similar to CC-CV, constant power constant voltage charges to a predetermined voltage limit before transitioning to constant voltage. In this case, constant power is utilized in place of constant current. In one study, CC-CV charging had higher retention at 0.5C, but CP-CV charging produced greater capacity retention when the cell was charged at 1C, presumably because of the reduced current at high SOC.

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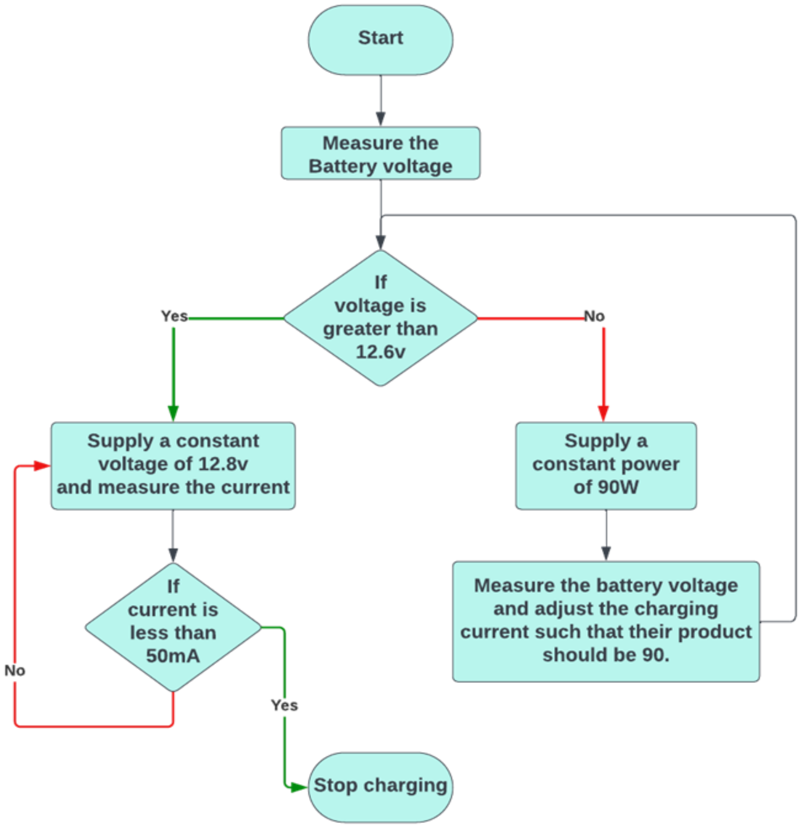

Fig. 1. Flow Diagram of CP-CV Protocol

A fast charging methodology for a 3S Li-Ion battery pack is described in the flow diagram (Fig. 1), which aims to shorten the charging time and improve the battery's state of health (SoH) in comparison to the traditional constant current-constant voltage (CC-CV) technique. The taken Li-ion cell for the battery pack is Samsung INR18650-25R. The maximum continuous charging current is 4A; the maximum charging voltage is 4.2V; and the charging current is 0.1A at 100% state of charge.

As such, when the current falls below 0.1A during the constant voltage phase, charging stops. The battery is charged at a steady power level during the constant power phase; the estimated power for the given battery is 88W. For example, the proposed charger will deliver an 8A current to maintain the charging power at 88 W if the observed battery voltage during the constant power phase is 11V. It is anticipated that this approach will greatly improve the battery pack's SoH and charging efficiency, cutting down on charging time and increasing battery life.

A lithium-ion battery, such as the Samsung 18650-25R, can withstand a certain number of cycles depending on a variety of parameters, such as usage patterns, charging practices, temperature conditions, and general maintenance. A lithium-ion battery is generally thought to last between 300 and 500 cycles before its capacity starts to noticeably deteriorate. This longevity can be increased, though, with the right upkeep and care, such as avoiding deep discharges and extremely high or low temperatures. Certain premium lithium-ion batteries have a longer cycle life; they may survive up to 1000 cycles or more and still function fairly well.

V. PROBLEM DESCRIPTION

A. Fast Charger Version I

The schematic (Fig. 2) displays the very first test created to experiment with the constant current-constant voltage. This prototype aims to transmit at a maximum of 0.5A at 8.2V, or 4.1W. When directly supplied with power, the Arduino Nano microcontroller's built-in regulator converts +12V to +5V. However, the regulator's design does not allow for prolonged operation. This caused the board's microcontroller to fail. The second significant error caused the PCB traces to be damaged: the trace width was not appropriately set to push 0.5A. The last error was that even if the maximum charging current is 0.5A, the charger can still pump electricity through any load. The testing battery is a 3 second (7.4 volt) 2.6 2.6Ah battery. The battery can run continuously at a maximum current of 1A. However, charging at 80% of the specified current is safe. The life cycle of this battery is 500. Shunt resistors are used to measure current. This is a 5W, 2 shunt resistor. The computation indicates that there is a 0.5W power loss when monitoring the current. However, it is designed to tolerate 2W.

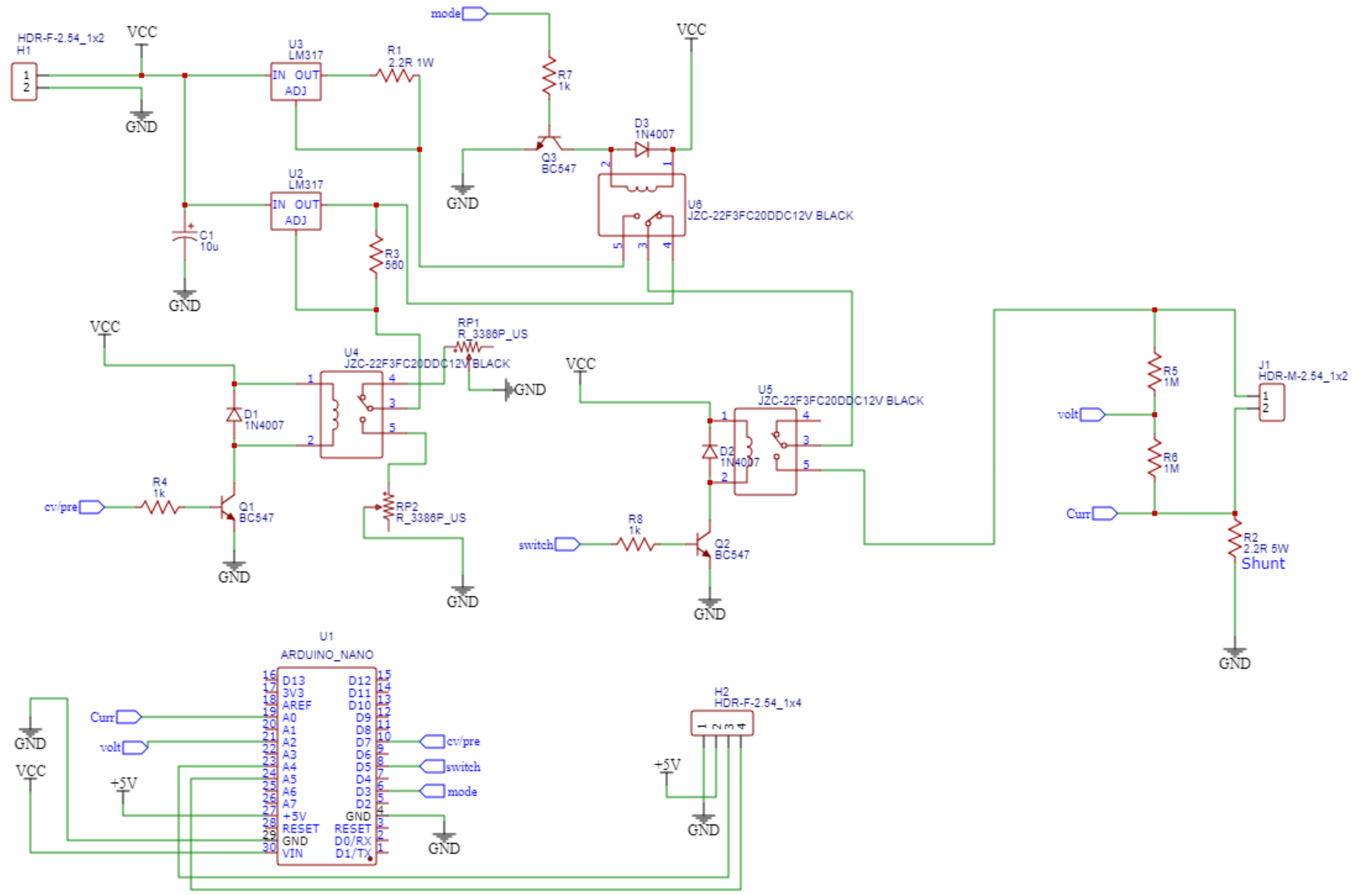

Fig. 2. Schematic of Fast Charger Version 1

B. Finalized version of Fast charger Board

A power source battery is a small electrochemical device that transforms chemical energy that has been stored into electrical energy. This device can power a variety of electronic devices and systems and is both portable and dependable. The 6s 10Ah Li-FePo4 battery pack from Orange is the power source that charges the 3s Li-Ion battery pack. The greatest current that this power source can push is 250A(25c). Buck converter DC-DC topology is chosen because the input voltage is higher than the necessary charging voltage. The efficiency will be further increased by employing a controlled switch (MOSFET) rather than an uncontrolled switch (diode). The synchronous switch should be able to withstand a DC blocking voltage of 22V, according to the calculation. The IRF540N is a readily available N-Channel Power MOSFET that has a maximum continuous drain current of 33A and a maximum drain-source voltage of 100V, making it appropriate for withstanding various conditions. Comparing N-Channel MOSFETs to P-Channel MOSFETs of comparable size and price, the former usually exhibit lower on-resistance. When driving an N-channel MOSFET, less gate voltage (Vgs) is usually needed than when driving a P-channel MOSFET. This can simplify the gate drive circuitry and save expenses. However, there is a problem with using IRF540N MOSFETs; according to the datasheet, Vgs should be 12V to fully flip on the switch. However, it is uncommon for a microcontroller with 12V logic to produce PWM. Logic-level MOSFETs are utilized to solve the problem; however, even they are not without problems. Logic level MOSFETs have a larger slew rate than power MOSFETs. Because there is less voltage difference between the gate and source when a MOSFET is used in an interconnection, this is a common issue that arises. Bootstrapping the MOSFET solves the problem.

In electronics, high-side MOSFETs and other high-side switching devices can be effectively driven by a mechanism called a bootstrap circuit, sometimes referred to as a bootstrap capacitor. The gate-source voltage (Vgs) of the high-side MOSFET must be greater than both the MOSFET's threshold value (Vth) and the voltage between the source and the load (V load) in order for it to fully switch on. Because the gate driver usually runs at a lower voltage level than Vload, this can be difficult. MOSFET drivers can be used in place of real bootstrap circuits. In high-speed switching applications, a MOSFET driver is a specialized integrated circuit (IC) or discrete component that is made to effectively drive MOSFETs (Metal-Oxide Semiconductor Field-Effect Transistors). Fast and dependable MOSFET switching is made possible in large part by MOSFET drivers, particularly in high-frequency and high-power circuits. For IRF540N MOSFET, the IR2101 MOSFET Driver works well. The inductor in a buck converter is essential for both energy storage and output voltage regulation. Current passes through the inductor when the buck converter's switch—typically a

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MOSFET—is closed, creating a magnetic field and storing energy as magnetic flux.

The output voltage across the load drops as the inductor accumulates energy. This is so because the load and the inductor itself share the energy stored in the inductor. The geometry and construction of inductor cores are frequently used to classify them; toroidal (ring-shaped), cylindrical, and E-shaped cores are typical forms. In terms of electromagnetic interference (EMI) reduction, space utilization, and magnetic coupling, each shape has a distinct benefit. Because of their high permeability, minimal core loss, and frequency stabilization, ferrite inductors are employed in this specification. According to calculations, a 35µH inductor that can sustain 7.8A is required for the buck converter. The selected ferrite torrid core is 17.2mm by 8.5mm by 7.3mm and has a magnetic permeability of 2200. Six turns are the estimated number of turns. A 7.8A RMS current should not be able to break through the enameled copper wire. Thus, the inductor is wound using gauge wire that is 18 AWG.

VI. RESULT AND DISCUSSION

A. Schematic Circuit Diagram of Finalized Fast Charger

An electrical circuit is represented visually in a schematic circuit diagram, which uses lines and standard symbols to show how the components are connected. It gives a succinct and straightforward summary of the circuit's construction and the flow of electricity across it. Our circuit's schematic diagram is shown in Fig. 3. The main circuit schematic diagram, the MOSFET driver circuit, the MCU circuit, the cooling fan circuit, and the regulator circuits (+5v and +12v). To produce the correct PWM duty cycle, the input voltage, current, and output voltages are measured. The MOSFET Driver changes the 3.3V logic used by the MCU PWM to 12V logic. Shunt resistors are used to measure input and output current. Usually, resistors with low resistance and high power ratings are utilized.

The i^2r losses diminish as the resistance value does. Let's take an example where the maximum current rating is approximately 10A and a shunt resistor of 0.05Ω 3 w is unable to withstand the power delivered, which is 5W, larger than 3W, and two resistors are connected in parallel. There are three resistors in total, thus the current will be divided in half by two. Therefore, the power across a single resistor is less than 3W at 1.25W (5 * 5 * 0.05). This 1210 package contains a surface-mounted, 0.05Ω, 3W resistor that even shrinks the size of the PCB board. By measuring the terminal voltage and dividing by the equivalent resistance, one can determine the current flowing through the resistor. With the instrumentation amplifier INA118, the terminal voltage may be calculated precisely. For the purpose of producing an output with high sensitivity and resolution, the gain resistors are accurately calculated.

Texas Instruments produces an in-amp, or precision instrumentation amplifier, called the INA118. It is especially made for applications requiring excellent common-mode rejection, low noise, and high precision. As a three-op-amp instrumentation amplifier, the INA118 is configured. It is appropriate for amplifying small differential signals in the presence of huge common-mode voltages due to its high input impedance and differential inputs. Perfect for precision measurement applications, the INA118 has low offset voltage, low offset drift, and low input bias current, all of which contribute to its exceptional DC accuracy. The INA118 provides accurate low-level signal measurement in noisy conditions by ensuring little noise contribution to the amplified signal through its low input voltage noise density. The device can handle high common-mode voltages with great precision since it can function across a wide common-mode voltage range, usually from -Vs to +Vs - 1.5V.

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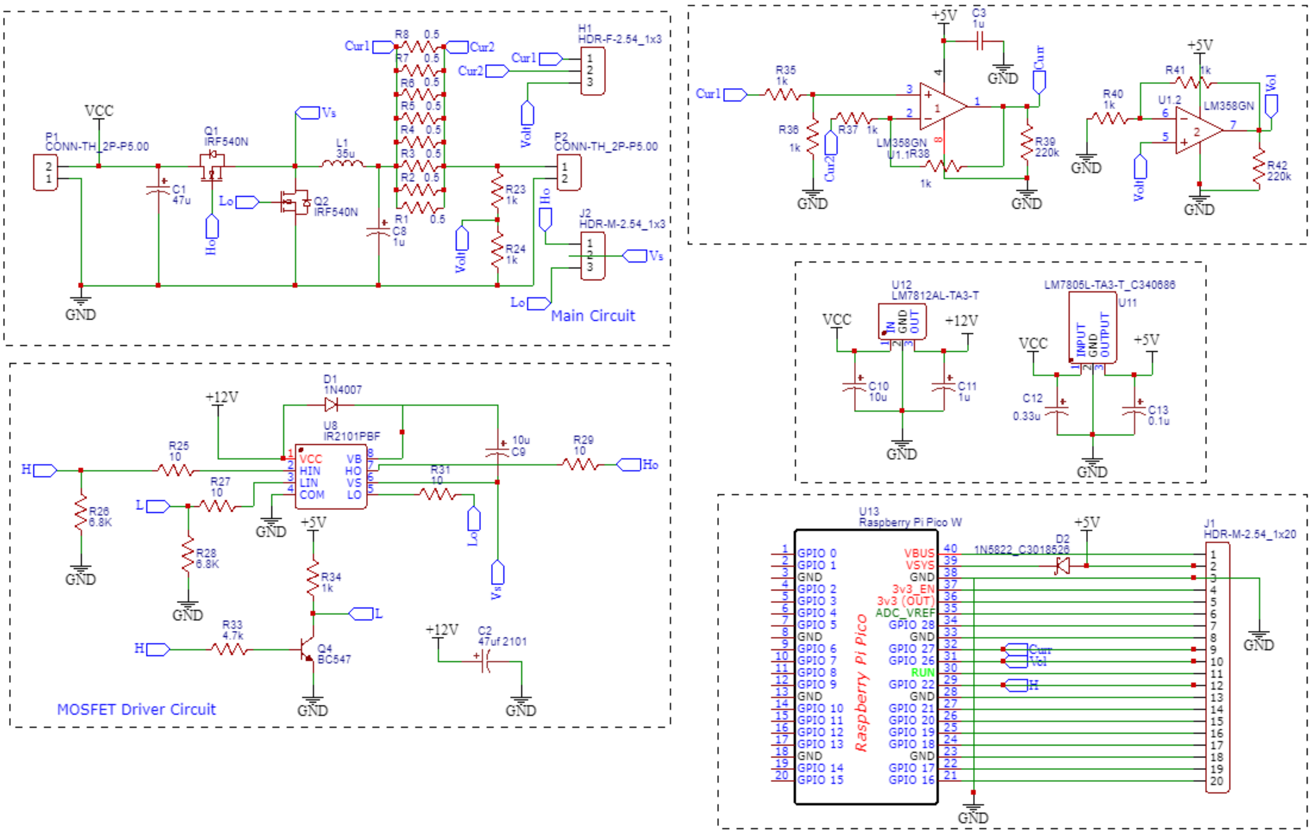

Fig. 3. Schematic of Finalized Fast Charger

B. PCB Layout of Finalized Fast Charger

An essential component of electrical design is PCB layout, which involves the positioning and joining of electronic components on a printed circuit board (PCB). For electronic systems to be useful, dependable and manufacturable, the layout process is crucial. Reducing trace lengths, minimizing signal interference, and enabling effective routing are all made possible by optimal component placement. The process of creating electrical channels, or traces, to connect the different PCB components is known as trace routing. To guarantee correct signal integrity, impedance matching, and noise immunity, traces must be routed. Fig .4 and Fig .5 display our circuit's PCB layout.

The PCB Layout is made to handle currents up to 11A. In order to prevent PCB burnout, a suitable trace width is necessary. 2.32 mm of trace width is required under the following conditions: 30amp maximum current, 30oz/ft^2 thickness, 20 °C temperature rise, and 25 °C ambient temperature. Power planes are sometimes drawn in order to keep the power supply constant. Rogers material, which is easily heat-resistant, is commonly utilized for PCBs in high-power applications. Since this material is more expensive, FR4 materials are utilized instead, and the parts are distributed evenly to keep the heat maintained.

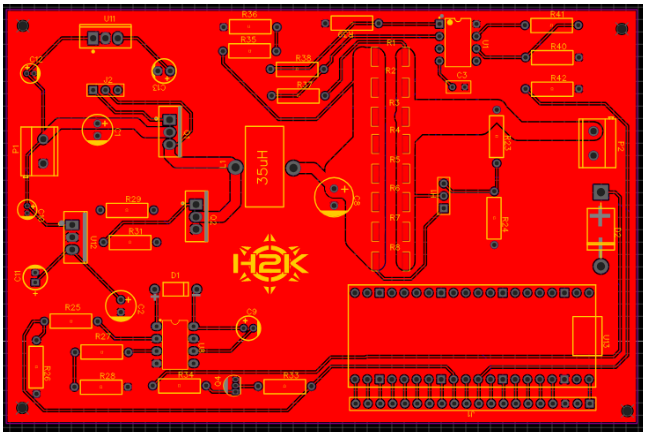

Fig. 4. PCB Layout (Top Layer)

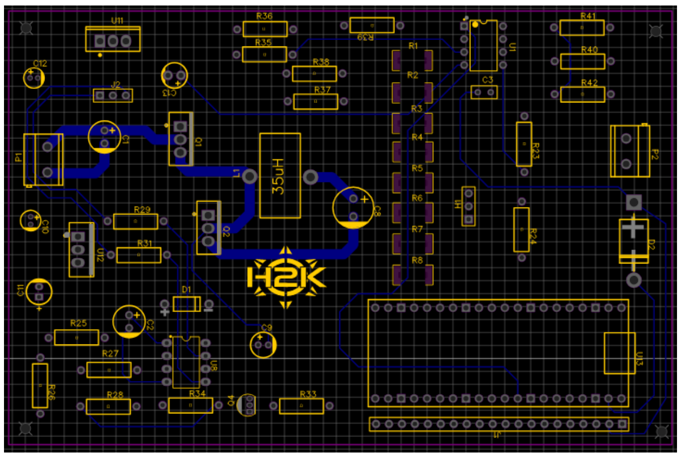

Fig. 5. PCB Layout (Bottom Layer)

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VII. CONCLUSION

The hardware board measures 120 x 80 mm (Fig. 6). To minimize electromagnetic interference and preserve signal integrity, the components are arranged so that the analog and digital circuits are kept apart. Because analog signals are often more noise-sensitive, they need cleaner grounds and power supplies. By arranging analog and digital circuits independently, you may create ground planes and power distribution schemes that are more suited to each kind of circuit, enhancing signal integrity and minimizing crosstalk. Despite the board's concessions, the desired result was obtained. The performance of analog circuits, particularly those with MOSFETs and inductors, tends to be lower overall due to increased heat production. These two elements are positioned in the middle to counterattack the problem. This will evenly distribute the heat, and putting a cooling system above the center will remove all of the heat produced by the constituent parts.

We have confirmed the result using the Fast Charger circuit's entire hardware (Figure 6.2). The needed value exhibits slight variations. After rebuilding it, we confirmed the output battery had charged properly to obtain the output.

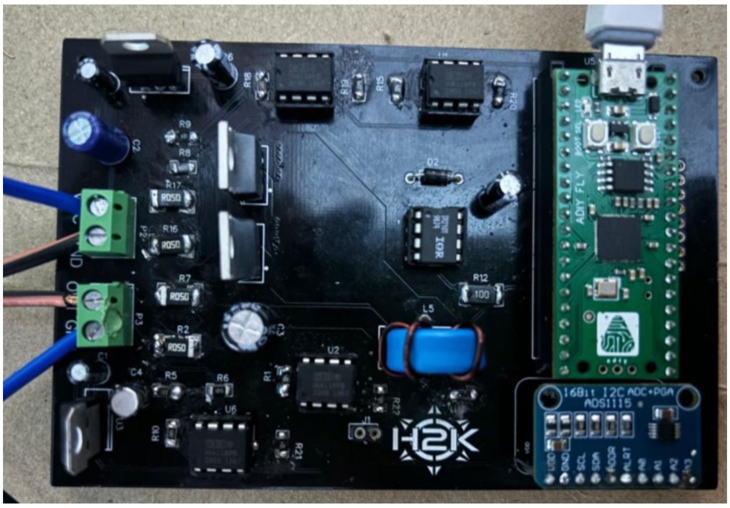

Fig. 6. Fast Charger (Hardware)

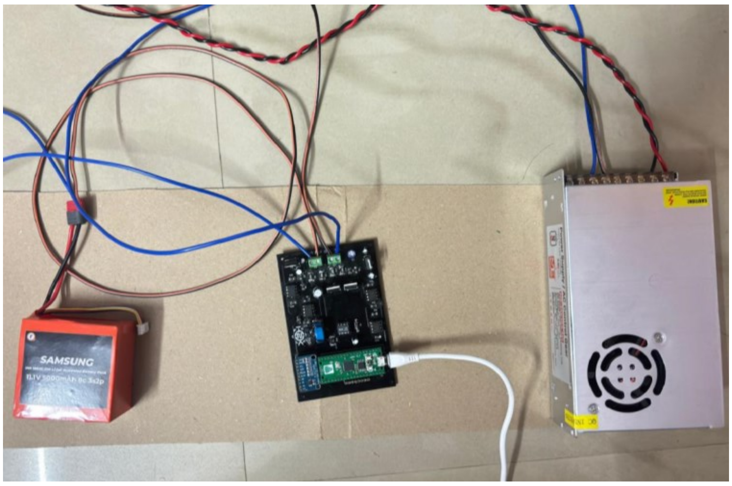

Fig. 7. Charging of Li-Ion battery pack using the Charger

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