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Modular Optimization Of Electric Vehicle Charging Systems: Collaborative Approach For Sustainable Solution

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Abstract : Electric vehicles are a great opportunity for the industry, academia and the regulatory authorities to collaborate for a sustainable future. The need for advanced charging solutions for electric vehicles arises from the requirement to address future market demands, ensure cost-effectiveness, and facilitate widespread adoption of electric vehicles by providing efficient, scalable, and affordable charging infrastructure. A modular system offers the advantage of increased flexibility, scalability, cost-effectiveness, and ease of maintenance through interchangeable components and targeted upgrades. A prototype is developed, implemented, and tested to validate the charging performance, with results recorded for analysis. The testing involved charging batteries of different voltage and current ratings. The prototype demonstrates how the addition of a simple module to the power block facilitates the modification of the output power required for efficient battery charging. Additionally, this approach provides insights into cost cutting measures, reducing complexity, minimizing downtime, and optimizing labor requirements. The findings of this study contribute to the advancement of charging systems, emphasizing the benefits of constant current charging mode in achieving faster and more flexible battery charging solutions. It is an effective way to promote sustainable practices and reduce the environmental impact of human activities.

***IndexTerms* - Electric Vehicles, Fast Charging, Decentralized System, Sustainability, Environmental Impact.**

I. INTRODUCTION

Advancements in electric vehicle technology have ushered in a new era of sustainable transportation, revolutionizing the automotive industry and paving the way for a greener future. Greenhouse gases that absorb or emit radiant energy within the thermal infrared range causing the greenhouse effect. Primary greenhouse gases in earth's atmosphere are water vapour (H_2O), carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O).[1] Gas molecules trap heat in earth atmosphere causing rise in temperature. Due to recent rise beyond normal accepted levels of greenhouse gases is resulting in increased earth's temperature. Every Year 55 billion tonnes of carbon emissions are dumped in our precious atmosphere. Hence in order to achieve that goal, carbon emissions need to be cut down at a quicker rate. Seventy-five percent of the emissions come from the 20 largest emitting countries With India standing at 3rd position in the list with 2411.73 CO_2 emissions (Mt).[2] As India is a fast growing economy its carbon dioxide emissions have increased in recent years. The major four sectors contributing are Grid, Transportation, Buildings, Industry. When carbon dioxide is dumped into the atmosphere, it is there for years or at least its impacts are there for many coming generations. Now in order to find solution for evolving digital world, recipe is to decarbonize the grid and then electrify everything.[3] Now, that would seem like a dream a few years ago, because it was expensive to create net zero carbon grid. However as the cost of solar and wind have plummeted in recent times. It's now cheaper to save the planet than to ruin it. Due to insufficient time, Immediate actions need to be considered, at speed and at scale, to meet the staggering challenge of decarbonising the global economy (which has only ever increased emissions throughout history).

The graph shows that carbon dioxide emissions have been increasing steadily since the Industrial Revolution, driven primarily by the burning of fossil fuels for energy.[4] As a result, global temperatures have also been rising, with the most significant increases occurring in the past few decades

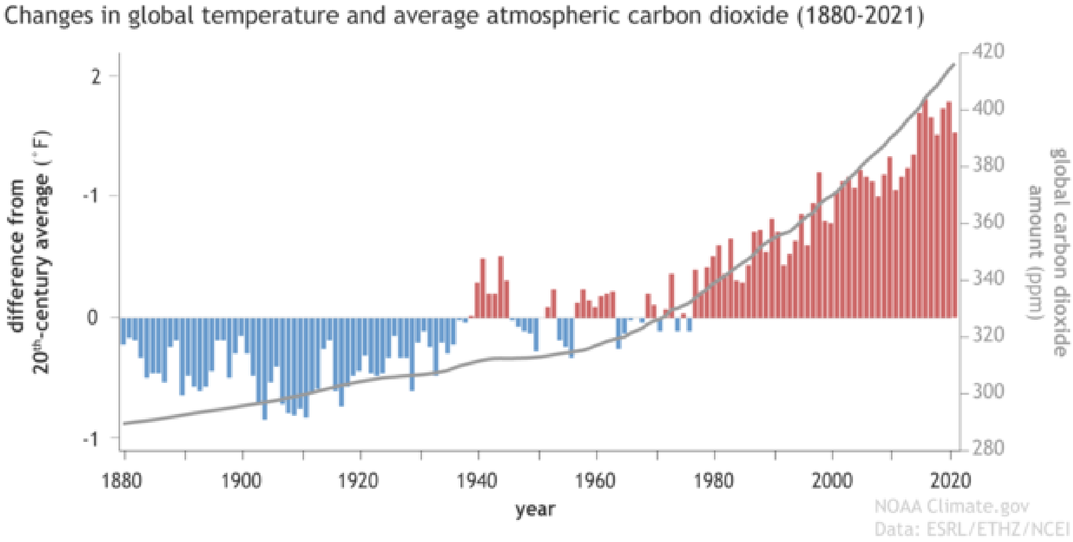

Fig. 1. The graph above shows the historical trend of global carbon dioxide emissions and global temperature rise[2]

1.1 Literature Survey

The market's primary electric vehicle (EV) and plug-in hybrid vehicle (PHEV) charging options are depicted in the following figure.[5] Note that Battery Electric Vehicles (BEV) is another term that is frequently used to refer to EVs and PHEVs.

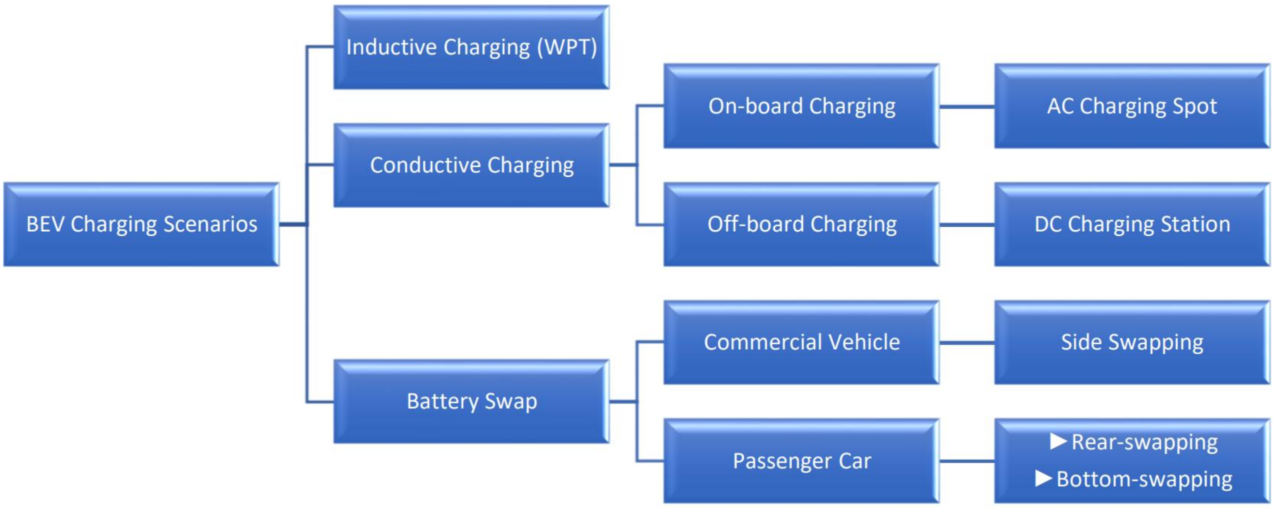

Fig. 2. The figure shows various charging options available for EVs in market

The introduction of three charging modes relates to the charging of batteries in electronic devices, particularly in mobile phones and electric vehicles.

Fast Charging Mode: This charging mode allows for a faster charging time compared to the normal charging mode. It typically involves the use of a higher charging current, which can significantly reduce the charging time of a device. However, fast charging can put more stress on the battery, leading to faster degradation of its capacity over time.

Normal Charging Mode: This mode involves charging a device with a lower charging current, which may take longer to fully charge the battery. Normal charging is typically less stressful on the battery and can help prolong its lifespan.

Quick Change of Battery Mode: This mode is typically used in electric vehicles, where the battery pack can be quickly replaced with a fully charged one. This allows for a rapid refueling process, similar to the traditional gas refueling process. The advantage of this mode is that it eliminates the need to wait for the battery to charge, allowing for longer journeys without lengthy charging times. However, the disadvantage is the need to have a spare battery pack and the infrastructure to quickly swap the battery packs.

The different levels of charging for electric vehicles (EVs) according to the power delivered are:

Level 1 Charging: This is the slowest level of charging and involves using a standard 120-volt AC household outlet to charge the EV. Level 1 charging typically provides a charging rate of 2-5 miles of range per hour of charging. This method is suitable for low-mileage EVs and is commonly used for charging overnight. This level of charging typically delivers power at 1.4 kW or less. It uses a standard 120-volt AC household outlet to charge the EV.

Level 2 Charging: This is a faster charging method that requires a 240-volt AC charging station. Level 2 charging can provide a charging rate of 10-60 miles of range per hour of charging, depending on the charging station and the EV's battery capacity. Level 2 charging is commonly used for home charging stations, workplace charging stations, and public charging stations.

DC Fast Charging (Level 3 Charging): This is the fastest charging method for EVs and requires a dedicated DC fast charging station. DC fast charging can provide a charging rate of 60-80 miles of range in just 20-30 minutes of charging. This level of charging typically delivers power at 50 kW or more, and in some cases, up to 350 kW. It requires a dedicated DC fast charging station and is capable of providing a rapid charging rate for the EV.

However, not all EVs are capable of using DC fast charging, and frequent use of this method can reduce the lifespan of the battery. DC fast charging stations are commonly found at highway rest stops, public charging stations, and commercial locations.[6]

	Power level	Current type
Normal power charging	P ≤ 7kW	AC & DC
	7kW < P ≤ 22kW	AC & DC
High power charging	22kW < P ≤ 50kW	DC
	50kW < P < 200kW	DC

Fig. 3. The figure shows various charging levels available for EVs in market[5]

For lithium-ion batteries, constant current charging is a frequent charging technique. It entails continuously charging the battery up until a certain voltage level is reached. The constant current stage and the constant voltage stage are the two steps that commonly make up the charging process. The charging current is maintained constant during the constant current phase, and the battery voltage progressively rises. This is because a voltage drop brought on by the battery's internal resistance lowers the voltage at the battery terminals. More current can enter the battery as the internal resistance of the battery drops as it charges. The charging procedure advances to the constant voltage stage after the battery reaches a particular voltage level. The charging voltage is maintained constant during this phase, but the charging current steadily declines. To prevent overcharging, the voltage level is often set at a level just below the battery's maximum voltage rating. The battery is regarded as fully charged when the charging current reaches a specific threshold. The battery is now detached from the charger and the charging procedure is terminated. Because it provides for quicker charging times than other charging techniques, constant current charging is a well-liked method for charging lithium-ion batteries. However, to avoid overcharging and guarantee the battery's security, it necessitates regular monitoring.[5]

1.2 Current Scenario

The electric two-wheeler market is growing rapidly, and the demand for electric two-wheeler chargers is increasing accordingly. There are several types of electric two-wheeler chargers available in the market, including:

(a) Portable chargers: These chargers are compact and portable, making them ideal for charging on the go. They are available in Level 1 and Level 2 charging and can be used with a standard electrical outlet or a 240-volt AC supply.

(b) Wall-mounted chargers: These chargers are mounted on a wall and are designed for Level 2 charging. They are faster than plug-in chargers and require a 240-volt AC supply.

(c) DC fast chargers: These chargers are designed for Level 3 charging and provide a high charging rate for electric twowheelers. They require a dedicated DC fast charging station and are capable of providing a rapid charging rate for the battery.[3]

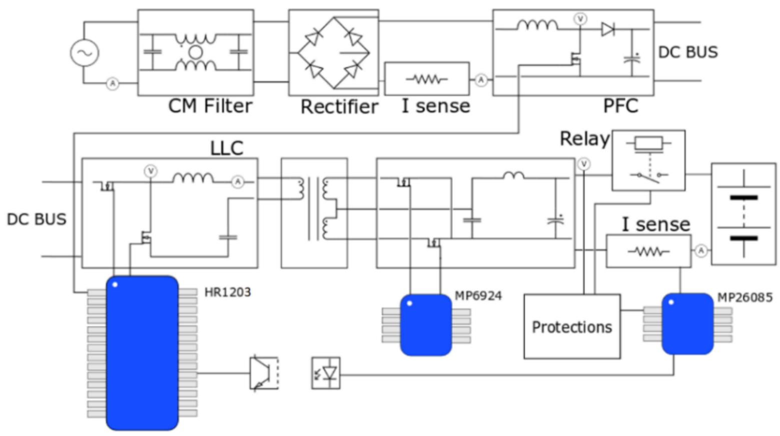

Fig. 4. The diagram describes a general charger's systems available in market[2]

The electric two-wheeler charger circuit is a device that converts AC power from a standard electrical outlet into DC power suitable for charging the battery of an electric twowheeler. The input stage of the charger circuit is designed to handle AC voltage from the electrical outlet. The AC voltage is first passed through a bridge rectifier circuit that converts it into DC voltage. A capacitor is also used to filter out any noise or ripples in the input voltage. The control stage is responsible for regulating the charging process. This stage uses a microcontroller or other control circuitry to monitor the battery voltage and current, and adjust the charging rate accordingly. The control circuitry may also include temperature sensors to prevent overheating of the battery during charging. The power stage is the output stage of the charger circuit and is responsible for delivering the DC power to the battery. This stage typically uses a switching power supply, which efficiently converts the input DC voltage to a higher or lower DC voltage suitable for charging the battery.[8]

II. TOPOLOGY

2.1 System Architecture

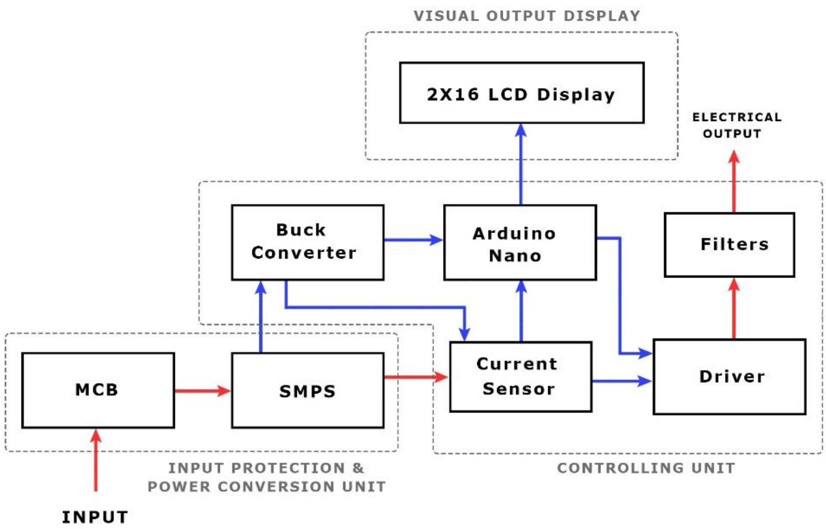

Fig. 5. General system architecture based on idea of distributed processing[11]

The system is designed in a modular way, based on the idea of distributed processing. This is done to ensure flexibility for future use of the system in other large or smaller archives, and took into consideration future access options through networks.

2.2 Functionality

The main use of MCBs (Miniature Circuit Breakers) is to provide protection to electrical circuits and appliances from overloading and short-circuiting. SMPS (Switched-Mode Power Supply) is a type of power supply that uses a switching regulator to convert electrical power efficiently from one form to another. The key advantage of SMPS over other types of power supplies is its high efficiency. The primary use of SMPS is to convert AC power from a mains supply into a DC voltage that can be used by electronic devices. The switching regulator in an SMPS converts the AC voltage to a high-frequency DC voltage, which is then filtered and regulated to produce a stable DC output voltage. A buck converter is a type of DC-DC converter that is used to step down or reduce the voltage level of a DC input voltage to a lower DC output voltage level. The buck converter is also known as a stepdown converter. A controller is a device or software program that is used to manage or regulate a system's behavior or output. The controller receives input signals from sensors or other sources and sends output signals to actuators or other devices to modify the system's behavior. Arduino Nano is a small, compact, and affordable micro-controller board based on the ATmega328P micro-controller. A current sensor is an electronic device that is used to measure the flow of electrical current in a circuit. The ACS712 module is an electronic sensor module that is used to measure current. It is based on the ACS712 current sensor IC, which is designed to measure both AC and DC current up to 30A. A 2x16 display is a type of alphanumeric LCD display that consists of two rows of 16 characters each, for a total of 32 characters. A metal oxide-semiconductor field-effect transistor (MOSFET) is an electronic device that falls under the category of field-effect transistors (FETs). These devices act as voltage-controlled current sources, and are mainly used as switches or for the amplification of electrical signals. The purpose of a filter circuit is to allow only the desired signal to pass through while attenuating or blocking unwanted frequencies. Filter circuits help to improve the quality of signals by removing unwanted noise or interference, leading to better performance and reliability of electronic systems.

III. METHODOLOGY

3.1 Operation

The converter topology that can be used is QR (Quasi-Resonant) flyback converter. It is a type of switch-mode power supply that uses a transformer to transfer energy from input to output. The main advantage of this topology is the reduction of switching losses and electromagnetic interference (EMI) due to the resonant behavior of the circuit. QR flyback converter operates by controlling the switching frequency of the power switch such that the converter operates in the resonant mode. This results in reduced switching losses and improved efficiency. Additionally, the converter provides soft-switching capabilities, which reduces stress on the power semiconductor devices and increases their lifespan. QR flyback converters are widely used in applications where low power levels and high efficiency are required.[11]

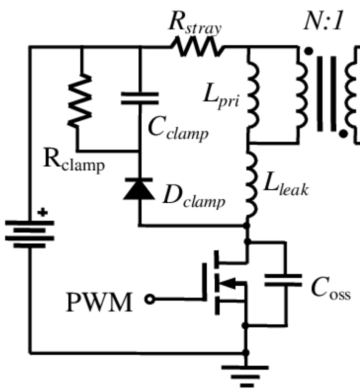

Fig. 6. The image shows DC/DC converter QR Flyback topology[11]

Another converter that can be used is phase-shift full-bridge (PSFB) converter and is depicted in Figure 7. The Dual Active Bridge (DAB) converter family includes the Phase Shifted Full Bridge (PSFB), which substitutes diodes for the active switches on the secondary. It permits unidirectional power transfer as a result. The decision to use DAB is based on its inherent benefits, including soft-switching, high power density, and a straightforward controller architecture.

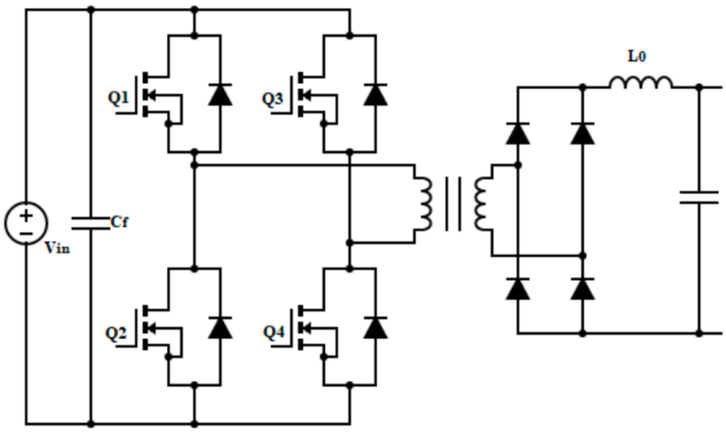

Fig. 7. The image shows DC/DC converter PSFB topology[10]

LLC converter is a resonant converter that uses an inductor, capacitor, and transformer to transfer energy from input to output. The converter operates in a resonant mode, which results in reduced switching losses and improved efficiency. Additionally, the converter provides zero-voltage switching (ZVS) and zero-current switching (ZCS) capabilities, which reduces stress on the power semiconductor devices and increases their lifespan. LLC converters are suitable for high power applications where high efficiency and high power density are required.[7]

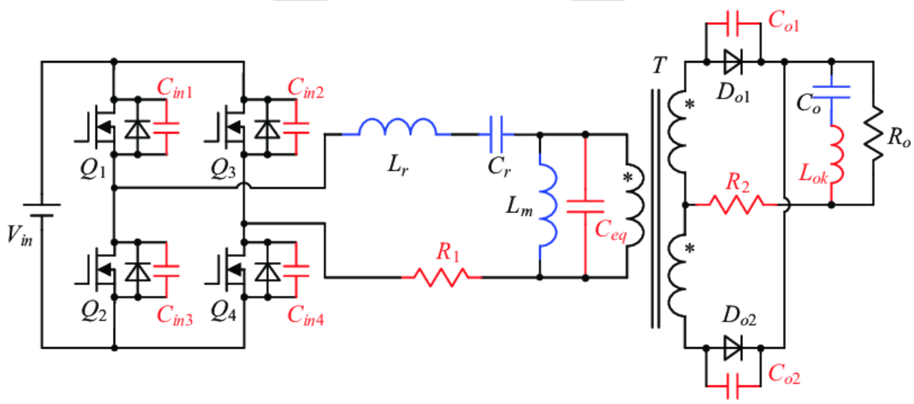

Fig. 8. The image shows DC/DC converter LLC topology[7]

In summary, QR flyback converter is suitable for low power applications where high efficiency is required, while PSFB converter is suitable for high power applications where high efficiency and good output voltage regulation are required. LLC converter is suitable for high power applications where high efficiency and high power density are required, and it provides ZVS and ZCS capabilities to reduce switching losses and improve device lifespan.[10]

The buck converter acts as a power source for internal system operations. In a constant current charging scheme, the feedback control loop typically consists of a current sensor that measures the actual current flowing into the battery, a control circuit that compares the actual current to the desired level of current, and a voltage regulator that adjusts the charging voltage to maintain the desired current level. The control circuit adjusts the charging voltage by varying the duty cycle of a switching regulator, such as a buck converter, which converts the input voltage to the desired output voltage. By maintaining a constant current level, the charging time can be reduced, while also ensuring that the battery is charged safely and efficiently.

Displays are an important part of charging equipment. They provide critical information about the charging process and the status of the charging equipment to the user. Some of the important uses of displays on charging equipment at charging stations are: Charging status, charging time. Display show the cost of charging, which is calculated based on the amount of energy (electrical units) consumed by the EV during the charging process. This information helps users to estimate the cost of charging their EV and plan their charging schedule accordingly.

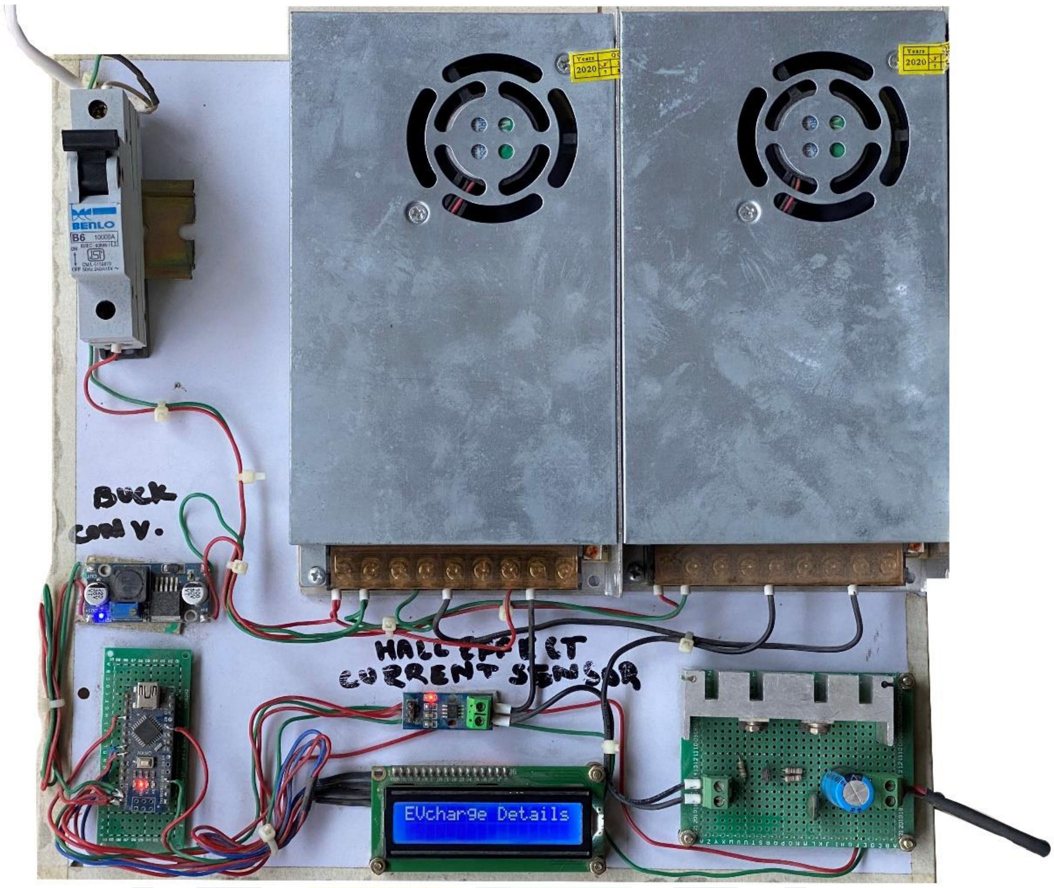

Fig. 9. The image shows working prototype model of the project

3.2 Features

Making a system decentralized and modular can significantly reduce the expansion costs in the future. Decentralized and modular systems can be designed to be easily scalable. This means that adding more components to the system can be done with minimal effort, and without the need to replace or modify the existing components. This reduces the overall cost of expansion, as it eliminates the need for major upgrades or replacements. These systems can be customized to meet specific requirements, such as the size of the system, the number of components, and the power requirements. These systems are easier to maintain than centralized systems. This is because each component can be maintained separately, without having to shut down the entire system. This reduces the overall cost of maintenance, as it eliminates the need for expensive shutdowns or maintenance procedures. It can be designed to be compatible with a wide range of components, regardless of their manufacturer or model. Constant current chargers are often used as fast chargers because they provide a higher charging current to the battery compared to other charging methods. This results in a faster charging time. Isolating components makes maintenance tasks easier and faster, allowing for quick and efficient repairs and replacements. Isolating operating equipment blocks can prove out to be beneficial in maintenance and root cause analysis during fault condition. This helps to minimize downtime and ensure the reliability of the electrical system. SMPS is a versatile and efficient power supply technology that is widely used in a wide range of applications, helping to improve energy efficiency and reduce operating costs. SMPS can convert electrical power at efficiencies of up to 95 percent, while traditional linear power supplies have an efficiency of around 50 to 60 percent. SMPS can also provide other features such as overvoltage protection, overcurrent protection, and short-circuit protection. Displays are an important part of charging equipment at a charging station, providing critical information to the user about the charging process and the status of the charging equipment. 2x16 LC Display provide a compact and low-power method of displaying information, helping to improve the usability and functionality of electronic devices. The controller uses a feedback loop to continuously monitor the system's performance and adjust its output to achieve a desired result. Arduino Nano is part of the popular Arduino family of boards and is designed for use in a wide range of electronic projects, from simple prototypes to more advanced projects. The feedback loop involves comparing the system's actual output with the desired output, and then adjusting the output based on the difference between the two. Overall, fast chargers offer a convenient and efficient way to charge EV batteries quickly, making them a key part of the growing EV charging infrastructure.

IV. TEST RESULTS AND DISCUSSIONS

Two tests are conducted on the prototype model that was prepared. The observed test results were recorded and are outlined below. In charging scheme, the current is maintained at a constant level during the charging process, regardless of the state of charge or the voltage of the battery being charged. This is typically achieved using a feedback control loop that measures the actual current flowing into the battery and compares it to the desired level of current. If the actual current is lower than the desired level, the charging circuit increases the charging voltage to compensate and maintain the desired current level. If the actual current is higher than the desired level, the charging circuit reduces the charging voltage to bring the current down to the desired level. The display unit is utilized to provide the customer with detailed information regarding the charging voltage, current, and the calculated cost incurred, which is derived from the power delivered during the charging process.

4.1 Test 1 Results

The experiment was conducted to charge a 12V battery using a 24-volt SMPS (Switched-Mode Power Supply) as the power module, with a current rating of 15 amps. The charging process employed the constant current charging method, and open circuit readings of the battery were recorded after allowing it to remain idle for 30 minutes.

Specifications of Battery used	
Single Cell Used	FB Tech 6000mAh
BMS Specification	4s20A LFP
Maximum Capacity	12 Ah or 12000 mAh
Max discharge current	20 A
Battery Voltage	12 V
Charger Specifications	
Charger Voltage	15 V
Charger Current	15 Amps

Results	
OCV before charging	11.7 V
OCV after charging	13.1 V
Charging current	9.8 A (constant)
Charging time elapsed	15 min
Total charging cost incured	Rs. 28.4

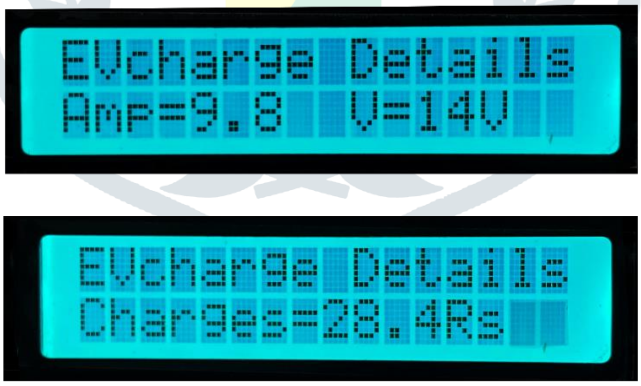

Fig. 11. Various charging parameters' visual output on display

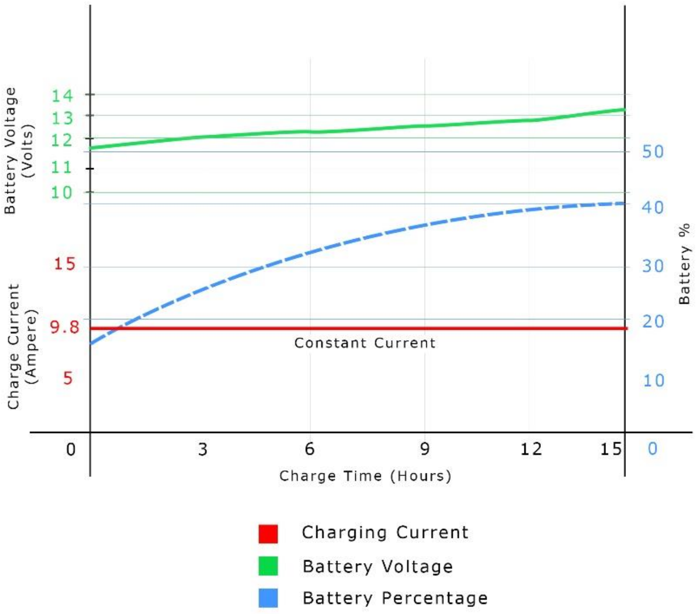

Fig. 10. The graph indicates charging current, voltage and state of charge (in percentage) of battery

4.2 Test 2 Results

The experiment was conducted to charge a 36V battery, employing two 24-volt similar SMPS units connected in series to provide an output voltage of 48 volts, thereby creating a power module with a current rating of 15 amps. The charging process utilized the constant current charging method, and open circuit readings of the battery were recorded after allowing it to remain idle for 30 minutes.

Specifications of Battery used	
Single Cell Used	2550 mAh EV Grade
BMS Specification	10S20A, Heat Sink protection
Maximum Capacity	15.6 AH or 15600 mah
Max discharge current	20 A
Battery Voltage	36 V
Charger Specifications	
Charger Voltage	42 V
Charger Current	15 Amps

Results	
OCV before charging	36 V
OCV after charging	40 V
Charging current	14.7 A (constant)
Charging time elapsed	15 min
Total charging cost incured	Rs. 57.6

Fig. 13. Various charging parameters' visual output on display

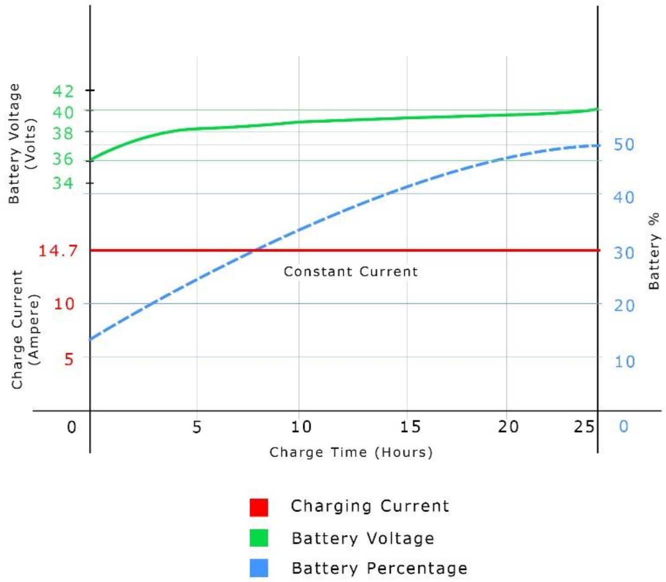

Fig. 12. The graph indicates charging current, voltage and state of charge (in percentage) of battery

4.3 Effect On System Cost

Two experiments were conducted to evaluate the charging of batteries with different voltage ratings. In the first experiment, a 12V battery was charged using a single SMPS as the power block. In the second experiment, a 36V battery was charged, necessitating the addition of another similar SMPS connected in series to the existing power block. This approach enables the scalability of the system by simply adding or removing modules within the power block and configuring them to deliver the desired current within the specified voltage range. Consequently, there is no need to replace the entire charging system when dealing with different power ratings. By keeping the control unit unchanged and reprogramming it to operate the power module at different current and voltage ratings, the system becomes adaptable. In the first experiment, the power block accounted for approximately 30% of the total project cost. However, in the second experiment, with the addition of one more identical SMPS, the power module's cost increased to approximately 46% of the project cost. This cost-effective approach significantly reduces overall expenses, as the control unit, which constitutes 70% of the project cost, remains unchanged. By making the system adaptable and scalable through the addition of a single SMPS module, approximately 35% in cost savings is achieved compared to replacing the entire charging unit. Consequently, the system proves to be highly cost-effective for scalability purposes.

V. FUTURE WORKS

The future scope for electric vehicle chargers is vast, as the adoption of electric vehicles continues to grow and the demand for charging infrastructure increases. Some of the possible areas of development and improvement for electric vehicle chargers are: 1. Wireless charging: Wireless charging is an emerging technology that eliminates the need for physical cables and connectors, enabling easy and convenient charging. This technology could be used for inductive charging of EVs, which would require the installation of charging pads or plates on the ground, and receivers on the underside of the EVs. 2. Vehicle-to-grid (V2G) charging: V2G technology allows EVs to serve as energy storage devices, enabling bidirectional energy flow between the vehicle and the grid. This technology could be used to provide energy services to the grid, such as load balancing and frequency regulation, while also providing benefits to EV owners, such as lower charging costs and increased battery life. 3. Solar-powered charging: These chargers use solar panels to convert sunlight into electrical energy to charge the battery. Solar-powered charging stations could be used to provide renewable energy to EVs, reducing the carbon footprint of the charging process and making EVs more sustainable. This technology could be used to integrate solar panels into the design of charging stations, enabling them to generate and store energy from the sun for use in charging EVs. They can be used to charge electric two-wheelers in remote locations where access to electrical power is limited. Overall, the future scope for electric vehicle chargers is promising, with many opportunities for development and innovation to meet the growing demand for charging infrastructure and support the widespread adoption of electric vehicles.

VI. CONCLUSION

In conclusion, the project of designing and implementing fast chargers for electric vehicles is a critical step towards achieving a sustainable transportation system. Fast chargers can help to reduce range anxiety, increase convenience, and improve infrastructure, while also reducing carbon emissions and improving air quality. By providing a higher charging current during the initial stage, constant current chargers can quickly charge the battery up to a certain level. This can be useful in situations where time is limited or when the battery needs to be quickly charged for immediate use. Decentralizing a system can increase its flexibility, future expansion scope, and reduce future costs by enabling local decision-making, allowing for modularity, and eliminating the need for expensive central control hardware and software. Modular systems reduce costs when designing for scalability by allowing for incremental expansions or additions of modular components instead of costly and time-consuming overhauls of the entire system. These benefits make decentralized systems a popular choice for systems that need to adapt to changing conditions or require future expansion. By increasing the life of a system, we reduce the need for new replacements or upgrades. This helps conserve natural resources such as minerals, metals, and other materials that are used in the production of new systems. This reduces the overall environmental impact of the system. It also reduces the amount of waste generated by the system. This includes waste generated during the production, transportation, and disposal of the system. By reducing the waste generated, we can minimize the impact on landfills, reduce pollution, and conserve natural resources. Overall, the electric vehicle fast charger project is an exciting and essential initiative that can help to accelerate the adoption of electric vehicles and reduce dependence on fossil fuels. By promoting sustainable transportation, we can improve the quality of life for people and the planet, while also creating new opportunities for innovation, investment, and growth.

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