

Conceptual Design and Development of Portable EV Charger

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Abstract

As more people turn to electric vehicles (EVs), the need for smarter, more adaptable charging solutions becomes clear. Conventional chargers often come with frustrating limitations with fixed locations, lack flexibility, and do not always fit the dynamic lifestyles of EV owners. This study introduces a portable battery EV charger designed to tackle these issues head-on. Traditional charging stations can be bulky, inefficient, and inconvenient in many scenarios. In contrast, the portable charger presented here is compact, lightweight, and built for high-efficiency charging. The methodology involved a detailed design process that included the specification of a battery pack rated at 799.2 V 8 Ah for simulation and 72 V 6 Ah for hardware implementation. A bidirectional dual active bridge (DAB) converter is applied as the power electronics horsepower to realize the energy transfer with current control capability. Simulation is conducted using MATLAB Simulink software to evaluate the system's behaviour in terms of energy transfer and current control under varying conditions and experimental results validate the feasibility and practicality of the design. The hardware implementation also incorporated safety measures such as fuses, thermal management, and automatic shutdown features to ensure reliable operation. The results from both simulation and experiment fulfil the expectation, including current control and consistent energy transfer from the battery pack to the targeted EV battery. The findings highlight how this portable battery EV charger can boost EV mobility, improve access to charging infrastructure, and make EV ownership more convenient, addressing the challenges posed by traditional charging methods.

Keywords

Bidirectional Dual Active Bridge Converter, DC Fast Charging, Portable EV Charger

1. Introduction

Driven by the need to lower greenhouse gas emissions and dependence on fossil fuels, the fast worldwide transition towards sustainable transportation has greatly accelerated the adoption of electric vehicles (EVs). Energy storage systems, power electronics, and battery technology have all advanced, improving the performance, economy, and cost of electric vehicles in facilitating this shift. However, one of the main obstacles preventing EVs from being widely adopted is the ease and accessibility of charging infrastructure. The traditional charging stations are usually fixed and immobile in particular places, causing the EV users to prearrange their trips according to when these stations are available. This restriction is a major deterrent to the wider use of electric cars and causes a great deal of hardship.

In recent years, there has been a growing interest in the conception of mobile electric vehicle chargers as a means of overcoming the constraints that are imposed by permanent charging infrastructure. Stationary charging stations are unable to provide the flexibility and convenience that these portable chargers do; ability to charge their vehicles at any location especially during emergency. Having this feature is very beneficial in situations like roadside crises, traveling long distances, or being in places where there is limited access to established charging networks.

This research was motivated by the necessity to fill in the gaps in the existing electric vehicle charging infrastructure, which is the source of the motivation. There is a growing demand for charging solutions that are both flexible and user-friendly as the number of EVs on the road continues to increase. One of the most significant developments in this area is the introduction of a mobile electric car charger, which offers a dependable and effective method of charging that accommodates the mobility of the user rather than limiting it. To alleviate range anxiety, which is one of the most common worries of people who are considering purchasing an electric vehicle, this convenience ensures that charging is available whenever and wherever it is required.

Mobile chargers that are not only small and lightweight but also capable of providing high-efficiency charging have become viable as a result of technological improvements in power electronics and energy storage systems. These advancements have made it possible to design portable chargers. These developments include the creation of batteries with a high density, the development of DC-DC converters that are efficient, and the development of thermal management systems that are robust. All of these things add to the performance and dependability of portable chargers. Additionally, the use of these technologies guarantees that the portable charger will be able to provide rapid charging times while preserving safety and being compatible with a variety of electric vehicle types.

This discovery is important because it has the potential to change the way that EV chargers operate. The project intends to improve the use and accessibility of electric vehicles by offering a portable and effective charging solution, therefore

encouraging their wider adoption. It is anticipated that this invention will be extremely important in lowering transportation's negative environmental effects and advancing sustainable mobility.

2. Literature Review

2.1. Electric Vehicle Charging System

Figure 1 illustrates the electrical components and power flow in a typical electric vehicle (EV) system, highlighting both bidirectional and unidirectional power paths. Power from the grid can flow through an onboard charger (Levels 1 and 2) to convert AC to DC for charging the EV battery, while a DC fast charging station (Level 3) provides direct DC charging. The EV battery powers electronic loads and the electric motor via DC-DC and DC-AC converters, respectively.

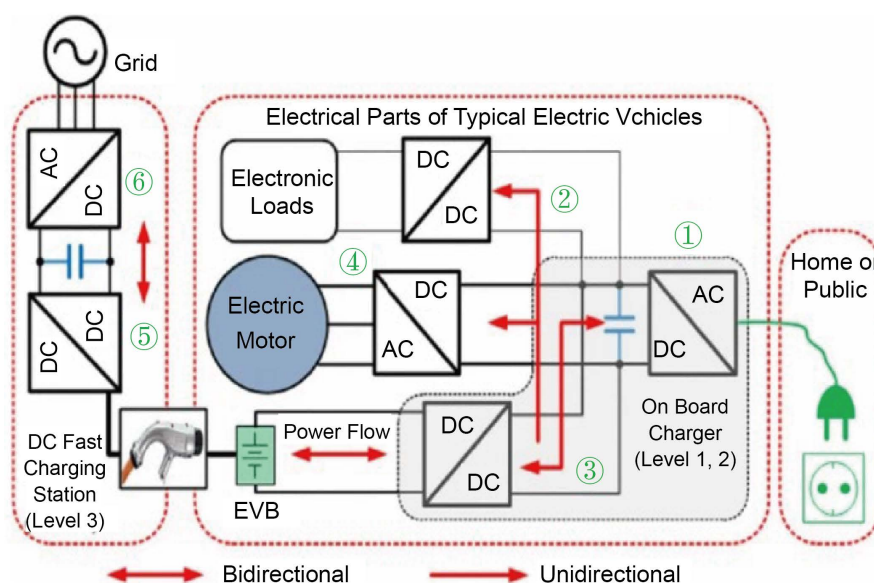


Figure 1. Electric vehicle charging system [1].

Table 1 shows that an electric vehicle's charging needs can be classified into 3 levels: Level 1, Level 2, and Level 3 or widely known as fast charging. For each level, the voltage, maximum current, type of current, power, maximum output and the charging time are defined. In Level 1, the voltage is 120 V and the maximum current is 16 A. In Level 2, the voltage is 220 V - 240 V and the maximum current is 80 A. In Level 3 or widely known as DC fast charging, the voltage range is 200 V - 450 V and the maximum current is 200 A. Both the power output and the charging time also change with level, where DC fast charging significantly charges at shorter time compared to Levels 1 and 2.

Figure 2 shows the typical example of DC fast charging station which currently available in the market. This type of charger offers fast charging, which is necessary for long distance travel and helps drivers feel less concerned about their range. It delivers direct current (DC) power to the car's battery instead of going

through the car's onboard charger, which usually takes alternating current (AC) from Level 1 and Level 2 chargers. This direct power transfer makes it possible to send much more power, usually between 50 kW and 350 kW. As a result, the charging time is shorter when more power is transferred, creating additional range to an EV in just a few minutes.

Table 1. Classification of EV charging.

Parameters	Level 1	Level 2	Level 3 (DC Fast Charging)
Voltage	120 V	220 - 240 V	200 - 450 V
Maximum Current	16 A	80 A	200 A
Current Type	AC	AC	DC
Power	1.4 kW	7.2 kW	50 kW
Maximum output	1.9 kW	19 kW	350 kW
Charging Time	12 hours	3 hours	20 minutes



Figure 2. Typical example of available DC fast charger in the market [2].

2.2. Types and Technologies of Mobile EV Charging Systems

A mobile EV charger is a new type of electrical charging apparatus for vehicles whether it has one or more charging ports that allow and facilitate on-demand charging to the electric vehicle users at their convenience at their place of work or at home [3]. In general, there are three basic categories of mobile charging technology currently available: truck mobile charger, portable charger and car-to-car power transfer charger.

2.2.1. Truck Mobile Charging System

The truck mobile charging stations (TMCSs) [4] as shown in **Figure 3** are an application where a vehicle, either a fully electric or hybrid type, typically a truck or van equipped with energy storage system (ESS). It has the capability to offer an on demand charging service. The ESS can be charged either from standard utility AC source or through DC fast charging at conventional charging station. As for the

user, it is a better option especially for those with limited access to AC charging facility, where they can charge their vehicle at anytime and anywhere, e.g. during leisure time or working hours. The drawback of this option is limitation in terms of energy storage capacity and in certain scenarios, users may need to wait in a queue due to limited availability due to high demand.

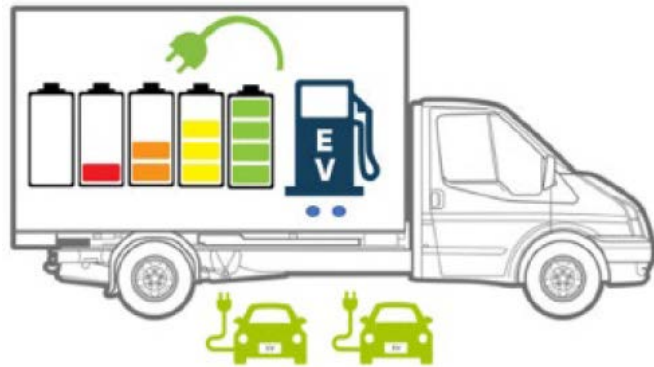


Figure 3. Typical example of available truck mobile DC fast charger in the market.

2.2.2. Vehicle-to-Vehicle Energy Transfer

Figure 4 is a concept of direct energy transfer between two vehicles or commonly referred to as a V2V energy sharing [5]. An EV with excess energy will normally transfer to other EV in need of energy either through wired or wireless induction. Most EV owners charge their vehicles at home each day for only a 25 to 30 miles journey per day, allowing them to take advantage of V2V charging based on the underutilized energy capacity. This helps to address range anxiety among EV drivers as they can depend on other EV in case of emergency. The EV maker then can consider having a smaller battery capacity which helps to reduce vehicle cost and weight, as well as contributing towards a more sustainable transportation. The successfulness of V2V concept, however, depends on the awareness and togetherness among EV users to practice energy sharing between them.

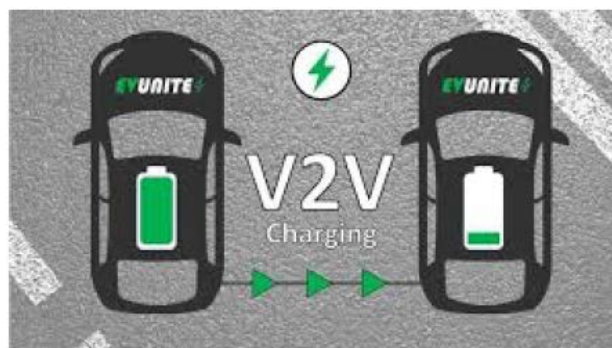


Figure 4. Vehicle to vehicle energy transfer.

2.2.3. Portable Charging System

The concept of portable charging system is to be able to charge the EV at higher

mobility compared with the previously discussed: the TMCS and V2V charging concept. For that purpose, it must be handy in terms of size and weight, easy to operate and still appreciated by EV users to address range anxiety. As discussed previously, EV users in average travel approximately 40 to 48 km per day with average battery energy consumption per kilometer being between 0.12 to 0.25 kWh, depending on car model, driving style and road conditions [6]. For that, to have a backup energy solution with a capacity between 10 to 12 kWh or even just 50% of that should be sufficient to provide peace of mind to the users in any emergency.

Figure 5 shows an example of portable EV charger currently available in the market, the Heliox Mobile Charger from Siemens [7]. It can be charged via an AC wall socket at 16 A (10 kW), 32 A (20 kW) and 63 A (40 kW). The charger weighs 120 kg with dimensions of 0.96 m (H) \times 0.72 m (L) \times 0.56 m (W). The DC output range is 100 to 1000 V with maximum output current of 67 A for 40 kW rated output power. The product target use is for fleet and bus charging. At the weight of 120 kg, it may not be very suitable for personal use where it can be kept at the back compartment for emergency use.



Figure 5. Heliox 40 kW portable charger from Siemens [7].

Figure 6 shows another example of portable EV charger from China Max Power [8]. It can be charged at standard AC supply of 380 V. It has variants of 7/20/30/40/60 kW output rated power with output voltage ranges between 200 to 1000 V. As for the 40 kW model, the output current based on the rated power is 120 A. It weighs 60 kg with dimensions of 0.45 m (H) \times 0.65 m (L) \times 0.12 m (W). It complies with current charging standards and protocols and is compatible with a wide range of available EV brands in the market.

2.3. DC-DC Converter for Charging System

A DC-DC converter is an electrical power device used to convert direct current (DC) from one voltage level to another. This converter can handle power levels ranging from very low, such as those from small batteries, to extremely high, such



Figure 6. Portable EV charger from China max power [8].

as those used in high-voltage power systems. It is essential because the voltage supplied by a source often does not match the requirements of the DC load. Power semiconductors, including MOSFETs and IGBTs, function as switches in combination with passive components such as capacitors, inductors, and transformers. Together, they modify the voltage from a DC source to the appropriate DC voltage required by a DC load [9]. This can come from a battery, solar panels, fuel cells, or a DC bus voltage that is fed by AC grid voltage that has been stepped down.

Figure 7 shows the circuit of the isolated DC-DC converter. An isolated DC-DC converter is a type of power converter that uses a transformer to keep the input and output electrically separated [10]. This way, there is no direct electrical link between the two sides. By stopping high voltages from going to the output, this separation offers important safety benefits, which are important in areas like medical devices, industrial systems, and consumer electronics. Isolated converters also help lower electrical noise and interference, which makes sensitive electronic equipment more reliable and better at what it does. These converters are flexible and can work with a lot of different input and output voltages [11]. This means they can be used in a lot of different situations, like charging stations for electric cars, green energy systems, and phone systems.

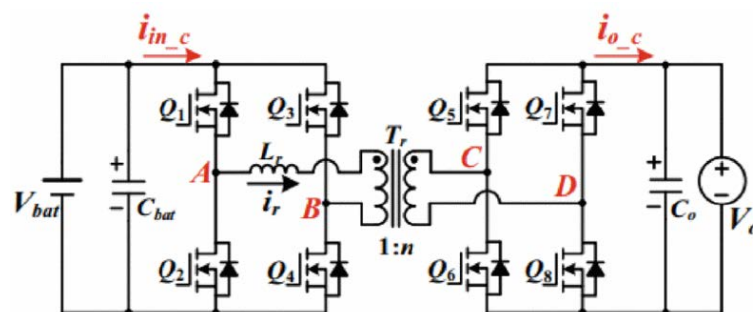


Figure 7. Isolated DC-DC converter [12].

The isolated DC-DC converter is a significantly important component in electric vehicle DC charging system. It functions to consistently regulate the voltage and current levels during EV charging and supports both fast and slow charging modes. The integration of MOSFET technology, known for its high efficiency and precise control of on/off current, demonstrates the system's capability to deliver optimal performance while effectively managing the voltage and current fluctuations typical in EV charging processes. This combination of advanced technology and adaptable design not only ensures optimal charging performance but also underscores the system's ability to meet the demanding energy management needs of modern EVs, ensuring efficiency, reliability, and compatibility across a wide range of charging scenarios.

3. Methodology

3.1. Proposal on Configuration of Portable EV Charger with Stackable 6.39 kWh Battery Pack

Figure 8 shows the application system of the portable EV charger. In general, the portable battery pack can be charged by using the currently available Level 2 AC charger. It can charge the battery pack at 3 kW to 22 kW at an approximate time of 4 to 10 hours using a single-phase or 3-phase AC source.

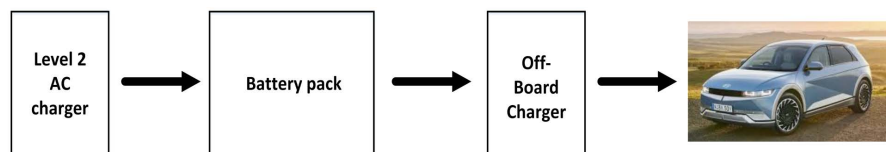


Figure 8. Application system of portable EV charger.

Considering that majority of EV brands comply with 400 V battery system, the total nominal voltage of the battery pack of the portable charger is designed at around 800 V. The advantages of this value are that in term of flexibility in the transformer turn ratio configuration and difference between the primary and secondary voltage of the transformer will provide higher range of current controllability. As shown in **Figure 9**, as the nominal voltage of the single LiFePO_4 is 3.7 V, connecting 216 cells in series will produce a total nominal voltage of 799.2 V. This value of nominal voltage is at 80 % SoC and can vary accordingly with the change in its SoC. The battery pack can be configured as a single stack of battery pack with capacity of 6.39 kWh or multiple stacks of it for better flexibility. The proposed configuration and dimensions of 2 2-stack battery pack with total capacity of 12.78 kWh are shown in **Figure 9**. The battery pack will also be equipped with the Battery Management System (BMS) and basic user interface. Each battery pack has dimensions of approximately 42 cm (L) \times 20 cm (H) and 31 cm (width) with an approximated weight of 31.5 kg (battery only). The battery pack can be stacked accordingly to achieve a certain desired capacity. As shown in the figure, with 2 stacks configuration, the achievable capacity is 12.78 kWh with dimension that

can be transported with a normal sedan vehicle.

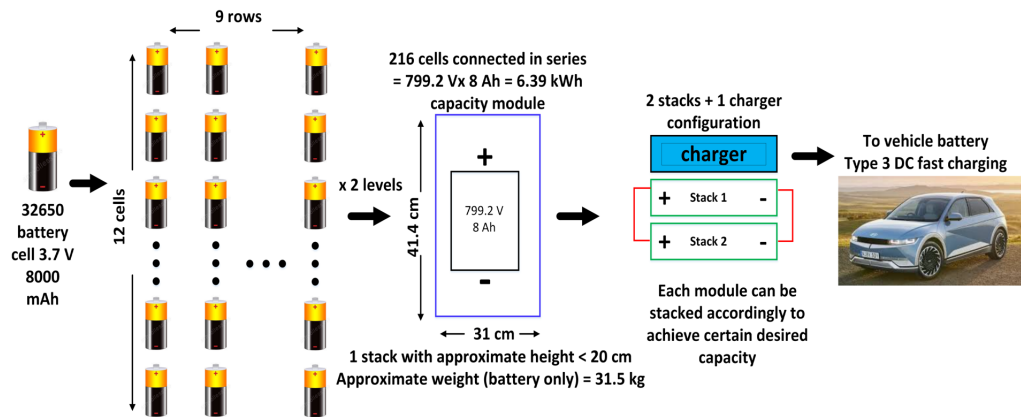


Figure 9. Configuration and dimension of 2 stacks battery pack with 12.78 kWh capacity.

The off-board charger as shown in Figure 10 functions to regulate the output DC voltage from the battery pack to the required DC voltage and current necessary to directly charge the battery inside the targeted EV [13]. In this work, a Bi-directional Dual Active Bridge (DAB) converter is selected for voltage and current conversion between the battery pack and the targeted EV battery. The DAB converter is stacked on top of the battery stacks. For this design, the charger can charge at nominal voltage of 400 V and maximum current of 80 A for total of 32 kW charging. This is considered based on the report in [14], where the 400 V battery architecture still dominates with 90% of EV brands compared to 800 V architecture. The design of the portable charger in this work is not targeting to fully charge the vehicle, rather just to add some miles for the vehicle to reach its next destination.

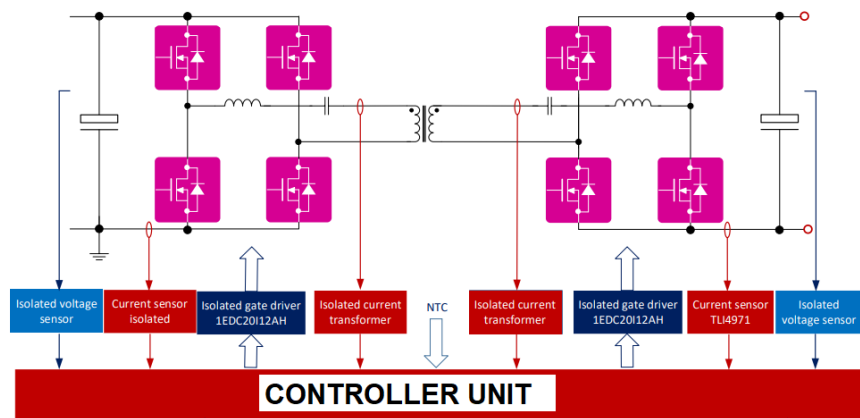


Figure 10. Bidirectional dual active bridge converter [13].

Table 2 compares the proposed portable charger with the currently available commercial products discussed previously in the literature review section in terms of dimensions, capacity and cost.

Table 2. Comparison of specifications of several commercial portable EV chargers.

Specifications	Siemens Heliox [7]	Guangzhou Max Power [8]	Proposed Portable Charger
Dimensions	0.96 m (H) × 0.72 m (L) × 0.56 m (W)	0.45 m (H) × 0.65 m (L) × 0.2 m (W)	0.2 m (H) × 0.42 m (L) × 0.31 m (W)
Weight	120 kg	60 kg	31 kg (battery only)
Rated power	40 kW	40 kW	32 kW
Output DC voltage	200 - 1000 V	200 - 1000 V	Max 400 V
Rated output current	67 A	120 A	80 A
Cost	> USD 20,000.00	USD 2260.00	< USD 1,000.00

3.2. Matlab Simulink Simulation Model

Figure 11 shows the Matlab Simulink model of the proposed portable EV charger adapted from the example in [15]. The important parameters related to the simulation are summarized in Table 3. The portable charger’s battery packs are using the Lithium Iron Phosphate (LiFePO₄) type battery with nominal voltage of 3.7 V, configured as 799.2 V 8 Ah × 2 stacks for a total of 12.79 kWh capacity. The targeted EV battery has a capacity of 54 kWh with nominal voltage of 350 V. The bidirectional dual active converter functions as a charger with current control capability. Feedback of output current from the converter is compared with the reference and PI controller is applied to produce the phase difference of switching signal between the primary side switches and the secondary side switches.

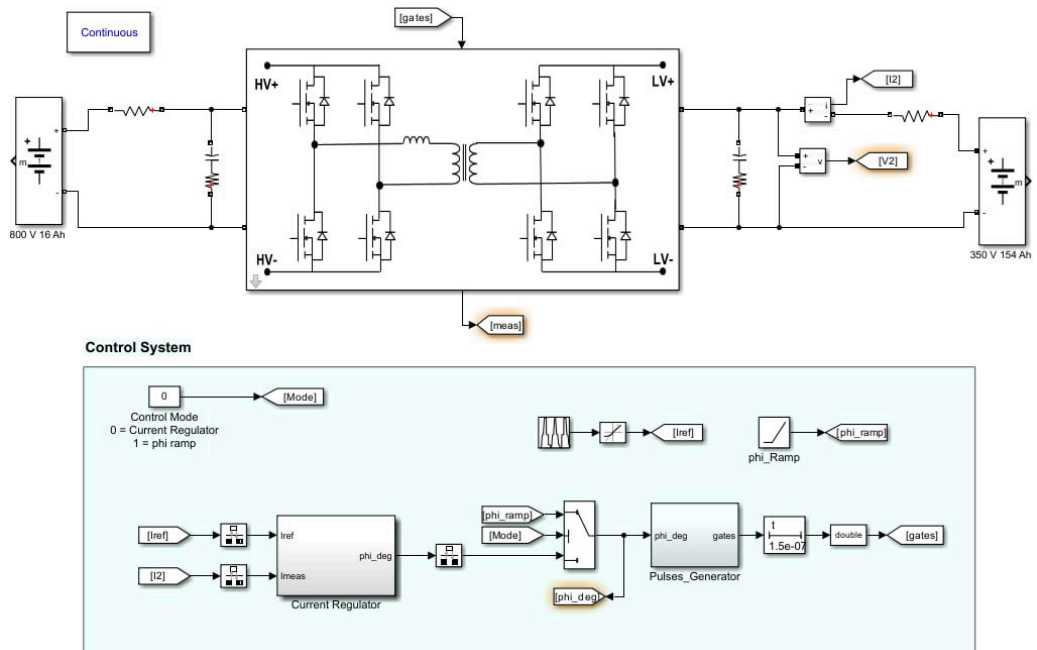


Figure 11. Matlab simulink model of dual active bridge DC-DC converter.

Table 3. Parameters for Matlab simulink simulation of portable EV charger.

Parameters	Value
Battery	
Type of Battery	Lithium Iron Phosphate (LiFePO ₄)
Charger Battery Pack	799.2 V × 8 Ah × 2 stacks = 12.79 kWh (at nominal)
EV Battery Pack	350 V × 155 Ah = 54 kWh
Converter	
Type	Bidirectional Dual Active Bridge Converter
Transformer Ratio N _p :N _s	2:1
Switching Frequency	100 kHz
Current controller type	PI controller

In this simulation work, the scenario of DC fast charging is executed where the objective is to verify that the proposed portable EV charger can be used to charge the EV battery for short time during emergency just to add few miles for the EV.

3.3. Hardware Prototype Development

A scaled down hardware prototype of the portable EV charging system is developed to verify the simulation work. The charger battery pack is configured at 72 V with 6 Ah capacity, while the targeted EV battery is configured at 36 V with 6 Ah capacity. This scaling allowed for cost-effective testing and validation of the system without compromising the functionality of the design. The charging process was facilitated using a 600-watt DC-DC converter, configured to step down from 72 V to 36 V, ensuring efficient energy transfer between the scaled-down battery pack and the targeted battery during hardware implementation.

Insights from the evaluation results based on the scaled down 72 V prototype are valid to represent the full scaled design as the battery normally has a linear behaviour and relationship in term of state of charge, battery, current and energy capacity.

Figure 12 shows a complete wiring diagram setup for charging system. The system includes a 12 V relay connected to a switch and an indicator light, which activates the charging circuit. The battery pack is connected to a Battery Management System module (BMS) to ensure safety by monitoring and controlling the battery's parameters. This configuration ensures the battery pack powers the targeted battery safely while being monitored for performance and protection through the BMS and other components.

Figure 13 shows the actual hardware prototype of the portable EV charger with a complete wiring connection. The hardware is developed with safety features to ensure reliable and efficient operation during the charging process. Key components, such as the Battery Management System (BMS) for both the battery pack and the targeted battery are implemented to monitor voltage, current, and tem-

perature, providing protection against overcharging, over-discharging and short circuits.

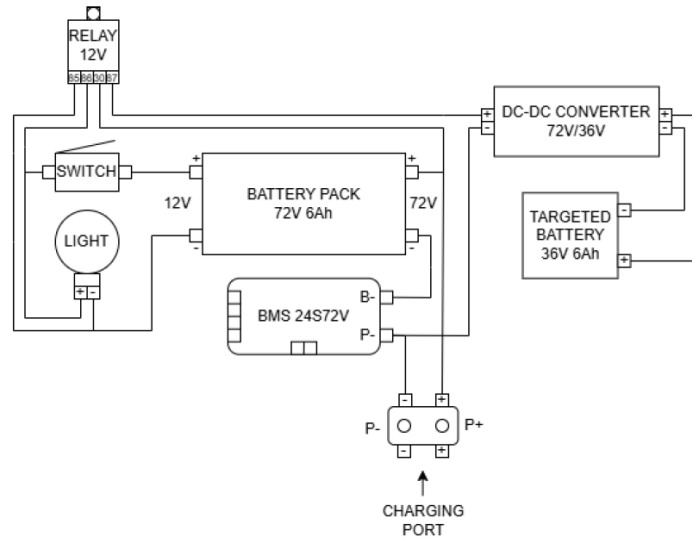


Figure 12. Wiring diagram setup for the charging system.

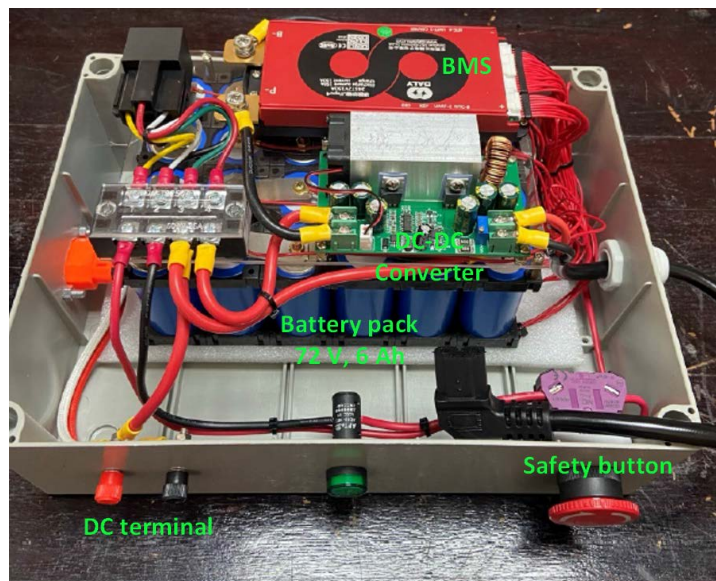


Figure 13. Hardware prototype of the portable EV charger.

4. Results and Discussions

Simulation is carried out to verify the workability of the EV portable charger. Charger's battery pack initial state of charge (SoC) is set at 90%, while the EV battery initial SoC is set at 20%. The charger is set to charge the EV battery at 60 A for 15 minutes (900 seconds). As shown in Figure 14, while the EV battery is charged at 60 A at nominal voltage of 350 V, the discharged current from the charger's battery pack is approximately 28 A at nominal voltage of 799.2 V. It is evident from Figure 15, that the discharged power from the battery pack is ap-

proximately the same with the amount of power charged to the EV battery at around 22.5 kW.

By calculation, based on charging time of 15 minutes, the total energy discharged is approximately 5.625 kWh, about 44% of the total energy capacity. While at the EV battery side, assuming the total charged energy is approximately same as what is discharged by the charger, the amount of energy represents approximately 10.42% of the total battery energy capacity. As shown in **Figure 16**, the charger's battery pack SoC drops about 43%, while the EV battery SoC increases about 9.5%, thus verifying the approximated calculation.

For the hardware validation, a 72 V, 6 Ah battery pack with an initial SoC of 100% is set to charge a 36 V, 6 Ah targeted EV battery with an initial SOC of 20%

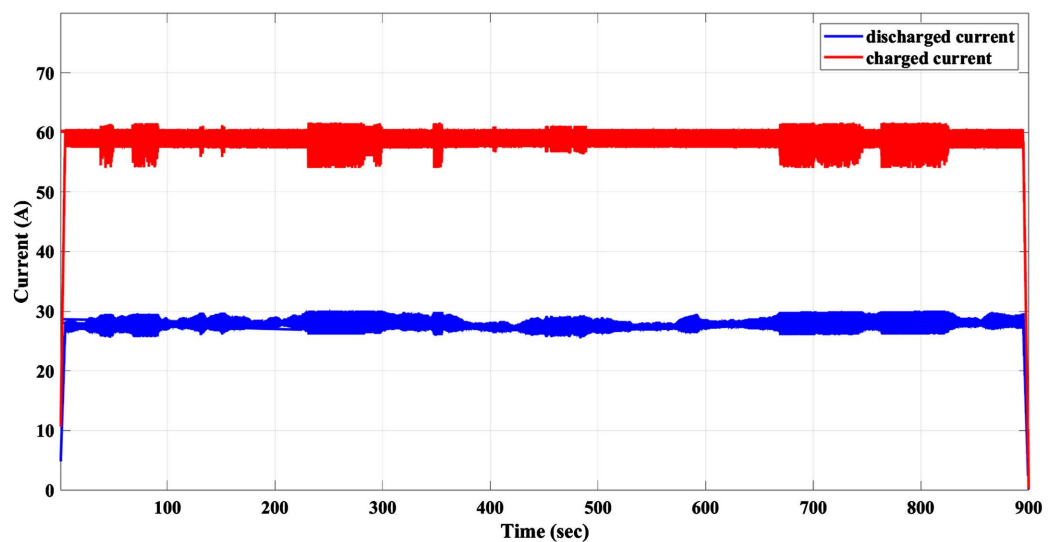


Figure 14. Simulation results of discharged and charged current during charging.

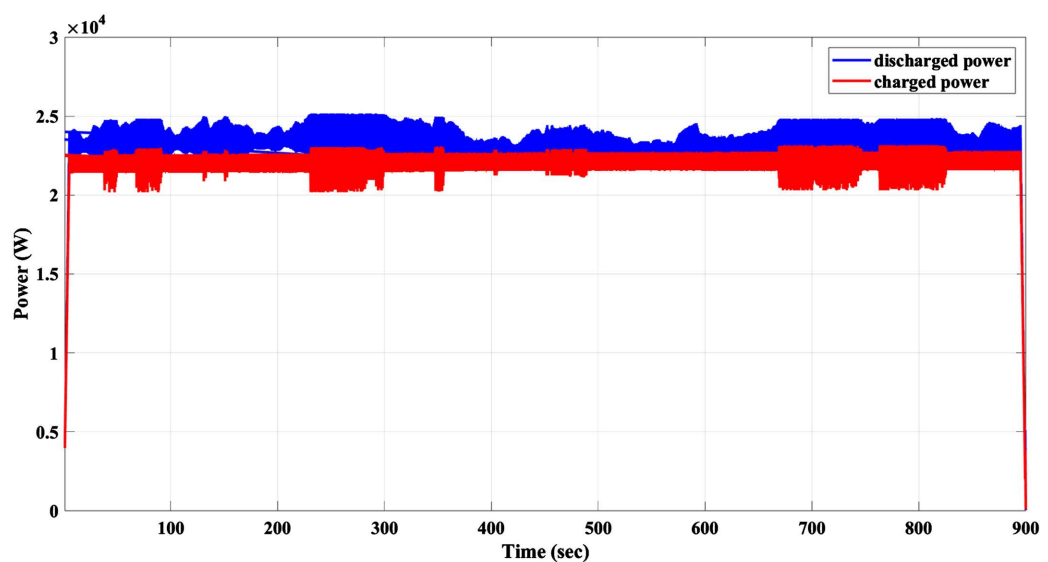


Figure 15. Simulation results of discharged and charged power during charging.

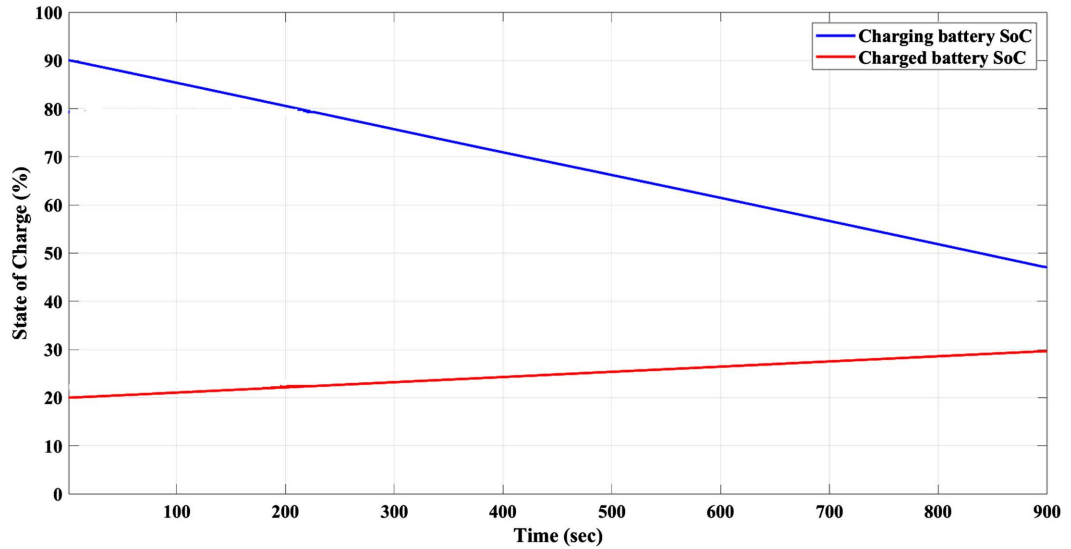


Figure 16. Simulation results of change in the SoC of both batteries during charging.

at a charging current of 11 A for 15 minutes. Figure 17 shows the discharged current from the battery pack and the charged current at the EV battery. The discharge and charged power at both batteries are also approximately match to each other as shown in Figure 18 at about 500 W. Based on the measurement data at Figure 18, where the charging efficiency can be calculated based on the ratio between the discharged power from the portable battery pack to the power received by the EV battery, Figure 19 shows the resulted charging efficiency during the 15 minutes charging process which proves the proposed portable charger has high efficiency of more than 90%. The less value of charged power at the EV battery might be caused by the losses along the converter. Figure 20 shows the change in SoC for both batteries. Based on rough calculation, the amount of discharged

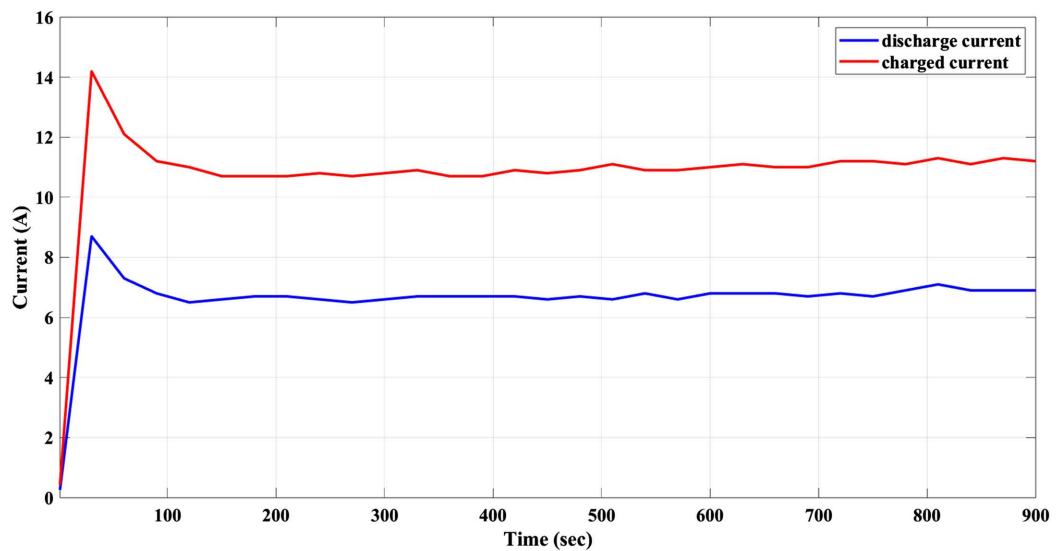


Figure 17. Experimental results of discharged and charged current during charging.

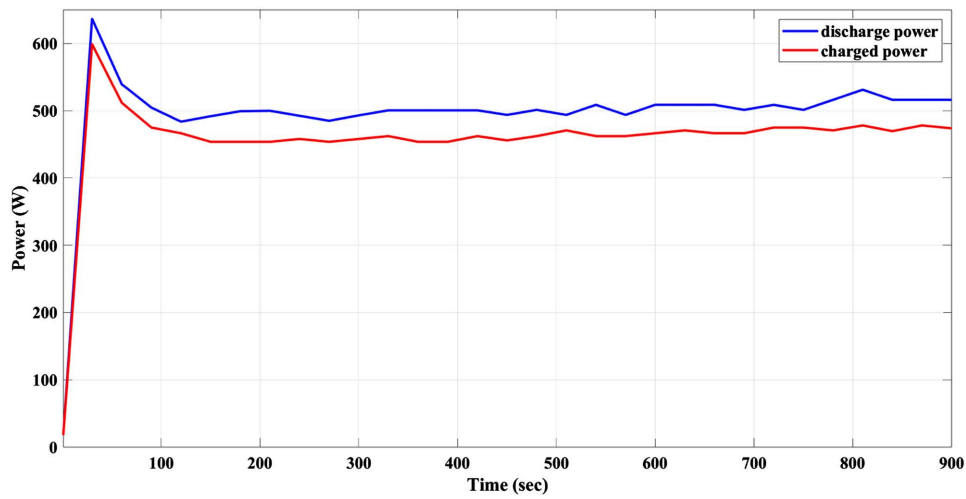


Figure 18. Experimental results of discharged and charged power during charging.

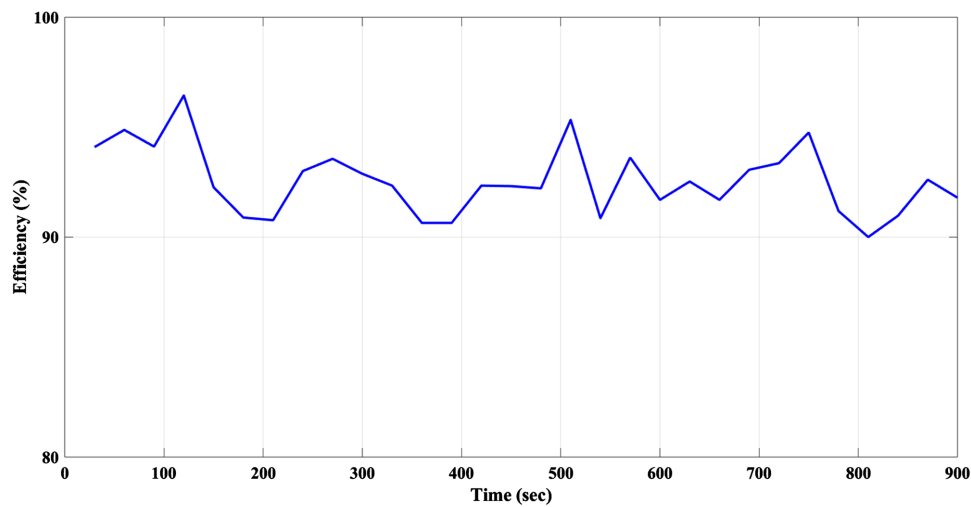


Figure 19. Experimental results of charging efficiency during the charging process.

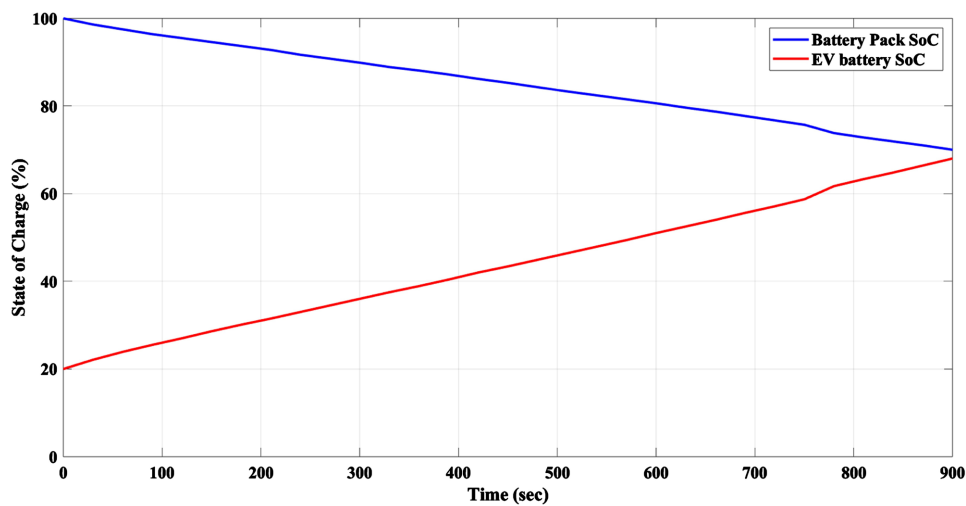


Figure 20. Experimental results of change in the SoC of both batteries during charging.

energy for 15 minutes is about 125 Wh, which represents about 28.9% of the battery pack capacity. This almost tallies with the SoC drop shown in **Figure 20** from an initial 100% to 70%. As for the EV battery, the amount of charged energy is roughly about 118.75 Wh, accounting for 55% of the total capacity. As shown in **Figure 20**, this approximately tallies with the increase in the SoC from 20% to 68%. The hardware experiment results confirm the efficient energy transfer and reliability of the charging system.

5. Conclusions

The primary objective of this project is to design and develop a portable battery charger for electric vehicle, focusing on efficiency, portability, and compatibility with EVs of varying specifications. This study successfully demonstrated the feasibility of achieving this through both simulation and hardware implementation.

In the simulation based on Matlab Simulink software, the portable charger is designed as a 799.2 V 16 Ah \times 2 stacks 12.79 kWh battery pack, charging a 350 V 54 kWh capacity EV battery at approximately 22.5 kW for 15 minutes. The results fulfil the expectation based on theoretical calculation.

As for the scaled-down hardware implementation, a battery pack with specifications of 72 V and 6 Ah is developed to charge the EV battery with specifications of 36 V and 6 Ah. The setup utilized a DC-DC converter charging a current of 11 A for a duration of 15 minutes. The results validate the effectiveness of the developed portable charger prototype in terms of energy transfer between the batteries.

The findings in this work highlight how this portable battery EV charger can boost EV mobility, improve access to charging infrastructure, and make EV ownership more convenient, addressing the challenges posed by traditional charging methods. However, there are still improvements that can be included in future works such as evaluation on thermal effects of battery and related safety issues.

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Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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