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*Original Article*

# Performance Analysis of EV Battery Module with Different Charging Techniques for Better Stability

Tipirisetti Rakesh[1], B. Suresh Kumar[2], J. Upendar[3]

[1,3]*Elelctrical Engineering Department, University College of Engineering, Osmania University, Telangana, India.*
[2]*Electrical and Electronics Engineering Department, Chaitanya Bharathi Institute of Technology, Telangana, India.*

[1]*Corresponding Author : traki284@gmail.com*

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***Abstract -*** *Electric vehicles are the replacement for conventional fossil fuel engine vehicles. The EV is installed with a battery pack to store electrical power which drives the vehicle. The charging circuit and the driving circuit have independently isolated circuit topologies. Each circuit operates individually and complimentarily, as during charging, the vehicle does not move. There are different types of charging circuits that control the charging current of the battery. In this paper, we consider a conventional buck-boost circuit topology for charging the battery, controlled by different charging techniques. The converter is controlled by either CV or CC charging which need voltage and current feedback, respectively. The different charging techniques include i) Continuous, ii) Pulse, iii) Burp, and iv) Taper. To improve the health of the battery, these charging techniques are employed which change the way of charging. For testing of the charging techniques, a high capacity (40kWh) battery of the 'TATA Nexon EV' vehicle is considered in the simulation. A comparative analysis is done in MATLAB software on the proposed charging circuit with different charging techniques and the results are presented concerning time.*

***Keywords -*** *Electric Vehicle (EV), Constant Voltage (CV), Constant Current (CC), Matrix Laboratory (MATLAB).*

## 1. Introduction

To reduce environmental pollution caused by conventional fossil fuel engine vehicles, Electric Vehicles (EVs) are introduced. These vehicles have no carbon emissions and no residue generation. They run on a power storage module which needs to be charged through mains. The charging of the vehicle can be either done by renewable sources or a conventional grid connection.

It is recommended to use renewable sources to charge the battery pack of the EV to eliminate carbon footprint. This way of charging the vehicle and utilizing it for transportation, either for commercial or domestic purposes, reduces environmental pollution. In the EV circuit structure, the charging and driving circuits are isolated and operate individually. Both the circuits have their control modules controlling the power electronic switches in the circuits. This paper discusses the charging side of the EV where the battery pack is charged with different charging techniques [1].

In previous research, many charging circuits are used to charge the EV battery. Converters like Buck, Boost, Power Factor Correction (PFC), Active Full Bridge (AFB), resonant bridge, and Partial Power Charging (PPC) circuits are used for the charging of the battery. Every circuit has its significance, which is installed as per the requirement and rating of the EV battery. The basic converters are buck and boost converters, which either decrease or increase the voltage, respectively. These basic circuits have heavy ripple and low efficiency but are economically low-cost and less complex [2].

For low-cost applications, these circuits may be integrated. The next generation circuits are PFC, AFB, Resonant bridge, and PPC converters which have very little ripple and disturbances. However, the advanced circuits are very complex to fabricate, and high-rating components need to be used. With a greater number of power electronic and passive components in the advanced circuits, the cost of the design will also go high. These circuits are recommended for high-rating applications in commercial charging stations where multiple EVs are charged [3].

The basic charging circuits are generally installed for domestic charging applications where a single EV is charged to a point. Therefore, a simple and less complex low-cost module is applicable for charging the EV battery. For wide-range voltage applications, the conventional Buck-Boost converter can be utilized as it can in buck and also in boost mode as per the requirement.

For low-voltage applications (two-wheeler EV battery charging), the converter can be operated in buck mode and for higher-voltage applications (four-wheeler EV battery charging), boost mode can activated. For any circuits as mentioned above, there are only two techniques of charging which are either Constant Voltage (CV) or Constant Current (CC) charging. These two techniques need voltage and current measurements of the EV battery pack [4].

The CC mode is selected during low State of Charge (SOC) levels of the battery, and the CV mode is opted for during higher SOC. The CV or CC modules control the duty ratio of the switch in the charging circuit, in turn, controlling the charging current.

Both the CV and CC charging techniques have continuous charging current injection which may lead to degrading of battery health. Continuous charging of high-rating Li-ion batteries causes high temperatures in the cells of the battery pack [5].

This leads to the failure of some of the cells over a period leading to complete damage to the battery pack. Most of the researches are done on CC and CV mode charging with a continuous current supply to the battery. For low-rating battery applications, continuous charging may not impact the health of the battery; however, with larger capacities in the range of 200-300Ahr, the charging time increases, which may impact the battery pack health and can also damage the battery at one instant of time.

To improve the reliability of the EV battery pack, different charging methods are adopted, which decrease the cell temperature reducing stress on the battery pack [6]. The charging methods considered are i) continuous, ii) pulse, iii) burp, and iv) taper.

The ‘continuous’ charging method is the conventional method mentioned previously updated by the other three methods. For the testing of the proposed charging methods, the buck-boost converter is connected to a 3-ph grid through an uncontrolled Diode Bridge Rectifier (DBR). The MOSFET switch of the converter is controlled by either CV or CC techniques with different charging methods. The circuit structure of the proposed topology can be observed in Figure 1.

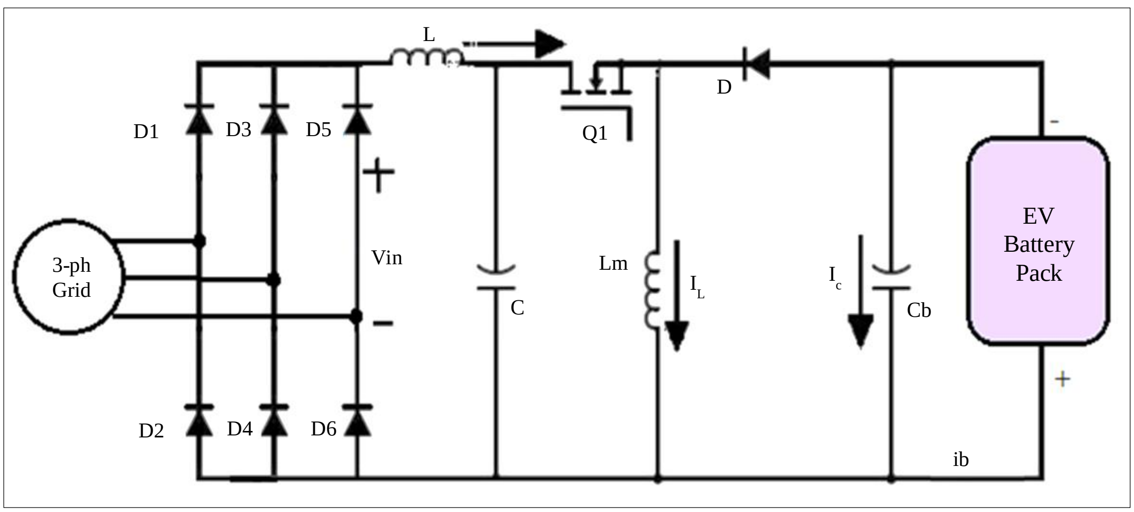


**Fig. 1 Buck-boost circuit for EV battery charging**

As presented, the switch Q1 controls the charge current to the inductor $L_m$, which discharges when the switch is turned off. The duty ratio of the switch to the CV or CC control modules controls Q1 [7]. This paper is organized with an introduction of the proposed circuit topology in Section 1, followed by circuit configuration and control techniques design in Section 2.

In Section 3 the charging methods are discussed for increasing the reliability of the battery. The modeling of the proposed circuit and control modules is carried out in MATLAB Simulink environment, and the results are presented in Section 4. The results finalization and conclusion to the paper are integrated in Section 5 followed by reference citations.

## 2. EV Charging Control

The EV battery packs are charged from either the single-phase AC line (domestic charging) or the DC link (commercial charging). The AC line charging is generally done in residential regions which have an external charging circuit. As the single-phase AC line has a very low current rating in the range of 10A-15A, the charging of the battery has a slower rate. Therefore, the DC line charging is needed, which can provide current ratings in the range of 45A – 60A which charges the battery at a faster rate [8]. The AC line charging has a very simple structure with a lower rating converter connected between the EV and the mains. However, the DC line charging has a 3-ph AC input to the converter with a diode bridge rectifier converting the AC to variable DC.

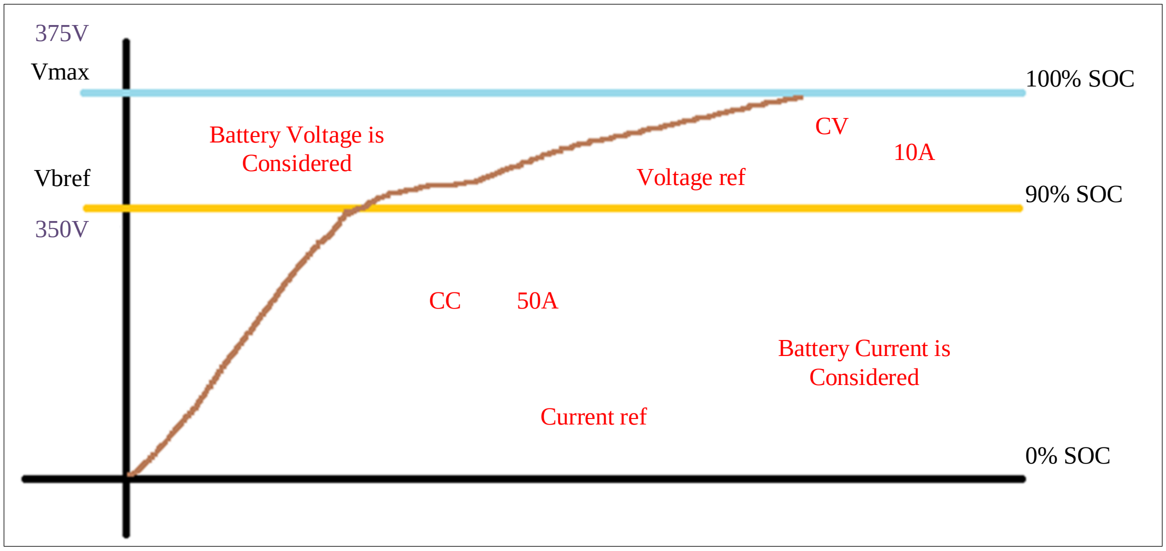


**Fig. 2 Mode selection of the controller**

The variable DC is stabilized by the buck-boost converter connected between the diode bridge rectifier and the EV battery pack. The duty ratio of the MOSFET Q1 in Figure 1 is controlled either by CV or CC charging. The selection of the CV or CC charging is done as per the voltage magnitude of the battery. The voltage of the battery varies in a specific range as per the SOC of the battery.

The battery voltage increases or decreases by about 15% of the nominal voltage by which the SOC is determined. During the lower SOC value of the battery pack, the CC mode is selected, which needs battery current feedback [9]. Moreover, when the SOC reaches higher values, the CV mode is activated. This switching of the modes is done to improve the reliability of the cells in the battery pack. Figure 2 shows the selection of the mode as per the SOC of the battery.

As observed in Figure 2, the CV mode is activated when the SOC of the battery crosses 90%. In CV mode the charging is lower as compared to CC mode. This reduces the rate of charge of the battery pack, ensuring reduced damage to the cells [10]. The charging completely stops when the SOC of the battery reaches 100%. The operating principles of the CV and CC modes are further explained in sub-sections.

### *2.1. CV Controller*

The CV controller uses reference voltage value for controlling the switch Q1 of the converter. The mode of charging is particularly selected when the SOC of the battery crosses the threshold value [11]. A conventional PI controller is used to generate the duty ratio for the switch Q1. The CV control for the EV battery pack charging can be observed in Figure 3.

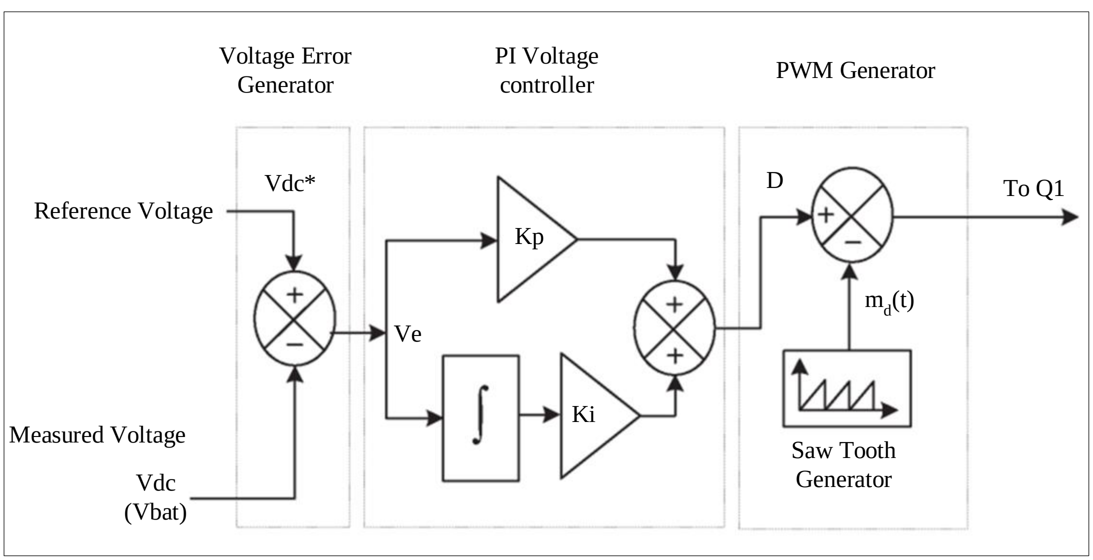


**Fig. 3 CV controller of the charging module**

As presented in Figure 3, the Reference voltage ($V_{dc}$*) is compared to the Measured voltage ($V_{dc}$), which is the Battery voltage ($V_{bat}$). After the comparison, an Error voltage ($V_e$) signal is generated, which is fed to a PI voltage controller. By tuning the $k_{pv}$ and $k_{iv}$ (proportional and integral gains) values of the PI controller duty ratio (D) signal is generated. The duty ratio from the controller is expressed as:

$$D = (V_{dc}^{*} - V_{bat})\left(k_{pv} + \frac{k_{iv}}{s}\right) \qquad (1)$$

This signal D is compared to a high-frequency sawtooth waveform generating a pulse for the switch Q1 [12]. When the $V_{bat}$ reaches the reference value, the error becomes zero in turn makes the duty ratio zero. The pulse to the switch Q1 stops, resulting full charging condition of the battery.

### *2.2. CC Controller*

The other charging mode is the CC mode, which needs a Battery Current ($I_{bat}$) signal as feedback to control the switch Q1. Similar to the CV mode there is a reference current value ($I_{ref}$) given as per the requirement. The control structure of the CC controller can be observed in Figure 4.

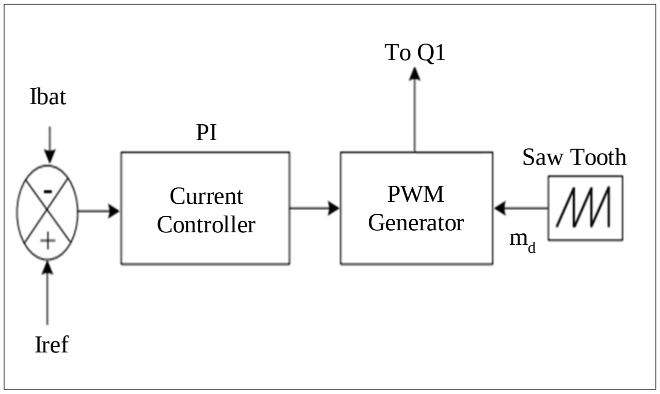


**Fig. 4 CC controller for charging module**

As presented in Figure 4, the $I_{ref}$ is compared to $I_{bat}$ generating Error current ($i_e$), which is fed to the PI current controller with Specific $k_{pi}$ and $k_{ii}$ gains. The values of the current controller are tuned as per the response of the battery current to the reference value [13]. The tuning of the gain values, either in CV or CC modes, is done through the 'trial-and-error' method. The values are varied as per the overshoot, settling time, and ripple of the controlling parameter. The D of the CC mode is expressed as:

$$D = \left(I_{ref} - I_{bat}\right)\left(k_{pi} + \frac{k_{ii}}{s}\right) \qquad (2)$$

Both these controllers are switched as per the SOC of the battery which is determined by the $V_{bat}$ feedback signal. These controller modules are introduced in every type of charging and an analysis is carried out with different SOCs of the EV battery pack in further sections.

## 3. Types of Charging

As mentioned previously in section 1, four charging types are introduced in this paper, which change the current input to the EV battery pack. Based on the charging, the slew rate of the SOC changes, concerning which the battery health improves. The conventional charging type gives continuous current to the battery, which is considered less reliable for battery charging applications [14]. Therefore, the continuous charging is modified to different types, for improving the reliability of the cells in the battery pack. The working principles and the battery characteristics as per the charging type are discussed in detail.

### *3.1. Taper Charging*

Taper charging is considered when the input is an unregulated voltage source where the magnitude varies continuously. This phenomenon is majorly occurring in rural areas and radial distribution systems. The taper charging is a voltage reference charging with a CV controller controlling the converter [15]. This method of charging is used only for Sealed Lead Acid (SLA) batteries. The Voltage vs Current graph concerning the type of charging can be observed in Figure 5.

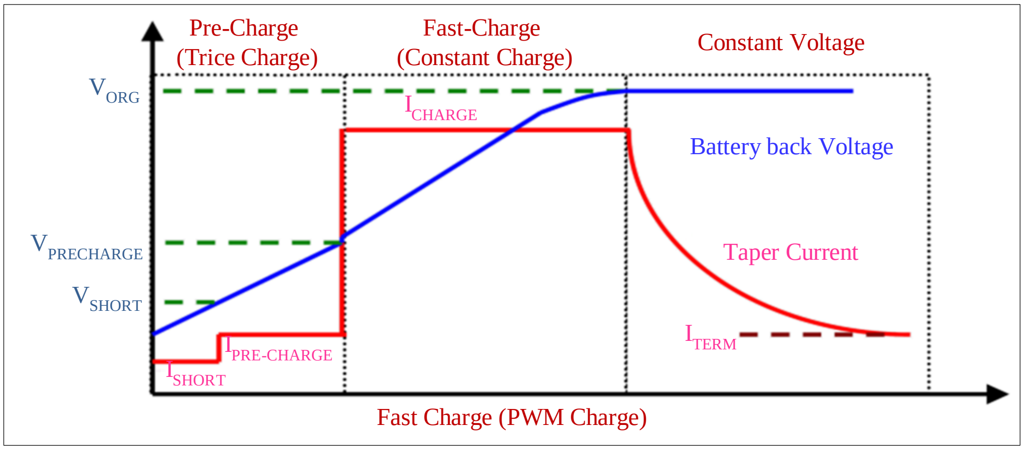


**Fig. 5 Taper charging representation**

As observed, when the $V_{bat}$ reaches the threshold value of $V_{OREG}$ the current input to the battery pack exponentially drops. This current is represented as a taper current, which ensures there is a gradual increase in battery SOC to the maximum limit. The current magnitude drops from $I_{CHARGE}$ to $I_{precharge}$ level over an instant of time. This is achieved by a 'loop-up table' in which the duty ratio is predefined as per the $V_{bat}$ value [16]. The Duty ratio (D) of the switch Q1 is exponentially reduced to zero after the threshold value limiting the current input to the battery pack.

### 3.2. Pulse Charging

Pulse charging is an advanced technique where the current is not fed to the battery continuously. The current to the battery is fed in pulses with a break for small instants of time. The rate of charging can be changed by varying the pulse width either in milliseconds or seconds [17]. With the small breaks from the charging, the rest period ensures battery stabilization, equalizing the electrodes. The pulse charging method, either for the CV or CC mode controllers, can be observed in Figure 6.

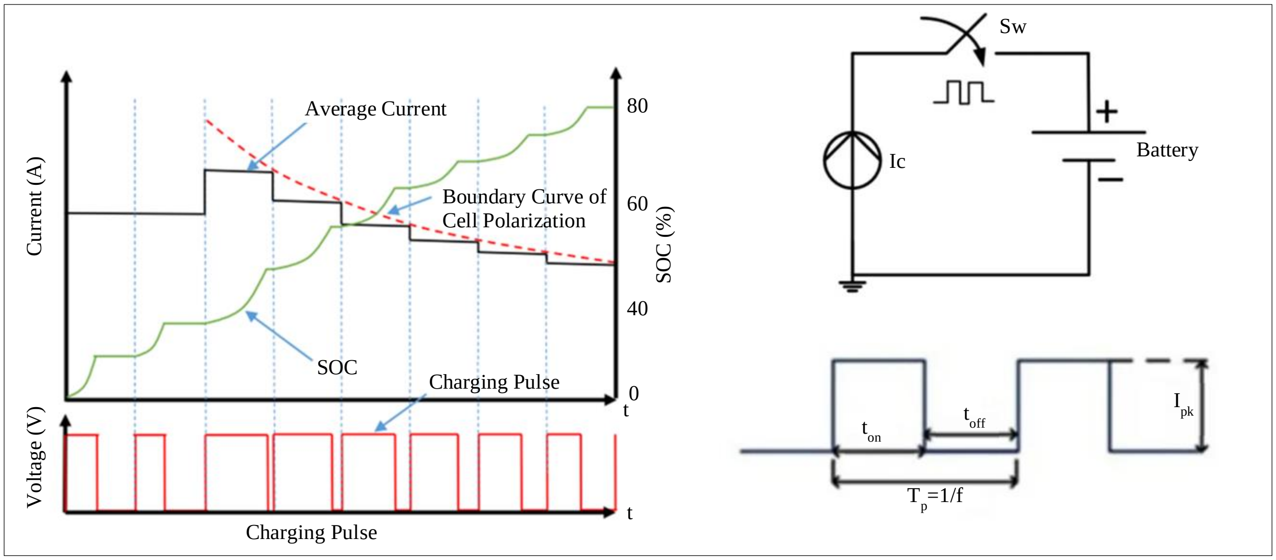


**Fig. 6 Pulse charging method**

As per Figure 6 the average current input to the battery varies as per the pulse width. During lower SOC states of the battery pack, the interval time is considered to be shorter, with a higher average current value. When the battery pack reaches the boundary curve polarization, the width of the pulse is reduced, creating more rest periods [18].

This increase in the rest period reduces the average current value, resulting in a lower slew rate of the SOC. The Average Charging Current ($I_{avg}$) of the battery is a dependent variable of the Duty ratio (D) of the Switch (Sw) and Peak Charging Current ($I_{pk}$). It is expressed as:

$$I_{avg} = D * I_{pk} \quad (3)$$

Moreover, the SOC of the battery can be determined by this $I_{avg}$ of the battery, which is expressed as:

$$SOC = SOC_{bo} - \frac{1}{3600\, C_n} \int I_{avg}\, dt \quad (4)$$

Here, $SOC_{bo}$ is the initial SOC of the battery and $C_n$ is the nominal capacity of the battery. This pulse charging method improves the reliability of the battery to a smaller extent as compared to continuous or tapper charging methods.

### 3.3. Burp Charging

The burp charging is considered to be the most advanced charging as compared to conventional methods. This method of charging is also called a 'negative pulse' or 'Reflex' charging in conjunction with pulse charging. The burp charging is similar to pulse charging but with a tiny discharge time between the charging pulses. The current signal of the battery pack with burp charging can be observed in Figure 7.

As per Figure 7, during the rest period of the pulse charging, the direction of the current is changed, making it discharge for a small period. The magnitude of the discharge current is set to be 3 times the charge current magnitude for 10% of the charge pulse time. This negative pulse, during a short period, depolarizes the cells, reducing stress in the battery pack. Because of the depolarization during fast charging any bubbles on the electrodes which are created will be diffused [19].

This improves the stabilization and overall charging method of the battery pack. As the bubbles are diffused during this process therefore, the name 'Burp charging' is given. Researchers have observed that there is an improvement in the charging rate, and also reliability of the battery pack is increased.

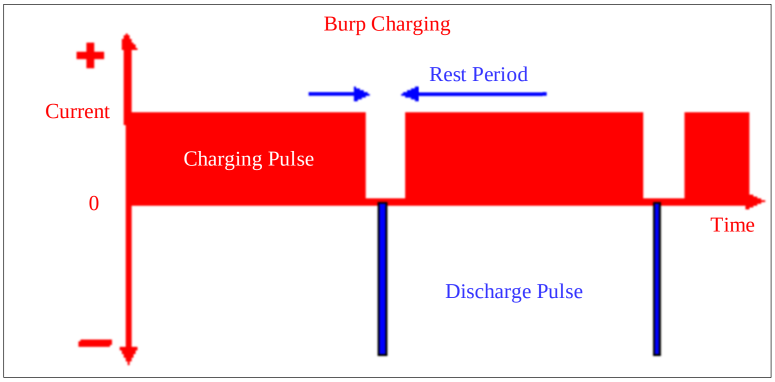


**Fig. 7 Burp charging current signal**

## 4. Result Analysis

A circuit model with different charging methods set to the CV and CC controllers are designed in MATLAB Simulink software using 'Powersystem' blocks. For the analysis of the charging circuit, a four-wheeler EV battery pack rating is considered. A comparative analysis is done with different charging methods on the same EV battery pack. The parameters of the designed charging circuit topology of each module are given in Table 1.

**Table 1. Charging circuit parameters**

| Name of the Module | Parameters |
|---|---|
| Grid | 10MVA 400$V_{rms\text{-}line}$ 50Hz |
| DBR | $R_{on}$ = 1mΩ, $R_{snubber}$ = 0.1MΩ, $C_{snubber}$ = inf, $V_f$ = 0.8V. |
| Buck-Boost Converter | $C_{in}$ = 100uF, $L_b$ = 100uH, $C_{out}$ = 12mF, $R_{igbt}$= 1mΩ |
| EV Battery | Type: Li-ion battery $V_{nom}$ = 320V, $I_{nom}$ = 90Ahr, $SOC_{int}$= 95% |
| CV Module | $k_{pv}$ = 0.01, $k_{iv}$ = 0.00023, $3V_{ref}$ = 372V, $f_c$ = 5kHz |
| CC Module | $k_{pi}$ = 0.012, $k_{ii}$ = 0.0023, $I_{ref}$ = 100A, $f_c$ = 5kHz |

As per the given values of the components of the proposed circuit the modeling is updated. The simulations run for 2s for each operating mode and charging generating comparative results. Graphs of all measurements with respect to time are taken from each module including voltages, currents and powers of the circuit and the EV battery pack.

### *4.1. CV Mode (SOC = 95%)*

The EV charging circuit is operated in CV mode when the SOC of the battery is above a threshold value. Considering 95% of the initial SOC of the EV battery pack, the CV mode is selected. As per the CV mode, Figure 8 presents the 3-ph AC voltages, currents and powers. The input AC voltage has a 325Vpeak value, and the currents have heavy harmonic content due to DBR and buck-boost converter switching. The active power is recorded at 4kW initially and drops to 2kW as per increase in SOC. A low value of reactive power of 500W is injected into the grid due to filter capacitance. In Figure 9, the DC link voltage and current after the DBR are presented.

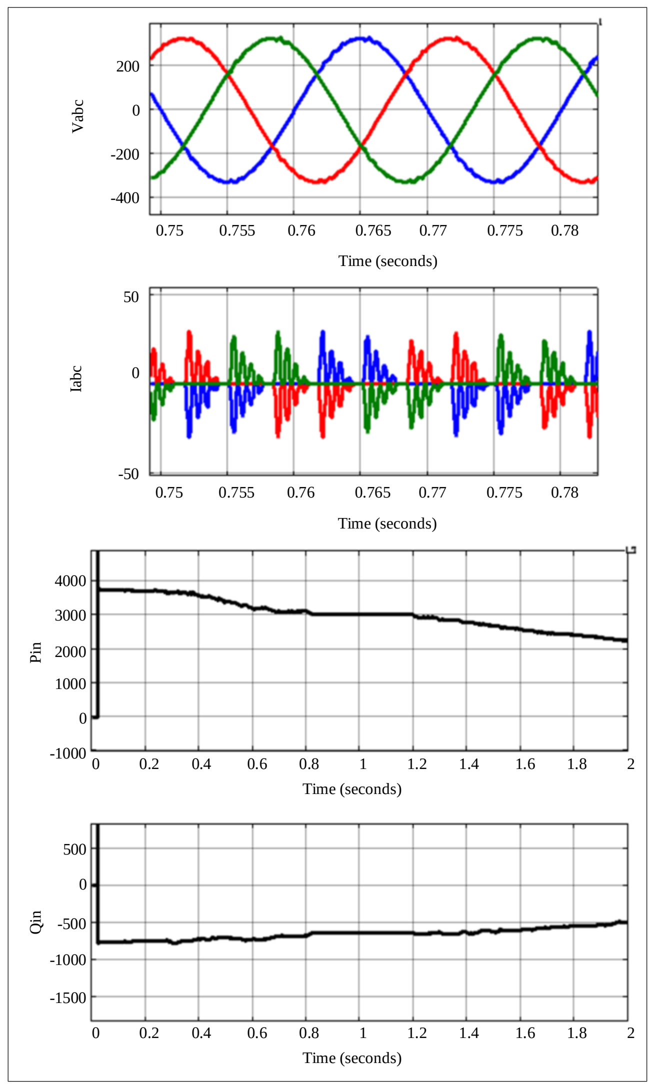


**Fig. 8 3-ph AC grid voltages, currents, active and reactive power in CV mode**

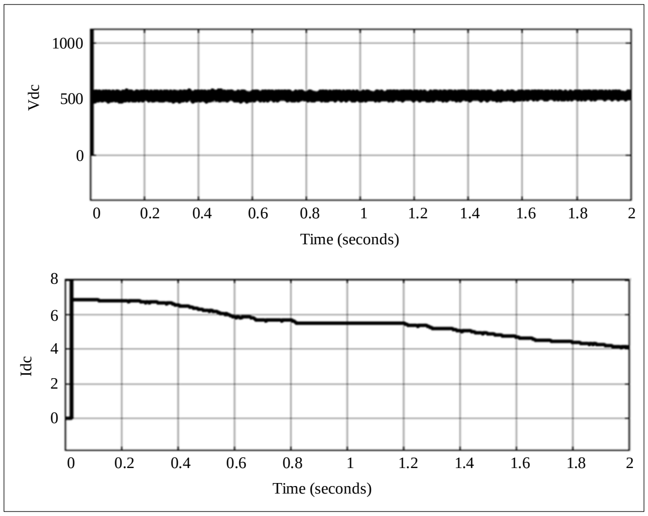


**Fig. 9 DC voltage and current after DBR in CV mode**

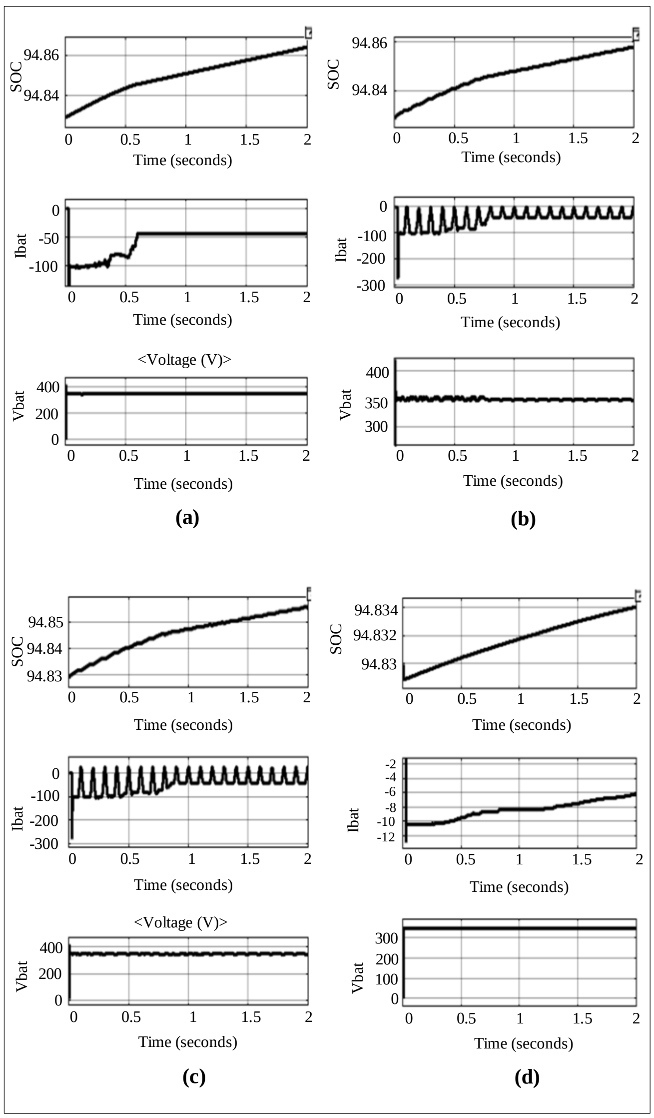


**Fig. 10 Battery characteristics of a) Continuous, b) Pulse, c) Burp, and d) Tapper charging methods in CV mode.**

As observed, the DC link voltage magnitude developed is 500V, and the average DC delivered is 6A – 4A. The EV battery characteristics for each method of charging are presented in Figure 10. It is seen that initially, the charging starts with CC mode with high current, which later on, after detection of higher SOC, the converter operates in CV mode. The average charging current is reduced from 100A to 50A as per the mode switch from CC to CV mode at 0.5s. In Figure 10(a), the current is continuously conducted with no breaks, representing continuous charging.

Figure 10(b) is the pulse charging, which has a rest period for a small instant of time where the charging current drops to zero. Figure 10(c) shows burp charging where the current shifts to the positive side, representing the discharge of the battery for a short instant of time. The last graph, Figure 10(d) is the tapper charging where the current magnitude is very low in the range of 10A – 6A. The tapper charging generates a very low duty ratio D for the given SOC of the battery using the predefined loop-up table.

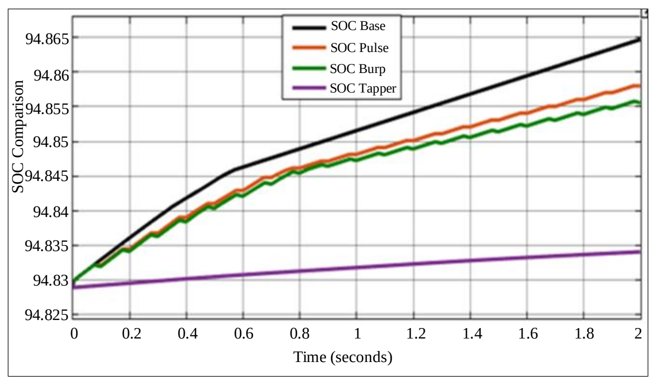


**Fig. 11 EV battery SOC comparison with CV mode**

Figure 11 shows the SOC comparison graph of the battery pack for all four charging methods. As observed the slew rate of the SOC is very high for the continuous charging method and lowest for the tapper charging. The pulse and burp charging methods have rest periods in between, because of which the rate of charge is slightly slower as compared to continuous charging. However, due to the rest periods for small instants of time, the battery module has higher reliability.

### *4.2. CC Mode (SOC = 20%)*

When the initial SOC of the EV battery is changed to 20%, the charging mode shifts to CC mode, where the current is considered as a reference. The 3-ph grid voltages, currents and powers during the CC mode are presented in Figure 12. The 3-ph voltage magnitudes are the same as in CV mode, but the currents are increased. Therefore, the active power is increased to 15kW, and a reactive power of 600W is injected into the grid. The DC link voltage and current in CC mode are presented in Figure 13, recorded at 500V and 27A, respectively.

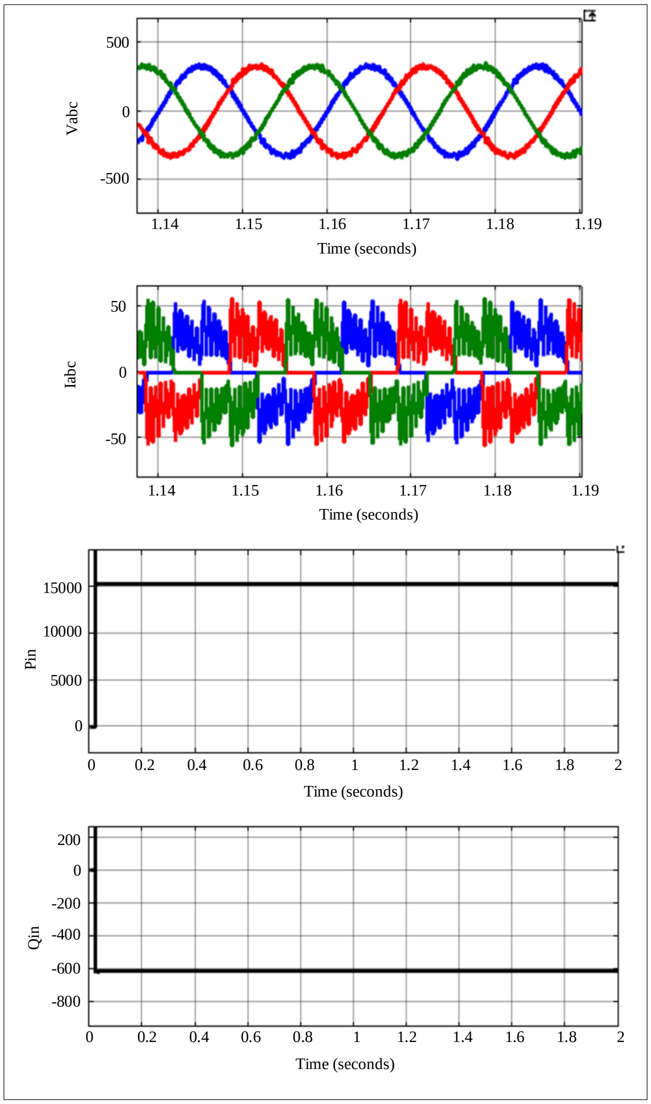


**Fig. 12 The 3-ph AC grid voltages, currents, active and reactive power in CC mode**

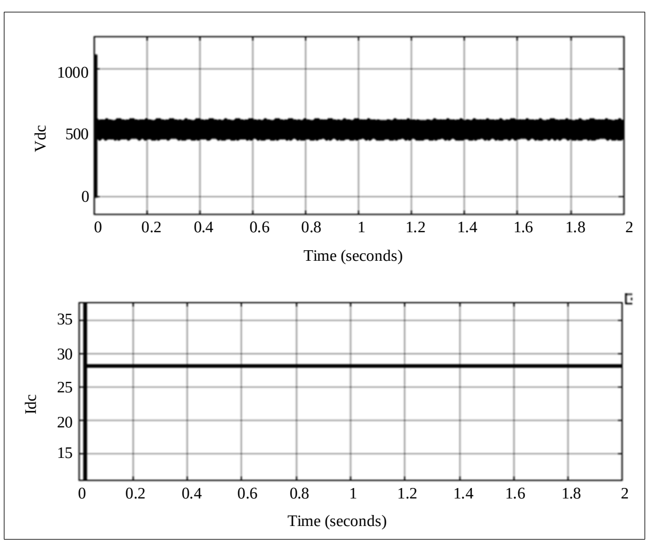


**Fig. 13 DC voltage and current after DBR in CC mode**

The magnitude of the current is increased as the duty ratio D is increased by the CC controller which induces more power to the battery. Figure 14 represents the battery characteristics for all four charging methods in CC mode.

As observed, the battery current maintains at 100A as per the given reference value. The current patterns for all the charging methods are similar to CV mode, with only a difference of magnitude. The comparison graph of the SOC of the battery pack is presented in Figure 15.

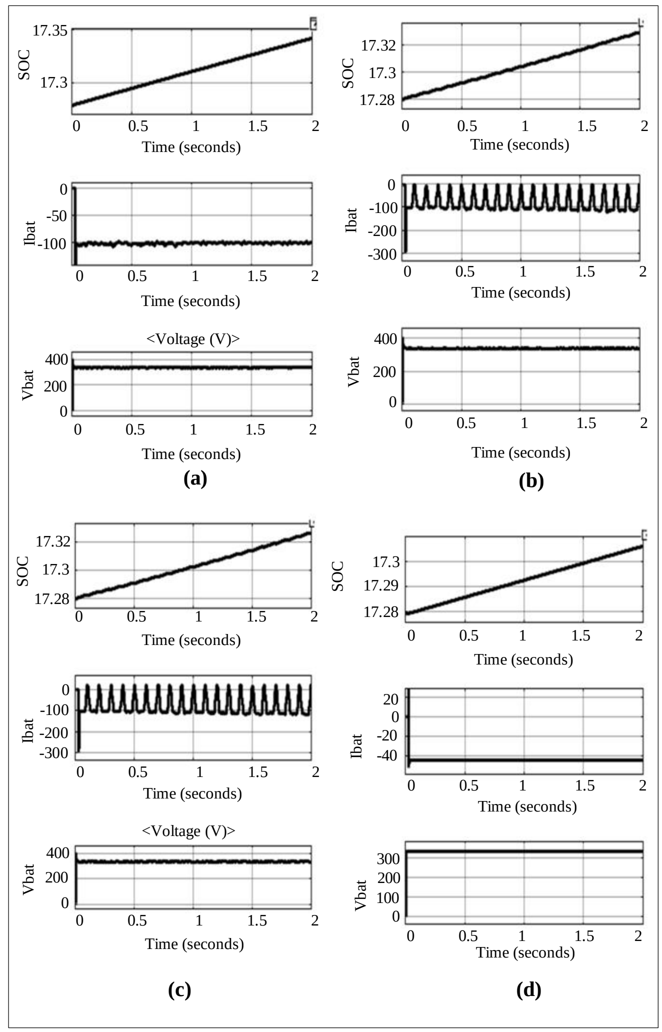


**Fig. 14 Battery characteristics of a) Continuous, b) Pulse, c) Burp, and d) Tapper charging methods in CC mode.**

As the charging current is high in CC mode the raising rate of the SOC is faster as compared to CV mode. The rate of charge is high for the continuous charging method as there is no rest period during the charge. The battery may be damaged due to high current injection, which increases the temperature inside the cells, creating disruptions in the electrodes. In the pulse and burp charging methods, due to the tiny rest time, the battery stabilization improves and the reliability of the battery improves.

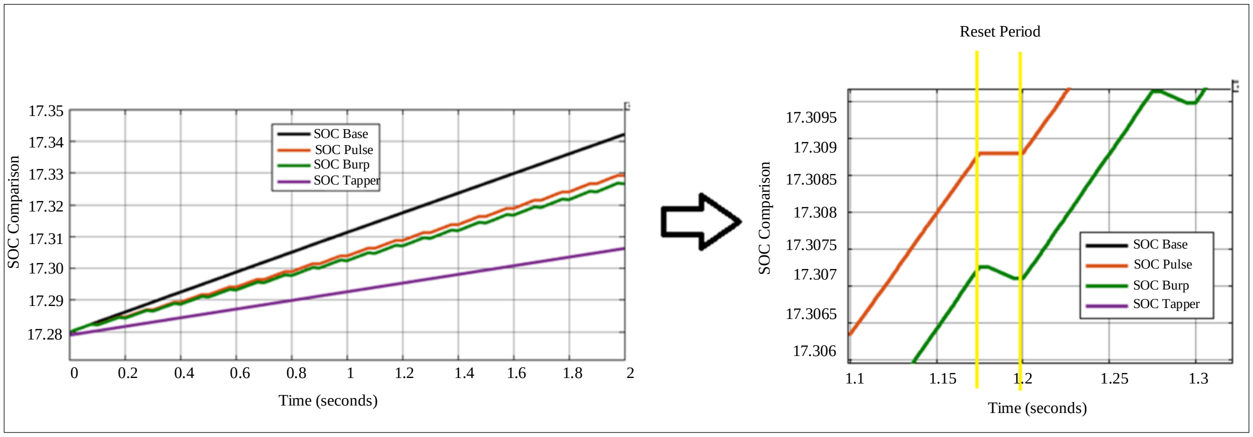


**Fig. 15 EV battery SOC comparison with CC mode**

## 5. Conclusion

A successful design of the EV charging circuit topology is modeled using MATLAB software and the analysis of the circuit is carried out with different modes and charging methods. All the parametric graphs of the source and battery pack are presented with time as reference using the 'powergui' tool. The battery SOC comparison is also presented with different charging methods operated in CV and CC mode. The modes are switched as per the SOC change, which varies the battery voltage used as a feedback signal. The CV mode takes voltage as a reference, and the CC mode takes current as a reference. To increase the stability of the battery, these modes are activated and the charging methods increase the reliability of the battery pack.

As per the analysis, the pulse and burp charging methods are considered to be optimal selection over continuous and tapper charging methods. The battery stability and reliability increase with these charging methods by reducing the polarization of cells and reducing electrode disruption.

## References


[1] Sithara S.G. Acharige et al., "Review of Electric Vehicle Charging Technologies, Standards, Architectures, and Converter Configurations," *IEEE Access*, vol. 11, pp. 41218-41255, 2023. [CrossRef] [Google Scholar] [Publisher Link]

[2] Halise Kilicoglu, and Pietro Tricoli, "Technical Review and Survey of Future Trends of Power Converters for Fast-Charging Stations of Electric Vehicles," *Energies*, vol. 16, no. 13, pp. 1-19, 2023. [CrossRef] [Google Scholar] [Publisher Link]

[3] M.C. Annamalai, and N. Amuthaprabha, "A Comprehensive Review on Isolated and Non-Isolated Converter Configuration and Fast Charging Technology: For Battery and Plug-in Hybrid Electric Vehicle," *Heliyon*, vol. 9, no. 8, pp. 1-35, 2023. [CrossRef] [Google Scholar] [Publisher Link]

[4] Rejaul Islam, S.M. Sajjad Hossain Rafin, and Osama A. Mohammed, "Comprehensive Review of Power Electronic Converters in Electric Vehicle Applications," *Forecasting*, vol. 5, no. 1, pp. 22-80, 2023. [CrossRef] [Google Scholar] [Publisher Link]

[5] Pradeep Vishnuram et al., "A Comprehensive Review on EV Power Converter Topologies Charger Types Infrastructure and Communication Techniques," *Frontiers in Energy Research*, vol. 11, 2023. [CrossRef] [Google Scholar] [Publisher Link]

[6] Mohammed Abdullah Ravindran et al., "A Novel Technological Review on Fast Charging Infrastructure for Electrical Vehicles: Challenges, Solutions, and Future Research Directions," *Alexandria Engineering Journal*, vol. 82, pp. 260-290, 2023. [CrossRef] [Google Scholar] [Publisher Link]

[7] S.S.M. Sajjad Hossain Rafin, Rejaul Islam, and Osama A. Mohammed, "Overview of Power Electronic Converters in Electric Vehicle Applications," *2023 Fourth International Symposium on 3D Power Electronics Integration and Manufacturing (3D-PEIM)*, USA, pp. 1-7, 2023. [CrossRef] [Publisher Link]

[8] Li Bao, Lingling Fan, and Zhixin Miao, "Real-Time Simulation of Electric Vehicle Battery Charging Systems," *2018 North American Power Symposium (NAPS)*, USA, pp. 1-6, 2018. [CrossRef] [Google Scholar] [Publisher Link]

[9] Guanxi Li, and Hao Ma, "A Hybrid IPT System with High-Misalignment Tolerance and Inherent CC–CV Output Characteristics for EVs Charging Applications," *IEEE Journal of Emerging and Selected Topics in Power Electronics*, vol. 10, no. 3, pp. 3152-3160, 2022. [CrossRef] [Google Scholar] [Publisher Link]

[10] Anyuti Tiwary, and Mukesh Singh, "A Modified PFC Rectifier Based EV Charger Employing CC/CV Mode of Charging," *IFAC-PapersOnLine*, vol. 53, no. 2, pp. 13551-13556, 2020. [CrossRef] [Google Scholar] [Publisher Link]

[11] Wajahat Khan, Furkan Ahmad, and Mohammad Saad Alam, "Fast EV Charging Station Integration with the Grid Ensures Optimal and Quality Power Exchange," *Engineering Science and Technology an International Journal*, vol. 22, no. 1, pp. 143-152, 2019. [CrossRef] [Google Scholar] [Publisher Link]

[12] Jutturit Thongpron, "Varied-Frequency CC-CV Inductive Wireless Power Transfer with Efficiency-Regulated EV Charging for an Electric Golf Cart," *Energies*, vol. 16, no. 21, pp. 1-25, 2023. [CrossRef] [Google Scholar] [Publisher Link]

[13] Thanet Sriprom et al., "Variable Frequency Control for Constant Current Constant Voltage Inductive Wireless EV Charging System," *International Power Electronics Conference (IPEC-Himeji 2022- ECCE Asia)*, Japan, pp. 1481-1488, 2022. [CrossRef] [Google Scholar] [Publisher Link]

[14] Salman Habib et al., "A Comprehensive Study of Implemented International Standards, Technical Challenges, Impacts and Prospects for Electric Vehicles," *IEEE Access*, vol. 6, pp. 13866-13890, 2018. [CrossRef] [Google Scholar] [Publisher Link]

[15] Yun-Sung Kim et al., "Development of a 3kW Fast Battery Charger with Various Charging Modes and Parallel Operation," *2012 IEEE Vehicle Power and Propulsion Conference*, Korea (South), pp. 1211-1216, 2012. [CrossRef] [Google Scholar] [Publisher Link]

[16] Ali Al Zyoud, and Ahmad Harb, "Cycle Recovery Charging (CRC) Methods for Single-Used Lead-Acid Batteries," *Electrical Engineering*, vol. 99. 1099-1108, 2017. [CrossRef] [Google Scholar] [Publisher Link]

[17] Cong-Long Nguyen, and Hong-Hee Lee, "Robust and Unity Input Power Factor Control Scheme for Electric Vehicle Battery Charger," *Transactions of the Korean Institute of Power Electronics*, vol. 20, no. 2, pp. 182-192, 2015. [CrossRef] [Google Scholar] [Publisher Link]

[18] Hung-I Hsieh, Cheng-Yuan Tsai, and Guan-Chyun Hsieh, "Photovoltaic Burp Charge System on Energy-Saving Configuration by Smart Charge Management," *IEEE Transactions on Power Electronics*, vol. 29, no. 4, pp. 1777-1790, 2014. [CrossRef] [Google Scholar] [Publisher Link]

[19] Ching-Ming Lai et al., "A High-Gain Reflex-Based Bidirectional DC Charger with Efficient Energy Recycling for Low-Voltage Battery Charging-Discharging Power Control," *Energies*, vol. 11, no. 3, pp. 1-14, 2018. [CrossRef] [Google Scholar] [Publisher Link]