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*Original Article*

# Fast Charging of Electric Vehicles Using Partial Power Charging Circuit Topology by Standalone Hybrid Renewable Source Charging Station

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***Abstract*** **-** *Charging the EV's battery packs is a crucial task as it needs DC voltage stability and reduced circulating currents. Conventional converters (Boost or Buck-Boost) have high disturbances, ripple, and lower efficiency. These converters are unsuitable for high-current applications such as electric vehicle battery charging. In this paper, fast charging of electric vehicle batteries is done using PPCC topology. The PPCC topology comprises a high-frequency inverter, HFTF and uncontrolled rectifier for the power transfer from the source to the battery. The PPCC topology has very little ripple in the output DC voltage, even during heavy power transfer conditions, which keeps the battery pack safe. Charging from conventional grid and fossil fuel power sources is not recommendable as EVs are considered zero-emission vehicles. The batteries of EVs need to be charged by renewable sources, which generate power using natural sources like solar radiation, wind, biogas, etc. A standalone renewable source module is modelled for the PPCC charging station, which comprises solar panels and a PMSG wind source. MPPT-based PI voltage control is adopted for voltage stability in renewable sources. The boost converter of the solar panel and wind generator sources is controlled by the proposed voltage controller, supplying maximum power at stable voltages. An analysis is done on the proposed standalone renewable source PPCC topology with different operating conditions using Simulink modeling of MATLAB software.*

***Keywords*** **-** *EV (Electric Vehicle), PPCC (Partial Power Charging Circuit), HFTF (High-Frequency Transformer), PMSG (Permanent Magnet Synchronous Generator), MPPT (Maximum Power Point Tracking), PI (Proportional Integral), Simulink, MATLAB.*

## 1. Introduction

The challenges associated with electric vehicle (EV) charging primarily involve infrastructure, technology, convenience, and adoption. One of the main issues is the insufficient number of public charging stations, especially in certain regions or rural areas, which can limit the usability and range of EVs [1]. Compatibility problems can arise due to different types of chargers (AC, DC fast chargers) and connectors (CHAdeMO, CCS, Tesla Supercharger), which may require adapters for some EV models. Despite advancements in fast-changing technology, EVs still have significantly longer charging times compared to refuelling a conventional vehicle with gasoline. AC charging is extremely slow, adding only 2 to 5 miles of range per hour. This becomes impractical for users with higher daily mileage needs. AC charging relies on the vehicle's onboard charger to convert AC power into the battery's direct current (DC) power. The speed of charging is limited by the capacity of the onboard charger. Due to its slow speed, AC charging is unsuitable for long trips, where rapid charging is essential to minimize downtime. Additionally, it uses standard household outlets, which often do not provide enough power for practical EV use. As EV battery capacities continue to increase, the time required for a full charge via AC charging becomes increasingly impractical, making DC charging a more attractive option. Prolonged use of AC charging, especially Level 1, can strain household electrical systems if not properly installed or maintained. Moreover, AC charging infrastructure is unsuitable for high-speed demands or the growing EV market. As EV adoption rises, public charging stations increasingly focus on faster DC charging solutions. While AC charging is suitable for daily and overnight commuting, its disadvantages limit its practicality in quick or long-range travel scenarios. Fast charging of EVs is essential for making them more practical and convenient by significantly reducing charging times compared to traditional methods [2]. Fast chargers can charge an EV much quicker than standard chargers, providing a substantial amount of charge in a short time frame.

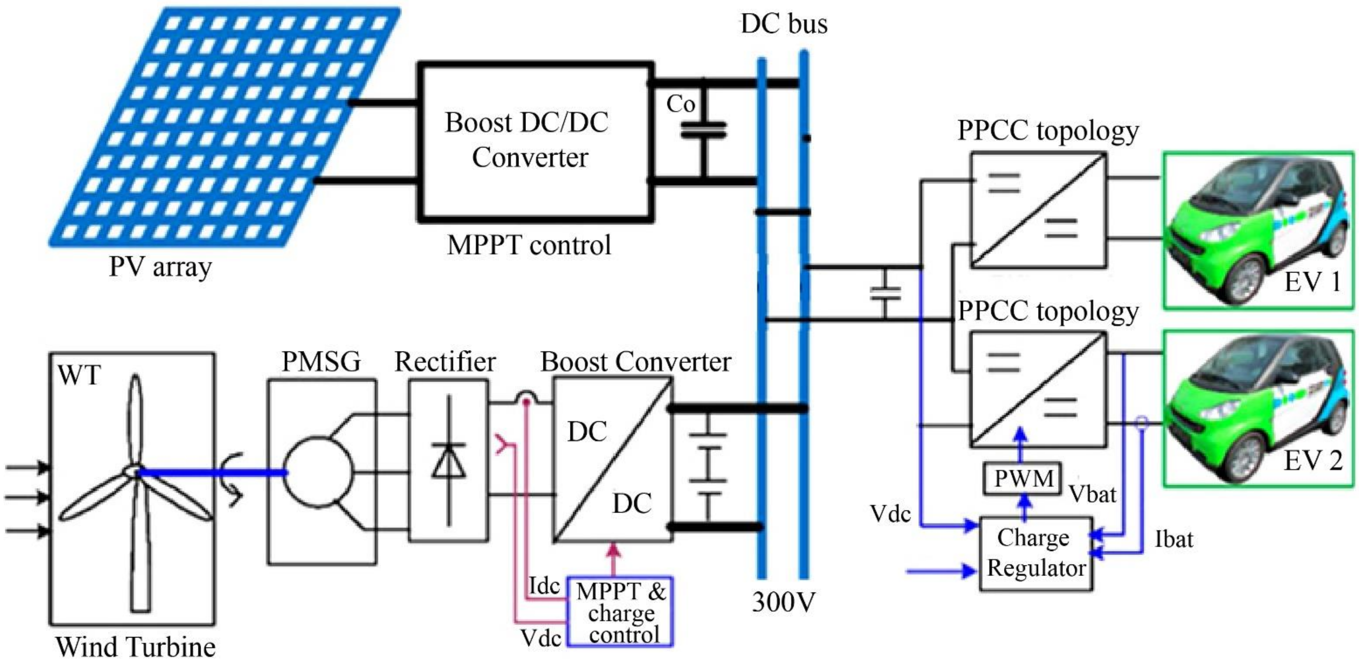



**Fig. 1 Standalone renewable source PPCC EV fast charging topology structure**

Faster charging reduces wait times at charging stations, making EVs more suitable for longer trips and reducing range anxiety. This increased convenience encourages broader adoption of electric vehicles. With faster charging, EVs can be used more frequently, making them more comparable to traditional vehicles in terms of daily usability. Fast chargers come in two main types: Direct Current (DC) and Alternating Current (AC). DC fast chargers provide high-power DC electricity directly to an electric vehicle's (EV) battery, while AC fast chargers provide higher-power AC charging, albeit slower than DC fast chargers [3]. Fast chargers can operate at power levels ranging from 50 kW to over 350 kW, and higher power levels can greatly reduce charging times. However, installing high-power fast chargers requires a significant investment in infrastructure, including upgrades to the electrical grid and installing charging equipment [4]. It's worth noting that fast charging can speed up battery degradation due to increased heat generation and stress on the battery cells, so it's crucial to manage charging protocols to minimize degradation. A new PPCC topology has been introduced to address the issues related to fast charging of EV batteries with the lowest ripple content at high charging currents [5]. The PPCC topology can be connected to a high-voltage grid through conventional load transformers or solid-state transformers. The EV batteries are protected by the HFTF, which is connected between the source and the load. The HFTF magnetically couples the source and load, providing electrical isolation to protect against faults. The large-scale adoption of EVs could strain local electricity grids, necessitating infrastructure upgrades to support increased demand. Pairing fast charging stations with renewable energy sources can help mitigate environmental impacts and reduce operating costs. Therefore, the PPCC topology is integrated with standalone renewable source modules that utilize renewable power to charge EV batteries [6]. The proposed standalone renewable source PPCC EV fast charging topology is presented in Figure 1. As per Figure 1, the powers from the PV array and PMSG at the DC bus are received through boost DC/DC converter and rectifier with boost converter respectively. The rectifier is an uncontrolled diode bridge, so it does not need any control [7]. The rectifier converts the PMSG three-phase voltages to DC voltage. This voltage is stabilized by the MPPT-based PI voltage control, generating stable reference voltages at the DC bus. The same control is adopted to the PV array connected to the boost converter for maximum power extraction at fixed reference voltages per the topology requirement [8]. The PPCC topology at the EV charging side is controlled by a charge regulator comprising constant current and constant voltage (CC and CV) modes. The modes of switches are as per the state of charge (SOC) of the battery. In the future, chargers with power outputs exceeding 350 kW are expected to become more common, allowing Electric Vehicles (EVs) to gain 200 to 300 miles of range in just 10 to 15 minutes. These advancements promise higher energy densities, reduced charging times, and improved thermal stability, making fast charging safer and more efficient. Advanced cooling technologies for cables and battery packs will enable higher power levels without the risk of overheating. Multi-port fast-charging hubs with various amenities are emerging to accommodate both long-distance travelers and urban commuters. Additionally, pairing fast chargers with renewable energy sources like solar and wind will help minimize the environmental impact. Innovations in materials and production techniques will lead to a decrease in the cost of fast-charging equipment, making it more accessible to users. Furthermore, specialized fast chargers will cater to the increasing number of electric trucks, buses, and other commercial vehicles. Overall, the fast-charging ecosystem is poised to play a crucial role in the widespread adoption of EVs, with innovations focused on making the charging process as quick, convenient, and sustainable as refueling a traditional vehicle. This paper is arranged by including proposed standalone renewable source PPCC EV fast charging topology modules in Section 1. Section 2 presents the configuration of the PPCC topology and the design of the charge control regulator of PPCC. Section 3 has the modeling and structure of the standalone renewable source modules with MPPT-based PI voltage controller design. The simulation of the proposed system with different modes of operation on the load side and the sources side is carried out. The simulation results are discussed in section 4, with the graphical representation of the powers and voltages of all modules. Section 5 includes the conclusion of the paper, determining the performance of the proposed system.

## 2. PPCC Design

The PPCC topology ensures stable charging of the EV battery even with fluctuating voltages and powers of the source. Bulk powers from the source are transferred to the EV battery for fast charging with reduced ripple. The PPCC avoids circulating currents between parallel connected circuits charging multiple EV batteries. As per the IEC 61851-23:2014 standard, the PPCC maintains the voltage ripple and current magnitude in the permissible range. The PPCC topology comprises an active full-bridge circuit on the primary side and an uncontrolled diode rectifier on the secondary side of HFTF [9]. At the output of the rectifier, the EV battery pack is connected for fast charging. Between the battery pack and rectifier, an active snubber circuit is connected to avoid circulating currents between parallel modules. Figure 2 represents the PPCC topologies connected in parallel with the source at a common DC link. As observed in Figure 2, the PPCC is an isolated DC-DC converter topology controlled by the ON time of the MOSFET switches on the primary side. The positive terminal of the DC link is commonly connected to the active full bridge's positive terminal and the rectifier's negative terminal. This conducts partial power through the rectifier, adding up the current at the output terminals and increasing the charging current to the EV battery. The current conduction path with partial current passing through the rectifier for more power delivery can be observed in Figure 3.

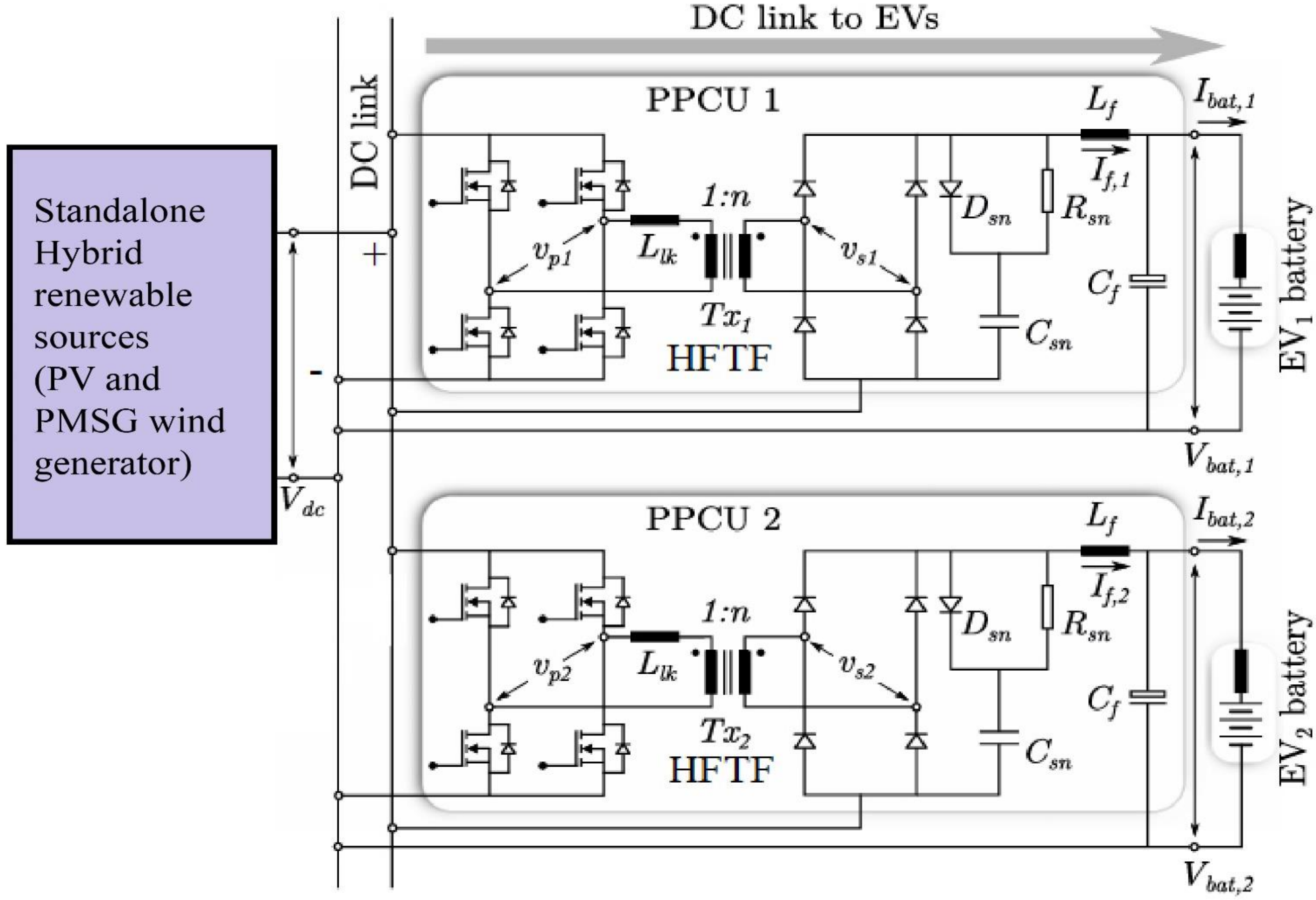



**Fig. 2 Multiple PPCC topologies with parallel connection**

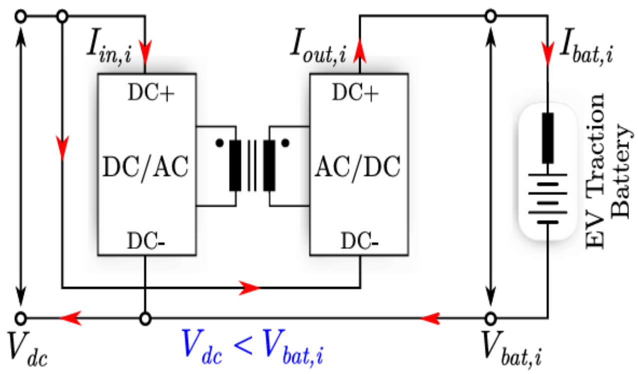


**Fig. 3 Partial power delivery through rectifier**

The current from the HFTF is controlled by the ON time of the MOSFET switches, which in turn controls the battery's charging current. High-frequency operation often results in higher-efficiency transformers. This is due to reduced core and lower winding losses at higher frequencies, improving energy efficiency overall [10]. Higher-efficiency transformers contribute to energy savings and reduced operating costs over the lifetime of the equipment. HFTF can operate with reduced EMI compared to low-frequency counterparts. This is partly because higher frequency signals can be more easily filtered and shielded, resulting in cleaner power delivery and reduced interference with other sensitive electronics in the vicinity. This increases the efficiency of the PPCC topology, avoiding any power consumption during delivery to the EV battery. Due to the clamping of the MOSFET switches, voltage overshooting may occur, which can damage the battery. To avoid the voltage peaks during switching, the 'Snubber' circuit with $D_{sn}$, $R_{sn}$ and $C_{sn}$ is connected to the output of the rectifier [11]. The turns ratio (k) of the HFTF is determined by the DC link voltage ($V_{dc}$), EV battery voltage ($V_{EVbat}$) and duty ratio ($\delta$) of the MOSFET switches given as:

$$k = \frac{V_{EVbat} - V_{dc}}{\delta . V_{dc}} \tag{1}$$

The duty ratio $\delta$ is calculated from the phase shift angle (α) of the active full bridge inverter given as:

$$\delta = \frac{\alpha}{\pi} \tag{2}$$

As per the given turn ratio of the HFTF, the output voltage either increases or decreases as per the requirement [12]. With respect to the input and output powers ($P_{in}$ and $P_{out}$) of the PPCC topology, the partiality ratio ($K_p$) is expressed as:

$$K_p = \frac{P_{in}}{P_{out}} \tag{3}$$

Here,
$P_{in} = V_{in}. I_{in}$ and

$$P_{out} = V_{EVbat}. I_{EVbat} \tag{4}$$

$$I_{in} = \frac{I_{EVbat} V_{EVbat}}{(1-\eta) V_{EVbat} + \eta V_{dc}} \tag{5}$$

$$I_{out} = \frac{\eta I_{EVbat} (V_{dc} - V_{EVbat})}{(1-\eta) V_{EVbat} + \eta V_{dc}} \tag{6}$$

$$K_p = \frac{V_{dc} - V_{EVbat}}{(1-\eta) V_{EVbat} + \eta V_{dc}} \tag{7}$$

$$\eta = \frac{P_{EVbat}}{P_{in}} \tag{8}$$

Here, $I_{in}$ is the input current, and $\eta$ is the efficiency of the PPCC topology. The HFTF is designed with a fixed turns ratio (k) either for increased or decreased voltages. The output power of the PPCC topology is controlled by CC/CV controller modules.

## 3. Renewable Sources Configuration

A PV-wind standalone system is a hybrid renewable energy setup that combines solar photovoltaic (PV) panels and wind turbines to generate electricity. This system is designed to utilize the strengths of both solar and wind energy, providing more reliable power generation during various weather conditions and times of day [13]. By combining PV and wind power, energy production is diversified, reducing reliance on a single energy source and ensuring more consistent power output. These systems can operate independently, making them suitable for off-grid applications where grid connection is impractical or costly. PV-wind systems produce clean energy, lowering greenhouse gas emissions and environmental impact compared to fossil fuel-based power generation. Systems can be scaled up or down depending on energy demand, making them versatile for both residential and commercial applications. They are ideal for powering remote homes, cabins, or communities where grid electricity is unavailable.

Additionally, they can serve as backup power systems for critical facilities during grid outages. A PV-wind standalone system offers a robust solution for generating renewable electricity in various settings [14]. By combining the strengths of solar and wind power, this system enhances reliability, energy independence, and environmental sustainability. The PV source and the wind farm are connected with individual DC/DC boost converters operated with MPPT-based PI voltage control. The circuit structure of the standalone renewable system is presented in Figure 4. As per Figure 4, the PV source is directly connected to the DC/DC boost converter, as the output of PV panels is DC voltage. A Diode Bridge Rectifier (DBR) in the wind generator module is connected between the PSMG and DC/DC boost converter [15]. The uncontrolled three-phase AC voltages from the PMSG are converted to variable DC by the DBR. The unstable and low-magnitude voltages from the PV and wind generator are stabilized and boosted to higher voltage levels by the DC/DC boost converter.

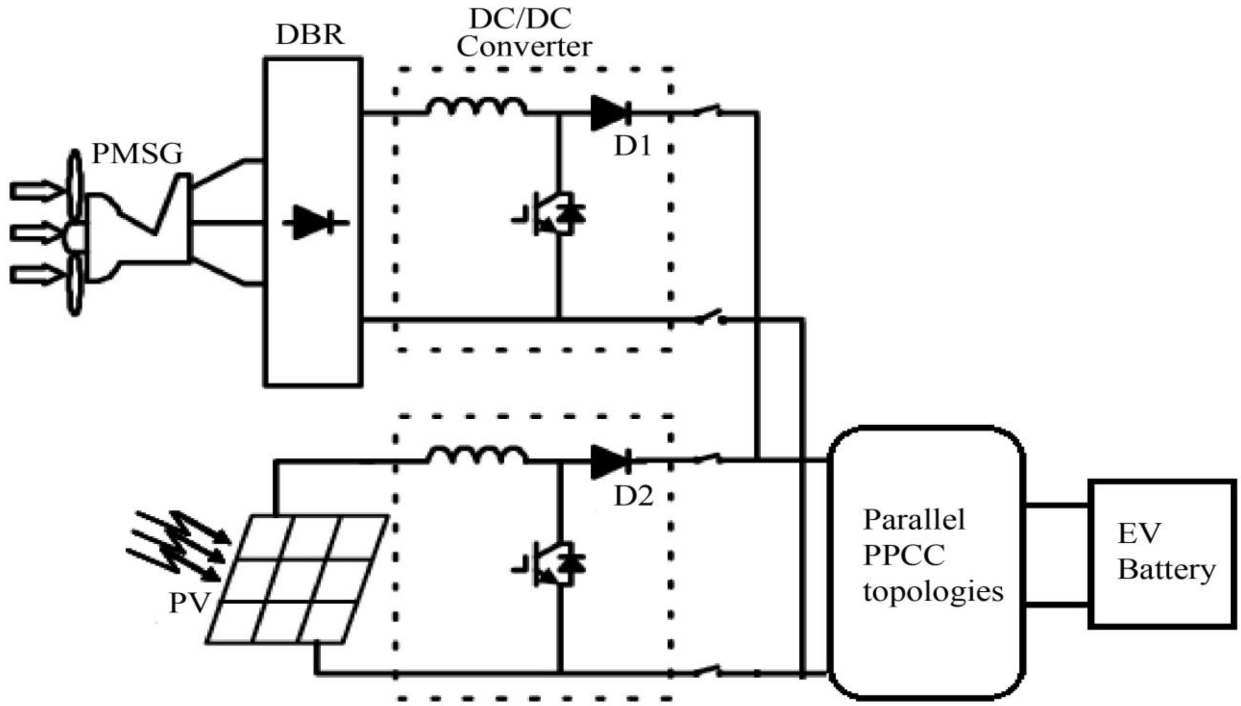



**Fig. 4 PV and wind generator standalone source**

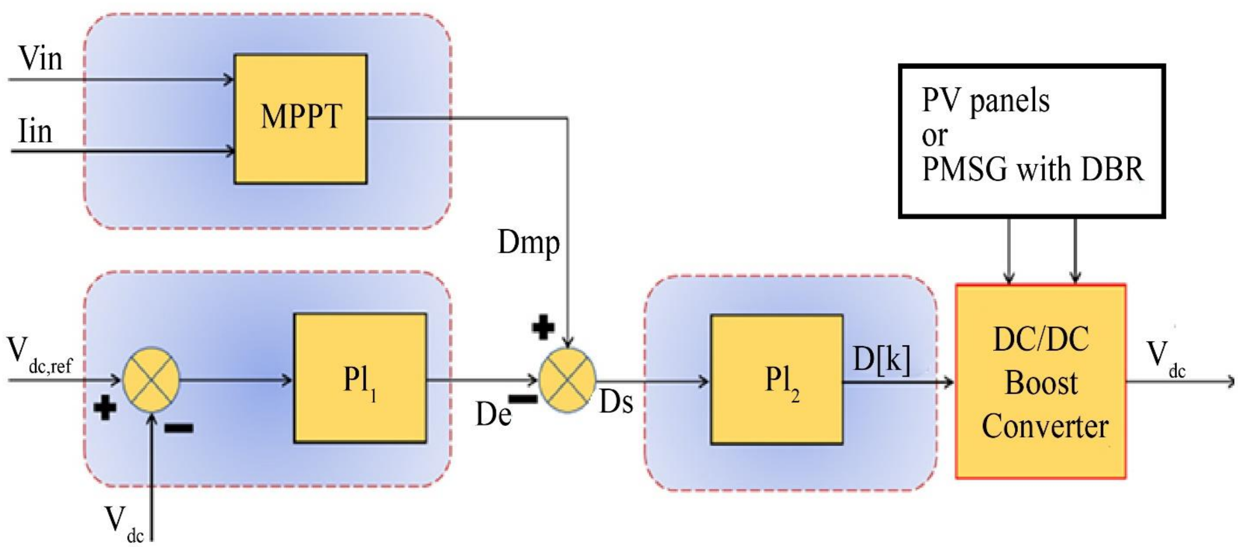



**Fig. 5 MPPT-based PI voltage control scheme**

For fixed reference voltage generation, the switch of these converters is operated by individual MPPT-based PI voltage control [16]. The control structure of the proposed MPPT-based PI voltage control is presented in Figure 5. In Figure 5, the final duty ratio D[k] is compared to a high-frequency sawtooth waveform generating pulses to the DC/DC Boost converter. The final duty ratio D[k] is given as:

$$D[k] = Ds\left(k_{p2} + \frac{k_{i2}}{s}\right) \quad (9)$$

Here, $k_{p2}$ $k_{i2}$ are the proportional and integral gains of the $PI_2$ duty ratio regulator. The reference duty ratio Ds is expressed as:

$$D_s = D_{mp} - D_e \quad (10)$$

The duty ratio at maximum power ($D_{mp}$) is generated by the P&O MPPT technique and error duty ratio ($D_e$) is generated by a voltage regulator expressed as:

$$D_e = \left(V_{dc,ref} - V_{dc}\right)\left(k_{p1} + \frac{k_{i1}}{s}\right) \quad (11)$$

Here, $V_{dc,ref}$ is the required DC link voltage reference, which is the input to the PPCC topology and $V_{dc}$ is the measured DC link voltage. The $D_{mp}$ is generated as per the input voltage and current (Vin and Iin) either from PV panels or the PMSG wind generator [17, 18]. The $D_{mp}$ is either increased or decreased with respect to the relational comparison of input power (Pin) and voltage. Figure 6 represents the flow chart for the P&O MPPT technique for the generation of $D_{mp}$.

As per the given figure, the output duty ratio $D_{mp}$ is expressed as:

$$D_{mp} = D(k-1) + dD[k] \begin{cases} If\ dP[k] > 0\ and\ V(k) < V(k-1) \\ If\ dP[k] < 0 amd\ V(k) > V(k-1) \end{cases} \quad (12)$$

$$D_{mp} = D(k-1) - dD[k] \begin{cases} If\ dP[k] > 0\ and\ V(k) > V(k-1) \\ If\ dP[k] < 0\ and\ V(k) < V(k-1) \end{cases} \quad (13)$$

## 4. Simulation Analysis

The proposed system with standalone renewable sources connected to PPCC topology fast charging EV batteries is modelled in Simulink environment using 'Electrical' library block sets. The simulation of the modelled system is run under different operating conditions for PV source and wind generation. As per the changes in the system, measurements of each module are plotted, and the performance of the circuit topology is validated. In the total simulation time of 1s, the solar irradiation is dropped from 900W/m$^2$ to 600W/m$^2$ at 0.3s, and wind speed is dropped from 13m/s to 10m/s at 0.6s. The initial SOCs of the EV batteries are set to 20%, which are charged by CC control. Figure 7 represents the characteristics of PV panels and PMSG wind generators. It is observed that the PV (Vpv) voltage is maintained constant at 140V for any changes in the solar irradiation.

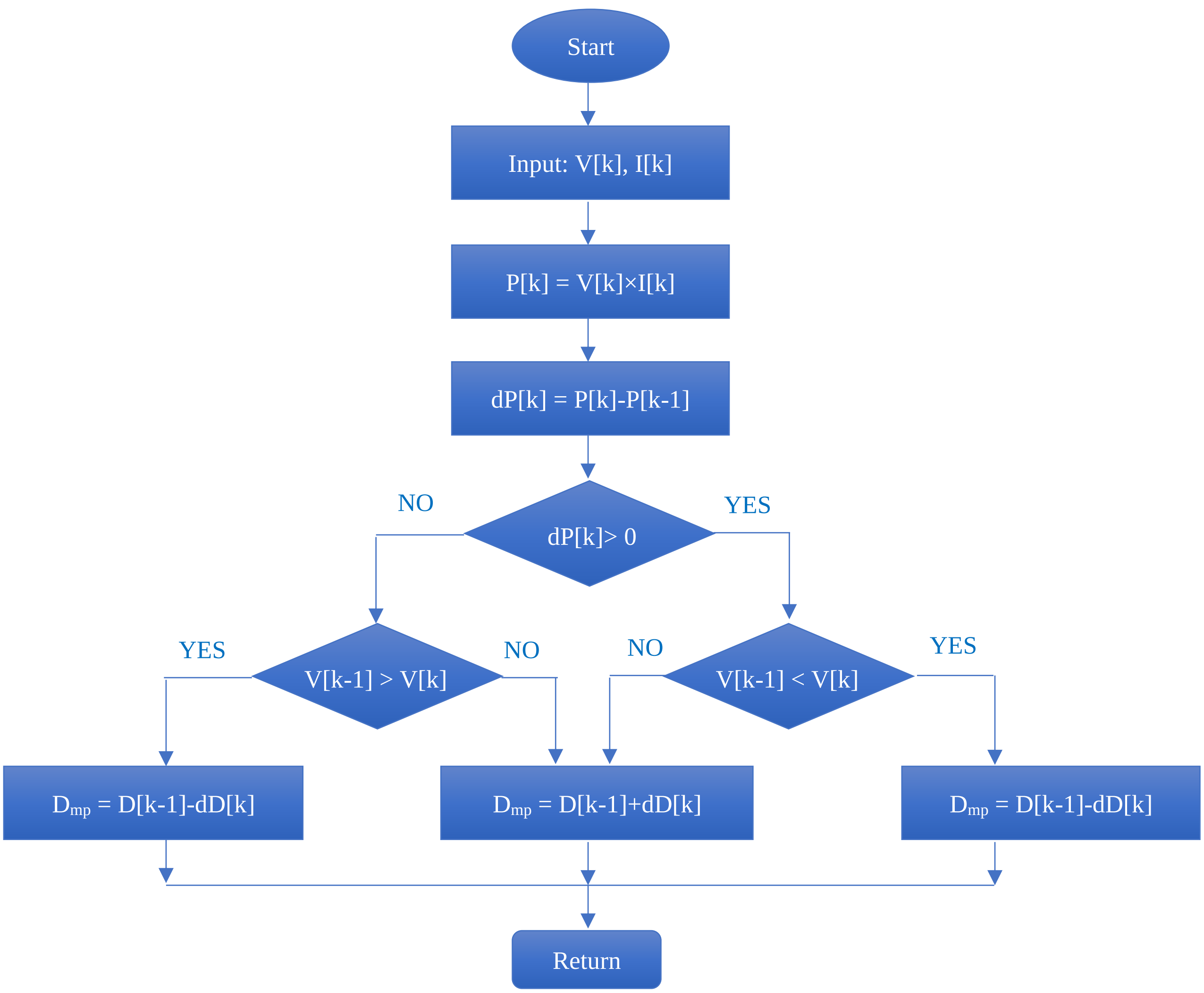
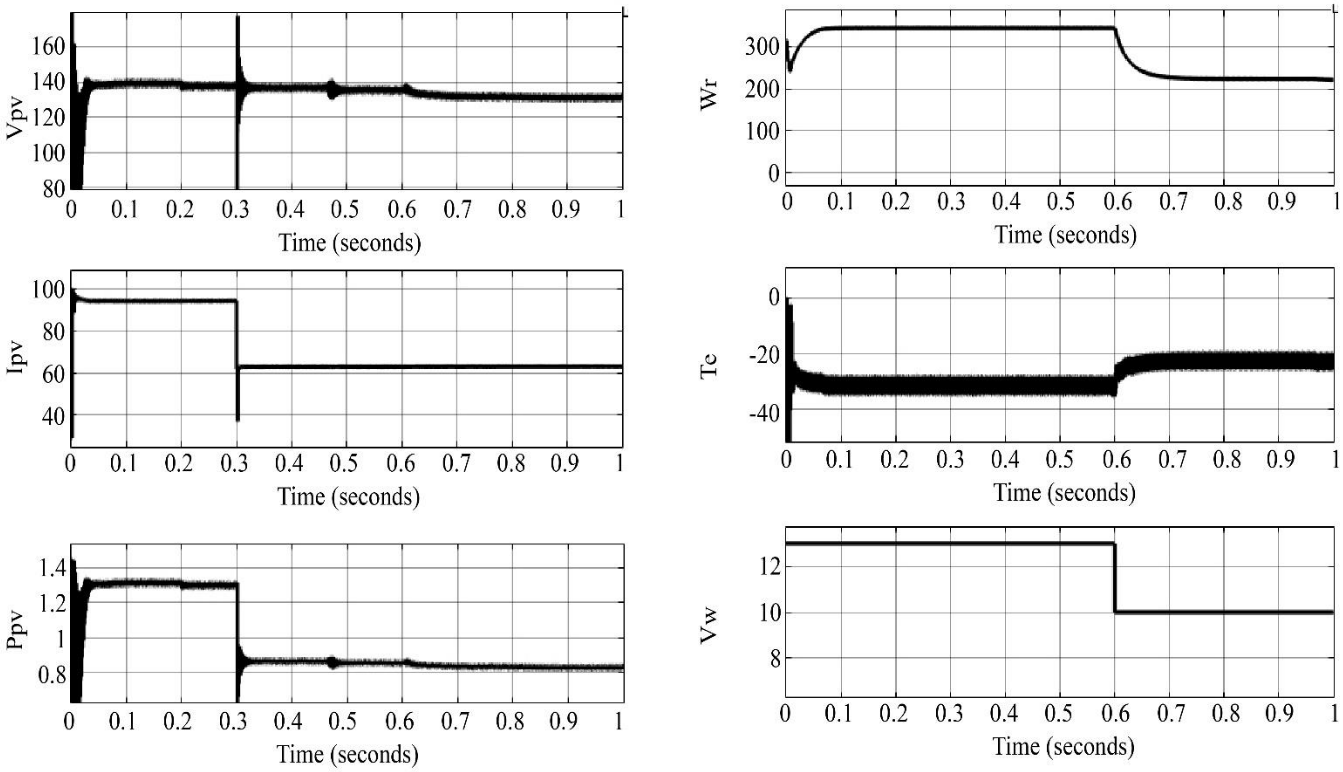


**Fig. 6 P&O MPPT flow chart**




(a) (b)

**Fig. 7 Characteristics of (a) PV panels (b) PMSG wind generator**

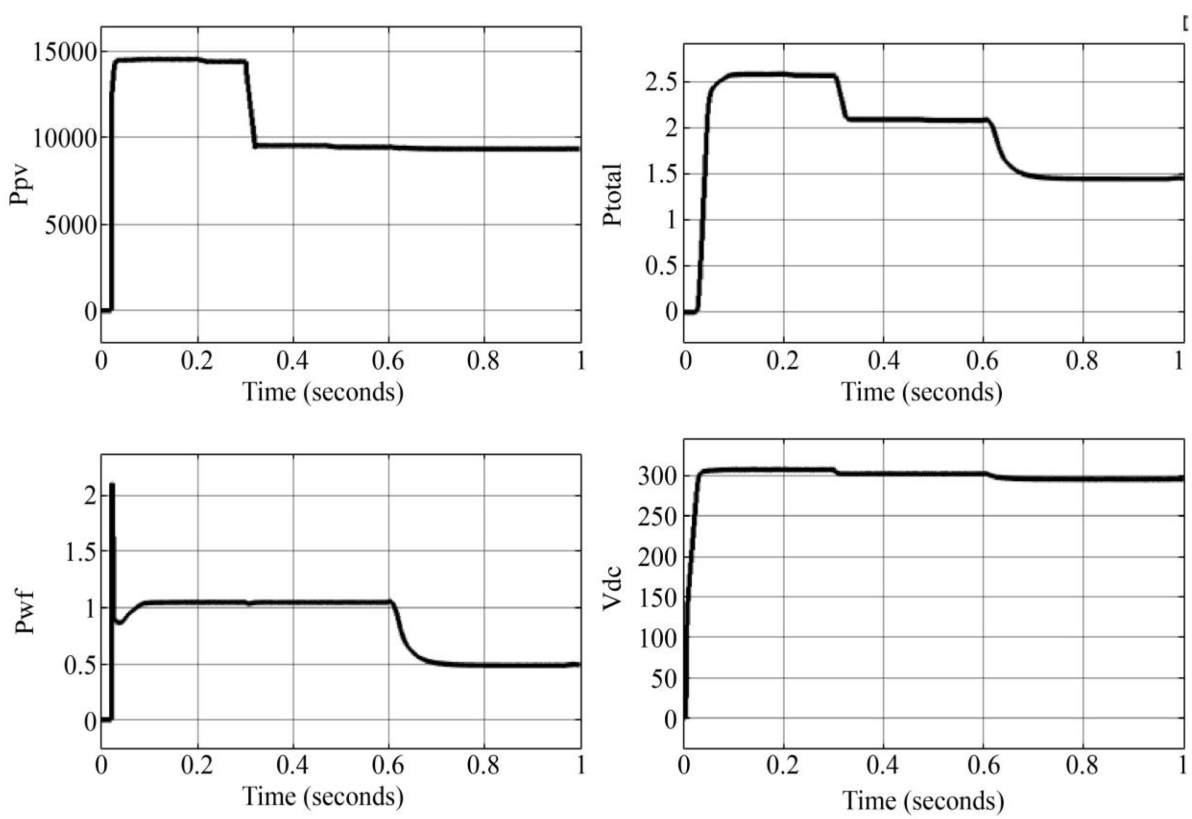



**Fig. 8 Active powers of PV panels, wind generator, total power generated and DC link voltage**

However, there is a drop in the current of PV (Ipv) at 0.3s from 95A to 62A when the irradiation drops to 600W/m$^2$. For this, the power of the PV panels drops from 14kW to 9kW at 0.3s. For the PSMG wind generator, the electromagnetic torque is initially noted to be 30Nm (negative sign indicates generator mode), which drops to 22Nm when the wind speed is reduced to 0.6s. As per the given changes in the system, the active powers of the renewable units and DC link voltage are presented in Figure 8. In Figure 8, the PV power drops from 14kW to 9kW and wind farm power from 10kW to 5kW at 0.3s and 0.7s, respectively. The total output power from the standalone renewable module initially is at 24kW which is dropped to 19kW at 0.3s and further dropped to 14kW at 0.7s. The total power is equally shared with the parallel PPCC topologies from which the EV batteries are charged. Figure 9 represents the characteristics of PPCC topology plotting graphs of EV battery current (Ievbat), primary voltage (Vprim), secondary voltage (Vsec) and primary current (Iprim). The switching of the MOSFET of the active full-bridge creates high-frequency square AC voltage at the primary side of HFTF. This voltage is transferred to the secondary side of the HFTF with reduced voltage amplitude.

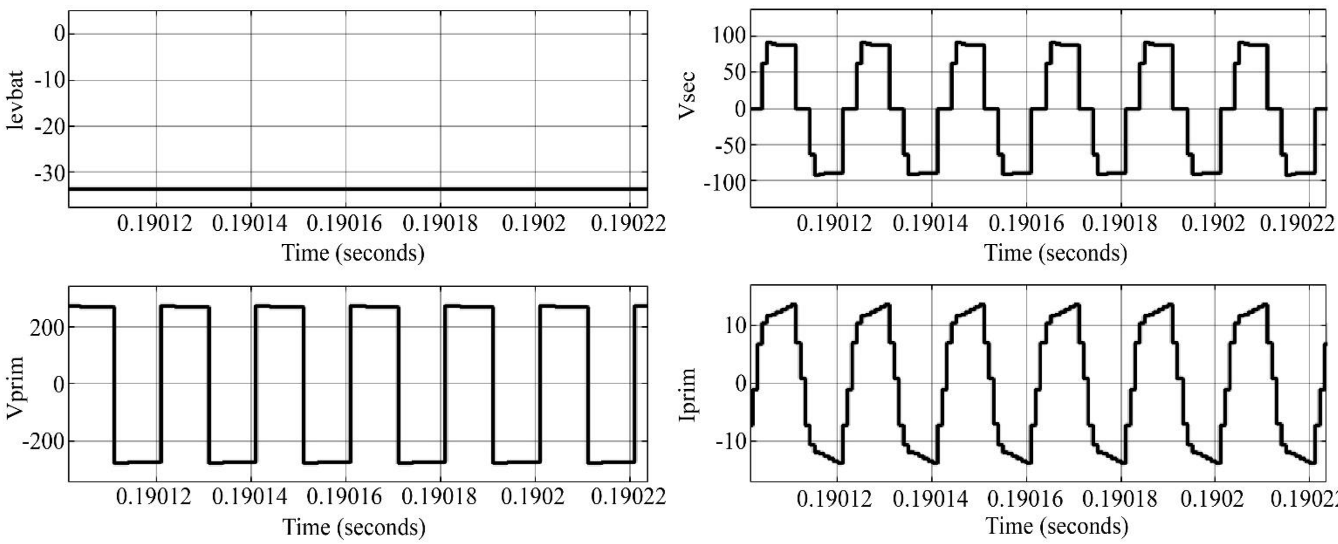



**Fig. 9 EV Battery current and HFTF primary, secondary voltages and primary current**

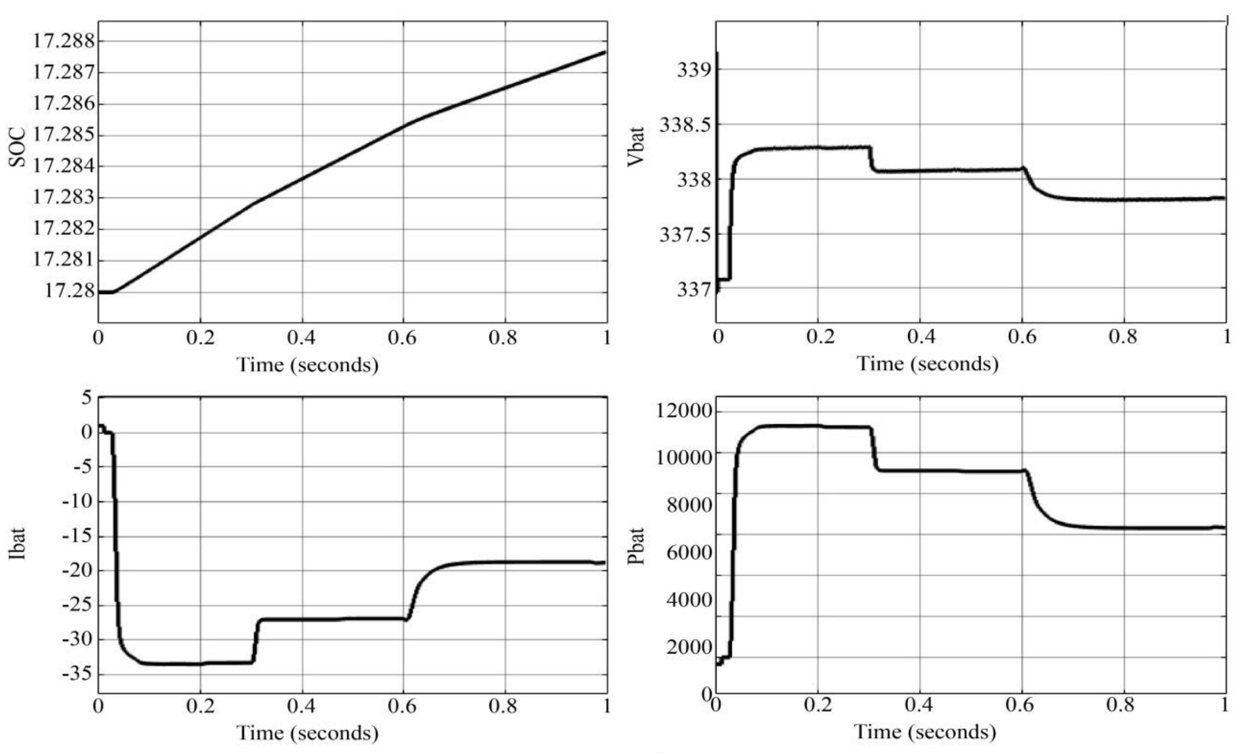



**Fig. 10 Characteristics of one EV battery**

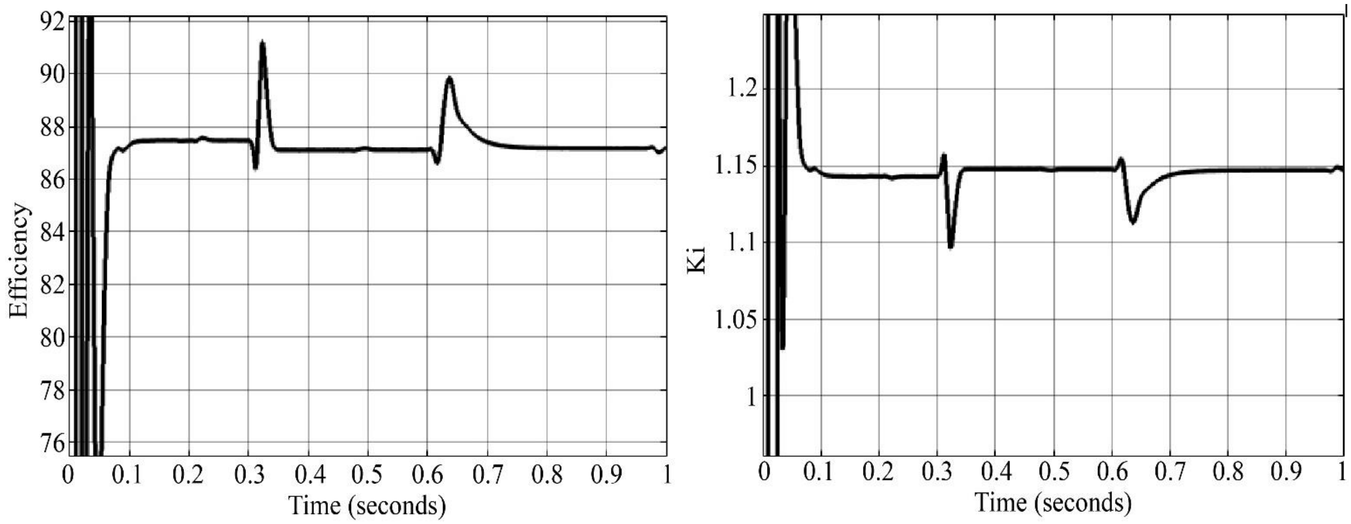



**Fig. 11 Efficiency and Ki of the complete system with two parallel PPCC topologies**

Figure 10 represents the characteristics of one EV battery connected to PPCC topology, including SOC, current, voltage and power of the EV battery. It is observed that there is a significant increase in the battery's SOC with variable slopes as per the charging current. The battery's current varies from 33A to 27A and further to 19A with respect to available renewable power. The battery voltage has very less impact with the variable power input maintained at 338V. The charging power of the battery drops from 11.5kW to 9kW and further to 6.3kW as per the changes on the source side. The efficiency of the complete system with both the PPCC topologies charging two EV batteries individually is recorded to be 87%. For the same, the partiality factor (Ki) is observed to be 1.15.

## 5. Conclusion

As per the results generated by the modeling of the standalone renewable source fast charging station, it is determined that the EV batteries receive equal powers from the renewable source for charging. The MPPT-based PI regulator ensures maximum power extraction from the PV panels and PMSG wind generator at a stable voltage level. The DC link voltage is maintained at a given specified reference value throughout the simulation, even during changes in the solar irradiation and wind speeds in standalone operation. The combined efficiency of PPCC topologies is maintained at 87%, representing very few losses during the power delivery to the EV batteries. At initial conditions with a total power generation of 25kW, each EV battery receives 11.5kW through the parallel PPCC topologies. The PV panel's power and PMSG wind generator power accumulate at the DC link because the same DC voltage levels are maintained by the MPPT-based PI voltage regulator. It is determined that EV charging stations can be adopted with standalone renewable sources with high efficiency, sustainable power and zero carbon footprint.

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