

A Review on Solar Based Electric Vehicle Charger in G2V and V2G Modes of Operation

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ABSTRACT

Solar based electric vehicle (EV) charging station was proposed in this paper. The maximum power of a PV module varies due to changing temperature, solar radiation, and load. In order to extract the Maximum power point in this work, an MPPT system consisting of a PV module, a DC-DC converter, and a fuzzy logic controller is designed and simulated in Simulink. The EV battery SOC characteristic is observed to be fully charged within short period. In this paper single Phase grid and the PV system with the Fuzzy controller MPPT is connected to the DC link, which is connected to the EV. Also in the absence of solar PV energy, electric vehicle is charged from the grid. A battery of rating 100AH is charged with the solar PV panel using a boost converter which generates output voltage of 400V. Then the voltage is stepped down for buck operation according to 220 V battery requirement. A Bidirectional AC-DC rectifier is connected to the Grid, and the DC-DC boost converter for the MPPT and the DC-DC bidirectional Converter is connected to the EV for the Charging and Discharging of the EV. During charging and discharging modes the battery voltage and current is presented. It is clear that the grid voltage and current are in phase during charging. During discharging they are said to be out of phase indicating the reverse power flow.

KEYWORDS: Single Phase, DC-DC Boost Converter, MPPT, Solar PV, Electric Vehicle (EV) etc.

I. INTRODUCTION

In day to day life increasing of the fuel expenses and emission standards require new technologies that are developed to achieve these needs. In the automotive industry always needs to satisfy its customers by keeping up a high performance standard. For that, engineers are trying to find away to accomplish it, having the hope that the electric vehicle can conquest the future. Solar Energy can be utilized for electric vehicle (EV) battery charging applications. Hence the burden and the complexity of on the grid gets reduced when EV's are assimilated to the solar charging stations [1]. Therefore, in this paper, a solar power based EV charging is proposed. Figure. 1 shows the EV charging with solar PV, the EV is charging with both the grid as well as with the solar PV. In the presence of the Sunlight EV is charged by the electric power which is generated by the solar PV, when the sunlight is absence the EV charges by the grid power. Moreover, when it was partially shading conditions to extract the maximum power from the solar panel MPPT methods are used to vary the duty ratios of the Boost converter which is connected to the PV array. The PV power generation changes with respect to sunlight irradiance and temperature [1]. In this paper, the MPPT method has been developed by using a fuzzy logic controller to track the MPPT of PV system [3]. The system battery of rating 100AH is charged with the solar PV panel using a boost converter which generates output voltage of 400V by the Fuzzy controller. Then the voltage is stepped down for buck operation according to 220 V battery requirement. The SOC characteristic is observed to be fully charged within short period under various environmental conditions by Matlab/Simulink. In this plant model there are two stages to charge the EV, one is through the Solar PV with the DC-DC boost converter, another is the AC-DC converter which is connected to the grid and these are connected to the DC-DC bidirectional converter of the EV to charge and discharge the EV.

II. PROBLEM IDENTIFICATION

The rapid adoption of electric vehicles has led to a growing demand for reliable and efficient charging infrastructure, placing significant stress on existing power grids. Conventional grid-based EV charging stations increase peak load demand and indirectly contribute to carbon emissions. Although solar photovoltaic (PV)-based charging systems offer

a sustainable solution, their performance is highly dependent on fluctuating solar irradiance and temperature. Many existing systems employ conventional MPPT techniques that suffer from slow tracking speed and power oscillations under dynamic conditions, resulting in reduced energy extraction. Furthermore, inadequate integration of bidirectional power flow limits the effective use of EV batteries for grid support through Vehicle-to-Grid (V2G) operation. Power quality issues, unstable DC-link voltage, and insufficient analysis of battery State of Charge (SOC) behavior further restrict system reliability. Hence, an intelligent, grid-connected solar EV charging system is required.

III. METHODOLOGY

3.1. Proposed System

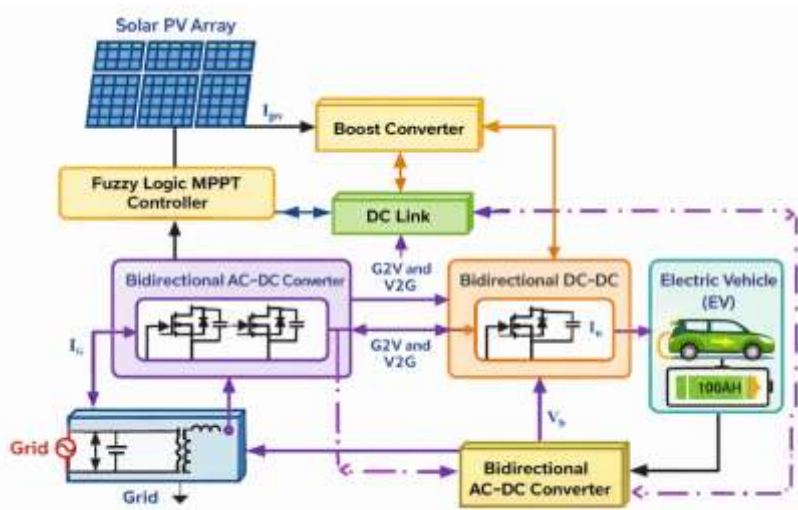


Figure 1. Proposed System

Working Principle :

- The diagram represents a solar PV-based electric vehicle (EV) charging station integrated with the utility grid.
- The solar PV array generates DC power, producing current I_{pv} that varies with solar irradiance and temperature.
- A fuzzy logic MPPT controller continuously monitors PV parameters and controls the DC-DC boost converter to extract maximum available power.
- The boost converter increases the PV voltage to match the required DC-link voltage level.
- The DC link acts as a common energy bus, stabilizing power flow between the PV system, grid, and EV.
- A bidirectional AC-DC converter connects the DC link to the grid, enabling controlled power exchange.
- During Grid-to-Vehicle (G2V) mode, grid power supports EV charging when solar energy is insufficient.
- A bidirectional DC-DC converter interfaces the DC link with the EV battery, regulating battery voltage V_b and current I_b .
- This converter allows both charging and discharging of the EV battery.
- In Vehicle-to-Grid (V2G) mode, stored energy from the EV battery is fed back to the grid through the DC link.
- The system ensures continuous EV charging, improved renewable energy utilization, and reduced grid stress.

Main Features :

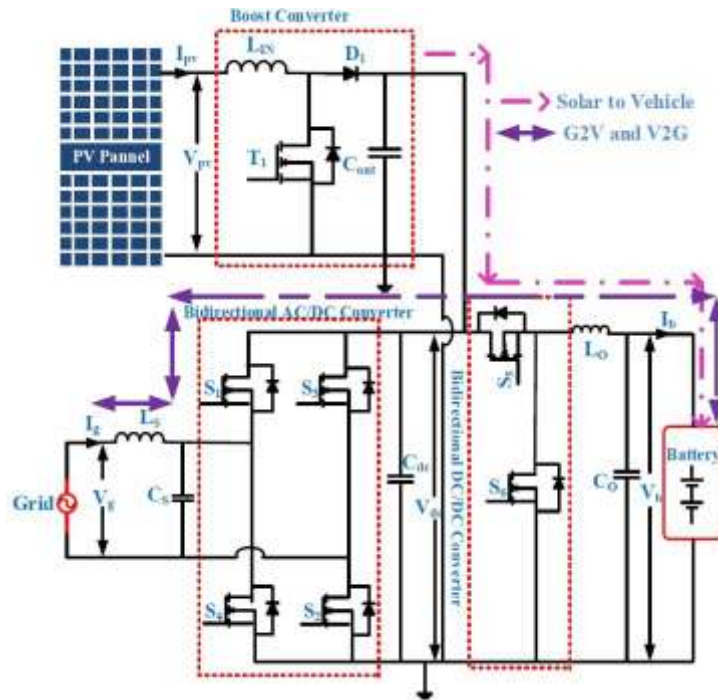


Fig.2. Electric Vehicle with Solar Charging Configuration

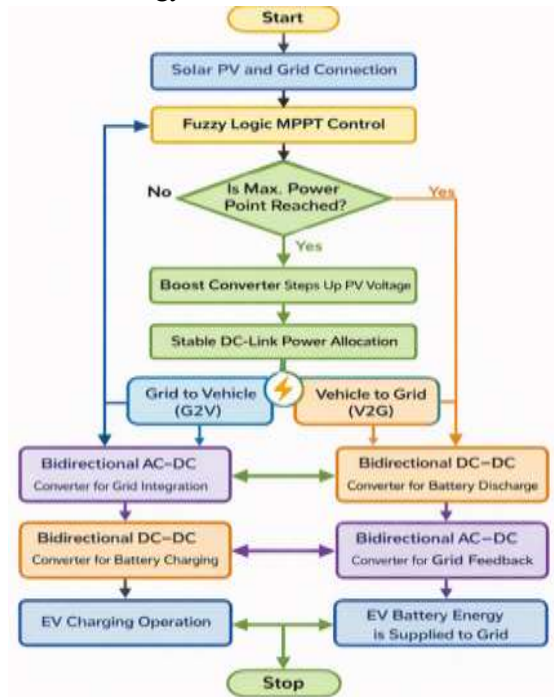
- Real-Time Battery Monitoring: Continuously monitors critical battery parameters such as temperature and fire presence to ensure safe operation.
- Early Hazard Detection: Detects abnormal conditions like overheating, smoke, or flame at an early stage to prevent thermal runaway.
- Automatic Safety Activation: Instantly activates high-speed DC fan, buzzer, and other protective mechanisms when unsafe conditions are detected.
- Microcontroller-Based Control: Uses Arduino Uno (ATmega328P) for fast data processing and intelligent decision-making.
- IoT-Based Remote Monitoring: Transmits real-time data to cloud platforms, enabling remote supervision by drivers or fleet operators.
- Visual Status Display: LCD screen provides live temperature readings and alert messages for user awareness.
- Audible Warning System: Buzzer generates immediate sound alerts during emergency situations.
- Relay-Controlled Isolation: Ensures safe switching between low-power control circuits and high-power devices.
- Cost-Effective Design: Utilizes affordable components for practical and scalable implementation.
- Compact and Integrated System: Designed for easy installation inside EV battery compartments without major modifications.

3.2. Flow Diagram

The process begins with system start, followed by establishing solar PV and grid connection.

- A fuzzy logic MPPT controller is applied to track the maximum power from the PV system.
- The system checks whether the maximum power point (MPP) is achieved.
- If not, the controller continuously adjusts until the MPP is reached.
- Once achieved, the boost converter steps up the PV voltage to the required level.
- The energy is transferred to the DC link, ensuring stable power distribution.
- The system then decides the mode of operation: Grid-to-Vehicle (G2V) or Vehicle-to-Grid (V2G).
- In G2V mode, power flows from the grid/PV to the EV through bidirectional converters for charging.
- In V2G mode, stored battery energy is supplied back to the grid via converters.
- Bidirectional AC-DC and DC-DC converters manage energy flow and conversion efficiently.

- The process ends with either EV charging completion or energy feedback to the grid, ensuring optimal energy utilization.



Flow chart of working system

IV.DESIGN AND CONFIGURATION OF THE EV CIRCUIT

Boost Converter

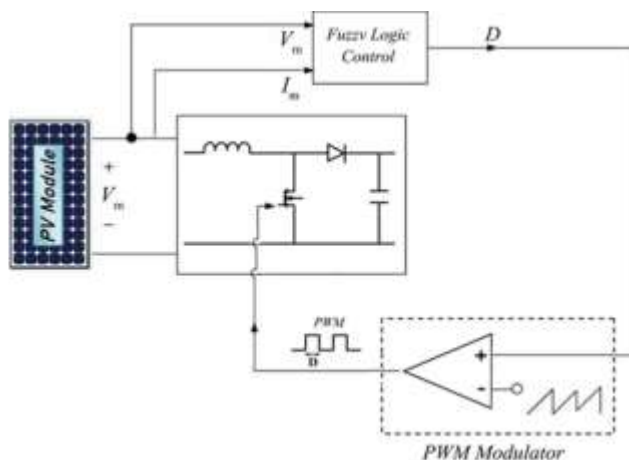


Figure 3. The PV array connected DC-DC converter with fuzzy controller.

The system comprises of PV panel which is connected to the boost converter to boost and regulate the output voltage of the PV array. The MPPT FLC controller is used to track the maximum power from PV array. The proposed block diagram of system is given away in Fig.1.

The main purpose of the DC-DC boost converter is to steps up the input voltage to required output voltage, the components of a boost converter are diode for the freewheeling, high frequency switch (MOSFET), and an inductor. Magnitude of the output side voltage greater than the input voltage. The control stratagem is used to operate the duty cycle of MOSFET which regulates the output voltage. When MOSFET is closed, then the inductor goes to charge by the PV array source by the MOSFET. The freewheeling diode restricts the stream of current from source to the DC link capacitor. When the MOSFET is operated, then the diode is conducted in forward biased. And inductor goes to the discharges and composed with the PV array charges the capacitor.

V. BI-DIRECTIONAL CONTROLLER CONCEPT

An integrated controller is proposed to simplify the controller while stabilizing the system during the mode change of the Bidirectional converter. As an example, a current mode controller is used, Figure 3 (a) depicts the typical method of using two distinct controllers, like buck and boost controllers. A power management command controls the switching between the two modes. Distinct current flow directions represent distinct modes; for example, buck mode charging current is positive, whereas boost mode discharging current is negative. In this manner, charging and discharging are only controlled by changing the reference current $iL0^*$ to positive and negative values, respectively.

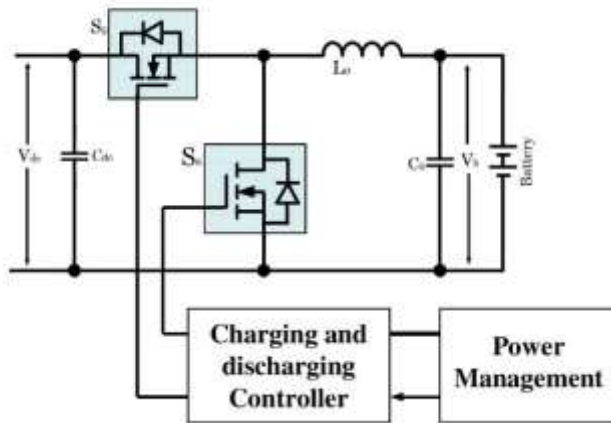


Figure4. Power management controller controlled power stage of the Bidirectional converter

Using Fuzzy logic controllers can provide a resilient response for complex in the non-linear systems with load disturbance, and uncertainty. These controllers employ a highly adaptable set of if-then logic. Because of their adaptability, these controllers are becoming increasingly popular for regulating bidirectional DC-DC converters. The main advantage of utilizing this methodology is that no prior knowledge of the system's parameters is required, and, in comparison to the sliding control method, less measurements are required to construct the controller. In MATLAB Simulink, the model for both controllers with voltage control mode is evaluated, as well as the system's steady-state and transient response. Simulations revealed that the fuzzy logic control system had a steadier and dynamic response and required less settling time than the PI and PR controllers. The correlations between Dc link bus voltage V_{dc} and EV side battery voltage V_b , inductor current $iL0$, and duty cycle d are derived using this DC model. Because buck charging and boost discharging current modes use the same power plant transfer function, they can be controlled by the same unified controller

The flow direction of the defined inductor averaged current $iL0$ reference is the same as the flow direction of the battery charging power. The operation between control duty cycle D and zero current duty cycles $S5$ and $S6$ determines the direction of $iL0$'s current flow. In order to charge the battery, the inductor averaged current $iL0$ must be greater than zero. Similarly, duty cycle D should be increased to be greater than D_0 .

VI. RESULTS AND DISCUSSION

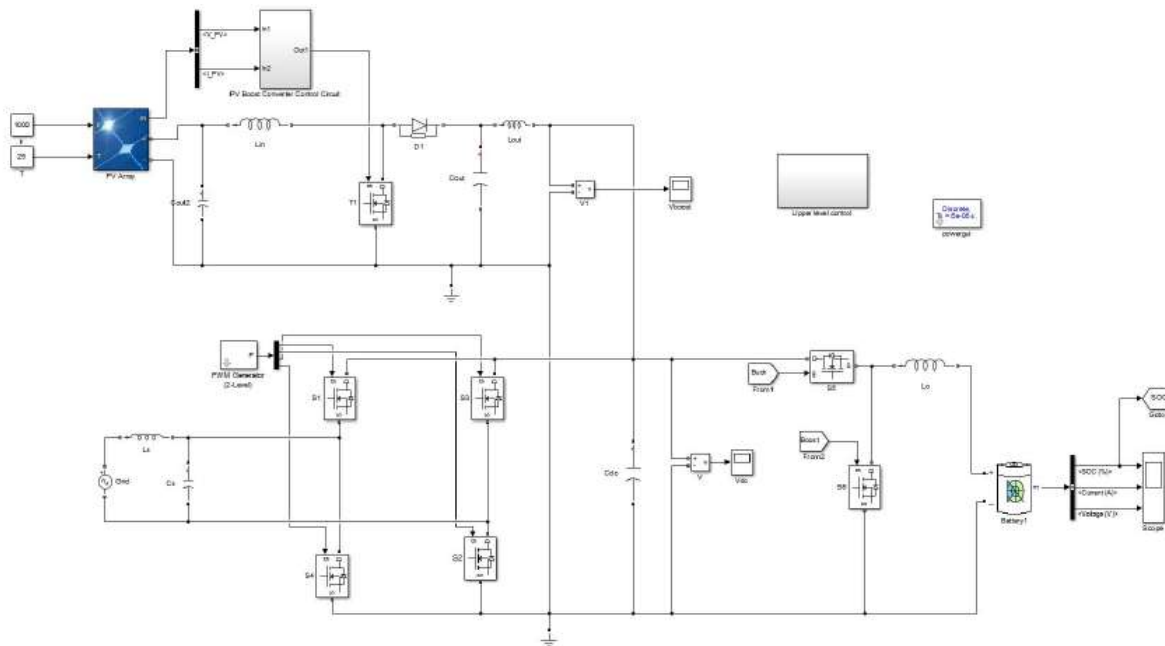


Figure 5. Simulation Diagram of the Electric Vehicle with Solar Charging System

During the day time, the solar PV energy charges the electric vehicle battery. A boost converter raises the voltage of the PV panel to 200v to 400v. In this paper, a 100AH, 230 V (20 kWh) battery is used. An on-board charging circuit can be implemented at home or in parking lots.

1) Case 1: Grid to Vehicle

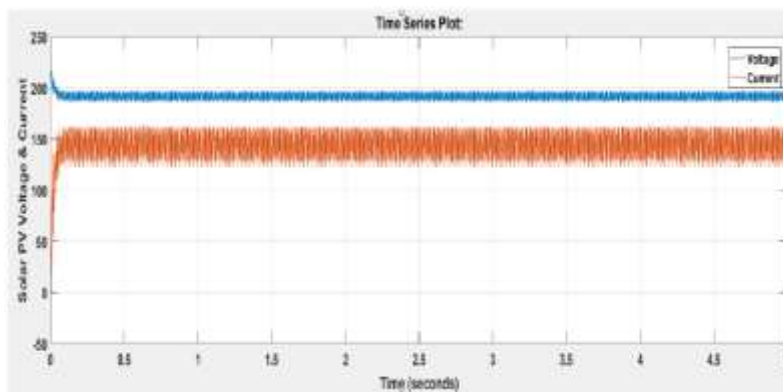


Figure 6. Solar PV Array and MPPT Voltage and Current Tracking.

Solar PV array output voltage is 200V. The solar PV voltage and MPPT voltage tracking, the PV array takes 0.122s time to track the MPPT reference voltage (V_{mppt}) and 0.5 % steady state error.5%. Fig. 9 shows the boost converter output voltage 400V. Battery Fig. 10 shows the battery voltage and the current. Fig. 11 shows the battery state of charge during the EV charging The PV array takes 0.022s to track the solar PV MPPT voltage. The boost converter output voltage 400V is shown in Fig. 6. Battery Figure 9. Depicts the battery voltage and current. Figure 8. Depicts the battery status of charge during EV charging.

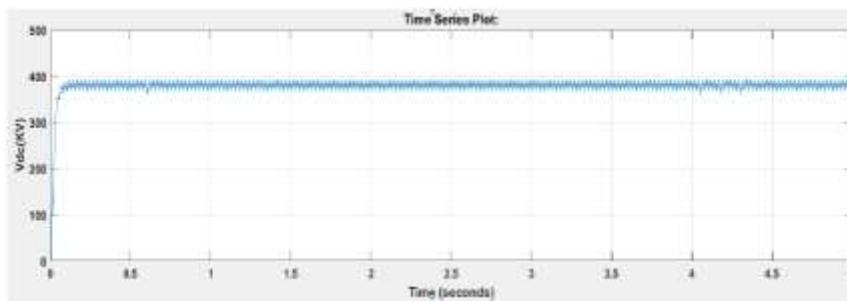


Figure7. Boost Converter Output DC Voltage

DC link Voltage of the boost converter is 400V.

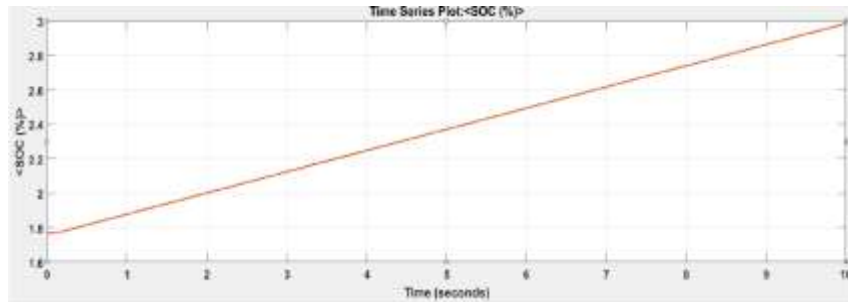


Figure8. Battery State of Charge during charging

State of Charge during charging of the EV from the minimum value.

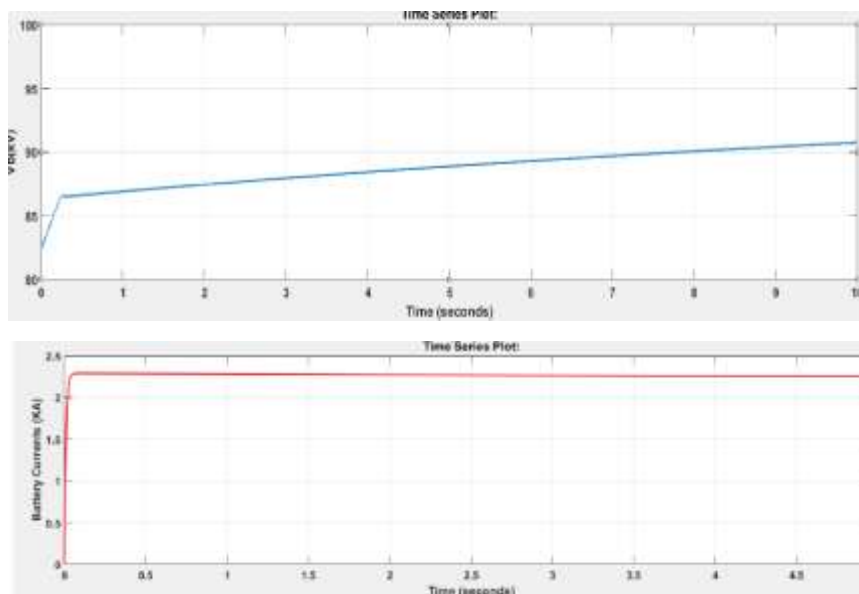


Figure9. Battery charging Voltage and Current

2) Case 2: Vehicle to grid

In this case, the bidirectional AC-DC converter serves as an inverter, controlling the output grid current. The battery provides power to the grid dependent on the needs of the grid and the convenience of the EV owner. During the charging of an electric car, switching pulses are given to a bidirectional AC-DC converter. The input voltage and current are synchronized. During charging, the battery current and voltage waveforms show a minor increase in voltage while the current waveform remains constant. During battery charging, the SOC waveform is displayed. During charging, the odd order harmonic component exists in grid voltage and current.

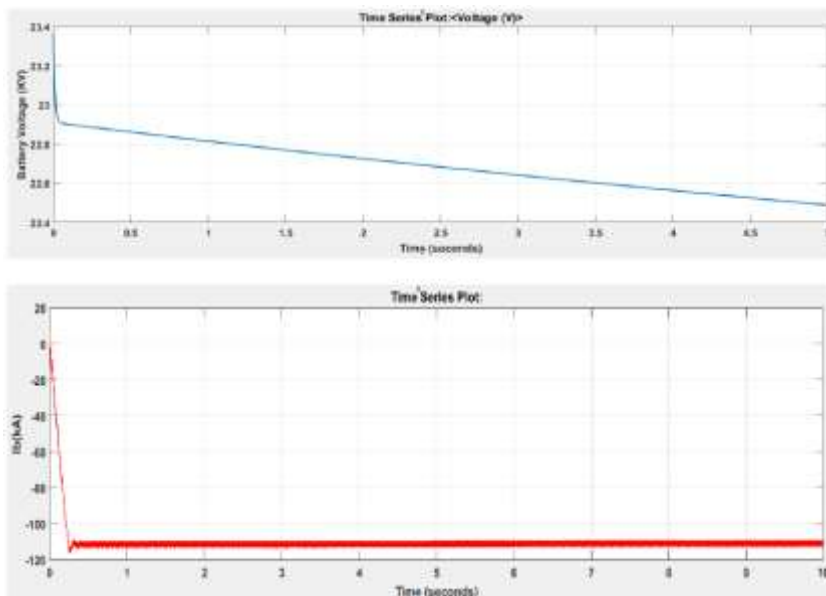


Figure10. Battery discharging Voltage and Current

During discharging, the grid voltage and current waveforms are out of phase with the grid voltage are shown in the fig12. It demonstrates how power travels from the EV battery to the power grid. During battery draining, the voltage and current waveforms decrease while the voltage wave remains constant. The battery's state of charge (SOC) when discharging is shown in the fig11.

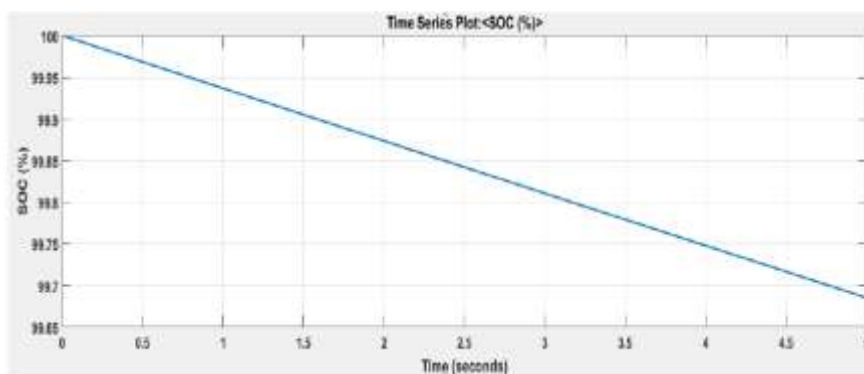


Figure11. SOC during discharging

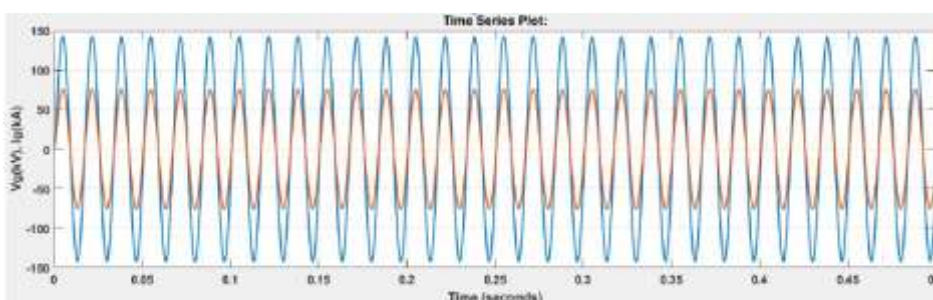


Figure12. Grid Current and Voltage Current waveforms

The solar PV system is designed to create an output voltage of 200 volts, which is then stepped up to 400 volts using a boost converter. The output voltage is filtered, and the filtered voltage is step-down to meet the charging requirements of an EV battery using a buck converter. The foregoing goals are met by modeling the mathematical architecture of the PV system and simulating the PV system under various weather situations using a fuzzy-based MPPT system. The fuzzy-based energy management system is designed and tested under a variety of power demands, and the functioning of battery charging and discharging is then examined. SOC has been found to be efficient in both charging and discharging modes. Based on the frequency response characteristic, a corner frequency of 10 rad/s was suitably chosen. Voltage and current in-phase and out-of-phase are used to depict EV charging from the grid and battery energy given

back to the grid. In a high power bidirectional dc-dc converter, the proposed unified controller performs well. Load step up and down tests under both buck charging and boost draining modes confirm stable operation. The results show that the derived model is correct and can be used in the construction of a unified controller to ensure constant current charging and discharging. Solar charging solves voltage issues and overloading in the distributed network caused by additional producing units and increased power demand caused by a greater number of EVs charging from the grid.

Table 1 CIRCUIT CONFIGURATION PARAMETERS

Circuit Variables	Ratings
Grid voltage V_g	120 V rms
Power frequency f_s	60 Hz
AC Filter inductor L_s	0.75 mH
AC Filter capacitor C_s	20 μ F
DC Capacitor C_{dc}	2 mF
Inductor L_o	41 μ H
Capacitor C_o	600 μ F
Battery capacity	100AH
Hysteresis band h	± 0.5 V
PR Controller parameters K_p, Γ_i	100, 0.1ms

Table 2. PARAMETERS OF PV BOOST CONVERTER

Parameters	Value
Boost converter input Voltage	200 V
Output Voltage	400 V
Input inductor, L_{IN}	1.3 mH
Output capacitor, C_{out}	2500 μ F
Duty ratio	0.5
Switching frequency	10kHz

Table3. PARAMETERS OF PV ARRAY

PV Array	Value
Parallel strings	50
Series connected modules per string	6
Cells per module	60
Open circuit voltage (V)	36.3
Short circuit current I_{SC} (A)	7.84
Voltage at maximum power V_{mp} (V)	29
Current at maximum power point I_{mp} (A)	7.35

VII. CONCLUSIONS

The proposed solar-based electric vehicle (EV) charging system presents an efficient and sustainable solution by integrating solar photovoltaic (PV) energy with the utility grid. The use of a fuzzy logic-based Maximum Power Point Tracking (MPPT) controller enables accurate and fast tracking of maximum power under varying environmental conditions, improving overall system efficiency. The incorporation of a DC–DC boost converter ensures proper voltage regulation, while the common DC-link architecture provides stable and reliable power transfer between different components.

The bidirectional AC–DC and DC–DC converters facilitate seamless energy exchange between the grid, PV system, and EV battery, enabling both Grid-to-Vehicle (G2V) and Vehicle-to-Grid (V2G) operations. This bidirectional capability allows EV batteries to function as distributed energy storage units, contributing to grid stability and peak load management. Simulation results demonstrate stable DC-link voltage, improved power quality with near-unity power factor, and reduced harmonic distortion. Overall, the system enhances renewable energy utilization, reduces dependency on conventional power sources, and supports the development of smart grid and microgrid-based EV charging infrastructure.

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