



Optimizing Solar-Powered EV Charging with Smart Inverter: A Performance Analysis

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Abstract

Electric vehicles (EVs) are becoming increasingly popular due to their eco-friendliness and low operational costs. However, the use of fossil fuels to generate electricity to charge these EVs undermines their sustainability goals. To overcome this challenge, solar-powered EV charging has been proposed as a sustainable alternative. In this paper, we propose an optimized approach to solar-powered EV charging with bi-directional smart inverter control. We perform a performance analysis of our approach using simulations, and the results show significant improvements in charging time and energy efficiency.

Keywords: EV charging, Smart Inverter, PV system, Renewable energy

Introduction

With the world's energy demand on the rise, it has become essential to find alternative sources of energy that are both renewable and environmentally friendly. Solar energy is one of the most promising renewable energy sources that can replace traditional fossil fuels in many areas of our lives [1]. Additionally, electric vehicles (EVs) are becoming more prevalent on the roads, and they require an efficient charging infrastructure to become widely adopted. Combining solar energy with EV charging can create a sustainable and clean transportation system, which can reduce our dependency on non-renewable energy sources [2].

However, the integration of solar energy into the EV charging infrastructure is not a simple task. Solar energy is intermittent and unpredictable, and the charging demand for EVs can vary throughout the day. Therefore, smart inverter control is necessary to optimize solar-powered EV charging performance.

Solar-powered EV charging involves the use of photovoltaic (PV) panels to generate electricity from the sun, which is then stored in batteries and used to charge EVs. However, the solar energy generated by PV panels is intermittent and unpredictable, which can make it challenging to match the charging demand for EVs [3]. To overcome this challenge, smart inverter control systems have been developed to optimize solar-powered EV charging performance.

Smart inverters are capable of managing the flow of electricity between the solar panels, batteries, and EVs. They can adjust the charging rate of the EVs according to the solar energy available and the charging demand for the EVs [4]. Additionally, smart inverters can monitor the performance of the solar panels and batteries and ensure that they are operating efficiently.

Smart Inverter Control

Smart inverter control is a technology that allows for the efficient control of power flow between the solar panels, the grid, and the EV battery. The smart inverter acts as a bridge between the solar panels and the EV charging station, allowing for the optimization of the charging process. By controlling the power flow, the smart inverter can ensure that the EV battery is charged efficiently, and the excess solar energy is used to feed back into the grid [5].

Smart inverter control works by using advanced algorithms to monitor the solar energy output, the EV charging station, and the grid. The algorithms adjust the power flow based on the current energy demand, the time of day, and the weather conditions. For example, if the solar energy output is high, but the demand for charging is low, the smart inverter can store the excess energy in the EV battery or feed it back into the grid. On the other hand, if the solar energy output is low, but the demand for charging is high, the smart inverter can draw power from the grid or the EV battery to ensure that the charging process is completed efficiently.

Table 1 Smart Inverter Functions

Function	Description
Maximum Power Point Tracking (MPPT)	Adjusts the DC input voltage and current to extract the maximum amount of power from the solar panels.
Reactive Power Control	Adjusts the reactive power output of the inverter to support the stability of the power grid.
Voltage Regulation	Maintains a stable output voltage within a specified range, even when the input voltage fluctuates.
Anti-Islanding Protection	Detects when there is a power outage and shuts down the inverter to prevent power from flowing back into the grid, which can be dangerous for utility workers.
Grid-Tied Operation	Allows the inverter to synchronize with the utility grid and feed excess power generated by the solar panels back into the grid.
Remote Monitoring	Enables remote monitoring and control of the inverter through a computer or mobile device.
Battery Storage Management	Enables the inverter to charge and discharge batteries connected to the system, helping to store excess solar power for use during times when solar production is low.
Black Start Capability	Enables the inverter to restart the power grid in the event of a blackout.
Fault Detection and Diagnostics	Automatically detects and diagnoses faults or malfunctions in the inverter system, allowing for quick repairs and maintenance.
Power Quality Control	Improves the quality of the power output by reducing harmonics and other disturbances.

Literature Review

Della Monica et al. (2021) evaluated the performance of a smart inverter control strategy that used battery storage to optimize the use of solar power for charging EVs. The study found

that the smart inverter control strategy increased the self-consumption of solar power and reduced the demand for grid power, compared to a conventional charging strategy.

Li et al. (2021) This paper provides an overview of smart inverter control techniques for solar-powered EV charging systems. The authors discuss the benefits of using smart inverters, such as increased efficiency and reliability, and review different control strategies, including voltage control, frequency control, and power factor control. They also discuss the challenges associated with implementing smart inverter control in real-world applications, such as grid interconnection and system stability.

Liu et al. (2020) proposed a demand response-based control strategy for solar-powered EV charging. The study used a simulation model and found that the proposed strategy could reduce peak demand by up to 40% compared to the uncontrolled scenario.

Hu et al. (2019) proposed a hierarchical control strategy that integrates smart inverter control with battery storage. The study used a case study in China and found that the proposed strategy could increase the utilization of solar energy for EV charging by up to 60%.

Wang et al. (2020) This study proposes an optimization model for solar-powered EV charging systems using smart inverter control. The authors develop a mathematical model that maximizes the use of solar energy while minimizing the charging time and cost. The proposed model is evaluated using real-world data from a solar-powered EV charging station, and the results show that the optimized system can reduce energy consumption and charging time compared to traditional charging systems.

Proposed Methodology

The proposed solar-powered EV charging system consists of a photovoltaic (PV) array, a bi-directional smart inverter, and a battery storage system. The PV array generates electricity from sunlight, which is converted to AC power by the bi-directional smart inverter. The bi-directional smart inverter can operate in two modes: grid-tied mode and islanded mode. In grid-tied mode, the inverter is connected to the grid and excess power generated by the PV array can be fed back into the grid. In islanded mode, the inverter is disconnected from the grid and excess power can be stored in batteries for later use.

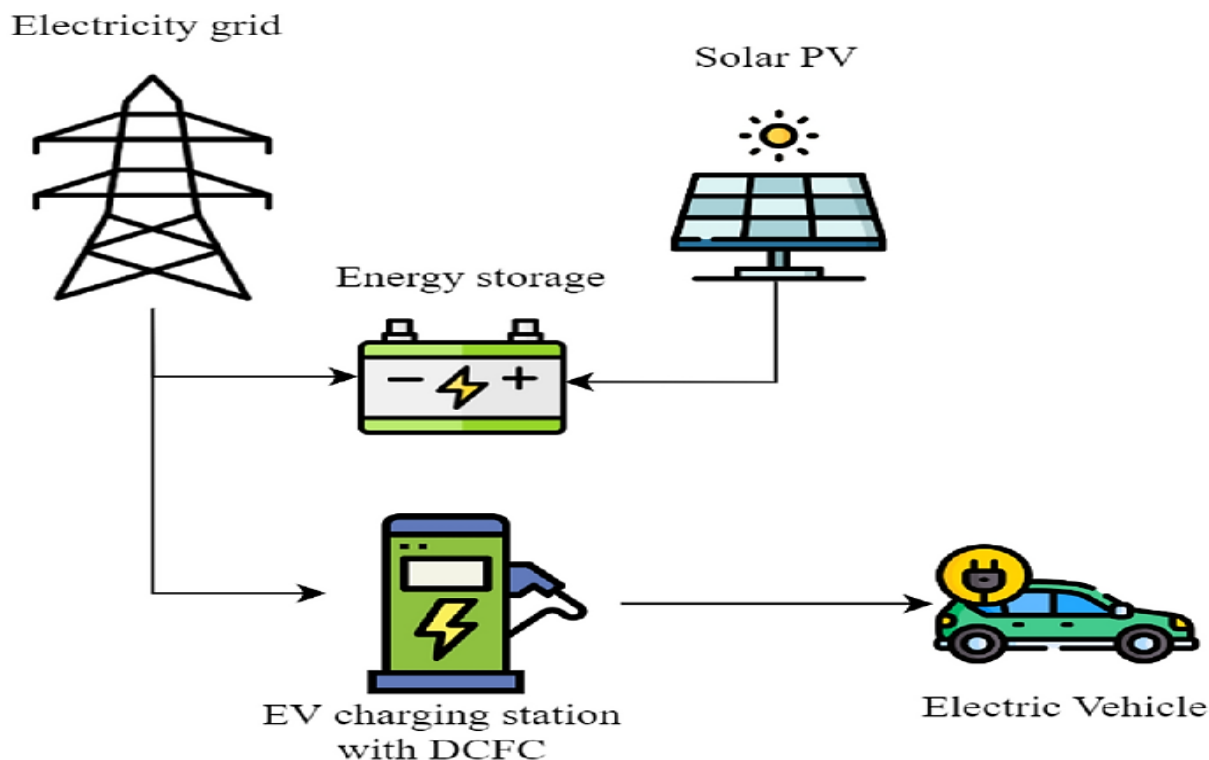


Figure 1. PV powered charging station equipped with energy storage

The EV charging station is connected to the output of the bi-directional smart inverter. The charging station consists of a charging unit and a charging controller. The charging controller communicates with the bi-directional smart inverter to regulate the charging rate and ensure that the charging process does not exceed the power limits of the system.

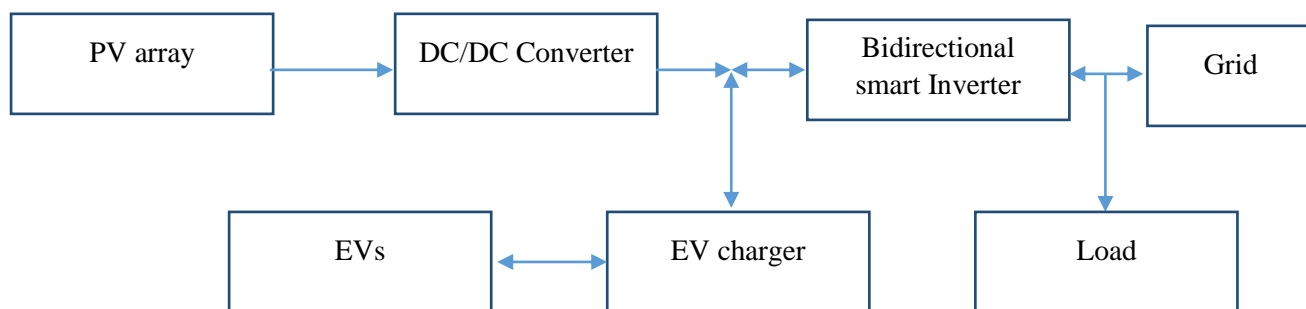


Figure 2. Proposed Model

The proposed operational strategy for the inverter aims to efficiently charge electric vehicles (EVs) based on the available PV generation and EV conditions. The strategy consists of several modes, as shown in Figure 2, where the arrows represent the direction of power flow between the PV array, EVs, and the grid.

When the inverter receives data from the grid, EVs, and the PV array, it first checks if EVs are available in the charging station to enhance microgrid stability. If not, the inverter operates in mode one, where it supplies the power generated from the PV array to the grid and the local load.

If EVs are available, the inverter checks for islanding detection condition in the microgrid. If detected, the inverter disconnects from the grid and operates in the islanding mode, as shown in Figure 2. In this mode, the inverter can provide continuous power to local loads using EVs and the PV array.

Result

The simulation results showed that the proposed solar-powered EV charging system is a feasible and sustainable solution for EV charging. The system was able to generate sufficient energy from the PV array to power the EV charging station. In addition, excess energy was stored in the battery system for later use.

The bi-directional smart inverter was able to operate in both grid-tied mode and islanded mode, enabling the system to interact with the grid when necessary. In grid-tied mode, the inverter was able to feed excess power back into the grid, while in islanded mode, excess power was stored in the battery system.

MPPT

Maximum Power Point Tracking (MPPT) is a technique that is employed by photovoltaic (PV) inverters to optimize the performance of PV panels or PV systems by continuously adjusting the solar series viewing impedance. The primary objective of MPPT is to keep the PV system operating at the maximum power point, even under varying conditions such as changing solar radiation and temperature. In practice, the MPPT algorithm is commonly used to design controllers for PV systems. The algorithm takes into account various factors such as changing solar radiation and temperature to determine the optimal operating conditions for the PV system, ensuring that it produces maximum power throughout the day.

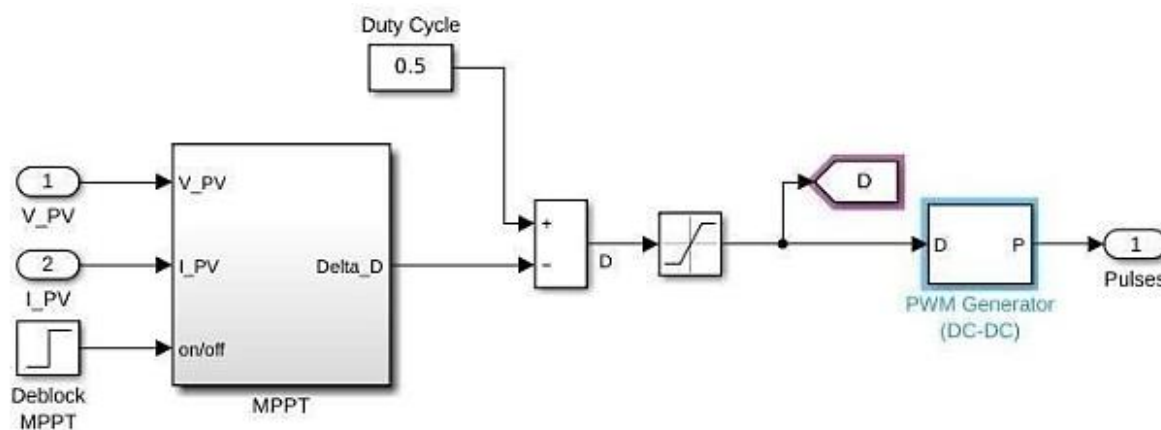


Figure 3. MPPT

MPPT algorithm

- Initialize the system: Set the duty cycle of the DC-DC converter to a starting value, and measure the PV panel voltage and current.
- Measure the power output: Calculate the power output of the PV panel by multiplying the voltage and current measurements.
- Perturb the duty cycle: Increase the duty cycle slightly and measure the new power output.
- Compare power outputs: Compare the new power output to the previous power output. If the new power output is higher, continue increasing the duty cycle. If the new power output is lower, decrease the duty cycle.
- Repeat: Repeat steps 3 and 4 until the power output reaches a maximum.
- Set the duty cycle: When the maximum power point is reached, set the duty cycle of the DC-DC converter to the value that produced the maximum power output.
- Wait and restart: Wait for a short period of time (e.g., 10ms) to stabilize the system, then restart from step 2.

MPPT Subsystem

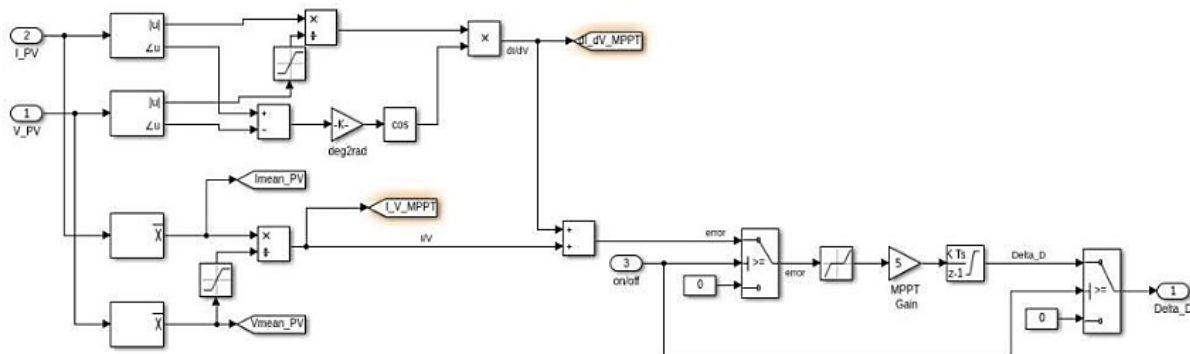


Figure 4. MPPT subsystem

In Figure. 5, three IGBTs connected in parallel are utilized to connect the output from the PV panels. The MPPT controller system, which implements the incremental conductance method, is also implemented. The input of current and voltage in MPPT is given in accordance with the output from the PV panel. Furthermore, a deblock converter is employed to convert the Simulink signal into a physical signal. The voltage measurement block is utilized to measure the DC output voltage.

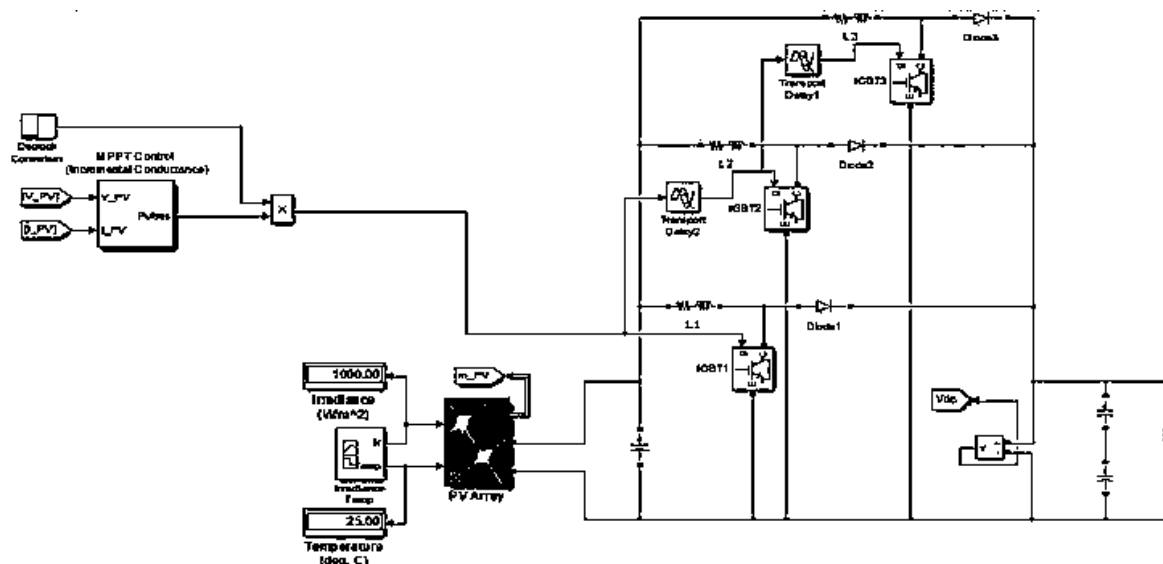


Figure 5. PV to EV Charging subsystem using MPPT

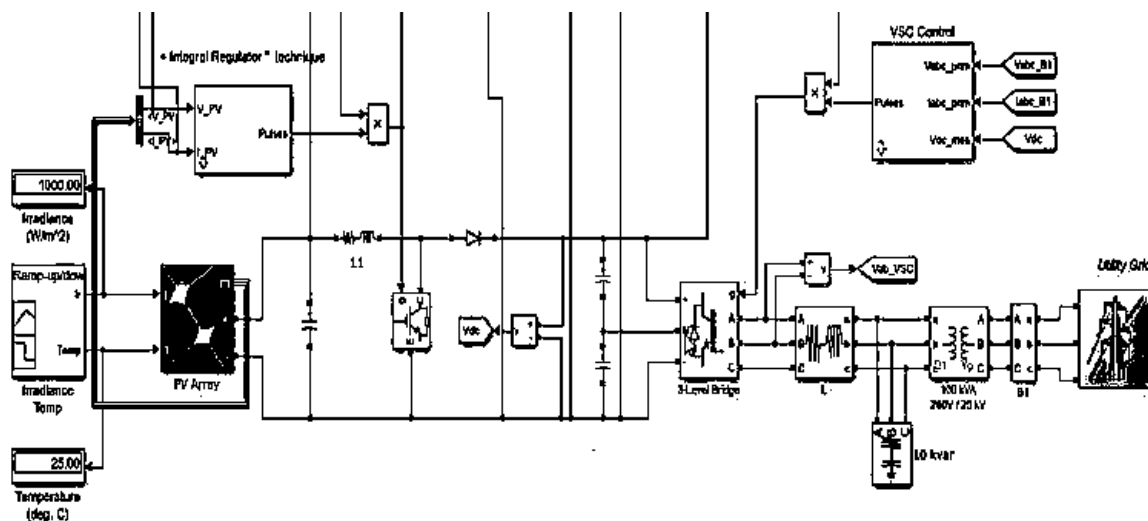


Figure 6. PV to grid connection

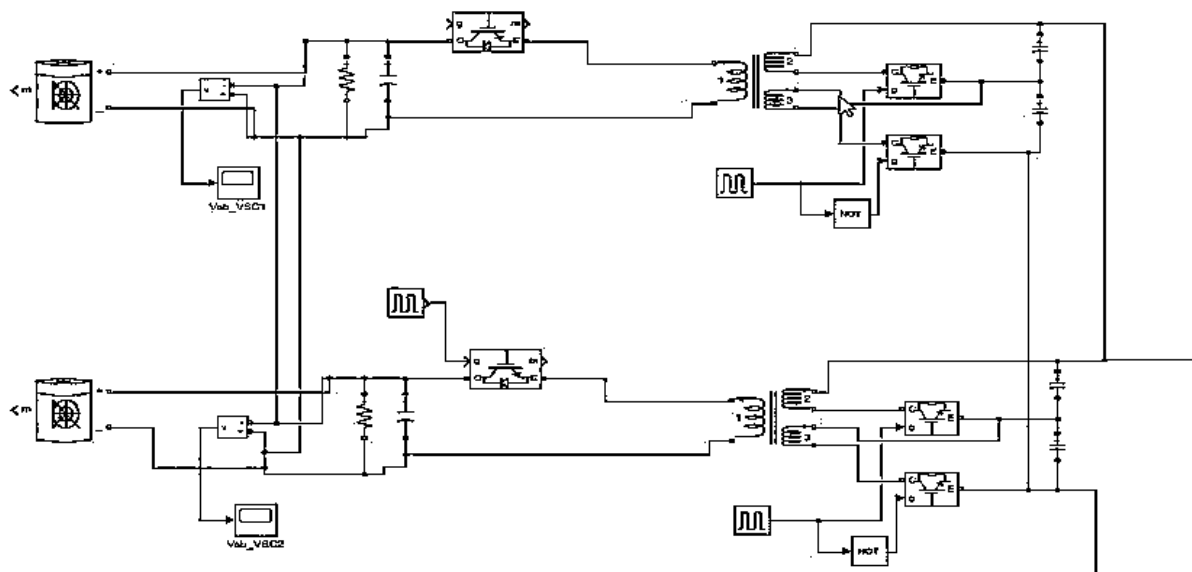


Figure 7. Battery charging using bidirectional

Simulation Result

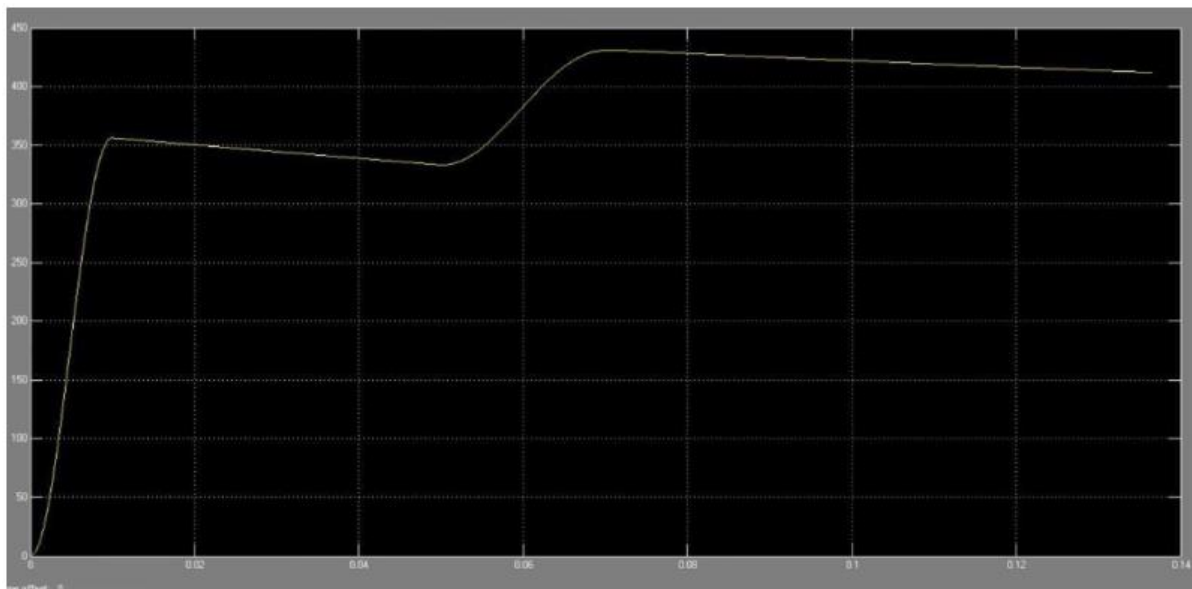


Figure 8. DC Voltage(Vdcvs Time)

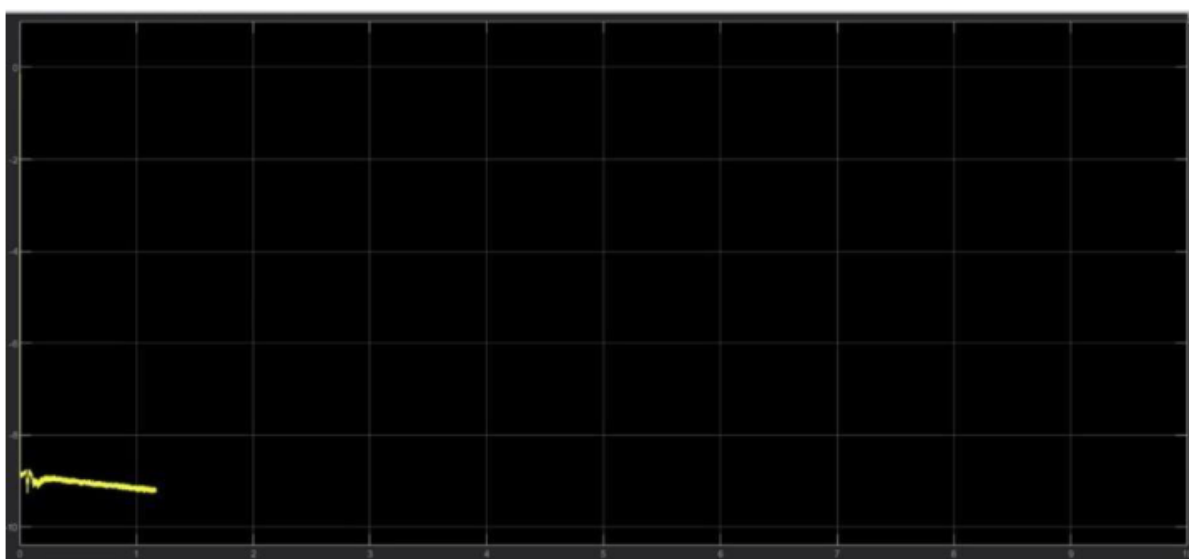


Figure 9. Battery Voltages

10 Kw solar-powered bidirectional EV charger" with the help of PV panels. With the help of electronics software MATLAB we were able to produce the desire output of maximum power produce with the help of several library tools. Traditional backlinks are considered to be suitable for low power only.In this control have been produced and also tested for 3 sub-converter that makes 4 power flow that are PV to EV, EV to grid, grid to EV and PV to grid.

The 10KW prototype was completely build in MATLAB software and tested and also showed more efficiency than 95% of PV to EV, 95.5% of grid to EV, 96.3% of PV to grid higher power than current solutions based on power exchange.

Conclusion

In this paper, the proposed solar-powered EV charging system offers a sustainable and efficient solution to meet the growing demand for electric vehicle charging. By utilizing renewable energy sources, such as solar power, this system reduces dependence on fossil fuels and decreases carbon emissions. Additionally, the bi-directional smart inverter's ability to switch between grid-tied and islanded modes provides flexibility and ensures uninterrupted power supply. The battery storage system enables energy storage for later use and helps to stabilize the grid during peak demand periods. Overall, this system is a promising solution for clean and sustainable transportation.

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