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An Investigation of Solar-Powered Grid-Integrated Electric Vehicle Charging Modules for Smart Cities

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Abstract—

In response to unpredictable power demands and heightened environmental consciousness about the need to combat climate change and the exhaustion of nonrenewable natural resources, EVs—electric vehicles powered by batteries—are replacing ICE vehicles in the transportation industry. Traditional fossil fuels are neither physically or economically feasible for charging these electric vehicles. A solar-powered electric vehicle (EV) charging module is planned for the future of smart cities in this project. Building a solar-powered electric vehicle charging system that is both efficient and scalable is the major focus of this piece. In order to encourage the use of electric cars and lessen India's reliance on fossil fuels, we want to build a long-term charging infrastructure that makes use of the plentiful sunshine found in metropolitan areas. The model is being implemented in this case using MATLAB/SIMULINK, and the results of the many parameters used, such as the battery voltage, grid voltage, PV array current, and voltage characteristics, are being obtained. Additionally, this project's completion would provide the groundwork for improved, safer, and more user-friendly electric vehicle charging systems in the future. Lastly, many parties involved in smart city infrastructure, including policymakers, EV users, and other organizations, stand to gain from this suggested approach, which aims to provide a sustainable transportation option.

Concepts—Photovoltaic Array, Boost Converter, Battery, and Dual Converter

I. INTRODUCTION

Both temperature and irradiance have an effect on the maximum power output from a solar array. Thanks to the development of more efficient renewable energy sources, solar-powered Charging modules for electric vehicles (EVs) that use solar power are becoming more popular. In an effort to lessen reliance on fossil fuels and increase use of green energy, this system is designed to be environmentally benign by supplying a clean, renewable energy source to power electric vehicles. By integrating Internet of Things (IoT) technology into the charging module, vital metrics including energy usage, crowd density at charging stations, and charging durations can be tracked in real-time [1-3]. This feature enhances the user experience by enhancing resource management and providing important information to users, such as charging station availability and waiting periods. Developing an eco-friendly system to accommodate the increasing number of electric vehicles is a primary objective of this project. The solar-powered charging module lowers carbon emissions and promotes the use of electric cars by providing an alternative to conventional fuel-powered automobiles. In the long run, this will help create a more environmentally friendly and sustainable future. Connectivity to the smart grid infrastructure may be established in both directions using this approach. [5-7]. Connectivity to the smart grid enhances urban infrastructure and energy management systems, which contributes to the growth of smart cities. In the end, the concept provides a clever and effective way to charge electric vehicles by integrating solar power. It helps achieve the bigger objective of creating a smarter, more energy-efficient city while simultaneously meeting the immediate demands of EV owners [8]. The gradual realization of the fast depletion of traditional energy sources, such as coal and petroleum products, has contributed to the growing global relevance of renewable energy sources in the modern period. The load balance of the power system may be affected by the growing energy demand caused by electric vehicle charging, however a smart and optimized charging approach will aid consumers with their electric vehicle energy consumption according to usage and sharing of charge to reduce charging costs. One possible outcome of investing in charging infrastructure is a tightening of the performance metric. the numbers 11–15. Our proposal will contribute to meeting the future need for accessible and environmentally friendly charging infrastructure, which is being driven by the increasing worldwide usage of electric vehicles. This project will provide the necessary model for more effective monitoring, maintenance, and dynamic pricing of electric vehicle charging infrastructure, made possible by the ongoing improvements in the internet of things (IoT). A smart electric vehicle charging infrastructure, based on this concept and the Internet of Things, will be built. Future intelligent development concepts, such as Smart City Services and EV fleet charging, will also benefit from this study. All things considered, energy conservation will benefit from integration with smart grids since it will stabilize power demand, optimize energy consumption, and make energy storage easier. Figure 1 provides a clear block diagram of the suggested technique. The remainder of the paper is organized as follows: Section II provides a concise overview of PV system modeling with the potential issue of numerous peaks in the P-V curve. All parts of the system, including their modeling, are detailed in Section III. Part IV displays the results from MATLAB. Lastly, section V drew conclusions.

II. PV SYSTEM DESCRIPTION

Electricity is generated from the sun's rays via photovoltaic processes, which PV cells collect. There is a wide range of possible configurations for PV systems. In PV cells, the photovoltaic reaction turns the sun's rays into electricity. Electrons from the array start to form and generate an electric current as soon as the photon energy from the solar panel's daytime irradiance exceeds the energy gap. A solar photovoltaic cell's circuit configuration is seen in Fig. 2. Every node in the network is linked in series and parallel with a current source, a diode, and a set of resistors. A PV cell's ideal output current may be equal to (1). Fig. 3 clearly displays the PV model's V-I and P-V features.

$$I_{OUT} = I_{PVC} - I_{D1} - I_{PL} \qquad (1)$$

in where IOUT and VPVL stand for the individual output current and voltage of the solar cell, the diode, the photovoltaic current (IPL), and the parallel resistance (RPL) (Eq. 2). Noted as RSER is the series resistance.

$$I_{D1} = I_{RSC} + e^{q\frac{V_{PVL}+I_{OUT*}R_{SER}}{nKT}-1} \qquad (2)$$

the reverse saturation current is represented by IRSC. The symbols q, T, n, and K represent the following: electron charge, ambient temperature, diode factor Boltzmann Constant and independently. The equation (3) represents the current that is produced in a PV cell.

$$I_{PVC} = \frac{W}{W_0}\left(I_{SCN} + \lambda(T - T_0)\right) \qquad (3)$$

While T0 and W0 stand for temperature and reference irradiance, respectively, ISCN represents short circuit current. & and W stand for the temperature of the atmosphere and the irradiance coefficient, respectively. After integrating Equations (2) and (3), we get Eq. (4).

$$I_{OUT} = I_{PVC} - I_{RSC} + [e^{q\,\frac{V_{PVL}+I_{OUT*}R_{SER}}{nKT}} - 1] - \frac{V_{PVL}+I_{OUT} * R_{SER}}{R_{PL}} \qquad (4)$$

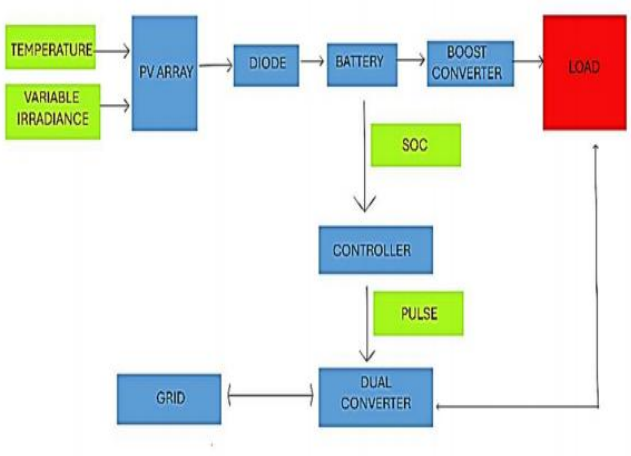


Fig. 1. Block diagram of proposed system

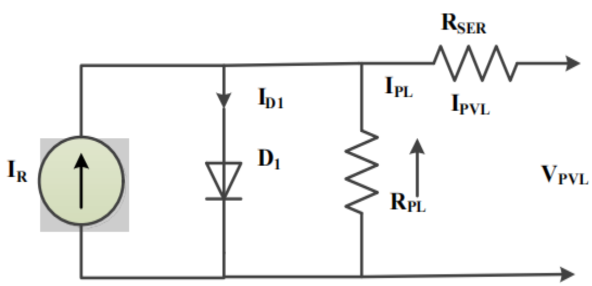
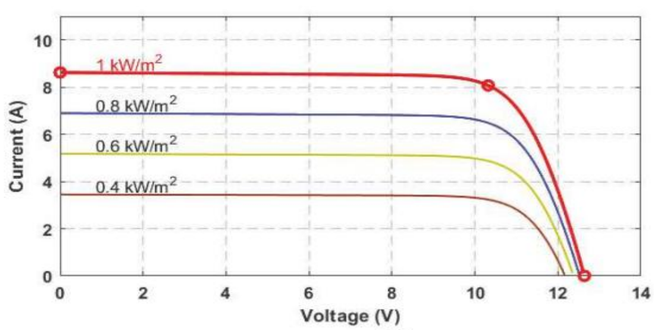
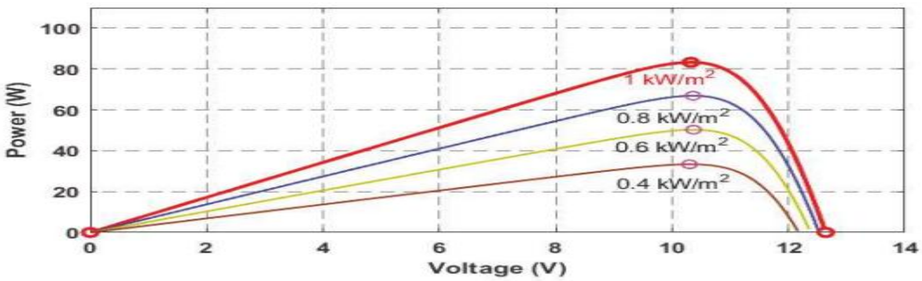


Fig. 2. PV cell's equivalent electrical circuit diagram



(a)



(b)

Fig. 3. (a) Current vs Voltage (b) Power vs Voltage characteristics of predefined solar cell.

III. SYSTEM MODELLING

Part A. Boost Controller The solar array can function according to MPP under certain weather and irradiance circumstances because of its DC-DC converter connection to the load. Using maximum power point tracking (MPPT) methods, the boost converter switch's duty ratio is adjusted so that the solar array continues to operate at its maximum power point. The boost converters used in this study have the following features: The input voltage is 12 V, the output voltage is 24 V, and the series inductance is 20 e-6 H, while the shunt inductance is 25 e-6 H. One example of the changes made to the DC-DC converter used in the research is this. The DC-DC boost converter layout model is seen in Figure 4. Division B: Representation of the battery's construction With the proliferation of intermittent energy sources, the need to set up storage systems will be more apparent. Because of their high power and energy densities, batteries have attracted interest among the various created electrical storage methods [16]. The battery that is used here is 7.2 ampere-hour (Ah) and has a 12V rating with an initial level of charge of 30%.

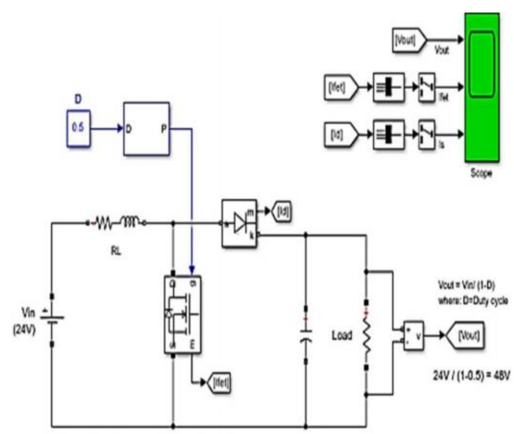


Fig. 4. Model of DC-DC Boost converter

C. Grid Integration with inverter module

A comprehensive analysis of the 230V, 50 Hz AC grid is conducted to meet the increased power requirements of the charging station. The grid is shown in the MATLAB/Simulink environment as an inverter-connected 230V AC source to a DC bus. This study makes use of a dual converter topology. A rectifier and an inverter are two types of converters that are included into this electrical equipment. It enables two-way power flow, meaning it can convert from AC to DC as well as DC to AC.

In order to adjust the voltage and current for optimal energy management, dual converters are often utilized in applications such as motor drives and power supply systems [17]. Here, a dual converter keeps the grid-to-vehicle and vehicle-to-grid connections active in both directions. Figure 5 shows the dual converter model for the suggested method.

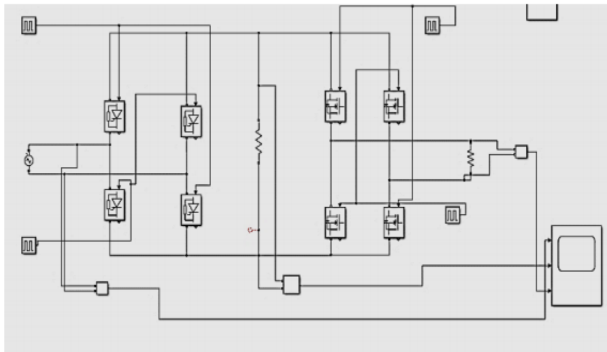


Fig. 5. Layout of Dual converter model

IV. SIMULATION DESIGN AND RESULT ANALYSIS

This section presents and analyzes the simulation's findings. The 2018a version of MATLAB/SIMULINK incorporates a grid-connected inverter system that operates on a single phase. Table I displays the specifications of the solar PV panels utilized in this study. Figure 6 displays the comprehensive block diagram.

TABLE I. SPECIFICATION OF PV MODULE USED IN SIMULATION

Specification	Value
Open circuit voltage; V_{oc}	6.6 Volt
Short circuit current; I_{SCN}	0.110 Amp
Maximum Power Point voltage	6.2 V
Maximum Power Point Current	0.100 A

Figure 7 shows the open circuit voltage (1) of the PV array, which is approximately 11 volts. This voltage is then sent to the battery for storage through a diode to prevent the reverse flow of voltage from the battery. In this setup, we have used two 6-volt panels to get an output of 12 volts. Figure 8 shows the curve that represents the current characteristics of the PV array, also known as the short circuit current, an important parameter to consider when building the model. Simply explained, it is the highest current that the PV array can provide under a short circuit, which occurs when the output connections are connected in series. As shown in Figure 9, the voltage at the DC bus, which is also the output from the Boost Converter, is around 24 volts. This is because the input voltage is 12 volts. This demonstrates that the DC voltage output at the station, which is fed by the Boost Converter and regulated by the battery voltage, is around 24 volts, and is used for charging the electric vehicle. In addition, the ideal output voltage from the dual converter—230 volts—that the charging station supplies to the grid is shown in Fig. 10. This demonstrates that the station's voltage is sinusoidal, which aids the grid in handling overloads during peak demand periods.

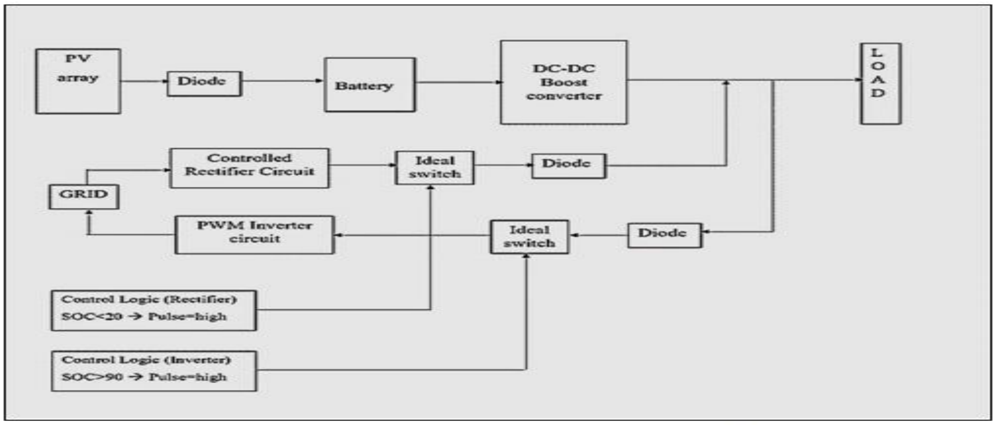


Fig. 6. Layout of proposed system model

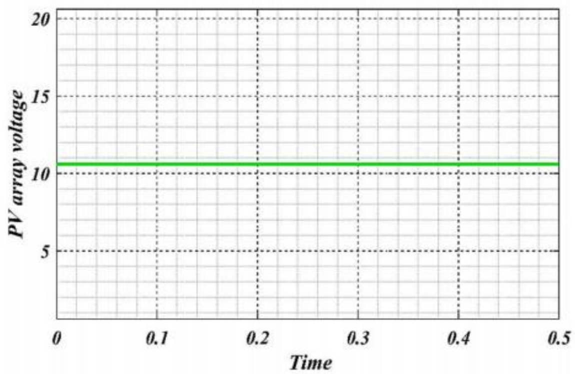


Fig. 7. PV array voltage of the proposed system

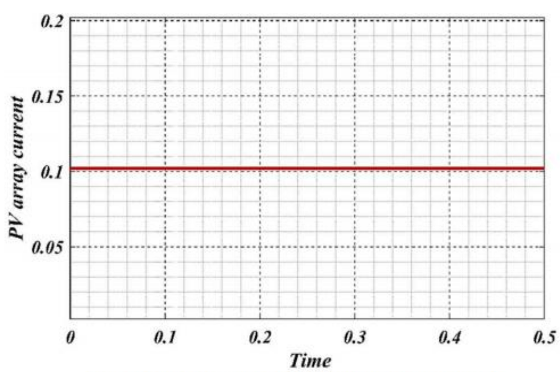


Fig. 8. PV array current for the developed method

A linear increase in the state of charge (SOC) of the battery indicates that it is constantly being charged, whereas a linear fall in the SOC curve upon discharge indicates that the battery is being utilized. Figure 11 provides a clear representation. To tell the converter when to get power from the grid and when to put it back into the grid, the state of charge (SOC) is a crucial metric.

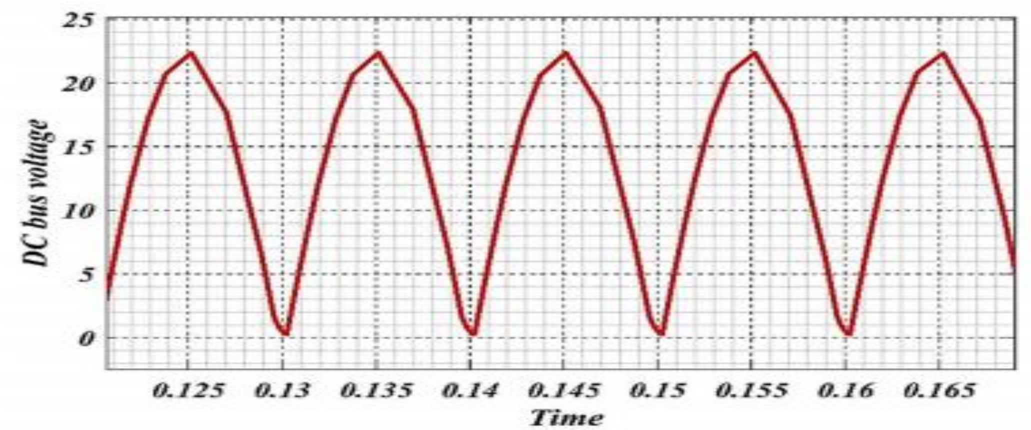


Fig. 9. Representation of DC Bus voltage

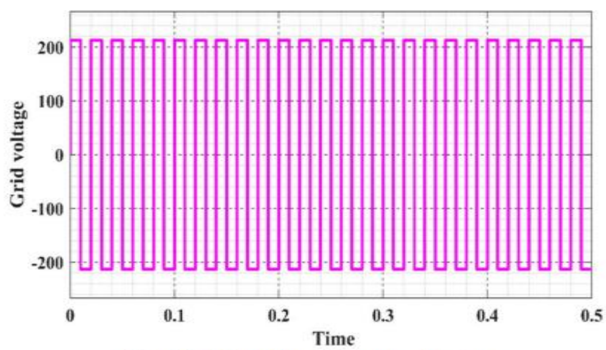


Fig. 10. Grid voltage of proposed system

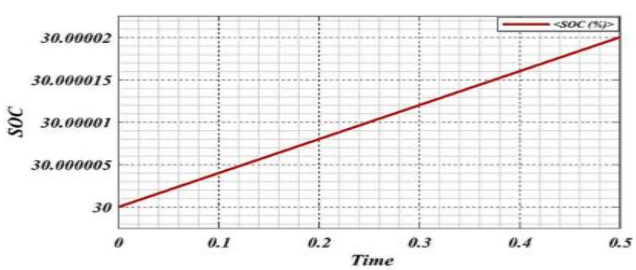


Fig. 11. SOC (%) of Lithium-Ion Battery

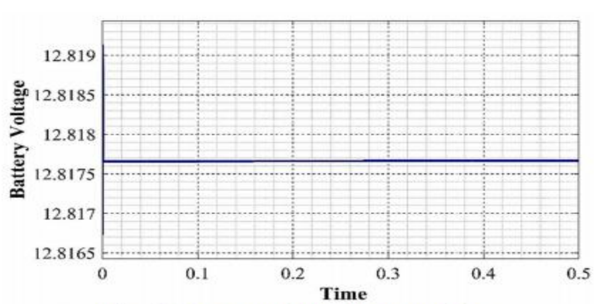


Fig. 12. Representation of Battery voltage

The battery voltage remains constant during the duration, which is the intended output, and it is around 12 volts, which is also the rated capacity of the battery employed in this study (Fig. 12). The voltage of the batteries is a crucial metric as it controls the whole circuit from the grid to the station and back again.

V. CONCLUSIONS

In order to address the increasing need for environmentally friendly electric vehicle infrastructure, this study lays the groundwork for an effective solar-powered EV charging module that incorporates the internet of things (IoT). The technology helps the environment by reducing carbon emissions and dependence on the grid by using solar energy. Adding IoT to the system improves its efficiency, user convenience, and predictive maintenance capabilities via real-time monitoring, smart energy management, and remote control. Additional research shows that electric vehicle charging infrastructure can adapt to future energy and transportation demands by combining renewable energy with modern internet of things technology. Increased operational efficiency, cost-effectiveness, scalability, and data-driven insights are some of the projected benefits that provide compelling business case for this technology to be widely used.

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