iJRASET
International Journal For Research in
Applied Science and Engineering Technology

INTERNATIONAL JOURNAL FOR RESEARCH
IN APPLIED SCIENCE & ENGINEERING TECHNOLOGY

Volume: 13 Issue: II Month of publication: February 2025

DOI: https://doi.org/10.22214/ijraset.2025.67046

International Journal for Research in Applied Science & Engineering Technology (IJRASET)
ISSN: 2321-9653; IC Value: 45.98; SJ Impact Factor: 7.538
Volume 13 Issue II Feb 2025- Available at www.ijraset.com

Bidirectional Electric Vehicle Charing using Integrated Renewable Energy Powered Grid for Energy Management

Dharavath Naveen[1], M. T. NAIK Professor[2]
[1]*Department of Centre for Energy Studies, JNTUH UCEST, Hyderabad, India*
[2]*Department of Centre For Energy Studies, JNTUH UCEST, Hyderabad, Hyderabad, India*

Abstract: An approach for grid-connected bidirectional charging stations (BCS) that use both solar and wind power is presented in this study. To meet the increasing demand for energy systems, the system dynamically adapts its operations to maximize energy use and interaction with the grid. Even when an EV isn't plugged in, the grid can still charge the storage battery with the excess power from wind turbines and solar panels. When an electric vehicle is in the area, the BDDC converter prioritizes charging the battery with energy from renewable sources like solar panels and wind turbines. Extra power is taken from the grid if the total output of these sources is inadequate. In addition, in V2G scenarios, all the electricity that is generated by solar panels, wind turbines, storage batteries, and electric vehicle batteries can be fed back into the grid. This improves grid stability and makes better use of renewable energy sources. Electric vehicle (EV) batteries can be charged straight from the grid (G2V) even when renewable energy sources like wind and sunlight aren't available. By utilizing the MATLAB Simulink software, the suggested approach has been validated.
Keywords: The terms "electric vehicle," "grid-to-vehicle," "interleaved bidirectional DC-DC converter," and "hybrid renewable energy" are all used interchangeably.

I. INTRODUCTION

The worldwide shift towards renewable energy the integration of renewable energy sources across several sectors has made considerable progress as a result of the solutions. To lessen our effect on the environment and cut down on carbon emissions, we must prioritise the transportation sector. To lessen our impact on the environment and our dependency on fossil fuels, electric vehicles (EVs) provide an alternative to vehicles powered by internal combustion engines. Fast charging infrastructure, grid stability, and renewable energy integration are some of the issues brought about by the rising adoption of EVs. Micro grids have become more popular in tandem with the increasing use of renewable energy sources. Localized energy systems known as micro grids can function both with and without an external power grid link; they use a variety of power sources and loads. First and foremost, they want to Upgrade the current electrical grid to be more dependable, environmentally friendly, and efficient [1]. Power storage and control algorithms are necessary for consistent power production from renewable energy sources (RES) notwithstanding their unpredictability. When it comes to micro grids that incorporate variable energy sources, a battery storage system (BSS) is essential for storing surplus energy and releasing it when needed. Off-board DCMG charging systems are available through DCMG interfaces, and they work with a wide range of battery types and charging speeds. The grid's stability, dependability, and efficiency can be improved with the help of off-board chargers, which also provide grid support and vehicle-to-grid (V2G) capabilities. In an effort to boost the use of renewable energy sources and aid in grid stability, Ravikant Yadav et al. [2] suggested a grid-linked solar-wind hybrid charging station. A solar-and wind-powered EV fast charger that can support grid operations while the car is parked has been proposed by Suryakant Kumar et al. [3]. A fast charging station that provides grid-linked solar PV electricity with improved power quality was proposed by Reenu Bose et al. [4]. Using SPWM inverters, Shubhangi S. Pawar et al. [5] suggest integrating solar and wind power systems into the grid. A wind energy conversion system based on PMSG and using a modified perturb and observe MPPT technique was proposed by Balaji Mendi et al. [6]. There are four distinct modes of operation for the suggested system.

1) Mode 1: No EVs present; Solar and wind power charge storage batteries, and any surplus power is fed back into the grid.
2) In Mode 2, when an EV is present, the battery is charged using energy from solar panels, wind turbines, and storage batteries.
3) Third Mode: No DC micro grid—Grid-direct charging of EV batteries.

4) Mode 4, which is known as V2G operation, involves the entire system—Solar, Wind, storage batteries, and EV batteries—supplying power to the grid.

II. SYSTEM CONFIGURATION

Various tiers of electric vehicle chargers exist on the market, and they all have their own set of advantages. Level-1 EV chargers are 110V AC and plug into any regular wall outlet. Level-1 charging is slower than other techniques and takes a long time to charge the electric vehicle completely. In contrast, level-2 chargers can charge at a faster pace than level-1 chargers because they can take currents up to 30A and can work with a power source of 220/240V AC. On the other hand, electric vehicles become heavier and more expensive when they include onboard chargers.

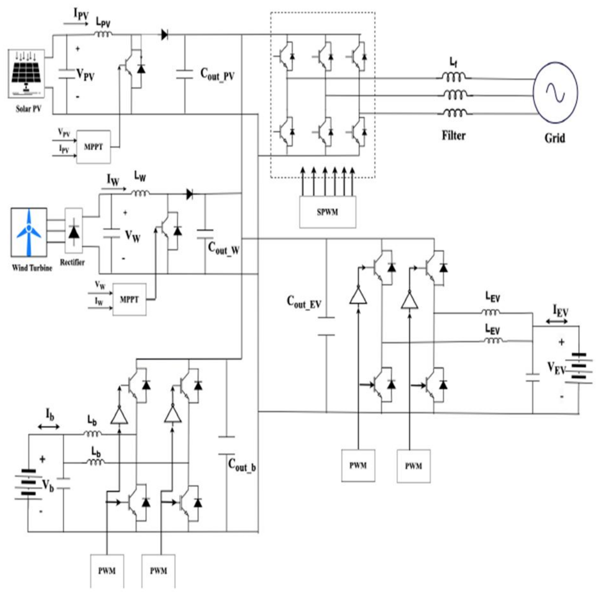

Fig. 1. The suggested system's schematic

Travelling great distances is no problem with level-3 chargers, which are also called DC quick chargers. Fast charging sessions are made possible by chargers with a current rating of 100A or more. When charging electric vehicle batteries at Level-3, it can be helpful to incorporate renewable energy sources (RES) such as wind and sun. Level-3 chargers can also supply grid support and act as backup power sources, which is useful because battery backup solutions have capacity constraints [3].

Power for the DC charging station primarily comes from solar panels, wind turbines, and batteries. To maximize power extraction, solar photovoltaic systems use the maximum power point tracking (MPPT) technology in conjunction with a DC-DC boost converter. Renewable energy sources (RES) like wind can also benefit from boost converters that use a modified perturb and observe strategy to extract the most power possible. In addition to charging the electric vehicle's battery with renewable energy sources, the charger can also provide power back into the grid.

In order to charge the electric vehicle's battery, a bidirectional DC-DC converter known as an interleaved BDDC is used. For optimal energy management, the BDDC switches between boost and buck modes when the EV is charging and discharging. Part of the RES is a 72-volt, 30Ah battery, while other components include a 3KW wind energy module that uses PMSG technology and a 3KW solar PV module. Electric vehicles and storage batteries both use BDDCs for charging and discharging. By use of the BDDC, the electric vehicle is linked to the micro grid. An inductive filter is employed to eliminate the harmonic content after the inverter. Figure 1 shows the basic layout of the system that is being suggested.

A. *Part A: Photovoltaic Cell*

To generate power from sunlight, a solar panel employs a number of photovoltaic cells. Common components of such modules include a number of solar cells arranged in series and/or parallel and housed in a tempered glass shell. From small-scale solar farms to residential rooftops, they find extensive usage in both grid-connected and off-grid applications, aiding in the shift towards renewable energy and reducing carbon emissions.

The parameter of solar panel is shown in Table I.

Parameter	Value
Input Irradiance	1000W/M2
Input Temperature	25°C
No. of Modules in Parallel	1
No. of Modules in Series	12
Maximum Power	3000W
Open Circuit Voltage (Voc)	35V
Cells per Module	60
Short Circuit Current (Isc)	9A
Current At Maximum Power Point (Imp)	8.17A
Voltage At Maximum Power Point (Vmp)	31V

TABLE I. PARAMETERS OF SOLAR PANEL

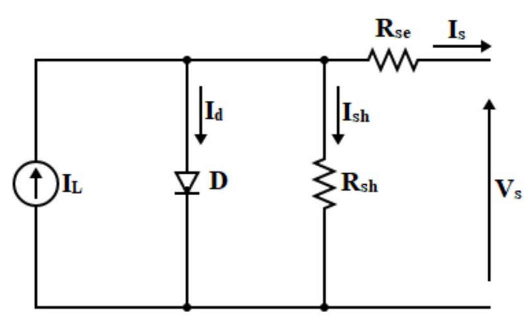

Fig. 2. A PV cell concept using a single diode

$$I = I_L - I_O\left[\exp\left(\frac{V + R_S I}{V_t a}\right) - 1\right] - \frac{V + R_S I}{Rsh} \quad (1)$$

$$V_t = \frac{KTNs}{q}$$

$$I_L = \frac{(I_{pvn} + k_{t\Delta T})G}{G_n} \quad (2)$$

Where $\Delta T = T - Tn$

$$I_{phn} = \frac{R_{sh} + R_s}{R_{sh}} I_{SCn}$$

$$I_O = \frac{I_{SCn} + K_I \Delta T}{\exp\left(\frac{V_{OC} + K_V \Delta T}{aV_t}\right) - 1} \quad (3)$$

B. PMSG based WECS

Wind energy conversion systems that use permanent magnet synchronous generators (PMSGs) to generate electricity are known as WECSs. The PMSG's rotor is made up of permanent magnets, unlike other generators, which means it doesn't need separate excitation and requires less maintenance. When connected to a wind turbine, the PMSG may convert mechanical wind energy into electricity, creating green power. From small-scale installations to massive wind farms, PMSG-based WECS modules excel in efficiency across a wide spectrum of wind speeds. Reduced carbon emissions are a direct result of the vital role these systems play in renewable energy generation. A rectifier and boost converter link a 3 KW PMSG wind turbine to an inverter input. Under normal wind conditions, the PMSG runs at its highest power point at a pitch angle of zero degrees and a rated speed of two thousand revolutions per minute. The turbine's wind and mechanical output powers are defined by equations (4) and (5).

$$\mathbf{p_w = \frac{1}{2}\,\rho A\, V^3} \qquad (4)$$

$$\mathbf{P = \frac{1}{2}\,\rho A\, V^3(\lambda, \beta)} \qquad (5)$$

$$\mathbf{\lambda = \frac{\omega.\,R}{v}} \qquad (6)$$

C. Storage Battery And Electric Vehicle Battery:

A 72-volt, 30 Ah storage battery and a 320-volt, 100 Ah EV batteries are linked to a DC link through an Interleaved Bidirectional DC-DC (BDDC) converter. When the EV is not in use, the storage battery charges. When the EV is in use, it uses energy from renewable sources like solar and wind to charge the EV battery. This bidirectional charges both batteries simultaneously. Lithium-ion (Li-ion) batteries have a longer life cycle, a smaller footprint, and a higher energy density than traditional battery technologies. Their dependability makes them an essential component of modern technology.

III. COMPONENT DESIGN

A. Filter design

An inductive filter is located between the inverter and the grid. It eliminates sharp edges and lowers the volume of background noise. Protecting our equipment and meeting rules, this guarantees clean and stable power going into the grid. In equation(7), V is the voltage on the grid, P is the nominal power per phase, and f is the frequency of the grid, which is used to determine the inductance.

$$L=\frac{\mathbf{0.2*V^{\wedge}2}}{\mathbf{2\pi fP}} \qquad (7)$$

B. Boost converter

Boost converters are a type of DC-DC converter that increases the output voltage from a lower input voltage. While the switching cycle is on, it saves energy in an inductor, and when it is off, it releases that energy into the output. A lower voltage source can be efficiently converted to a higher voltage output in this way. Numerous applications rely on boost converters for dependable voltage regulation and efficient power transfer. These include power supply, battery charging systems, and renewable energy setups.

1) Boost Inductor

$$\mathbf{L_{PV} = \frac{V_{PV}*D_{PV}}{\Delta I_{PV}*f_{sw}}} \qquad (8)$$

Where VPV is the PV output voltage, ΔIPV is the current ripple, $f$sw is switching frequency, $\mathbf{D_{PV}}$ is duty cycle.

2) Output Capacitor

$$\mathbf{C_{out} = \frac{I*D_{PV}}{\Delta V_{DC}*f_{sw}}} \qquad (9)$$

Where IO is the output current of solar PV, $\mathbf{\Delta V_{DC}}$ is the voltage ripple.

C. Interleaved Buck-Boost Converter

Any two voltage sources, such as batteries and the grid, can have their power transferred using an interleaved buck boost converter. It improves bidirectional power efficiency and voltage management by combining the best features of buck and boost converters. Efficient and long-lasting components are guaranteed by implementing stages in a way that minimizes input and output current variations. In order to find the values of the boost inductor and the output capacitor, the calculations are performed using equations (8) and (9).

$$\mathbf{D_{Boost} = 1 - \frac{V_b}{V_{DC}}} \qquad \mathbf{(10)}$$

$$\mathbf{D_{Boost} = \frac{V_{DC}}{V_b}} \qquad \mathbf{(11)}$$

Where $\mathbf{V_{DC}}$ is DC link voltage and $\mathbf{V_b}$ is battery voltage.

IV. CONTROL METHODOLOGY

A. Incremental Conductance MPPT for Solar PV

Photovoltaic (PV) systems frequently employ Incremental Conductance Maximum Power Point Tracking (MPPT) for optimizing power output. In this method, the panels' operating points are adjusted to correspond to the maximum power point (MPP) in various environmental conditions. Better tracking in dynamic environments is achieved by comparing it to the Perturb and Observe approach, which does not take voltage into account while evaluating conductance change. Incremental Conductance MPPT improves the efficiency and performance of solar energy systems in a variety of applications by adjusting the voltage and current to increase energy extraction from panels.

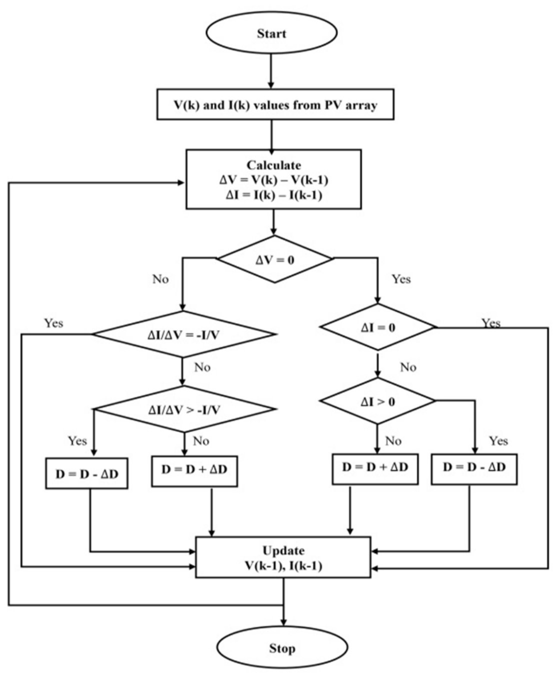

Fig.3. Visual representation of the incremental conductance MPPT algorithm

B. Modified P&O MPPT for Wind Energy Conversion System

With the integration of dc link current Slope details combating variations, the resolution of the search path observed in the P&O approach, and proximity to the Maximum Power Point (MPP), the Modified Perturb and Observe (P&O) MPPT method improves efficiency. The main distinction is that the algorithm modifies the duty cycle in response to changes in variables like DC-link power (Pdc), voltage (ΔVdc), and current (ΔIdc), guaranteeing accurate tracking of the maximum power point (MPP).

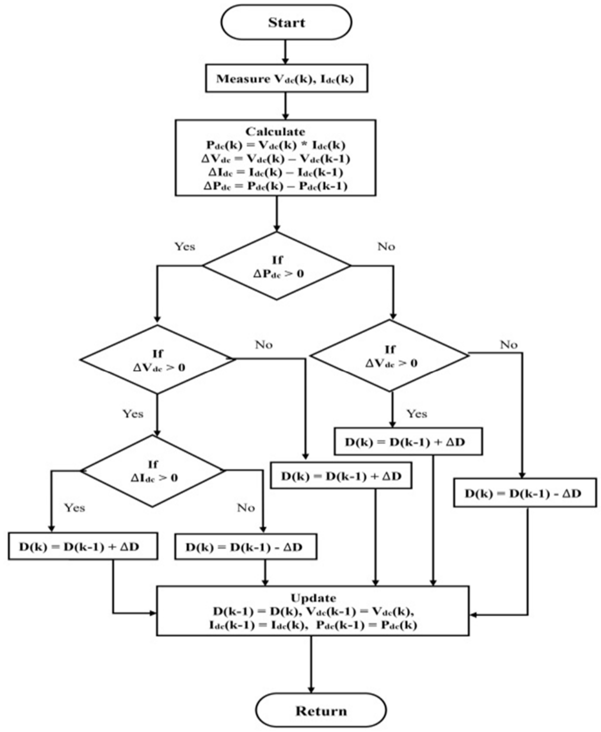

Fig. 4. Flow diagram for the P&O MPPT variant

C. Bidirectional DC-DC Converter Control

In grid-linked mode, the bidirectional converter works mainly to maximize the storage battery's power capacity. Storage batteries are charged using renewable energy sources (RES) such as solar and wind, and excess electricity is pumped into the grid when electric vehicles (EVs) are not in use. A combination of solar, wind, and the electric vehicle's battery is used to charge the vehicle's battery when the vehicle is in motion. In order to keep the electricity flowing smoothly between the inverter's DC and AC sides, the micro grid keeps the DC link voltage steady. We draw power from the grid to make up the difference if the irradiance or wind speed changes. The goal of the control approach is to maximize power production from RESs while ensuring DC link voltage stability. It does this by using pulses generated by the bidirectional converter, which are based on the inner current and outer power loops. With this method, electric vehicle charging can be seamlessly integrated into the micro grid, and renewable energy sources can be used more efficiently.

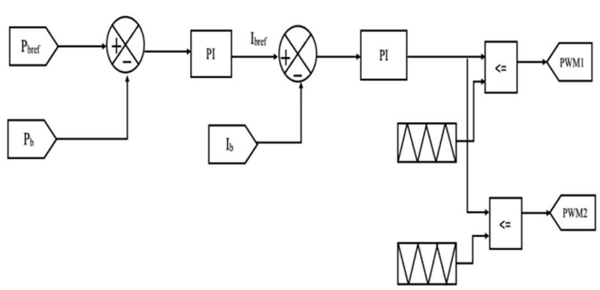

Fig. 5. Control of a bidirectional DC-DC converter

D. Grid Side Converter Control

Achieving d-q management is essential for regulating the flow of active and reactive power in a grid-linked inverter system. CV control is employed. Modulating the d-axis allows us to control the power in order to maintain a DC link voltage or satisfy the grid's demands.

At the same time, the q-axis controls power so that the power factor stays close to 1. The inverter improves energy flow between power sources, the grid, and the battery of an electric vehicle (EV) by controlling these variables. Integrating renewable energy sources, ensuring grid stability, and efficiently charging and discharging electric vehicles are all made possible by this control method. The d-axis control loop uses the PI controller to achieve precise power management by fine-tuning the current reference; this improves the grid-integrated bidirectional charging station's overall performance and dependability.

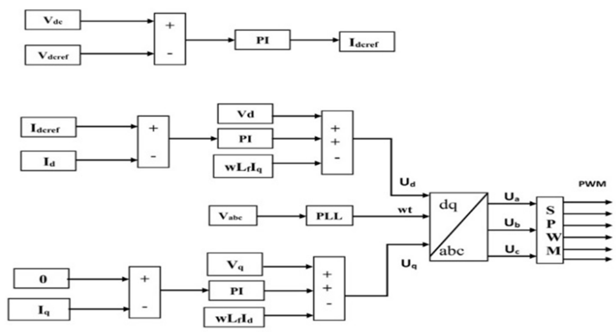

Fig. 6. Variable control for PCCs

V. SIMULATION RESULTS

The suggested system has four distinct modes of operation. When an electric vehicle is not in use, Mode-1 charges the storage battery using energy from renewable sources like solar and wind, and any surplus is transferred back into the grid. Upon detection of an electric vehicle (EV), Mode-2 directs the charging of the EV using energy from the storage battery, the sun, and the wind. When operating in Mode 3, electric vehicles charge straight from the power grid, bypassing the DC micro grid. The Mode-4 enables V2G operations, in which the whole system—solar panels, wind turbines, storage batteries, and electric vehicle batteries—supplies power to the grid. In order to accommodate the varied needs of electric vehicle charging and grid support, these modes guarantee effective energy utilisation and the smooth incorporation of renewable sources.

A. Mode – 1

There is no electric vehicle (EV) in operation in Mode-1. In this mode, 3 KW of power is produced by the sun and 3 KW by the wind. The first 2 KW are used to charge the battery storage, and the remaining 4 KW are fed into the grid as excess energy from the wind and solar systems, adding to the integration of renewable energy. This mode optimizes system efficiency and enhances grid stability by prioritizing energy storage when EV demand is absent, ensuring optimal exploitation of renewable energy sources. Solar, wind, storage, and electric vehicle (EV) battery power output is illustrated in Figure 7. Figure 8 displays the DC link voltage and grid power. The grid voltage and current are displayed in Figure 9. Both the EV battery and the storage battery's state of charge are displayed in Figure 10.

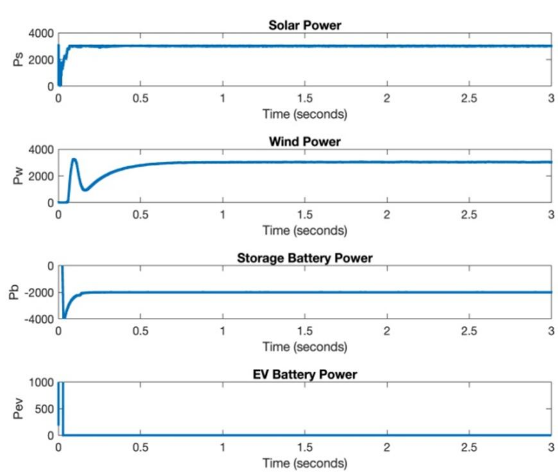

Fig. 7. Total energy production from renewable sources (solar, wind, storage batteries, and EVs)

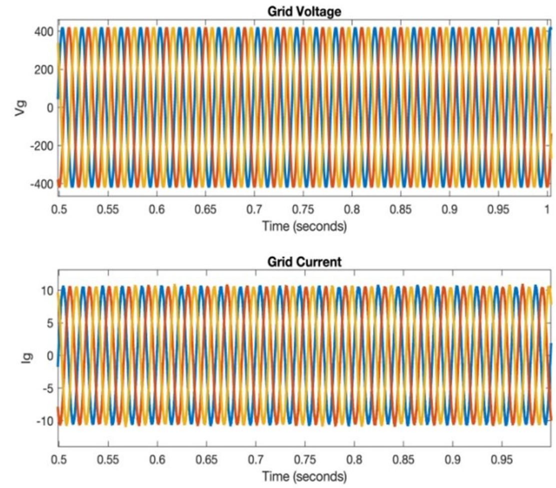

Fig 8. Power grid current and voltage

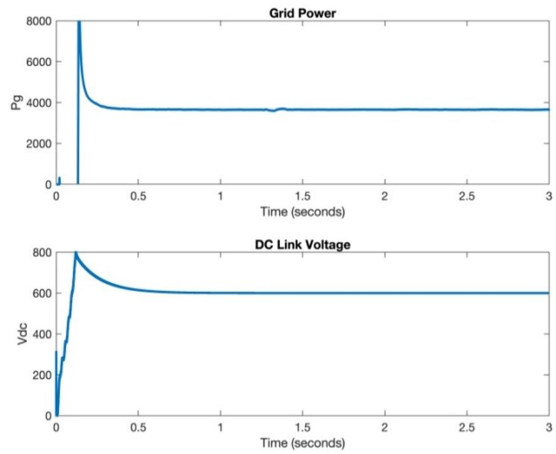

Fig 9. Voltage at the DC link and grid power

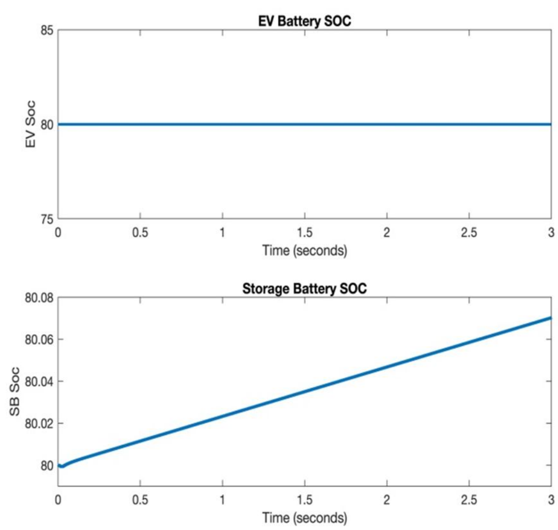

Fig. 10. State of Charge for Electric Vehicle Batteries and Storage Batteries

International Journal for Research in Applied Science & Engineering Technology (IJRASET)
ISSN: 2321-9653; IC Value: 45.98; SJ Impact Factor: 7.538
Volume 13 Issue II Feb 2025- Available at www.ijraset.com

B. Mode-2

Connecting an electric vehicle (EV) to the system allows it to charge in this manner. Charges the electric vehicle's battery using energy from renewable sources like solar and wind as well as the storage battery. In this mode, the electric vehicle's battery is charged using 100% renewable energy sources, with no power going into the grid. The total power output is 3 KW from solar, 3 KW from wind, and 2.25 KW from storage batteries. By charging the EV using renewable energy, this option contributes to a greener future. Power input from the EV battery and power output from the solar array, wind turbine, and storage battery are shown in Figure 11. In mode-2, the grid voltage and current are shown in Figure 12. Voltage and electricity from the grid are shown in Fig. 13. Electric vehicle and storage battery system architecture is depicted in Figure 14.

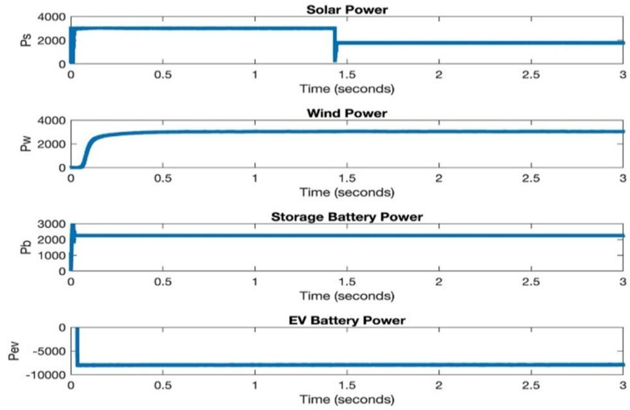

Fig. 11. Electric vehicle (EV) battery power input and output from renewable energy sources

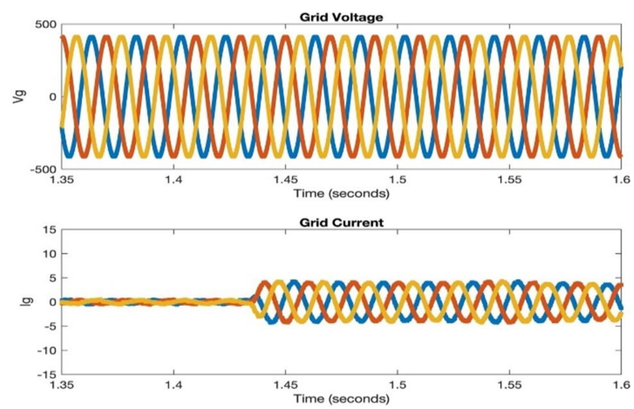

Fig. 12. Grid voltage and grid current

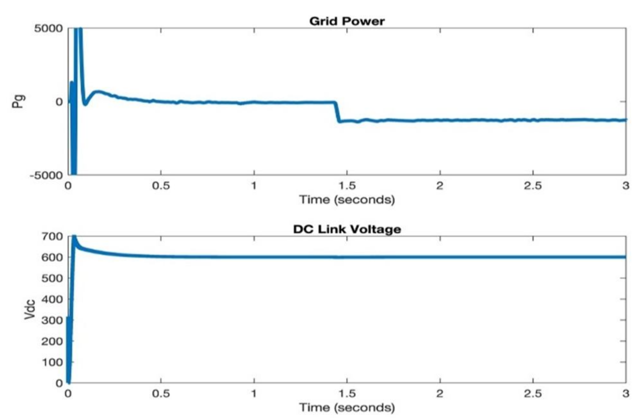

Fig. 13. Grid power and DC link Voltage

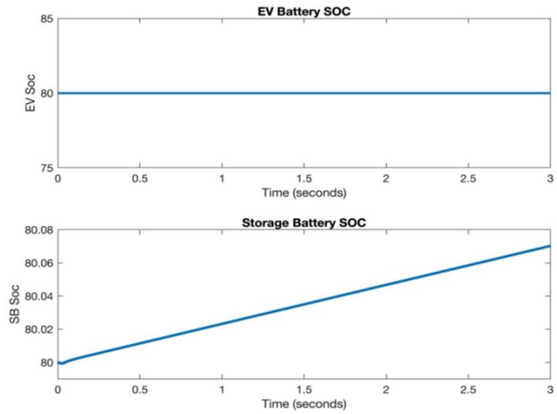

Fig. 14. State of Charge for Electric Vehicle Batteries and Storage Batteries

C. Mode-3

When irradiance and wind are nonexistent, and the electric vehicle (EV) has to be charged, this mode kicks in since the DC micro grid isn't available. Since the power output from solar panels, wind turbines, and the battery is all zero kilowatts, this charging option involves drawing the eight kilowatts of power needed to charge the electric vehicle's battery from the power grid. In the event that renewable energy sources are unavailable, this will guarantee that the EV can continue to run. This mode showcases the system's adaptability to different conditions, making sure that electric vehicle charging goes smoothly. Solar, wind, and storage battery power output, as well as electric vehicle battery input, are illustrated in Figure 15. The grid's voltage and current are displayed in Figure 16. The DC link voltage and grid power are displayed in Figure 17. Fig. 18 displays the state of charge (SOC) for both EV and storage batteries.

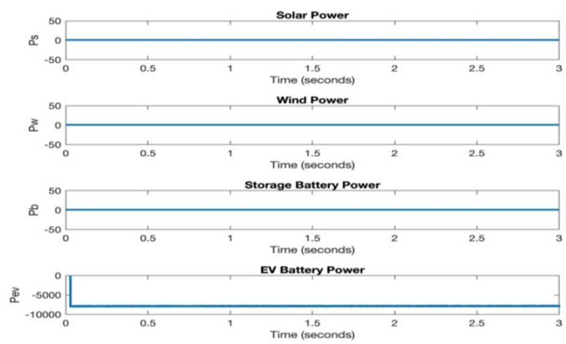

Fig. 15. Electric vehicle (EV) battery power input and output from renewable energy sources

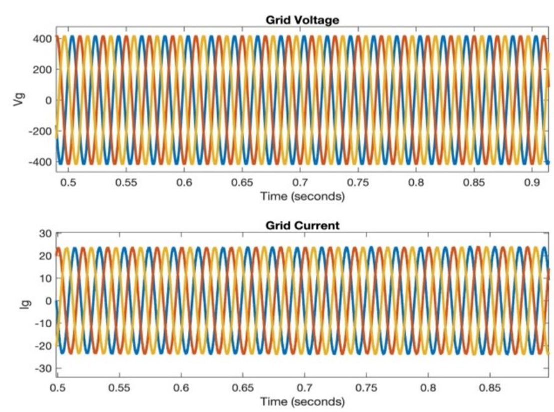

Fig 16. Grid voltage and grid current

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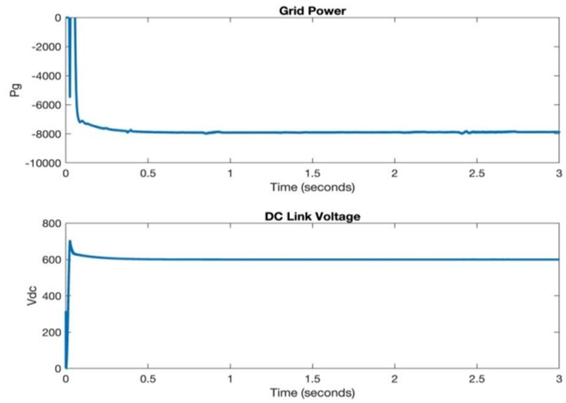

Fig 17. Grid power and DC link voltage

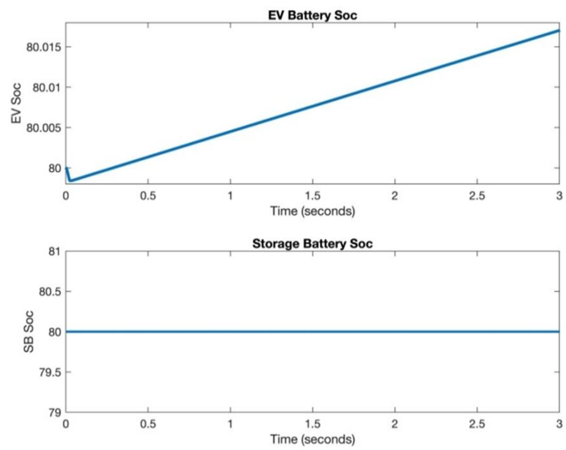

Fig 18. EV battery SOC and storage battery SOC

D. Mode-4

In this mode, the system functions when Vehicle-to-Grid (V2G) capabilities is required. Recharging the grid is the end result of this system's integration of solar, wind, storage, and electric vehicle batteries. Power generation in this mode comes from solar panels, wind turbines, storage batteries, and electric vehicle batteries, totaling 8 kilowatts. Aside from charging electric vehicles, the system can also feedback extra power to the grid when needed, thanks to the two-way flow of energy. Mode-4 helps integrate sustainable energy solutions, reduces dependence on fossil fuels, and enhances grid stability by using EV batteries and renewable energy sources. The plot of power output for solar, wind, storage, and electric vehicle batteries is depicted in Figure 19. The grid's voltage and current are displayed in Figure 20. The DC link voltage and Grid power are shown in Figure 21. Standby power of EV and storage batteries is depicted in Fig. 22.

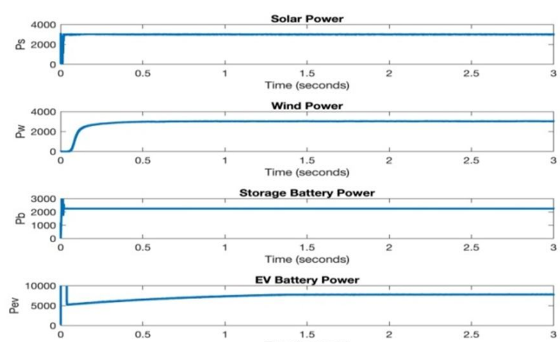

Fig. 19. Electric vehicle (EV) battery, storage, solar, and wind power generation output

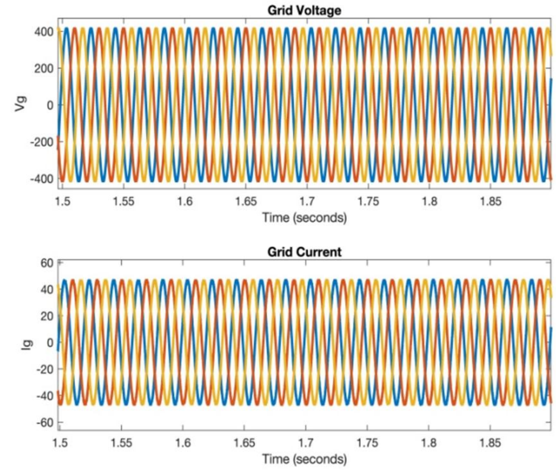

Fig. 20. Grid voltage and grid current

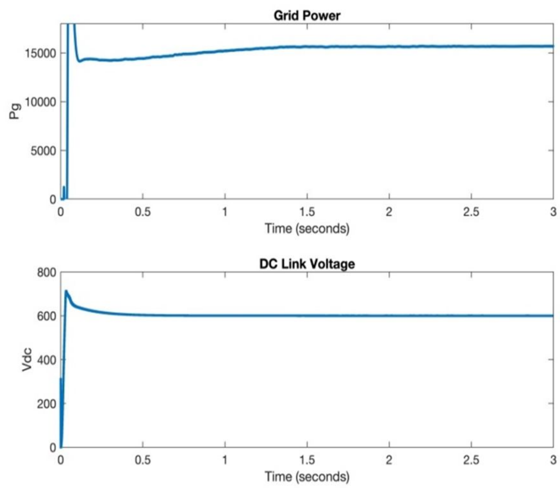

Fig 21. Grid power and DC link voltage

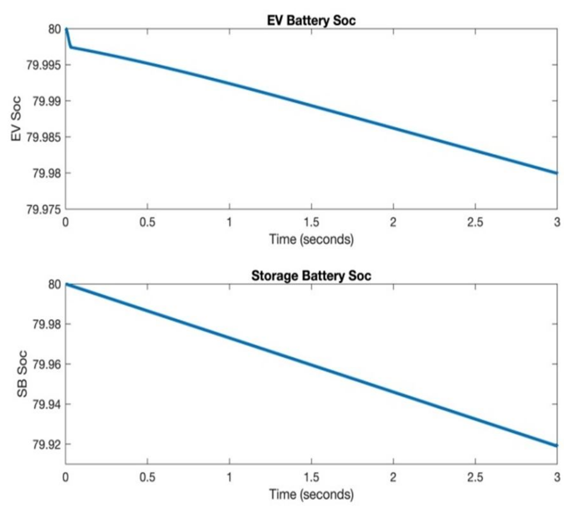

Fig 22. State of Charge for Electric Vehicle Batteries and Storage Batteries

VI. CONCLUSION

A bidirectional electric vehicle charger that integrates with the grid and uses renewable energy sources is proposed in this research. The suggested system incorporates both G2V and V2G modes and operates continuously in grid-connected mode. The results are generated using the MATLAB Simulink software. The system efficiently manages the flow of active and reactive power, guaranteeing a stable DC-link voltage and efficient energy transmission. It does this by integrating solar and wind power with battery storage and using the d-q control technique. To lessen reliance on the grid, EV charging stations employ maximum power point tracking (MPPT) techniques to glean the greatest energy possible from renewable sources. It also adds high-quality, additional power to the system. There is a 2.6% THD in mode-1 and a 1.47% THD in mode-4.

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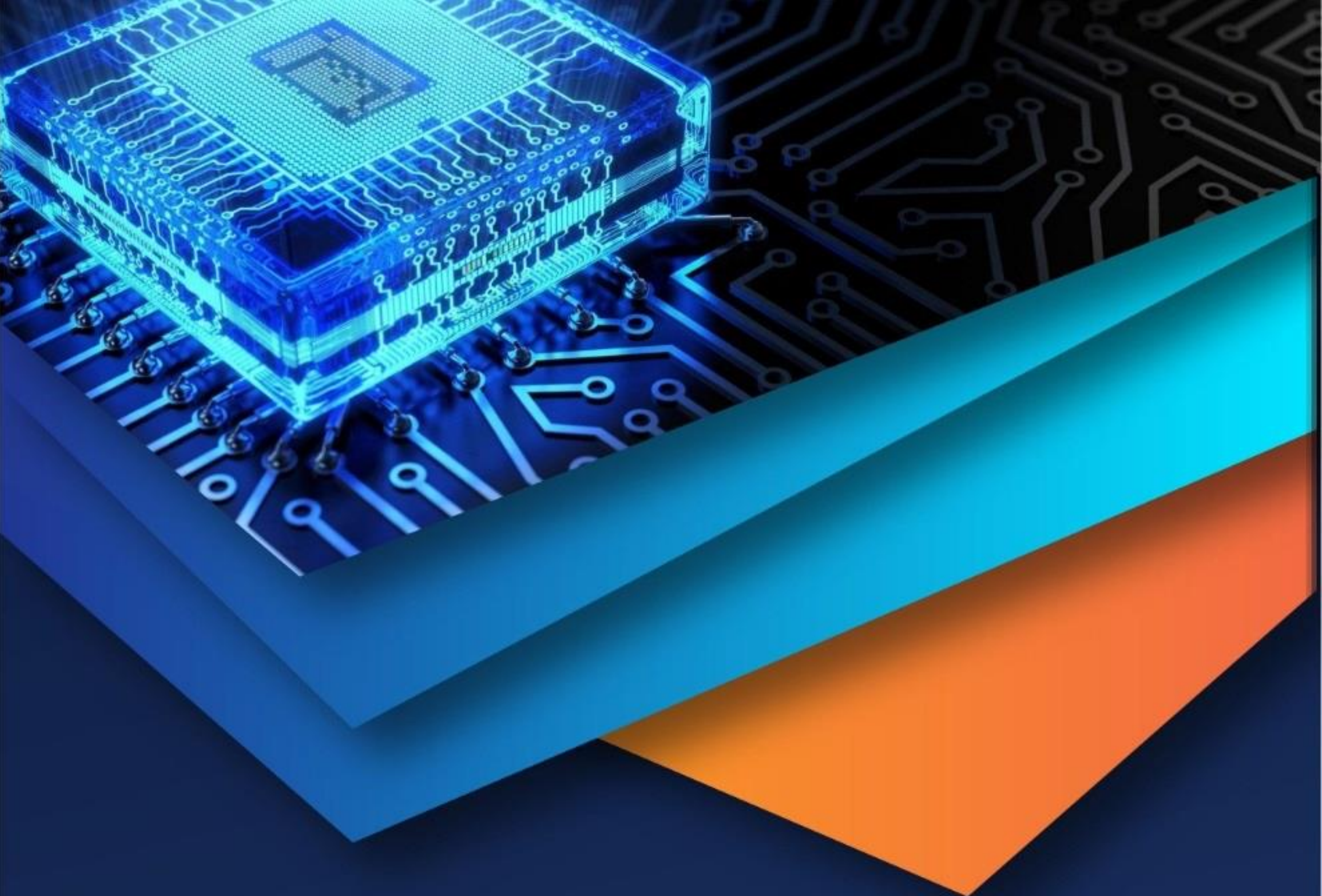

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