PV/ Wind/ Battery/ Grid Integrated Hybrid Energy System for EV Charging Station

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Abstract: As fossil fuel supplies run out, renewable energy sources, or RESs, are becoming increasingly important. Due to their accessibility and user-friendliness, solar and wind energy systems are the most popular RESs. In order to improve energy efficiency and dependability, this work combines solar (PV) panels, wind energy systems, and electric vehicle (EV) charging stations into a hybrid energy system (HES). A Maximum Power Point Tracking (MPPT) system based on fuzzy logic is used to maximize energy conversion in wind and photovoltaic systems. A fuzzy MPPT controller is used by the wind subsystem to maximize turbine output under variable wind conditions, while the PV system adapts to changing irradiance, temperature, and nonlinear circumstances for optimal solar energy harvesting. A charge controller regulates battery energy, ensuring efficient charging and state of charge (SOC) monitoring. A grid-connected inverter transforms DC to AC for grid interfacing and a boost converter controls DC voltage for DC loads. Buck-boost converters control voltage and provide real-time SOC, current, and voltage monitoring for EV batteries. When paired with pulse width modulation (PWM), the fuzzy MPPT algorithm ensures efficient power flow throughout the system. Key performance variables, including battery state of charge, load voltage, and current, are continuously monitored. This hybrid system aims to enhance sustainability and energy efficiency for EV charging applications in MATLAB/Simulink.

1 INTRODUCTION

The growing need for efficient and sustainable energy solutions emphasizes how important renewable energy sources are to solving the world's energy problems. In particular, solar and wind energy provide clean, plentiful, and environmentally friendly substitutes for traditional fossil fuels, which makes them crucial for cutting greenhouse gas emissions and halting climate change. In hybrid energy systems, combining photovoltaic (PV) and wind energy units takes advantage of their complementary qualities, where wind may make up for decreased solar output in low light levels, guaranteeing a more steady and dependable energy supply. Furthermore, by optimizing energy extraction under various environmental conditions, Maximum Power Point Tracking (MPPT) algorithms increase the efficiency of these systems, maximizing performance and lowering operating costs.

Hybrid energy systems not only improve energy reliability, but they also help to maintain grid stability by eliminating variations in power generation and demand. By incorporating energy storage technologies such as modern battery systems, these setups may store extra energy created during peak production periods and release it during high-demand periods, assuring continuous energy availability. Furthermore, the hybrid approach reduces the chance of power interruptions, especially in rural or off-grid areas, making it an excellent choice for increasing energy access in underserved areas.

Grid connectivity strengthens these systems by allowing for bi-directional energy flow, where surplus energy may be supplied back into the grid, generating additional revenue streams and encouraging a circular energy economy. This also enables flawless synchronization with the main grid during periods of high demand, improving system adaptability and scalability for future energy requirements.

This work aims to create an integrated energy system that maximizes the possibilities of renewable energy and innovative storage technologies. It

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includes sophisticated control systems to ensure energy efficiency and system stability. The technology seeks to serve essential applications like EV charging infrastructure by offering a sustainable and efficient energy solution. This approach not only promotes the adoption of electric vehicles by addressing their charging needs, but it also helps to achieve the larger aims of lowering greenhouse gas emissions, improving energy security, and fostering energy independence. Furthermore, the hybrid system's adaptability allows for scaling, making it suitable for a variety of geographical regions and energy demands. This ensures its relevance in both urban and remote places, encouraging widespread adoption of sustainable energy technologies.

1.1 MPPT METHODS

MPPT (Maximum Power Point Tracking) is an algorithm in charge controllers that maximizes the output power of PV modules by changing the operating point to the maximum power point. This maximizes the energy yield from sunlight, increasing the efficiency of solar power systems.

The efficiency of The HES (Hybrid Energy System) based EV Charging Station can be enhanced by applying following MPPT algorithms:

1.1.1 Perturb and Observe Technique (P&O)

The Perturb and Observe (P&O) technique tracks the maximum power point (MPP) by gradually adjusting PV voltage. While oscillations can happen near the maximum power point (MPP) in steady-state settings, it tends to shift toward the MPP as power increases. It is extensively used because of its versatility and simplicity, and improvements increase its efficiency.

1.1.2 Incremental Conductance (INC)

The Incremental Conductance method calculates the maximum power point (MPP) by comparing incremental conductance to array conductance. It carefully adjusts voltage to maintain MPP under changing situations. In comparison to P&O, this approach is speedier and less likely to cause oscillations.

1.1.3 Modified Perturb and Observe (P&O)

The modified P&O MPPT algorithm improves on classic P&O by decreasing oscillations around the MPP and increasing tracking speed. It handles quick variations in irradiance or temperature by using adaptive step sizes or anticipatory adjustments. This improves both efficiency and stability in power extraction.

1.1.4 Fuzzy MPPT

The fuzzy MPPT algorithm uses fuzzy logic to determine the maximum power point (MPP) by modifying step size in response to irradiance and temperature. It provides rapid, steady, and adaptive tracking with minimal oscillations, making it perfect for dynamic environments.

Among the MPPT algorithms stated above, the fuzzy MPPT method was chosen for the hybrid energy EV charging station because it is fast, adaptive, resistant to nonlinearity, and successfully manages hybrid system integration.

Because of its versatility, accuracy, and dynamic reaction, the fuzzy MPPT algorithm is favoured for managing abrupt changes in temperature and irradiance. It employs fuzzy logic to deliver faster, more reliable tracking of the maximum power point (MPP) with fewer oscillations than traditional techniques like P&O and INC. It effectively harvests maximum power under a variety of scenarios by dynamically altering step sizes, guaranteeing the smooth integration of grid, PV, wind, and battery systems. This outperforms conventional MPPT algorithms in terms of energy yield, stability, and overall hybrid energy system performance for EV charging.

2 LITERATURE SURVEY

The proposed work(Muthammal, 2018) focuses on a hybrid solar and wind energy system for EV recharging to meet long-distance travel needs. A MATLAB-Simulink model demonstrates significant power generation under various scenarios. Battery swapping reduces charging time, increasing EV adoption and lowering emissions.

In this work titled (Jatoth, 2024) MATLAB/Simulink is used to demonstrate a multi-input transformer-coupled active bridge converter with PV, wind, and battery storage. The stand-alone system maintains steady DC and AC voltages and utilizes P&O MPPT to maximize power extraction. It ensures consistent power delivery under fluctuating load and environmental circumstances.

In the study (Savio, Juliet, et al. , 2019), the author proposed an on-grid solar and wind hybrid system for EV charging that provides dependable power while decreasing grid dependency. It reduces renewable intermittency, lowers carbon emissions, and provides long-term savings. The system promotes green transportation and encourages the use of hybrid renewable energy systems.

In this work (Katageri, Nisahathfareen, et al. , 2021) the researcher, In order to reduce pollution and grid reliance, the author developed a hybrid fast-charging system that uses local renewable energy. For EV charging, a MATLAB-Simulink model illustrates how solar and wind energy operate under various circumstances. By cutting down on charging time, battery switching encourages EV adoption and contributes to a cleaner environment.

In the proposed work (Reddy and Birudala, 2024), the researcher developed an off-grid PV-based EV charging station that uses energy storage systems (ESS) rather than grid electricity. The system produces enough energy based on irradiance and temperature, with ESS providing backup when solar power is insufficient. The model is both cost-effective and sustainable. It demonstrates the potential for future EV charging applications.

In this work (Kumar and Rajan, et al. , 2023), the author in order to efficiently satisfy load demands, MATLAB/Simulink was used to simulate a hybrid energy system (HES) that included PV, WECS, a diesel generator, and battery storage. MPPT algorithms and converters ensure voltage management and consistent performance. The method is ideal for both remote communication and precise watering. During periods of low demand, surplus power can be fed back into the system.

3 METHODOLOGY

Fig.1 shows the block diagram of the proposed method and the motivation behind developing the HES based EV Charging station is to promote a cleaner and eco-friendly transportation instead of depending on fossil fuels.

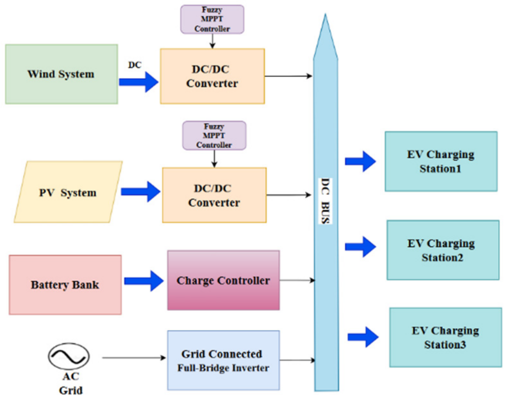

Figure 1: Block Diagram of HES based EV Charging Station

This block diagram illustrates a hybrid energy system that combines wind, solar (PV), battery storage, and the AC grid to power EV charging stations.

The wind and PV systems create DC power, which is optimized with fuzzy MPPT controllers and DC/DC converters. Excess energy is stored in the battery bank and regulated by a charge controller. When renewable sources are insufficient, the AC grid provides electricity, which is converted to DC using a full-bridge inverter. The DC bus takes electricity from multiple sources and transfers it to three EV charging stations, ensuring efficient and long-lasting power delivery.

The proposed system Illustrates the MATLAB/Simulink model of HES based EV Charging Station. In order to guarantee a dependable power source for EV charging, the hybrid energy system integrates solar (PV) and wind energy with battery storage, charge controllers, and grid connectivity. Energy from renewable sources is controlled and directed by charge controllers to either the DC bus for instant consumption or the battery for storage. While buck-boost regulators effectively charge EV batteries, the grid-connected inverter synchronizes with the grid for energy consumption or output.

Hence let’s understand the working of whole model in a Detailed manner :

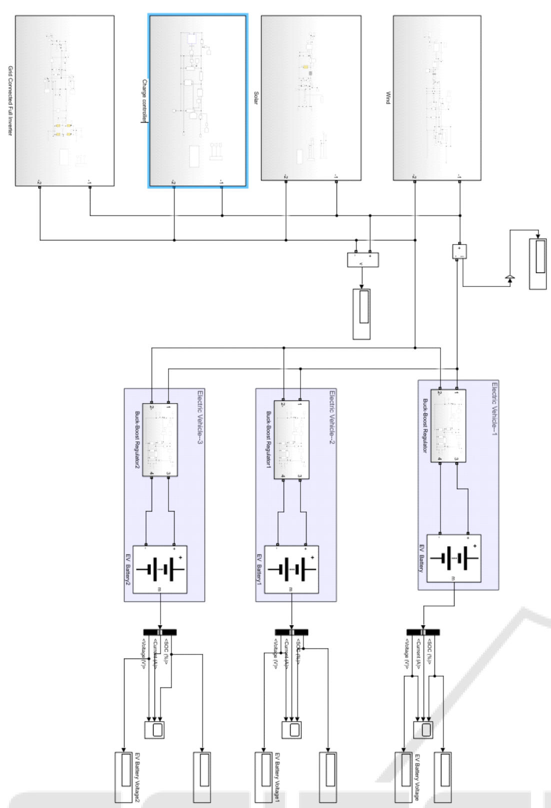

Figure 2: Shows the Simulation of the proposed system

3.1 Wind System

The figure depicts the wind system which has a variable input source. In a In a hybrid energy system, wind energy is converted into electrical power using a turbine, generator, rectifier, and boost converter with MPPT management. The generated electricity is fed into a DC bus, which charges batteries, powers the grid, and provides renewable energy for EV charging. It ensures effective energy use and complements solar PV. Therefore, the specifications of Wind System are illustrated in the given below Table 1

Table 1: Specifications of Wind System

Nominal mechanical output power	2.5kW
Base power of the electrical generator	2777.8VA
Base wind speed	12m/s
Maximum power at base wind speed	1pu
Base rotational speed	1.3m/s

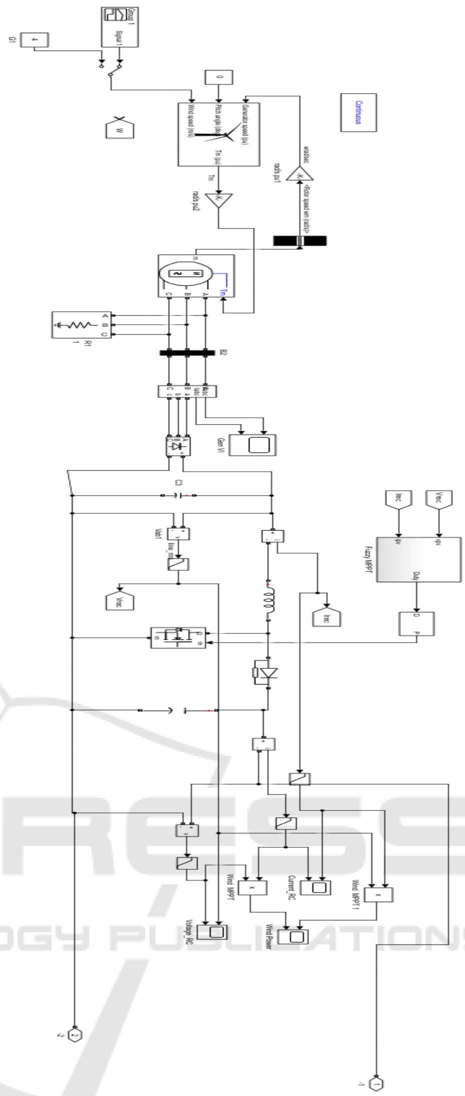

Figure 3: Simulation of Wind System

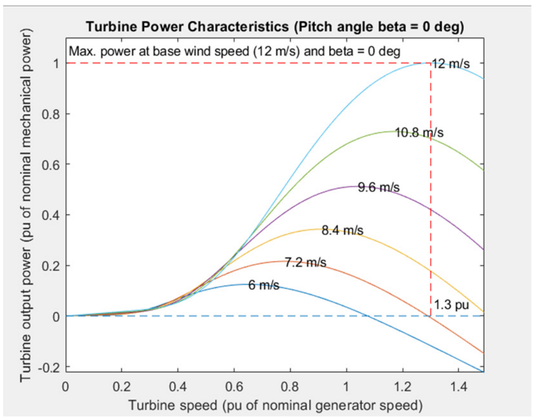

Figure 4: Turbine Speed vs Turbine output power characteristics of wind Turbine for 6 to 12m/s

The above figure depicts the speed vs output power characteristics of WECS or Wind system of EV Charging station for 6 to 12m/s and a fixed pitch angle (β=0 degrees). The turbine highlights the ideal operating locations for the greatest efficiency at each wind speed by achieving maximum power at a certain turbine speed.

3.2 PV System

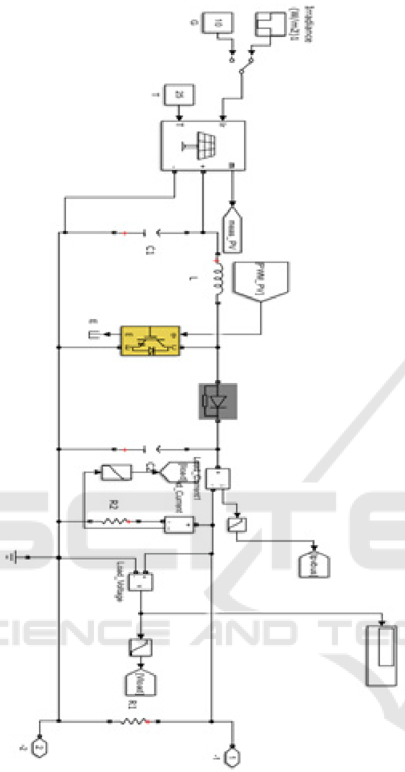

Figure 5: Simulation of PV system

The above figure illustrates the PV system in which the hybrid energy arrangement that turns solar irradiance into DC electricity via solar panels. A DC-DC converter with MPPT optimizes power production, and energy is stored in batteries or delivered directly for EV charging. It integrates smoothly with wind and grid inputs to ensure consistent energy delivery.

Table 2: Specifications of PV System

Maximum Power (W)	250.205
Open circuit voltage Voc (V)	37.3
Short circuit current Isc (A)	8.66
Voltage at maximum power point Vmp (V)	30.7
Current at maximum power point Imp (A)	8.15

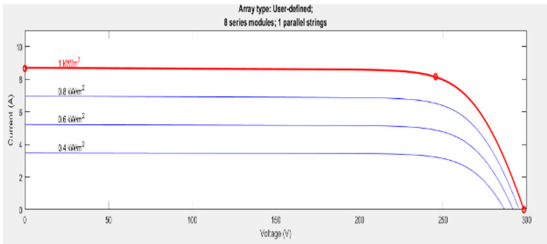

Figure 6(a): V-I Characteristics of PV Panel

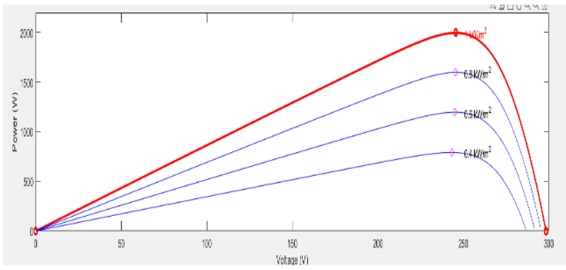

Figure 6 (b): P-V Characteristics of PV Panel

Figure 6(a) Illustrates the V-I Characteristics of PV Panel Which is a plot of Current(A) vs Voltage (V) of PV Panel where the results reveal that the voltage and current oscillate steadily following transients, and the power stabilizes at a constant amount. This demonstrates that the recommended control technique is successful.

Figure 6(b) Illustrate the P-V Characteristics of PV Panel under varying irradiance levels, which is plot of Power (W) vs Voltage (V) of PV Panel that shows the system's versatility that indicate a change in the maximum power point with increasing irradiance. This demonstrates how adaptable it is to changes in the environment.

The PV installation has to ensure that the panels receive the most sunlight possible, and the charging station's solar plant area (Area α Power output) is minimal. Some may suggest using high-power concentrators to boost power production; however, doing so raises the cost.

The plant's cost and upkeep. Choosing hybrid solutions like wind, biomass, or small hydro plants is a better idea. For dry regions, a solar-wind hybrid is the greatest choice when taking integration costs and efficiency into account.

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3.2 Fuzzy MPPT controller for Wind and PV System

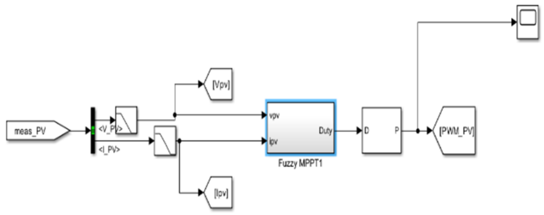

Figure 7: Simulation of Fuzzy MPPT controller

The fuzzy MPPT controller uses fuzzy logic to calculate the appropriate duty cycle for the DC-DC converter. It uses inputs such as PV voltage and current to track the maximum power point (MPP) under changing irradiance and temperature conditions, assuring maximum energy extraction from the PV system.

3.3 Charge Controller

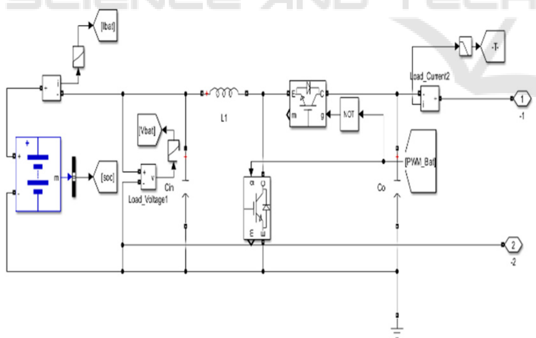

Figure 8: Simulation of Charge controller

The above figure illustrates the charge controller controls the flow of power between the battery, EVs, and PV/wind energy sources. It keeps the battery from being overcharged or deeply discharged, extending its lifespan. For optimum system efficiency and smooth grid integration, it also controls energy distribution. Let’s understand the working of charge controller in depth

The producing plant uses MPPT control, and the charging control is mostly reliant on the ESS's SOC and power supply. The terms Power from Hybrid Plant (Hp), Power Demand (Pd), and SOC of ESS (Se) refer to its four operating modes.

Mode 1: When PP > PD and SE is within maximum and minimum limits, electricity is given to the EV and surplus power is sent to ESS.

Mode 2: When PP>PD and SE is out of limits, the surplus power will be given to grid or connected to dummy loads for Power balance.

Mode 3: When PP, PD, and SE are between limitations, ESS supplies the demand from EV.

Mode 4: When Hp < Pd and Se < minimal value, energy demand is taken from grid to DC bus. If our charging station is in an off- grid area, we intend to operate in the above 3 modes. Similar to a solar plant.

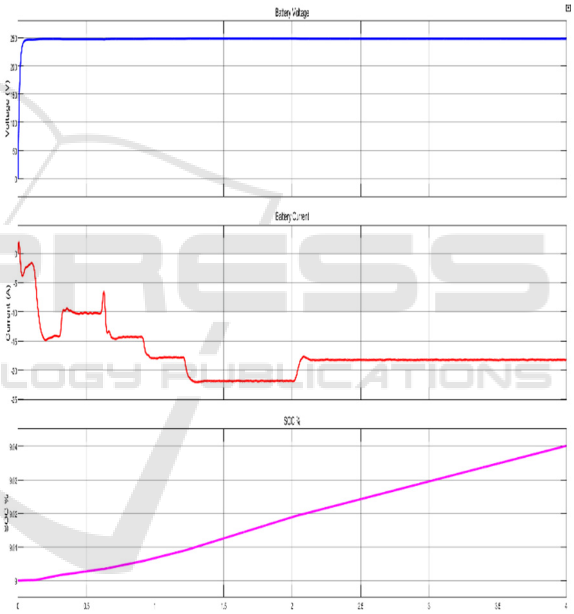

Figure 9: Battery Voltage vs Time, Battery Current vs Time, SOC vs Time output

The above figure illustrates the output of battery whose working is observed in Charge controller. The battery voltage stabilizes, the current varies while charging, and the state of charge (SOC) increases linearly with time, according to the data. This attests to the battery charging system's efficient operation.

3.3 Grid connected Full bridge DC-AC Converter

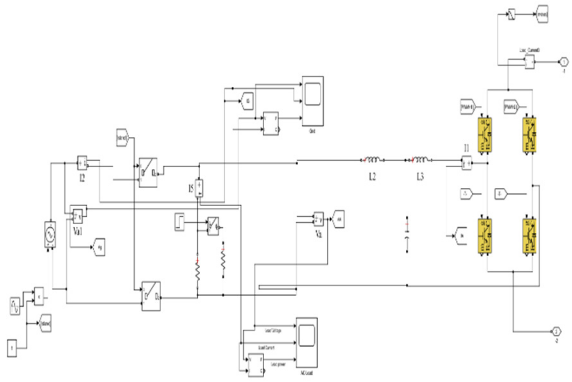

Figure 9: Simulation of Grid connected Full bridge DC-AC Converter

The hybrid energy system's grid-connected full-bridge DC-AC converter converts DC power from renewable sources and batteries into AC power that is synced with the voltage and frequency of the power grid. It allows the system to either export surplus energy to the grid or draw energy when demand exceeds generation, guaranteeing a consistent power supply for EV charging.

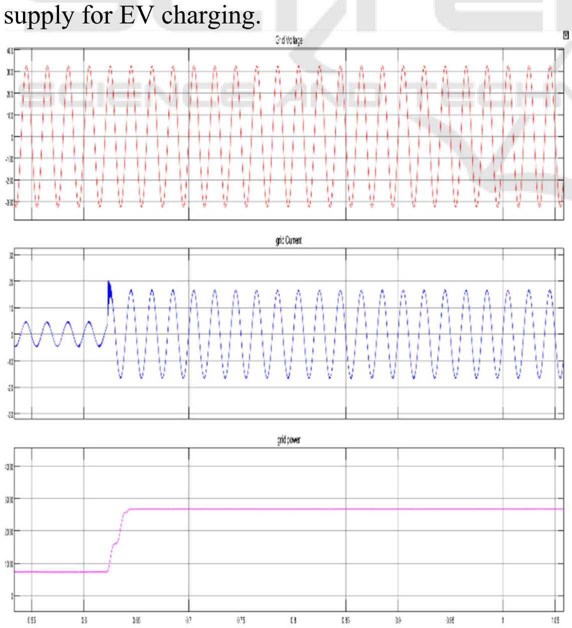

Figure 10: Grid Voltage vs Time, Grid Current vs Time, Grid power vs Time outputs

Figure 10 illustrates the output Grid whose working is observed in Grid connected Full bridge DC-AC Converter. Here we can observe that battery performs efficiently when the SOC rises gradually, the voltage stays constant, and the current dynamically fluctuates in response to changes in the load.

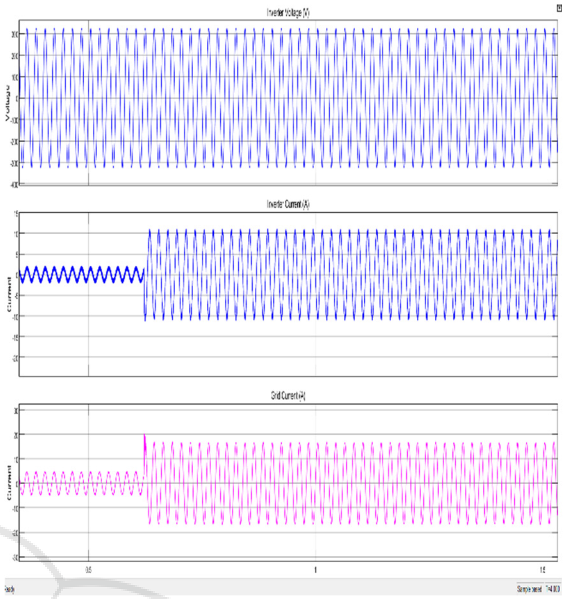

Figure 11. Inverter Voltage vs Time, Inverter Current vs Time, Grid Current vs Time output

Figure 11 illustrates the outputs of inverter whose working is observed in Grid connected Full bridge DC-AC Converter. The results indicate that after initial transients, inverter voltage and current stabilize, and grid current synchronizes. This attests to reliable functioning and good grid integration.

3.4 EV Charging Station

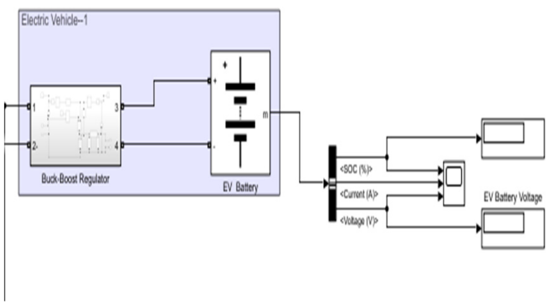

Figure 12: Simulation of EV Charging Station

If the EV charging station above is not linked to the hybrid energy system, it gets its electricity straight from the grid. Power converters transform the AC power from the grid into the proper DC voltage. Buck-boost regulators guarantee that the voltage is changed to satisfy the unique charging needs of the EV battery, resulting in safe and effective charging. The Specifications of EV battery are shown below.

Table 2. Specifications of EV Battery

Type	Lithium-Ion
Nominal Voltage (V)	12
Rated Capacity (Ah)	100
Initial State-of-Charge(%)	75
Battery response time (s)	30

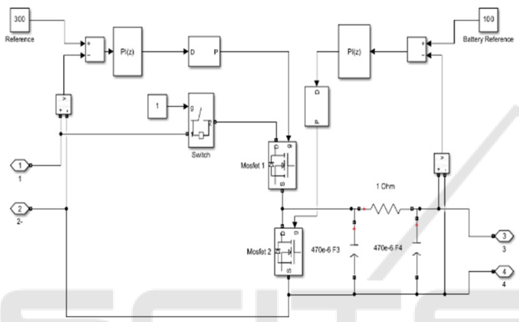

Figure 13: Simulation of Buck-Boost Regulator of EV Charging Station

An EV charging station's buck-boost regulator modifies the hybrid energy system's voltage to meet the needs of the EV battery. In order to ensure a steady and effective charging process and safeguard the battery from overvoltage or undervoltage situations, it adjusts the input voltage as necessary. In this way all the subsystems integrated with Hybrid energy system collectively work together.

4 RESULTS

4.1 Results for EV Charging Station 1

The simulation results in Figure 14 indicate that while charging, SOC increases linearly, current decreases exponentially, and voltage stabilizes with time. This attests to the system's effective and regulated battery charging mechanism.

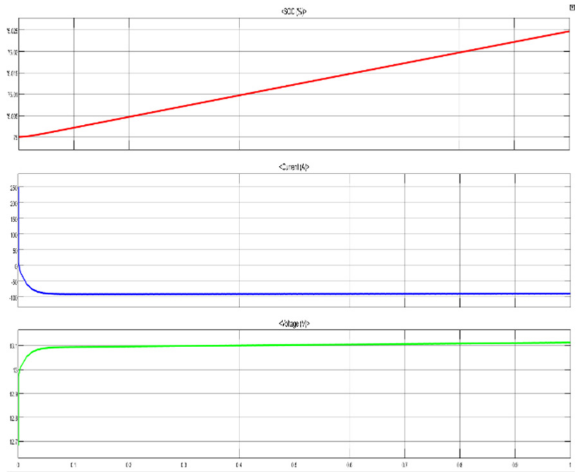

Figure 14: SOC, current and voltage vs time for EV Charging Station 1

4.2 Results for EV Charging Station 2

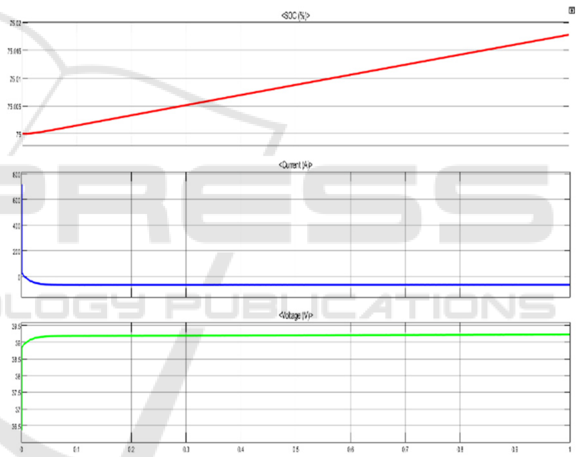

Figure 15: SOC, current and voltage vs time for EV Charging Station 2

The simulation results in Figure 15 demonstrate the battery's performance under load, with SOC dropping linearly, current stabilizing following an initial transient, and voltage attaining steady state, assuring a consistent energy supply.

4.3 Results for EV Charging Station 3

The simulation results demonstrate the battery's behaviour under load, with SOC dropping linearly, current stabilizing after an initial transient, and voltage attaining steady state, resulting in constant energy production.

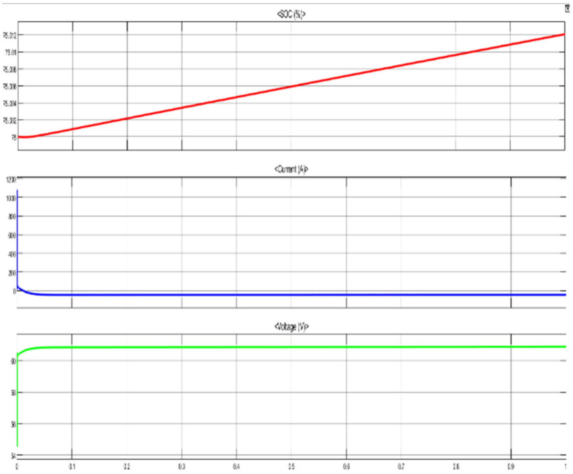

Figure 16: SOC, current and voltage vs time for EV Charging Station 3

5 CONCLUSIONS

The PV/Wind/Battery/Grid Integrated Hybrid Energy System for EV Charging Stations provides an economical and environmentally friendly way to satisfy the increasing energy needs of EVs. The system guarantees a consistent and dependable power supply by utilizing renewable energy sources such as wind and solar power, in addition to battery storage and grid connectivity.

It limits reliance on non-renewable energy sources, maximizes energy use, and lowers carbon emissions. Sophisticated power converters, charge controllers, and energy management systems enhance its overall efficiency and operating stability. In addition to meeting EV charging requirements, this hybrid strategy makes a substantial contribution to the worldwide shift to cleaner and greener energy systems.

6 FUTURE SCOPE

Future improvements include incorporating AI-powered smart grids, blockchain for energy trading, and vehicle-to-grid (V2G) technology to improve energy management. Improvements in battery technology, Calculation of both SOC and SOH. Ultra-fast charging will boost system performance.

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