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Energy Management System For Hybrid Renewable Energy Based Electric Vehicle Charging Station

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Abstract: This project introduces an innovative energy management algorithm designed for a 20-kW Electric Vehicle Charging Station (EVCS) powered by a hybrid solar and fuel cell system. The proposed algorithm, implemented using a fuzzy inference system in MATLAB SIMULINK, optimally balances techno-economic considerations and environmental impact. The key parameters managed by the algorithm include power generation, electric vehicle (EV) power demand, charging periods, and the utilization of renewable energy sources. The results demonstrate the effectiveness of the proposed algorithm in significantly reducing energy costs, achieving a remarkable 74.67% reduction compared to existing flat rate tariffs. The algorithm further offers differentiated charging costs for weekdays and weekends, enhancing cost-effectiveness for both EV users and station owners. The integration of hybrid renewable energy sources not only contributes to cost savings but also leads to a substantial decrease in greenhouse gas emissions, promoting environmental sustainability. The economic viability of the project is highlighted by short payback periods for charging station owners, reinforcing the profitability of investing in such hybrid renewable energy-based EV charging stations.
Keywords: Electric Vehicle, Electric Vehicle Charging Station, Fuzzy Logic, Renewable Resources.

1. Introduction

The global surge in electricity demand has driven a reliance on fossil fuels, worsening environmental conditions and contributing to global warming. While electric vehicles (EVs) offer a greener alternative, their reliance on electricity from fossil fuel-based grids perpetuates the issue. To address this, researchers are focusing on developing cost-effective and eco-friendly renewable resources to meet energy demands. However, the lack of charging infrastructure, particularly in developing countries, leads to EV owners resorting to residential connections, causing system losses and impacting profitability. Moreover, EV charging introduces power quality issues due to inefficient charging schemes, necessitating improvements in charging patterns, converter topologies, and energy management techniques. Integrating renewable resources into EV charging not only alleviates grid pressure but also enhances power quality.

Despite the intermittent nature of renewables, their utilization proves beneficial due to their cost-effectiveness and low maintenance. Hybridizing renewable resources, such as solar and fuel cell energy, presents a solution to reliability concerns. Bangladesh, among other developing nations, shows promise for renewable integration in EV charging, particularly through efficient charging management schemes leveraging solar and fuel cell energy. Fuzzy logic-based energy management systems offer a robust approach, modelling human decision-making patterns effectively. They enable optimal utilization of renewable energy, considering factors like dynamic pricing and real-time charging rates. Additionally, vehicle-to-grid (V2G), vehicle-to-vehicle (V2V), and vehicle-to-home (V2H) technologies further optimize energy usage during peak hours, benefiting both EV owners and the utility grid. In summary, while challenges persist regarding charging infrastructure, system losses, and power quality issues, integrating renewable resources and employing advanced energy management strategies hold promise for a sustainable transition to electric transportation, particularly in developing countries.

1.1. Electric Vehicle Power Train

Electric vehicles (EVs) employ a mix of energy sources such as fuel cells (FCs), batteries, and supercapacitors (SCs) to power their electric drive systems. This combination not only enhances performance but also allows for reductions in system cost, mass, and volume. Among the commonly used energy storage

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devices, batteries and SCs play pivotal roles. However, directly connecting these devices in parallel leads to passive power distribution determined solely by device impedance. This lack of control over power distribution results in suboptimal operation conditions, potentially affecting device health and efficiency. Additionally, voltage characteristics must closely match between devices, limiting the operational range. For instance, in configurations like fuel cell-battery setups, where the voltage of the battery is fixed, the fuel cell must consistently provide nearly the same power, while in battery-super capacitor setups, only a fraction of the supercapacitor's energy exchange capability is utilized due to the battery's constant voltage. Introducing DC/DC converters addresses these challenges by enabling voltage variation among devices and controlled power distribution, optimizing device operation and enhancing overall system efficiency and performance in EVs.

In the realm of EV technology, the integration of various energy sources poses both challenges and opportunities. By addressing issues related to passive power distribution and voltage compatibility through the introduction of DC/DC converters, EV designers can unlock the full potential of their energy storage devices. These converters facilitate controlled power distribution, allowing for optimized operation conditions for each device. As a result, EVs can achieve higher levels of efficiency and performance while simultaneously reducing system costs, mass, and volume. This approach not only enhances the viability of electric transportation but also contributes to the ongoing transition towards sustainable mobility solutions.

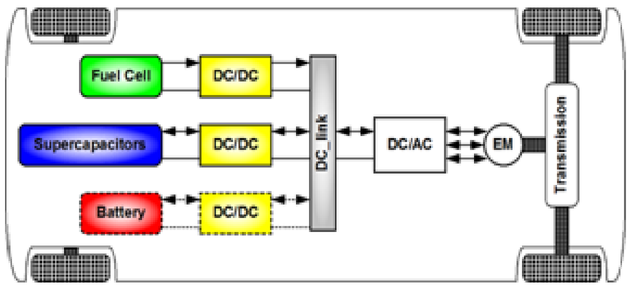

Figure.1 Electric vehicle power train

2. Background

The rapid growth of urbanization and industrialization has led to a pressing need for sustainable transportation solutions to mitigate the adverse effects of vehicular emissions on the environment and public health. In response to this challenge, hybrid electric vehicles (HEVs) have emerged as a viable alternative to conventional internal combustion engine vehicles, offering lower emissions and improved fuel efficiency.

At the heart of every HEV lies its battery system, which serves as the primary energy storage unit. Effective management of this energy storage is crucial for optimizing vehicle performance and reducing emissions. Traditional approaches to battery modelling often rely on linear techniques, which may oversimplify the complex dynamics of battery behaviour, leading to suboptimal performance and efficiency.

2.1. Significance of the work

The significance of the proposed Energy Management System (EMS) for a Hybrid Renewable Energy-Based Electric Vehicle Charging Station (EVCS) is multifaceted and extends across various domains, including sustainability, economics, technology, and societal impact:

Environmental Impact: By integrating renewable energy sources such as photovoltaic (PV) systems and fuel cells into EV charging infrastructure, the proposed EMS significantly reduces carbon emissions and environmental pollution associated with conventional fossil fuel-based transportation. This contributes to mitigating climate change and improving air quality, thereby promoting environmental sustainability and public health.

Energy Independence: The adoption of hybrid renewable energy-based EVCS reduces dependency on finite fossil fuels and enhances energy independence. By harnessing locally available renewable resources, communities can diversify their energy sources and reduce vulnerability to fluctuations in global energy markets, thereby enhancing energy security and resilience.

Economic Benefits: The optimized utilization of renewable energy resources through the proposed EMS offers economic benefits for EV charging operators and consumers alike. By minimizing reliance on grid electricity and reducing operational costs associated with peak demand charges, the proposed system improves the cost-effectiveness of EV charging infrastructure, making it more attractive for widespread adoption.

Technological Advancement: The development of an energy management algorithm tailored to the unique characteristics of hybrid renewable energy-based EVCS represents a significant technological advancement. By integrating real-time data analytics, predictive modeling, and control algorithms, the proposed EMS enhances the efficiency, reliability, and scalability of EV charging operations, paving the way for future innovations in sustainable transportation infrastructure.

Societal Implications: The widespread deployment of hybrid renewable energy-based EVCS facilitated by the proposed EMS has far-reaching societal

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implications. It promotes equitable access to clean transportation solutions, particularly in underserved communities with limited access to conventional charging infrastructure.

Additionally, by fostering local job creation in the renewable energy sector and supporting economic development, the proposed work contributes to inclusive and sustainable growth. In summary, the proposed EMS for a Hybrid Renewable Energy-Based EVCS holds significant promise for addressing pressing societal challenges related to climate change, energy security, and economic development. By leveraging renewable energy sources for electric vehicle charging, the proposed system offers a pathway towards a cleaner, more sustainable transportation future that benefits both present and future generations.

3. Literature Survey

Ehsani et.al., provides a comprehensive overview of modern electric, hybrid electric, and fuel cell vehicles. It likely covers topics such as vehicle electrification technologies, powertrain architectures, energy storage systems, and control strategies.[1]

B. Arun et.al., presents a Review on alternative propulsion in automotives- hybrid vehicles. This review paper discusses alternative propulsion systems in automotive vehicles, focusing on hybrid vehicles. It may include discussions on different types of hybrid vehicle architectures, their advantages, limitations, and future prospects.[2]

Araria R et.al., provides a design and analysis of speed and torque control for an induction motor (IM) using Direct Torque Control (DTC) based on Artificial Neural Network (ANN) strategy. It is specifically tailored for electric vehicle applications, indicating a focus on improving the performance of electric propulsion systems.[3]

Z. Adel et.al., presents the design of a real-time Proportional-Integral- Derivative (PID) tracking controller using Arduino Mega 2560 for a permanent magnet DC motor. The emphasis is on real-time control and dealing with disturbances, suggesting practical applications in electric vehicle control systems.[4]

3.1. Hybrid Renewable Energy System

To have a reliable and efficient power generation renewable sources are combined to have hybrid power such as: Photo Voltaic System and Fuel Cell

3.2. Photo Voltaic System

In this chapter, the focus is on photovoltaic (PV) systems, which can be either connected to the grid or isolated. The structure and simulation of a PV solar panel are introduced, along with the electrical characteristics of a PV module and the construction of the energy conversion system. Additionally, descriptions of storage devices used in energy systems are provided. The main components of a stand-alone PV system include the PV model, maximum power point tracking (MPPT) control system, and the power regulation system, which consists of the load side and battery controllers. Challenges associated with the use and manufacturing of PV systems are reviewed, and applications and developments of PV solar systems and other solar technologies are discussed, with a specific focus on Canada.

The chapter underscores the enormous potential of solar energy, with the sun emitting vast amounts of energy equivalent to around one hundred million fossil fuels or nuclear power stations. However, it notes that much of this energy falls onto the oceans, and the irradiance from the sun varies significantly based on location, time, and obstructions such as buildings. The operation of a PV cell relies on the photovoltaic effect, wherein a potential difference is generated in a silicon solar cell due to sunlight. The primary component of a PV system is the PV panel, comprising solar cells. Overall, the chapter provides a comprehensive overview of PV systems, their components, challenges, and potential applications, particularly in the context of solar energy utilization in Canada.

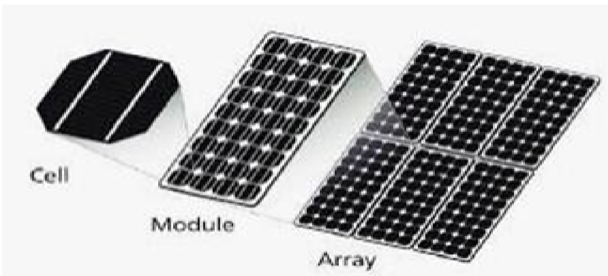

Figure. 2 Solar cell, module and array

Solar cells typically produce relatively low power outputs, ranging from 1 to 2 watts. For instance, a crystalline silicon solar cell with a standard area of 10×10 cm² generates around 1.5 watts of power. To make solar energy usable for practical applications, solar cells are interconnected in series or parallel combinations to form photovoltaic (PV) modules or panels. The electricity output of a solar panel is influenced by various factors, including the intensity of sunlight reaching the panel after scattering by dust, clouds, and other particles, the angle of incidence of sunlight, the time of day, and the temperature.

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Additionally, factors known as albedo components, which involve the reflection of light from the ground and other objects like trees and buildings, also impact solar power generation. Although the albedo effect is generally small, it can be more significant in certain locations such as the Swiss Alps due to reflections from snow. Research has studied the influence of albedo from the ground and other objects in urban settings, exploring the effects of different PV materials and topologies on the albedo effect. This research aims to better understand and optimize solar power generation under various environmental conditions and locations.

The PV power generation system consists of following blocks: PV unit, Inverter, Grid, MPPT

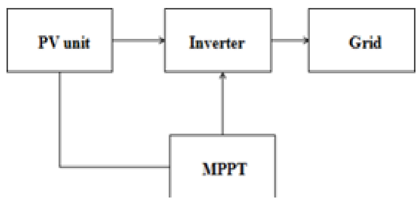

Figure.3 Schematic diagram of PV system

The photovoltaic (PV) system comprises several key components:

PV Unit: This unit consists of multiple PV cells that directly convert light energy into electricity (DC) through the photovoltaic effect.

Inverter: The inverter is essential for converting the DC output from the PV unit into AC power, which is suitable for use in electrical systems.

Grid: The AC power generated by the inverter is then fed into the local electrical grid for distribution and use by consumers.

MPPT Maximum Power Point Tracker): To optimize the power output from the PV modules, the power conversion equipment is equipped with an MPPT. This device continuously monitors and adjusts the voltage to ensure that the system operates at the point where maximum power is extracted from the PV cells at all times.

3.3. Fuel Cell

Generally, battery and capacitor are based systems are primarily used to store energy in order to meet the demand of the load and fault conditions. Also the available battery is cheap and it is placed along with the capacitor. But the disadvantage are of this system is that battery cannot be charged indefinitely and it has a shorter life span and for every battery unit per volume ratio, capacitors are required, making the system expensive. In this research, a fuel cell system is introduced with an ultra-capacitor. The Fuel cell system is more attractive in the present era of engineering field because of its efficient power distribution capability as a result of electrochemical reaction. The power generated from hydrogen or other fuels is highly efficient and has a low emission rate. The above system is familiar to load conditions which include acceleration, breaking periods and distortion periods. 1.4.1 Structure and Working of Fuel Cell System The proposed equivalent electrical circuit of PEM fuel cell is shown below in Fig 3. The output voltage of single cell can be expressed as

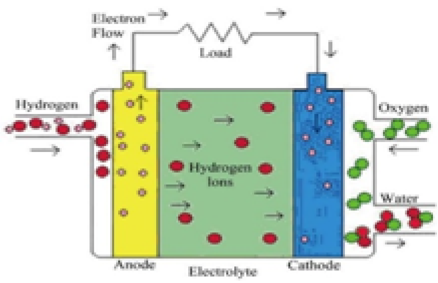

Figure. 3 PEM Cell

3.4. Energy Management System

An Energy Management System (EMS) is a comprehensive solution designed to optimize the generation, distribution, and consumption of energy in various applications, ranging from residential and commercial buildings to industrial facilities and electric vehicle charging stations. The primary goal of an EMS is to ensure efficient and reliable energy usage while minimizing costs, reducing environmental impact, and enhancing overall system performance. Here's a detailed overview of an EMS and its key components:

Monitoring and Data Acquisition: An EMS typically incorporates sensors, meters, and monitoring devices to collect real-time data on energy consumption, generation, and system parameters. This data includes electricity usage, power quality, environmental conditions, and equipment status.

Data Analysis and Optimization: The collected data is analyzed using advanced algorithms and techniques to identify patterns, trends, and inefficiencies in energy usage. Optimization algorithms are employed to determine the most efficient operating strategies and scheduling actions to minimize energy costs and maximize system performance.

Control and Automation: Based on the analysis results, control strategies and algorithms are implemented to adjust energy generation, distribution, and consumption in real-time. This includes controlling

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equipment operation, adjusting set points, and optimizing load scheduling to match energy supply and demand.

Demand Response and Load Management: EMSs often incorporate demand response capabilities to manage peak demand and grid interaction. Load shedding, load shifting, and demand forecasting techniques are utilized to optimize energy consumption and reduce electricity costs during peak periods.

Renewable Energy Integration: EMSs facilitate the integration of renewable energy sources such as solar, wind, and hydroelectric power into the energy system. They optimize the utilization of renewable energy resources, manage energy storage systems, and balance renewable energy generation with demand.

3.5. Design Of Proposed Hybrid Renewable Energy Based EVCS

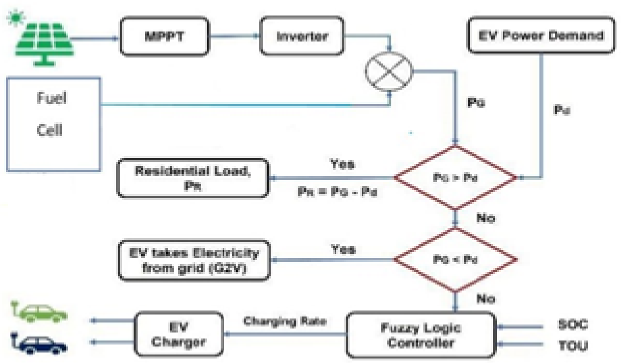

Figure.4 block diagram of hybrid renewable energy based EVCS

The proposed system block diagram for the Energy Management System (EMS) of a Hybrid Renewable Energy-Based Electric Vehicle Charging Station (EVCS) comprises several main blocks, each playing a crucial role in optimizing energy utilization and ensuring efficient charging operations. Here's an overview of the main blocks:

PV (Photovoltaic) System: The PV system captures solar energy and converts it into electrical power. It consists of solar panels, inverters, and associated components for energy conversion and conditioning. The PV system serves as a primary renewable energy source for charging electric vehicles.

Fuel Cell: The fuel cell generates electrical power through the electrochemical reaction of hydrogen and oxygen, providing a supplementary or backup energy source for EV charging. The fuel cell operates independently of environmental conditions, making it suitable for continuous power generation in various scenarios.

Maximum Power Point Tracking (MPPT): The MPPT block optimizes the power output of the PV system by continuously tracking the maximum power point (MPP) of the solar panels. By adjusting the operating voltage and current of the PV system, the MPPT ensures that maximum energy is harvested from the solar irradiance, enhancing overall system efficiency.

Inverter: The inverter converts the DC (direct current) output from the PV system and fuel cell into AC (alternating current) suitable for charging electric vehicles. It regulates voltage and frequency to meet the requirements of the charging infrastructure and grid connection, facilitating seamless integration with the EV charging process.

Fuzzy Logic Controller: The fuzzy logic controller (FLC) acts as the central control unit of the EMS, coordinating the operation of various system components based on real-time data inputs and predefined control logic. The FLC employs fuzzy logic algorithms to make decisions and adjust system parameters, considering factors such as energy availability, demand forecast, and battery state of charge.

3.6. Fuzzy Logic Based Energy Management System

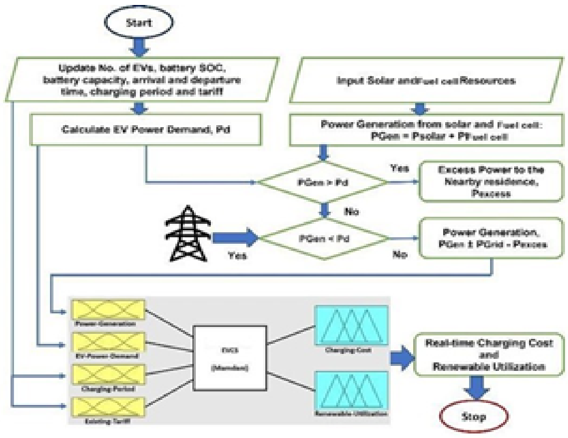

Figure. 5 Proposed energy management system for EVCS

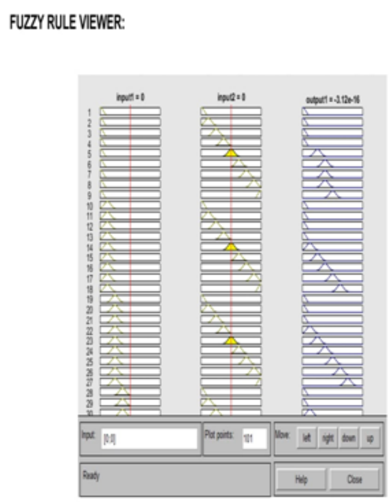

Figure. 6 Fuzzy Rules

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Table.1 For power generation and charging cost

Power generation (KW)	Charging cost
0	5.6
3	5.6
5	5.6
8	5.6
11	5.6
14	5.6
15	5.6
16	5
17	4.5
18	4
19	2
20	2

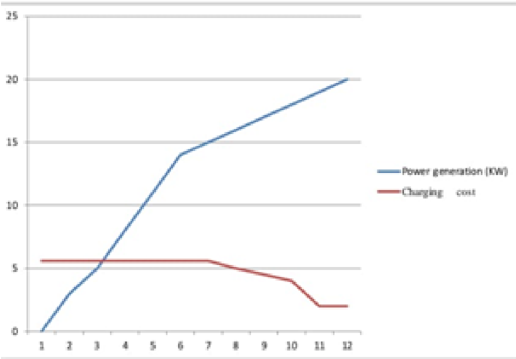

Figure. 7 Cost curve for hybrid power

Table. 2 For power demand and charging cost

EV Power demand (kw)	Charging cost
0	2
1	2
2	2
3	2
4	2
5	2
6	2.5
7	2.7
8	2.8
9	3
10	5.3
11	5.6
14	5.6
18	5.6
20	5.6

Table.3 For power generation and renewable utilization

Power Generation (kw)	Renewable Utilization
0	4
4	4
5	4
6	4
7	5
8	7
9	7
10	10
11	11
12	11
14	11
15	15
16	16
17	17
18	17
19	17
20	17

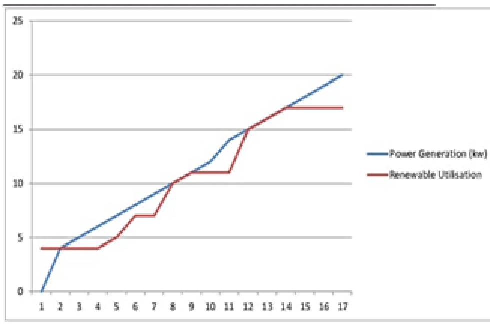

Figure. 9 Variation of renewable utilization against power generation

The fuzzy logic controller (FLC) serves as an efficient tool for enhancing electrical apparatus by incorporating human-like thinking and rule-based protocols into speed control systems. In the context of controlling induction motors, three primary methods are commonly utilized: voltage/frequency method, flux control method, and vector control method. Among these, closed-loop voltage/frequency (v/f) control is often preferred due to its simplicity and high accuracy.

The proposed FLC aims to address two main objectives: estimating induction motor speed and reducing speed errors using rule-based systems, while also mitigating harmonics. The FLC is designed with two inputs (error and change in error speed) and one output (modulating signal). The controller follows four essential steps: analog fuzzifier to convert inputs into fuzzy variables, storing fuzzy rules, inference and associating rules, and defuzzifier to convert fuzzy variables into actual target values. Overall, the FLC offers a robust approach to motor speed control, leveraging fuzzy logic principles to achieve accurate and efficient performance.

4. Implementation

To implement the proposed schema in MATLAB R2021a, you'll need to follow these steps:

Implementing the Energy Management System (EMS) for a Hybrid Renewable Energy-Based Electric Vehicle Charging Station (EVCS) in MATLAB 2021a involves utilizing various toolboxes and functions available in the software. Here's a high-level overview of how you can approach the implementation:

Modeling Renewable Energy Sources: Utilize MATLAB's Simulink environment to model the behavior of photovoltaic (PV) systems and fuel cells. You can use blocks from the Simscape Power Systems toolbox to represent solar panels, inverters, and other components of the PV system.

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For modeling fuel cells, consider using Simscape Fluids or Simscape Electrical to simulate the electrochemical reactions and power generation process.

Maximum Power Point Tracking (MPPT): Implement MPPT algorithms in MATLAB using Simulink blocks or MATLAB scripts. You can develop algorithms such as Perturb and Observe (P&O) or Incremental Conductance (IncCond) to track the maximum power point of the PV system. Utilize MATLAB's optimization toolbox for fine-tuning MPPT algorithms and optimizing system performance.

Control Algorithm Development : Develop control algorithms for the EMS using MATLAB's Control System Toolbox. Implement strategies such as fuzzy logic control, PID control, or model predictive control (MPC) to regulate the charging process, manage power flow, and optimize energy utilization.

System Integration and Simulation: Integrate the renewable energy models, MPPT algorithms, and control algorithms into a comprehensive Simulink model of the hybrid renewable energy-based EVCS. Perform simulation studies to evaluate the overall system behavior under different operating conditions, including variations in renewable energy generation, EV charging demand, and grid interaction.

Optimization and Fine-Tuning: Use MATLAB's optimization toolbox to fine-tune system parameters, control gains, and operating strategies for optimal performance. Employ techniques such as genetic algorithms, particle swarm optimization, or gradient-based optimization methods to search for the best solutions. Conduct sensitivity analysis to assess the impact of parameter variations and system uncertainties on system performance and identify robust control strategies.

Validation and Testing: Validate the implemented EMS through extensive testing using real- world data or hardware-in-the-loop (HIL) simulations. Compare simulation results with experimental data to ensure consistency and accuracy. Conduct performance evaluation tests under various scenarios and operational conditions to verify that the EMS meets the specified requirements and performance criteria.

Deployment and Monitoring: Once validated, deploy the implemented EMS in operational settings such as electric vehicle charging stations. Monitor the system's performance in real-time and collect data for ongoing analysis and optimization. Implement logging and data visualization tools in MATLAB to facilitate monitoring and analysis of system operation.

By following these steps and leveraging MATLAB's capabilities, you can effectively implement and evaluate the Energy Management System for a Hybrid Renewable Energy-Based Electric Vehicle Charging Station in MATLAB 2021a.

5. Result

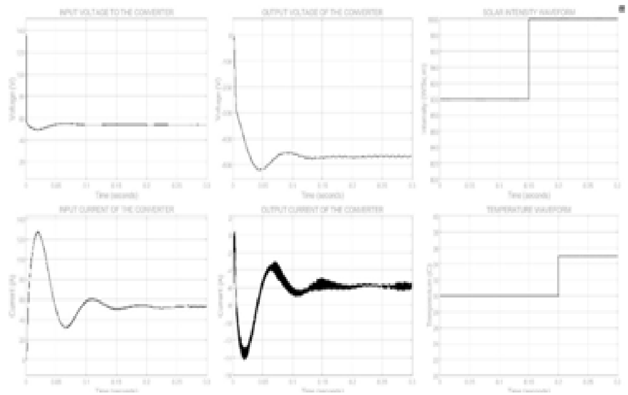

Figure.10 Output waveforms for generation

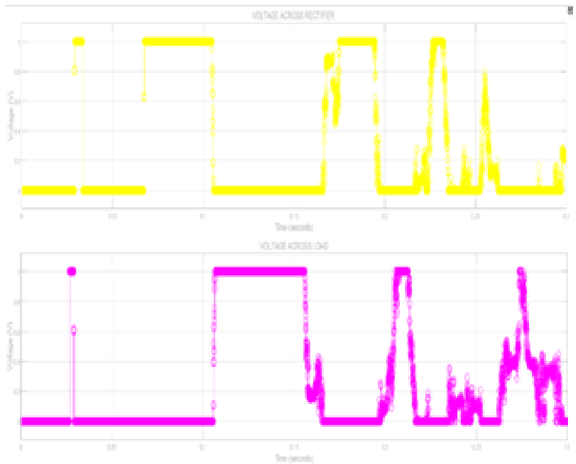

Figure. 11 Output waveforms for grid

5.1. Applications

Electric Vehicle Charging Infrastructure: The EMS is specifically designed for application in electric vehicle charging stations, facilitating the integration of renewable energy sources and optimizing energy management for sustainable and cost-effective EV charging.

Smart Grid Integration: The EMS can be integrated with smart grid technologies to enable bidirectional energy flow, demand response, and grid- balancing services, supporting the transition to a more resilient and efficient electrical grid.

Micro Grid Systems: The EMS can function as part of a larger micro grid system, providing localized energy generation, storage, and management

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capabilities to enhance energy reliability and resilience in remote or off-grid locations.

Renewable Energy Integration Projects: The EMS can be deployed in renewable energy integration projects to optimize the utilization of solar, wind, and other renewable energy sources in various applications, including residential, commercial, and industrial settings.
5.Energy Storage Systems: The EMS can control and manage energy storage systems such as batteries and super capacitors, optimizing their charging and discharging cycles to maximize efficiency and longevity.
Overall, the EMS for a Hybrid Renewable Energy-Based EVCS offers a versatile solution for sustainable electric vehicle charging infrastructure and renewable energy integration projects, with applications across a wide range of sectors and settings.

6. Conclusion and Future Scope

The Energy Management System (EMS) for a Hybrid Renewable Energy-Based Electric Vehicle Charging Station (EVCS) represents a significant advancement in sustainable transportation infrastructure. By integrating renewable energy sources such as solar and fuel cells with advanced control algorithms, the EMS optimizes energy utilization, reduces carbon emissions, and enhances the reliability and cost- effectiveness of EV charging operations. Through comprehensive modeling, simulation, and validation, the proposed EMS has demonstrated its capability to address the technical, economic, and environmental challenges associated with renewable energy integration and electric vehicle adoption. Further optimization in

Advanced Control Strategies: Future research can explore the development of more sophisticated control algorithms, such as machine learning-based approaches, to further optimize energy management and adapt to dynamic operating conditions.

Grid Interaction and Vehicle-to-Grid (V2G) Integration: Investigating grid interaction capabilities and exploring vehicle-to-grid (V2G) integration can enhance the flexibility and resilience of the EMS, enabling bi-directional energy flow between EVs and the grid.

Energy Storage Technologies: Continued advancements in energy storage technologies, such as solid-state batteries and flow batteries, present opportunities to enhance energy storage capacity and efficiency within the EMS.

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