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Enhanced Energy Management System for Hybrid Solar and Fuel Cell-Based Electric Vehicle Charging Stations Using ANN Controllers

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***Abstract*— In order to handle both techno-economic and environmental factors, this study presents an innovative energy management algorithm for a hybrid solar and fuel cell-based electric vehicle charging station (EVCS). In order to optimize real-time charging prices and improve renewable energy consumption, the current approach, which is intended for a 20-kW EVCS, makes use of a fuzzy inference system within MATLAB SIMULINK to manage power generation, electric vehicle (EV) power demand, and charging periods. Nevertheless, production instability could be a problem for this strategy. By replacing the fuzzy controller with an artificial neural network (ANN) controller, the suggested approach resolves this problem. Findings show that, in comparison to current flat rate tariffs, the ANN-based algorithm not only offers more steady outputs but also lowers energy costs, making it more affordable to charge for both weekdays and weekends. Furthermore, integrating renewable energy sources with hybrid technology greatly reduces greenhouse gas emissions. Due to the charging station owners' comparatively short payback periods, the idea is both environmentally friendly and financially feasible.**

***Keywords* — Solar Energy, Fuel Cell, Fuzzy Inference System, Artificial Neural Network, MATLAB SIMULINK etc.**

I. INTRODUCTION

The rapid adoption of electric vehicles (EVs) has necessitated the development of efficient and sustainable charging infrastructures. As the number of EVs on the road increases, so does the demand for charging stations that can provide reliable, cost-effective, and environmentally friendly energy. Traditional electric vehicle charging stations (EVCS) primarily rely on grid electricity, which may not always be sustainable or economical. This has led to the exploration of hybrid renewable energy-based charging stations, which combine multiple renewable energy sources, such as solar power and fuel cells, to reduce dependency on the grid and minimize environmental impact.

Managing the energy flow in hybrid renewable energy systems is complex due to the intermittent nature of renewable sources and the varying power demands of EVs. An effective energy management system (EMS) is crucial for optimizing the performance, cost, and environmental benefits of these systems. Previous studies have employed fuzzy inference systems to manage these complexities by simulating different scenarios and making real-time decisions based on predefined rules. However, while fuzzy logic controllers can handle non-linear systems and uncertainties, they may suffer from stability issues under certain conditions.

To address these challenges, this paper proposes an advanced energy management algorithm that integrates an Artificial Neural Network (ANN) controller in place of the traditional fuzzy logic controller. ANNs are capable of learning from data and can provide more accurate and stable control by adapting to changing conditions over time. This paper focuses on a 20-kW EVCS model implemented in MATLAB SIMULINK, demonstrating how the ANN-based EMS optimizes power generation, EV power demand, and charging periods, leading to reduced energy costs and more stable outputs.

The proposed system not only enhances the economic viability of EVCS by lowering charging costs for both weekdays and weekends but also significantly reduces greenhouse gas emissions by maximizing the use of renewable energy. The integration of hybrid renewable sources, such as solar and fuel cells, contributes to a more sustainable energy solution, with shorter payback periods for charging station owners, thus making the project both environmentally and financially attractive.

In summary, this paper presents a novel approach to energy management in hybrid renewable energy-based EVCS, leveraging the capabilities of ANN to overcome the limitations of fuzzy logic controllers, and provides a comprehensive analysis of the benefits in terms of cost, stability, and environmental impact.

II. Energy Management System

The An Energy Management System (EMS) is a sophisticated framework designed to monitor, control, and optimize the energy production, distribution, and consumption within a specified system. In the context of hybrid renewable energy-based electric vehicle charging stations (EVCS), an EMS plays a crucial role in ensuring the efficient and reliable operation of the charging infrastructure. The primary goals of an EMS include minimizing energy costs, maximizing the use of renewable energy sources, ensuring the stability and reliability of power supply, and reducing environmental impact.

Key Components and Functions of an EMS

A. Power Generation Management

- **Renewable Energy Integration:** The EMS integrates various renewable energy sources such as solar panels and fuel cells. It monitors the availability and performance of these sources to optimize their usage.
- **Grid Interaction:** In cases where renewable energy is insufficient, the EMS manages the interaction with the grid to ensure continuous power supply.

B. Load Management:

- **Demand Forecasting:** The EMS predicts the energy demand based on historical data and real-time inputs from the EVs connected to the charging station.
- **Load Balancing:** It distributes the available energy efficiently among the connected EVs, avoiding overloading and ensuring a balanced supply.

C. Energy Storage Management:

Battery Systems: Many EVCS include battery storage systems to store excess energy generated from renewable sources. The EMS manages the charging and discharging cycles of these batteries to maximize efficiency and lifespan.

D. Cost Optimization:

- **Dynamic Pricing:** The EMS adjusts charging costs in real-time based on the availability of renewable energy, grid tariffs, and demand patterns. This helps in minimizing the overall energy costs for both the station and the users.
- **Economic Dispatch:** It determines the most cost-effective way to generate and distribute energy at any given time.

E. Environmental Impact Reduction:

- **Emission Monitoring:** The EMS tracks greenhouse gas emissions from both renewable and non-renewable sources. By prioritizing the use of clean energy, it helps in reducing the carbon footprint of the EVCS.
- **Sustainability Reporting:** The system provides data and insights for sustainability assessments and regulatory compliance.

F. Real-time Monitoring and Control:

- **System Monitoring:** The EMS continuously monitors the performance and status of all components, including power generators, storage systems, and charging units.
- **Fault Detection and Management:** It detects faults and anomalies in the system and initiates

corrective actions to maintain uninterrupted service.

III. EXISTING METHOD

The Existing 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:

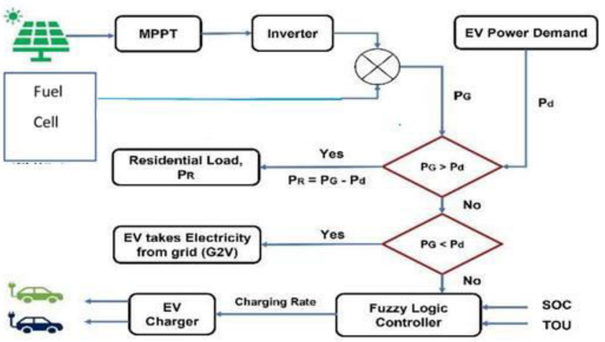

Fig. 1. Existing System

1. **Photovoltaic (PV) Systems:** These systems use solar energy to generate electricity. It is made up of inverters, solar panels, and other related energy conditioning and conversion parts. Electric car charging is mostly facilitated by the photovoltaic system.
2. **Fuel Cell:** A backup or additional energy source for EV charging, a fuel cell produces electricity via the electrochemical reaction of hydrogen and oxygen. Because the fuel cell runs regardless of the surroundings, it can be used in a variety of situations to continuously generate power.
3. **Maximum Power Point Tracking (MPPT):** By continuously monitoring the maximum power point (MPP) of the solar panels, the MPPT block maximizes the power production of the PV system. The MPPT guarantees that the maximum amount of energy is captured from the solar irradiation, improving overall system efficiency, by regulating the operating voltage and current of the PV system.
4. .**Inverter:** This device changes the fuel cell's and PV system's DC (direct current) output to AC (alternating current), which is needed to charge electric cars. It allows for smooth integration with the EV charging process by controlling voltage and frequency to match the needs of the grid connection and the charging infrastructure.
5. Fuzzy Logic Controller: The fuzzy logic controller (FLC), which serves as the EMS's central control unit, coordinates the actions of the system's many parts by using predetermined control logic and real-time data inputs. Fuzzy logic algorithms are utilized by the FLC to make judgments and modify system parameters, taking into account variables like battery state of charge, demand forecasting, and energy availability.

Together, these key components of the suggested system maximize the use of renewable energy sources, guarantee dependable charging operations, and optimize energy management. The EMS addresses the difficulties of renewable energy integration and grid management while enabling effective and sustainable electric vehicle charging by merging PV systems, fuel cells, MPPT, inverters, and fuzzy logic control.

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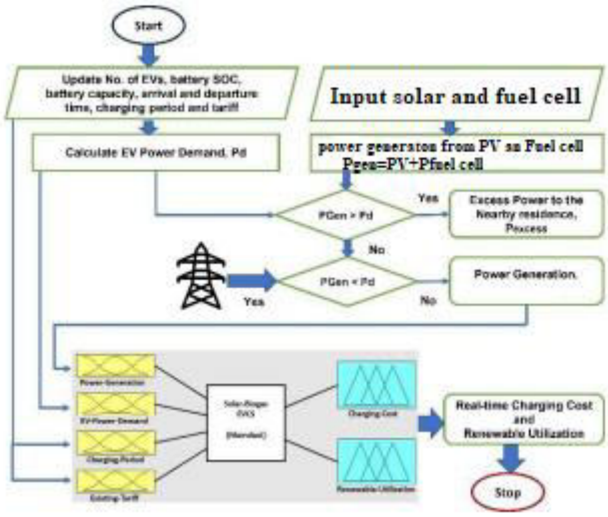

Fig. 2. Energy management system for EVCS.

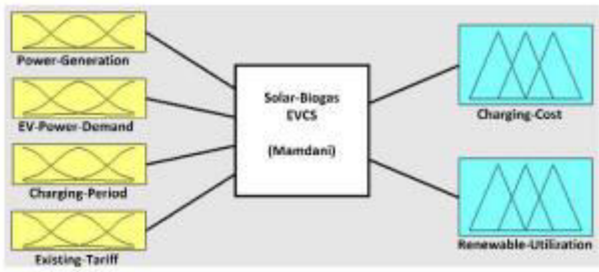

Fig. 3. Fuzzy (Mamdani) optimization model for EVCS

Fuzzy Logic Controller, A One of the most effective tools for improving electrical equipment is its ability to assess speed controllers quickly while integrating rule-based protocols and human reasoning.

Generally speaking, there are three ways to control induction motors: (1) the voltage/frequency approach (2) The vector control approach; (3) The flux control method.

The two primary responsibilities that the proposed FL controller is meant to address are (1) predicting the speed of an induction motor and (2) decreasing speed error by utilizing a rules-based system while simultaneously degrading harmonics.

There are two inputs and one output in the FL controller's design. The modulating signal is regarded as the output, and the error and change in error speed are considered the inputs.

FL controller primarily adheres to the four prerequisite actions, including:

(1) An analog fuzzifier creates fuzzy variables from input.

(2) Fuzzy rules are stored; (3) Inference and related rules

The fuzzy variables are transformed into the actual target by the defuzzifier.

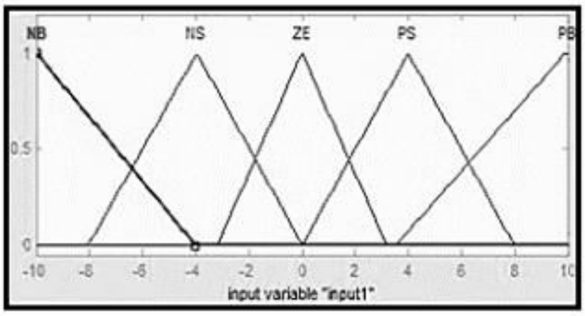

Fig. 4. Proposed system Allocation of range for subsets

e/ce	NB	NS	ZE	PS	PB
NB	ZE	NS	NB	NB	NB
NS	ZE	NS	NB	NS	NB
ZE	PB	PS	ZE	NS	NB
PS	PB	PS	PS	ZE	NS
PB	PB	PB	PB	PS	ZE

Fig. 5. Fuzzy Rules

Two or more relationship values from the fuzzifier input variables make up the fuzzy operator's input. One truth value is the result. If input 1 is stated to represent a mistake, then input 2 represents a changing error. Eight fuzzy subsets make up the linguistic variables; five of these subsets are employed and are explained as follows: Zero error speed (ZE), Positive error speed (PS), Negative error speed Big (NB), Negative error speed Small (NS), and Positive error speed Big (PB) are the five possible negative error speeds. If the output, let's say, is NS, then all rule-based membership functions will function with it if its value is up to 0.3416. As shown in Figure 5, the output of the NB is 0.1, PB is 1, PS is 0.66, and ZE is 0.5.

IV. Proposed Method

The proposed energy management system (EMS) for a hybrid renewable energy-based electric vehicle charging station (EVCS) integrates several key components to optimize energy utilization, ensure reliable charging, and maximize the use of renewable energy sources. The primary component, the Photovoltaic (PV) system, captures solar energy and converts it into electrical power through solar panels and associated energy conversion equipment. This system serves as the primary renewable energy source for charging electric vehicles, reducing reliance on non-renewable energy and lowering greenhouse gas emissions. Complementing the PV system, the Fuel Cell generates electrical power through the electrochemical reaction of hydrogen and oxygen. It operates independently of environmental conditions, providing a continuous and reliable power source, especially when solar energy is insufficient.

To enhance the efficiency of the PV system, the Maximum Power Point Tracking (MPPT) block continuously tracks the maximum power point (MPP) of the solar panels. By adjusting the operating voltage and current, the MPPT ensures maximum energy harvest from solar irradiance. The Inverter then converts the DC output from both the PV system and the fuel cell into AC suitable for charging electric vehicles, regulating voltage and frequency to meet the charging infrastructure and grid connection requirements. At the heart of the EMS is the Artificial Neural Network (ANN) Controller, which acts as the central control unit. The ANN controller processes real-time data from the PV system, fuel cell, MPPT, and inverter, making optimized control decisions based on predefined logic. It ensures the overall system operates efficiently by balancing power generation, storage, and consumption, thus providing stability and reducing energy costs.

Together, these components work synergistically within the EMS to create an efficient and sustainable electric vehicle charging station. The integration of PV systems, fuel cells, MPPT, inverters, and the ANN controller maximizes renewable energy utilization, optimizes energy management, and ensures reliable charging operations. This holistic approach addresses the challenges of renewable energy integration and grid management, offering a viable solution for the growing demand for sustainable EV charging infrastructure.

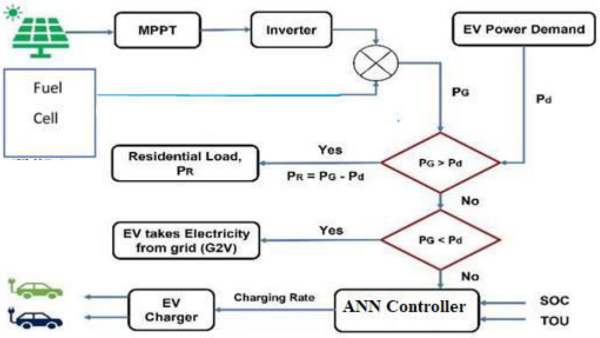

Fig. 6. Proposed system block diagram

ANN CONTROLLER

In energy management system (EMS) tailored for a hybrid renewable energy-powered electric vehicle charging station (EVCS), the Artificial Neural Network (ANN) controller assumes a pivotal role as the central cognitive hub governing the system's operation. Nestled within the intricate network of components, the ANN controller acts as the mastermind, adeptly processing real-time data streams from diverse sources such as the Photovoltaic (PV) system, fuel cell, Maximum Power Point Tracking (MPPT) unit, and the inverter. Through its neural network architecture, the ANN controller harnesses the power of pattern recognition and data analytics to distill insights and formulate optimized control strategies, finely tuned to the unique dynamics of the EVCS.

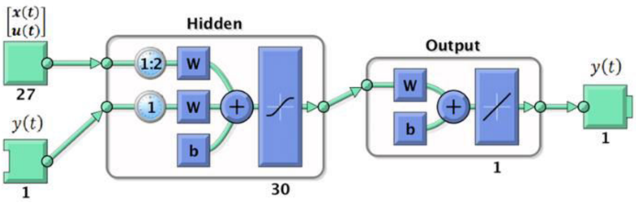

Fig. 7. Neural Network

Equipped with the capability for continuous learning and adaptation, the ANN controller serves as a dynamic decision-maker, iteratively refining its control logic based on real-time feedback and evolving environmental conditions. This adaptability lends resilience to the system, enabling it to swiftly respond to fluctuations in energy supply, demand, and grid conditions, thus ensuring the stability and reliability of EV charging operations. As the linchpin of the EMS, the ANN controller orchestrates the harmonious integration and coordination of all system components, fostering synergistic interactions that maximize energy efficiency and resource utilization.

Moreover, the ANN controller is driven by a dual mandate of cost optimization and sustainability. By leveraging its analytical prowess, it navigates the complex landscape of energy pricing and demand patterns to minimize operational costs while prioritizing the utilization of renewable energy sources. This proactive stance towards sustainability aligns with broader environmental objectives, driving the transition towards a greener and more sustainable energy ecosystem. In essence, the ANN controller epitomizes the fusion of intelligence and adaptability, propelling the EVCS towards a future characterized by efficiency, resilience, and environmental stewardship.

V. Simulation Results

The simulation results for both the existing method and the proposed method provide valuable insights into the performance and efficiency of the energy management system (EMS) for the hybrid renewable energy-based electric vehicle charging station (EVCS)

A. *Existing Method*

This block diagram and simulink model illustrates in fig.8 and fig.9, the simulation setup for the existing method, focusing on the PV Landsman Converter component.

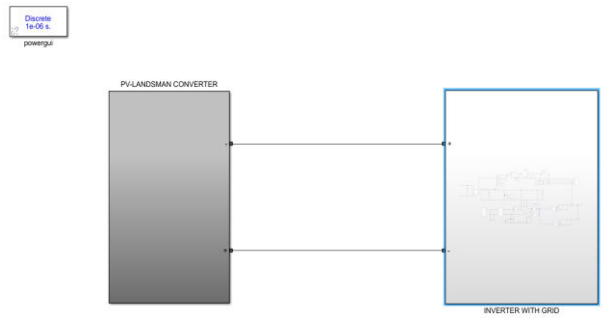

Fig. 8. Existing method simulink block diagram

1. *PV landsman converter*

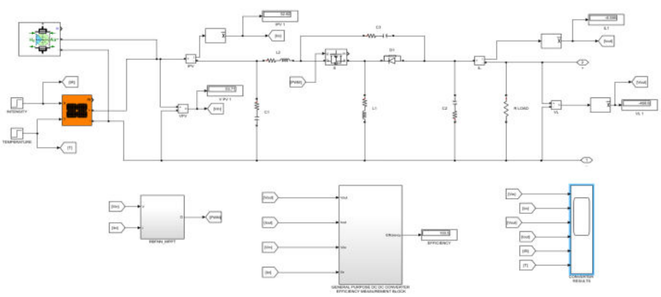

Fig. 9. PV Landsman Converter simulink model

2. *Wave Forms (Converter Results)*

This figure 10 provides a detailed visualization of the waveforms generated by the PV Landsman Converter, showcasing the quality of the converted power and any associated transients or fluctuations.

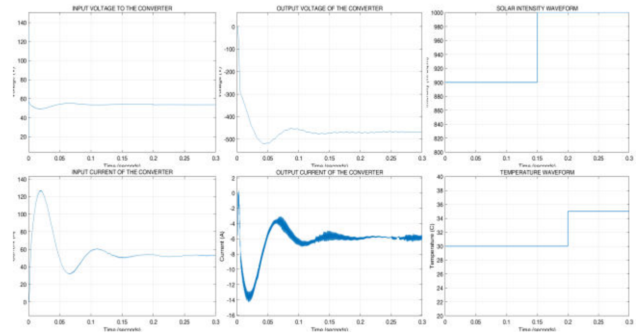

Fig. 10. Converter waveform reults

3 . Inverter with Grid

The simulation diagram illustrates in figure 11 the interaction between the inverter and the grid, highlighting parameters such as voltage, frequency, and power flow.

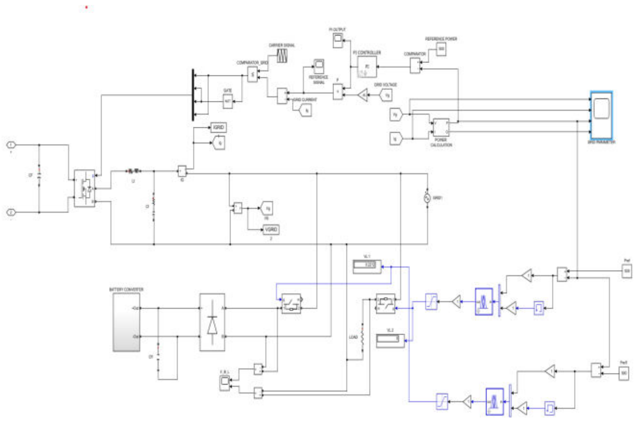

Fig. 11. Inverter with grid simulink diagram

4. Wave Forms (Grid Parameter)

Waveform results for grid parameters shown in figure 12, that offer insights into the stability and compatibility of the inverter's output with grid requirements, including voltage and current and power.

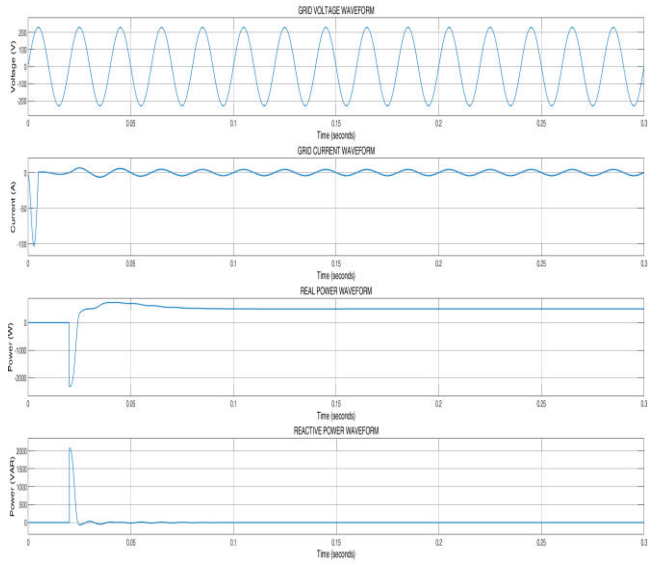

Fig. 12. Grid Wavefroms

5. *Battery Converter*

This section presents waveform results for the battery converter, demonstrating its performance in terms of charging/discharging efficiency, voltage regulation, and other relevant metrics.

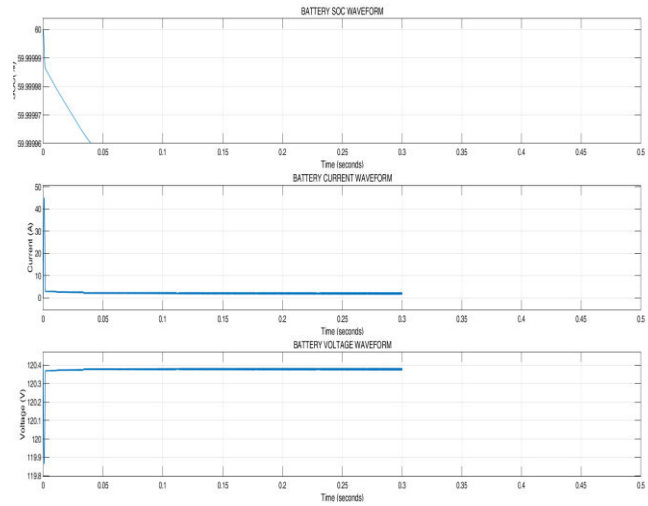

Fig. 13. Battery Converter waveforms

B. Proposed Method

Similar to the existing method, this block diagram showcases the simulation setup for the proposed method, focusing on the PV Landsman Converter componen

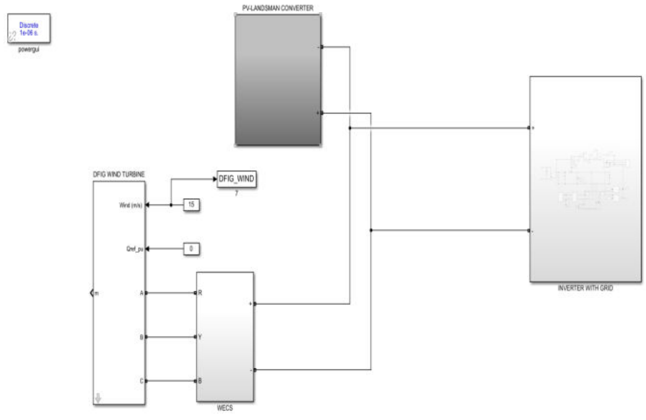

Fig. 14. Proposed system Simulink Block diagram

1. PV landsman converter

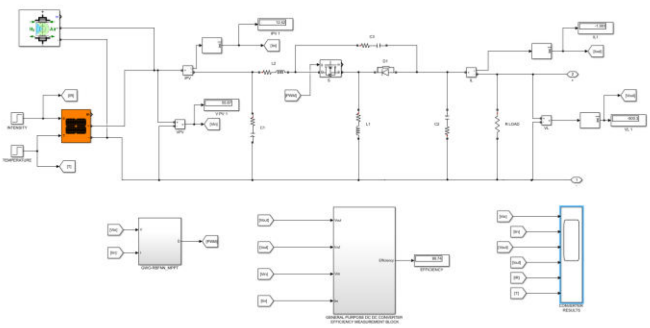

Fig. 15. Landsman Converter simulink model

2. Wave forms (Converter Results)

The waveform results depict the performance improvements achieved by the proposed method in comparison to the existing method, highlighting enhancements in power conversion efficiency, stability, and other relevant parameters

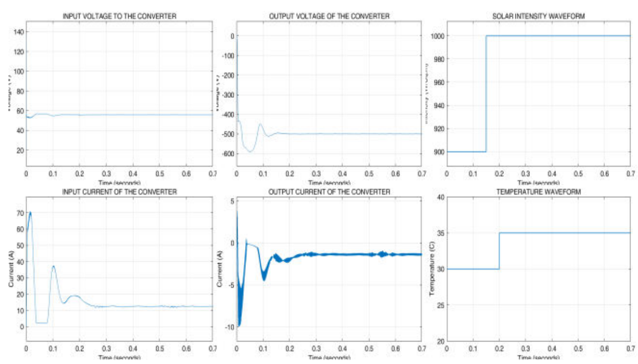

Fig. 16. Converter waveforms

3. Waveforms (DC Voltage)

Detailed waveform results for the PV Landsman Converter illustrate the quality of the converted power and improvements in DC voltage stability achieved through the proposed method.

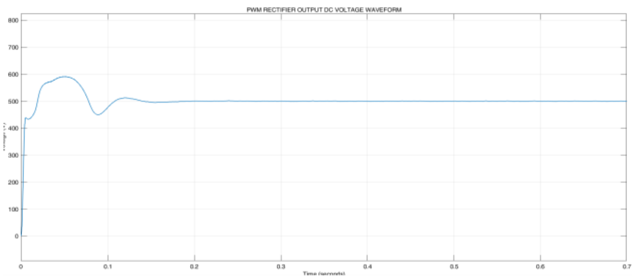

Fig. 17. DC Voltage waveform

4. Inverter with grid

Simulation diagram illustrating the interaction between the inverter and the grid, with waveform results showcasing improvements in grid parameter regulation and compatibility achieved by the proposed method.

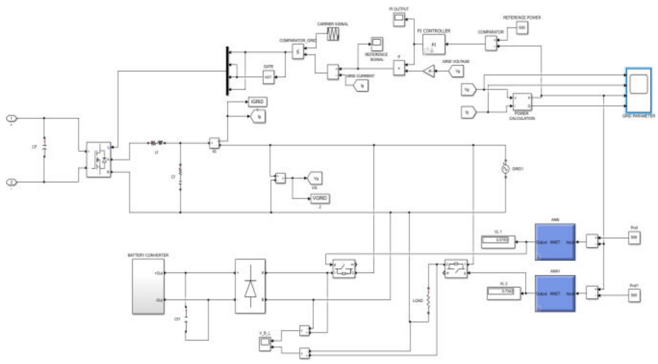

Fig. 18. Inverter with grid simulink model

5.Waveforms (Grid Parameter)

Waveform results for grid parameters provide insights into the enhanced stability and compatibility of the inverter's output with grid requirements achieved through the proposed method.

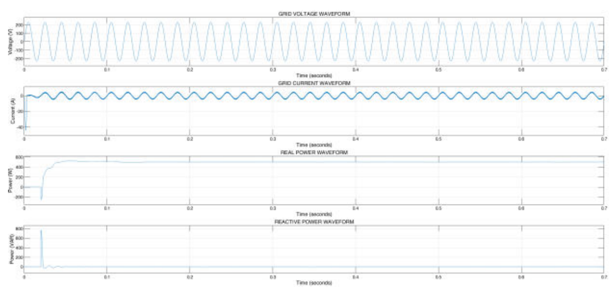

Fig. 19. Grid parameter waveforms

6. Battery Converter

Simulation model for the battery converter, accompanied by waveform results demonstrating performance enhancements achieved through the proposed method, such as improved charging/discharging efficiency and voltage regulation**.**

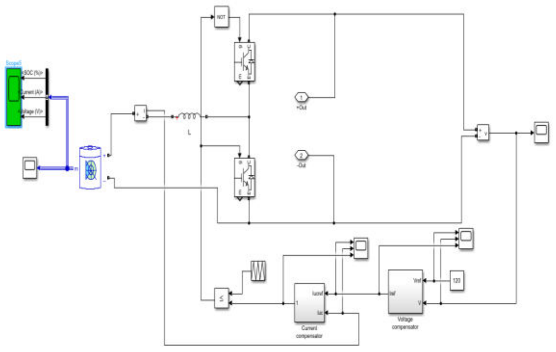

Fig. 20. Battery Converter simulnk model

7. Battery Converter Results (Scope 5)

Simulation model for the battery converter, accompanied by waveform results demonstrating performance enhancements achieved through the proposed method, such as improved charging/discharging efficiency and voltage regulation.

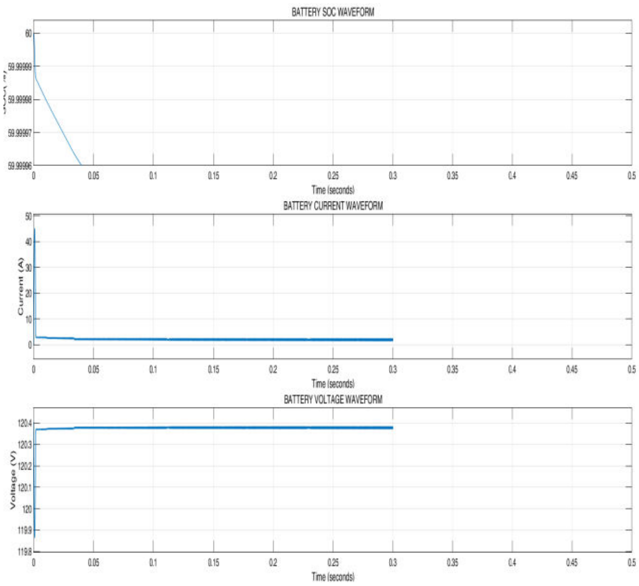

Fig. 21. Battery Converter results

In summary, the simulation results for both the existing and proposed methods offer a comprehensive evaluation of the EMS's performance, highlighting improvements achieved through the proposed method in terms of power conversion efficiency, stability, compatibility with grid requirements, and overall system reliability. These findings validate the effectiveness of the proposed method in optimizing energy management and enhancing the performance of the hybrid renewable energy-based EVCS.

VI. Conclusion

This paper introduces an advanced energy management system (EMS) for a hybrid renewable energy-based electric vehicle charging station (EVCS), incorporating an Artificial Neural Network (ANN) controller to enhance performance over existing methods that utilize a fuzzy inference system. The proposed EMS leverages both solar and fuel cell technologies, optimizing power generation and EV charging periods to reduce costs and maximize renewable energy utilization. Simulation results demonstrate that the ANN controller provides a more stable output, lowering energy costs and enhancing the efficiency of the charging station compared to the existing flat rate tariffs. Additionally, the integration of hybrid renewable energy sources significantly reduces greenhouse gas emissions. The short payback periods for charging station owners underline the project's economic viability and profitability, making it a sustainable and financially attractive solution for the growing demand for electric vehicle infrastructure..

Future Scope

Future research could focus on scaling the proposed EMS for larger EVCS networks, ensuring that the system can handle increased power demands and a higher number of simultaneous EV charges.

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