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Design and Control of a Renewable Energy Based Multiport Ultrafast Electric Vehicle Charging Station

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Abstract - **In this paper an ultra-fast electric vehicle (EV) charging system based on renewable energy sources is presented with a multiport partial power converter. The proposed system uses a common DC-link between solar PV, wind, battery and ultra-capacitor sources to supply clean and reliable power for EV charging and grid stabilization. A partial power converter to minimize conversion losses and enhance charging efficiency. Moreover, bidirectional converters used to facilitate efficient power between the battery and ultra-capacitor to cope with the rapid fluctuation of the load; DC-link voltage stability is also required to be maintained by the bidirectional converter. Control strategy proposed meets power sharing requirements between renewable energy sources, energy storage devices, utility grid and EV charging stations under various operating scenarios. The whole system is designed and modelled in MATLAB/Simulink. The simulation validate the proposed system and show that the system can effectively achieve the following goals: voltage regulation, fast dynamic response, and reduction of power oscillations, efficient tracking performance, and reliable ultra-fast charging capability,**

Keywords - multi port converter, solar, wind, battery, and ultra-capacitor. Electricvehicle charging station.

I. INTRODUCTION

Now a day's increase in electric vehicles (EVs), the demand for reliable and sustainable charging stations has also increased. Conventional EV charging stations mainly depend on the utility grid, which increases power demand, operating cost, and environmental pollution. Renewable energy integrated EV charging systems provide an effective solution for clean transportation electrification [1]–[3]. Solar PV systems are widely used in EV charging applications because of their simple installation and low maintenance. However, fluctuations in solar irradiation affect the charging process and DC-link voltage stability. Therefore, energy storage systems are required to maintain continuous EV charging operation [4]–[6].Hybrid renewable energy systems using solar and wind sources improve system reliability and power availability. PMSG based wind systems provide high efficiency and good dynamic performance under varying wind conditions. The integration of renewable energy sources with battery storage and ultra-capacitors improves energy management, stabilizes the DC-link voltage, and supports fast charging operation [7]–[12]. Power electronic converters are important for controlling power flow between renewable sources, storage systems, the grid, and EV loads. Advanced converter structures such as interleaved boost converters and single-port converters improve voltage gain, reduce ripple, and increase power conversion efficiency [13]–[15]. In addition, advanced control methods are necessary to maintain stable operation under varying conditions and ensure proper power sharing between different energy sources [16]–[18].In this work, a hybrid renewable energy based EV charging system with PV, PMSG wind generation, battery storage, ultra-capacitor support, and single-port converter topology is proposed. The system is designed to achieve stable DC-link voltage, efficient energy utilization, reduced converter stress, and reliable EV fast charging performance under different operating conditions [19], [20].A hybrid renewables-based EV charging system with PV generation, PMSG wind energy conversion, battery storage, ultra-capacitor support and a single-port converter topology is proposed. The boost output voltage and suppress current ripple, and the single-port converter is used to realize the effective transfer of power in the common DC-link. Energy management controller that coordinates the phase shifting of the power flow between renewable energy sources, energy storage, the grid, and energy load. The system design proposed to achieve the following goals: stable DC-link voltage, efficient energy utilization, less stress on the converter, less complicated configuration and reliable EV fast charging performance under various operating conditions.

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II.SYSTEM DESCRIPTION

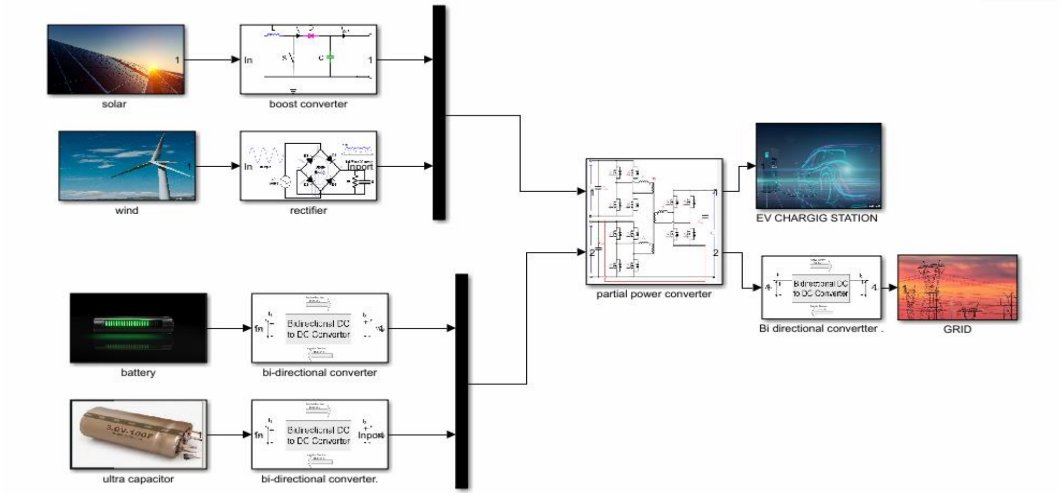

Fig.1.Proposed Block Diagram

A. System Overview

The proposed system represents a multiport DC-based architecture designed for ultrafast electric vehicle (EV) charging using renewable energy sources. It integrates solar photovoltaic (PV), wind energy, hybrid energy storage, and grid support within a unified framework. The primary objective is to ensure reliable, efficient, and continuous power delivery to EV loads under varying environmental and operating conditions.

B. Renewable Energy Generation Unit

Renewable energy subsystem comprises of Solar and Wind energy.PV array is connected to output voltage regulated boost converter which steps up and regulates output voltage to the requirement of DC bus.The wind energy system produces variable AC which is rectified to DC.Both sources are interfaced together at common DC link, which is the major DC renewable power source of the system.

C. Hybrid Energy Storage System

A Hess is used that includes a battery and an ultra-capacitor, to improve the reliability and dynamic performance of the system.Bidirectional DC–DC converters are used to connect the storage devices to the DC bus..The ultra-capacitor supplies a quick response to the transient demands for power, maintaining system stability, while the battery supplies steady state power and stores excess energy.

D. DC Bus and Power Integration

Many power sources (Renewables, storage etc) can be linked to a common DC bus. This is a DC link that acts as the main energy transfer point.This DC link serves as the central hub for energy transfers, allowing for seamless connectivity and power distribution among various components. It also helps to simplify the system design due to the reduction of multiple conversion stages

E. Partial Power Converter

The main (PPC) in between the DC bus and the EV charging station uses a Wants to use a partial power converter. Only a part of the power is processed in this converter thus the efficiency and switching losses are increased. It enables optimum and controlled power supply to the EV load and maintaining stability of the power system... It allows for optimal and controlled power supply to the EV load, while at the same time keeping the system stable.

F. EV Charging Station Interface

The partial power converter used for connect of EV charging station to the system. It is provided regulated-DC power for charge electric vehicles. The system will be designed to facilitate the very rapid charging of e-mobility applications, with sufficient renewable energy and energy storage facilities

G. Grid Integration Unit

The converter is bidirectional connected to the utility grid. This interface can be used for bi-directional power exchange. For low renewable generation, charging can be powered up from the grid to ensure continuity of charging. On the other hand, surplus electricity may be sold back to the electrical power grid, thus maximizing the use of energy and contributing to grid stability.

H. Overall System Operation

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The system works by intelligently managing a variety of energy sources and storage to satisfy the EV charging requirement. The hybrid storage system deals with the variability and renewable sources are prioritized in energy supply. The grid is used as a 'drop-in' or 'back-up' data source when it is required. This synchronized operation guarantees stable, efficient and continuous charging operations.

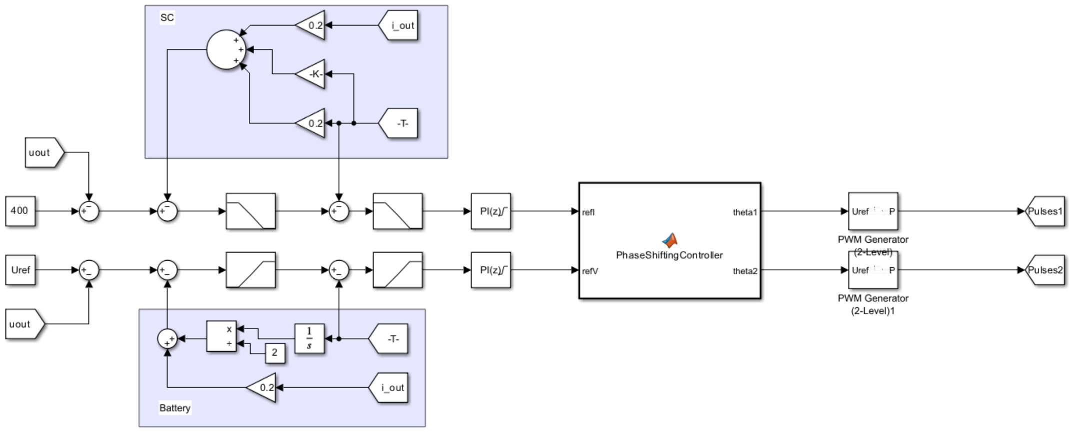

Fig.2.PI-Based Hybrid Energy Storage Phase-Shifting Controller

III.CONTROL TOPOLOGY

The proposed control topology is developed to regulate the power and maintain stable operation of the renewable energy based multiport ultra-fast EV charging station. The controller continuously monitors the DC-link voltage, battery condition, ultra-capacitor response, and converter operation to ensure reliable charging performance under different operating conditions.

Initially, the measured output voltage is compared generate the voltage error signal::

$$e(t) \;\; = Vref - Vout$$

The generated error signal is processed through PI controllers to reduce voltage fluctuations and maintain stable DC-link voltage:

$$u(t) = Kpe(t) + Ki\int e(t)dt$$

The upper control loop is associated with the ultra-capacitor system, which provides fast dynamic support during sudden load changes and transient conditions. The lower control loop controls the battery system to provide backup energy during low renewable generation conditions. Both energy storage systems are connected through bidirectional converters to regulate charging and discharging operations.

The controller output is supplied to the phase shift controller, where the required phase angle is generated for converter switching operation:

$$\boldsymbol{\phi} = \boldsymbol{k} \times \boldsymbol{u}(\boldsymbol{t})$$

The generated phase-shifted signals are applied to the PWM generators to produce switching pulses for the MOSFET switches used in the Multiport Partial Power Converter. The transferred power between source and load is controlled by the phase shift angle and is represented as:

$$p = \frac{v1v2}{wL}\theta(1 - \frac{\theta}{\pi})$$

Where V1 and V2 represent converter side voltages, L is the leakage inductance is the switching angular frequency, and ϕ is the phase angle.

Proposed control topology ensures stable DC-link voltage regulation, smooth power sharing, reduced power fluctuations, and efficient ultra-fast charging operation for multiple electric vehicles connected to the charging station.

IV. PROPOSED METHOD

A. Hybrid Renewable Energy EV Charging System

The proposed work develops a res based EV charging system by integrating solar PV, wind energy, BS, ultra-capacitor support, and utility grid connection through a common DC-link. The system has been designed so as to deliver continuous power support to EV charging while maintaining stable operation during fluctuations in renewable power generation and load demand. The coordination of the converter and storage system facilitates power sharing and enhances the reliability of the system.

B. Solar Energy (PV) and Energy Conversion

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The solar PV source is connected to a boost converter to boost and regulate voltage in order to supply it to the DC-link. The converter is designed to deliver a constant output voltage and facilitates the efficient transfer of solar electricity to the charging system. This setup can increase the use of the solar energy available and assist in keeping the apparatus in operation during varying atmospheric conditions.

C. Wind Energy Integration

The wind generation unit is connected to a rectifier stage which converts the AC output generated by the wind to DC output. The rectified power is fed into the common DC-link to provide power to the EV charging load. During periods of low solar energy production, the charging station depends on the wind energy, which helps to extend its use.

D. Battery/Ultra-Capacitor Energy Support

DC–DC converter is connected to a battery and ultra-capacitor to enhance energy balancing and system stability. The battery supplies power during low renewable energy periods and the ultra-capacitor will buffer for load and transient conditions. Both charging and discharging operations are possible through the bidirectional converters, depending on the requirements of the system. This stabilizes the voltage and decreases power variations.

E. Partial Power Converter for EV Charging

A partial power converter is connected between the DC-link and the EV charging station to realize the high power transfer efficiency.Only part of the total power is flowing through the converter and hence switching losses and converter stress reduced.The converter maintains suitable charging voltage and current levels for the EV battery and supports stable charging operation under different loading conditions.

F. Phase-Shifting Control Technique

The proposed system uses a phase-shifting control method along with PI controllers for converter operation. The controller continuously compares reference and measured values of voltage and current to generate switching pulses for the converters. This method helps regulate power flow between renewable sources, storage devices, the grid, and the EV charging station. The controller also improves transient response and maintains stable DC-link voltage during system disturbances.

G. Energy Management and Grid Support

An Ems is deployed to manage the flow of power between the renewable power sources, storage and the EV charging station and the utility grid.Excess power is generated by renewable sources when production is high, and is fed into the grid or into the battery storage system.In times of inadequate renewable energy supply, stored energy and grid support are available to ensure continuous EV charging operation.The bidirectional converter allows for flexible bidirectional power transfer – Grid-to-Vehicle and Vehicle-to-Grid operation...

H. Benefits of the proposed one

The proposed provides several operational improvements, including:

- Effective utilization of solar and wind energy for EV charging
- Stable DC-link voltage under changing operating conditions
- Reduced converter losses using partial power conversion
- Improved transient response and voltage regulation
- Reliable bidirectional power transfer between EV and grid
- Reduced voltage and current fluctuations
- Enhanced charging stability and system reliability
- Better overall efficiency and power management performance

V. SIMULATION RESULTS & DISCUSSION

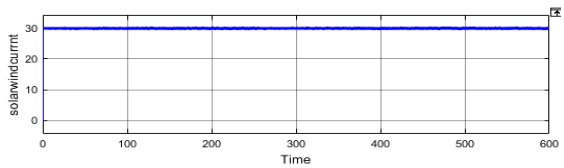
Table 1. Simulink parameters

Parameters	Values
Maximum Power pv	50400 w
Open Circuit Voltage	200 v
Cells per Module	60
Current at MPP	28A
Base wind speed	12m/s
Base nominal power	8.5e3
Tata nexon	35kw
Tata tiago	24kw
Hyundai	64kw
mg zs Ev	50kw
Vdc	700v

Table 2. Total efficiency of the multi-port converter

Parameter	Existing method	Proposed method
Efficiency	<90%	94.2

Solar and wind side current and voltage



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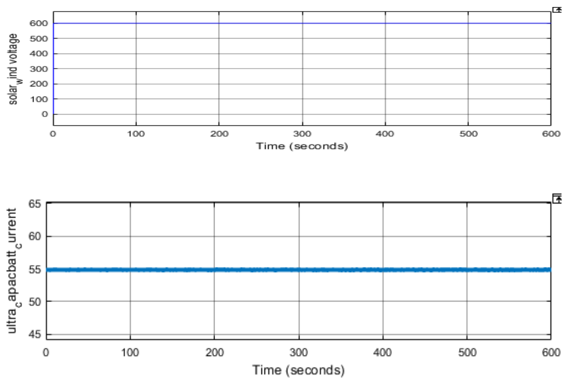

Fig.3. Solar and Ultra-Capacitor Performance Using Extension-Based Control

The figure shows the solar source, DC-link voltage, and ultra-capacitor responses using the proposed extension-based control strategy in the renewable energy integrated EV charging system. The solar current, solar voltage, and DC-link voltage remain stable with reduced fluctuations during the simulation period. The ultra-capacitor current also shows smooth charging and discharging operation with low ripple content. The obtained results confirm stable energy balancing, improved power quality, and reliable EV charging performance under different operating conditions

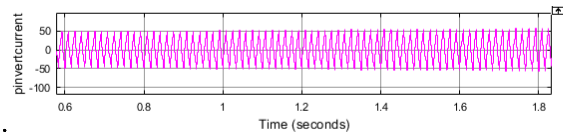

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Fig.4. Primary Inverter Current Response Based on Extension Based Control technology.

Theabove figure shows the primary inverter current response using the proposed extension-based control strategy. The inverter current waveform remains stable and continuous throughout the simulation period, indicating proper current regulation and stable switching operation. The reduced oscillations and smooth waveform confirm effective current control and stable energy transfer between the DC and AC system. The obtained results demonstrate that the proposed controller provides improved power quality, efficient power conversion, better dynamic response, and reliable operation in renewable energy based EV charging applications.

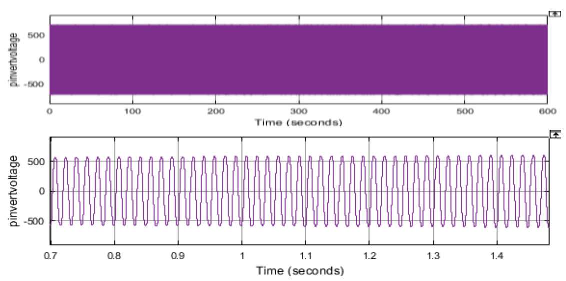

Fig.5.Primary inverter voltage response with extension based control.

The figure shows the solar source, DC-link voltage, and ultra-capacitor responses using the proposed extension-based control strategy in the renewable energy integrated EV charging system. The solar current, solar voltage, and DC voltage remain stable with low fluctuated, while the ultra-capacitor current shows smooth operation with reduced ripple content. The results confirm stable energy balancing and reliable EV charging performance under different operating conditions.

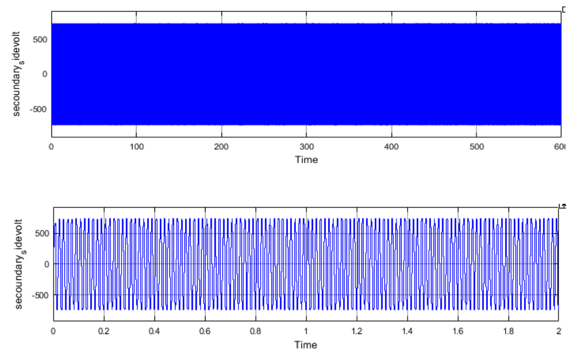

Fig.6.Secondary Side Voltage Response Based on Extension Based Control

The figure shows the secondary side voltage response of the renewable energy integrated EV charging system using the proposed strategy. The voltage waveform remains stable and continuous throughout period with reduced fluctuations and smooth switching characteristics. The obtained results confirm stable voltage regulation, reliable power transfer, and proper coordination between the renewable, storage system, and EV charging load. The smooth waveform response also indicates efficient converter operation and improved system reliability under different operating conditions.

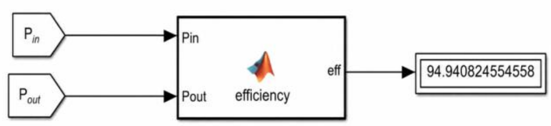

Fig.7. overall efficiency of the dab converter. In converter

The figure shows the efficiency measurement result obtained using the proposed extension-based control approach for the renewable energy integrated EV charging system. The block diagram represents the efficiency calculation process using input and output power values. The obtained efficiency is around 94.94%, indicating efficient power conversion and energy transfer in the system.

The high efficiency confirms reduced power loss and better coordination between res, BS, converters, and EV charging units. The result also shows stable system operation, improved energy management, and reliable EV charging performance under different operating conditions.

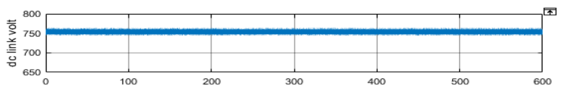

Fig.8. voltage response of the DC-Link.

The figure shows the DC-link voltage response of the proposed the renewable energy integrated EV charging system. The DC-link voltage remains nearly constant around the desired value during the simulation period, indicating stable voltage regulation and proper power control between the reS , Bs , EV load, and grid interface. The obtained result shows reduced ripple content, smooth voltage response, and improved converter performance. The stable DC-link voltage also confirms efficient energy management, reduced oscillations, better dynamic response,

Ev specifications

Tata nexon battery

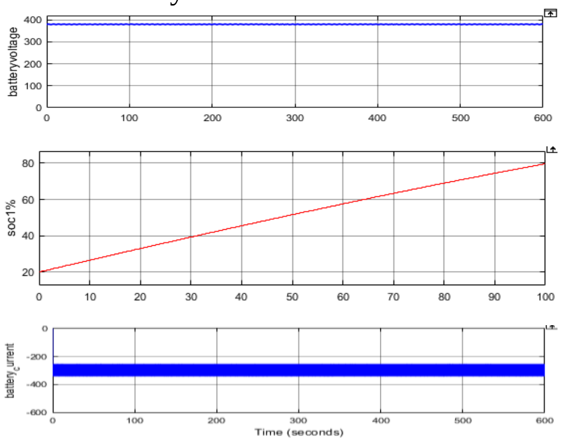

Fig.9. Battery Voltage, SOC, and Current Response with Extension Based Control

The figure shows the battery voltage, SOC, and current responses using the proposed extension-based control strategy in the renewable energy integrated EV charging system. The battery voltage remains stable with very low ripple during the simulation period. The SOC increases gradually from 20% to 80%, showing smooth and continuous charging operation. For the Tata Nexon battery with a 35 kW capacity, the charging time from 20% to 80% is nearly 100 seconds.

The battery current response remains stable with reduced oscillations, indicating proper charging control and steady energy transfer between the renewable energy sources and battery storagesystem. The obtained results confirm stable battery operation, efficient energy management, and reliable charging performance under different operating conditions.

Tata taiga

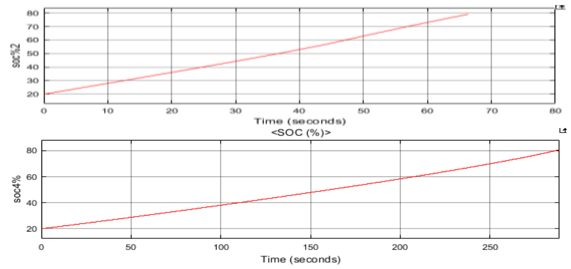

Fig.10. Battery SoC Response Control Based on Extension.

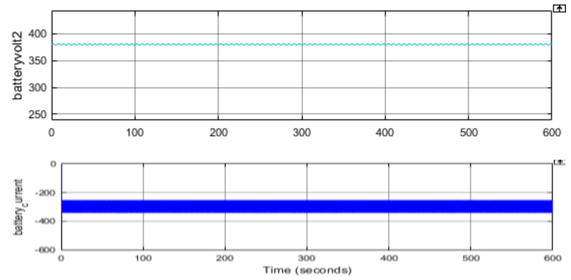

Fig.11. Battery Voltage and Current Response (Extension Based Control)

The figure shows the Battery State of Charge (SOC) response using the proposed extension-based control strategy in the renewable energy integrated EV charging system. The SOC increases smoothly from 20% to 80%, indicating stable battery charging operation and proper energy flow control. For the Tata Tiago EV battery capacity of 24 kW, the battery reaches 80% SOC from 20% in nearly 1.5 minutes using a 750 V charging system..

Hyundai Kona EV 64KWh

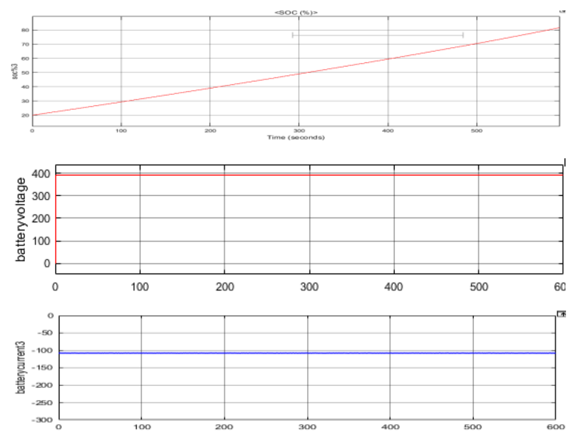

Fig.12. Explore the charging characteristics of these batteries with extension based control.

The figure shows the battery charging performance obtained using the proposed extension-based control strategy in the renewable energy integrated EV charging system. The results include battery SOC, voltage, and current responses during the simulation period. The SOC gradually increases from 20% to 80%, indicating stable and continuous charging operation. For the Hyundai battery capacity of 64 kW with a high-voltage charging system, the battery reaches 80% SOC in nearly 600 seconds. The battery voltage remains stable

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throughout the simulation period, confirming proper voltage regulation and smooth energy transfer. The battery current also remains nearly constant with low ripple content, indicating stable charging operation and reduced battery stress. The obtained results confirm efficient battery charging, voltage stability, reduced current fluctuations, and reliable operation under different operating conditions.

Mg zs Ev 50kw

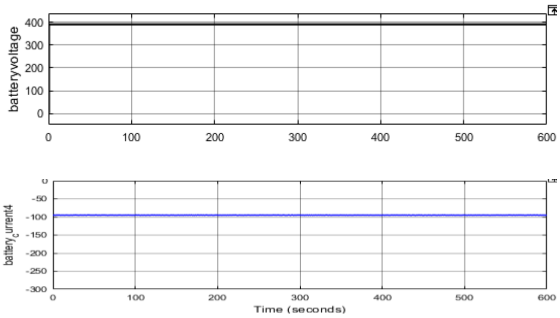


Fig.13. Evaluating battery performance with extension-based control.

The figure shows the battery SOC, voltage, and current responses using the proposed extension-based control strategy in the renewable energy integrated EV charging system. The SOC gradually increases from 20% to 80%, indicating stable charging operation and proper energy management. For the MG ZS EV battery capacity of 50 kW, the battery reaches 80% SOC in nearly 280 seconds.Grid voltage

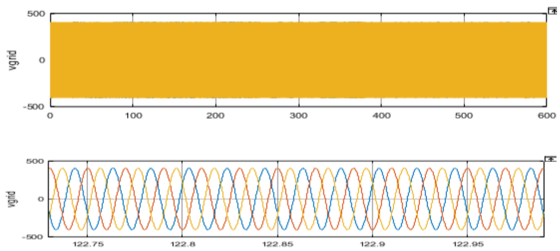
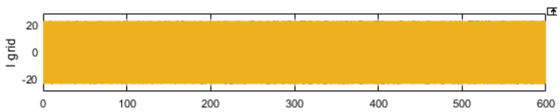


Fig.14.Grid Voltage Response Using Extension-Based Control

The figure shows the three-phase grid voltage response using the proposed extension-based control strategy in the renewable energy integrated EV charging system. The grid voltage remains stable and balanced throughout the simulation period with proper three-phase sinusoidal waveforms and 120° phase shift. The smooth voltage response confirms stable synchronization, reduced distortions, improved power quality, and reliable operation under different operating conditions.



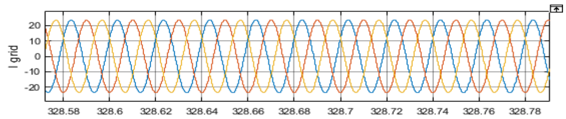


Fig.15. Grid Current Response under Proposed Extension-Based Control Strategy

The figure shows the Grid current response using the proposed control method in the renewable energy integrated EV charging system. The grid current remains stable and balanced during the simulation period, indicating proper power transfer between the renewable energy sources, battery system, EV load, and utility grid

.VI. CONCLUSION

This project concluded that a renewable energy based multiport ultra-fast EV charging system using solar, wind, battery storage, and ultra-capacitor sources connected through a DC-link structure. The system provides stable energy flow and reliable EV charging under different operating conditions. The bidirectional converter and Multiport Partial Power Converter support efficient power conversion and fast charging of EVs such as Tata Nexon EV, Tata Tiago EV, Hyundai Kona EV, and MG ZS EV. The obtained simulation results confirm stable DC-link operation, reliable converter performance, and effective renewable energy integrated EV charging operation.

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