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EV Battery Exchange Charging System with a Diesel Generator Set and Solar PV Powered Battery

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ABSTRACT: The rapid growth of electric vehicles (EVs) has increased the demand for reliable and sustainable charging infrastructure. Conventional charging stations mainly depend on the utility grid, which may lead to higher peak demand, voltage instability, and increased carbon emissions. To address these challenges, this paper presents a hybrid EV battery exchange charging system integrated with a solar photovoltaic (PV) array, battery energy storage system (BESS), and diesel generator (DG) set for uninterrupted charging operation under different operating conditions. The proposed system is designed to operate in grid-connected, islanded, and DG-supported modes while maintaining continuous charging capability and stable power flow. A coordinated control strategy is implemented to manage seamless mode transition, regulate DC-link voltage, and maintain voltage and frequency stability during load and irradiation variations. The battery swapping approach significantly reduces EV charging time and improves charging station utilization. The complete system is modeled and analyzed in MATLAB/Simulink under varying solar irradiance and charging demand conditions. Simulation results demonstrate that the proposed charging station maintains stable operation during mode transitions and effectively balances power between the PV source, storage battery, grid, and DG set. The photovoltaic source supplies the major share of charging power during normal operating conditions, while the storage battery and DG set support the system during low irradiance and high-load conditions. The obtained results also confirm reduced dependency on the utility grid, improved charging continuity, regulated PCC voltage, and low harmonic distortion within IEEE permissible limits.

KEYWORDS: Electric Vehicles (EVs), Battery Swapping Station (BSS), Solar Photovoltaic (PV) System, Diesel Generator (DG) Set, Battery Energy Storage System (BESS), Vehicle-to-Grid (V2G), Grid-Connected Charging Station, Islanded Mode Operation, Power Quality, MATLAB/Simulink, Renewable Energy Integration, Smart Charging Infrastructure.

I. INTRODUCTION

The rapid increase in fossil fuel consumption and greenhouse gas emissions has accelerated the transition toward sustainable transportation systems. Electric vehicles (EVs) have emerged as an effective alternative to conventional internal combustion engine vehicles due to their high efficiency, low operating cost, and reduced environmental impact. However, the large-scale deployment of EVs requires reliable and intelligent charging infrastructure capable of supporting continuous charging demand without causing instability in the electrical grid. Conventional EV charging stations mainly rely on utility grid power, which may increase peak demand, voltage fluctuations, harmonic distortion, and operational stress on the distribution network. In addition, the charging duration associated with plug-in charging systems remains one of the major limitations for widespread EV adoption. Battery swapping technology has recently gained significant attention because it minimizes charging time by replacing discharged batteries with fully charged batteries within a few minutes. This approach improves charging convenience and enhances utilization of charging infrastructure.

The integration of renewable energy sources into EV charging stations provides an effective solution for reducing grid dependency and carbon emissions. Among different renewable energy sources, solar photovoltaic (PV) systems are highly suitable for EV charging applications because of their wide availability, modular structure, and environmentally friendly operation. However, the intermittent nature of solar energy introduces challenges in maintaining uninterrupted charging operation during low irradiance conditions or nighttime operation. Therefore, an additional backup energy source and intelligent energy management system are required to ensure reliable charging performance. To address these challenges, this paper proposes a hybrid EV battery exchange charging system integrated with a solar PV array, battery energy storage system (BESS), diesel generator (DG) set, and utility grid. The proposed charging station

operates in grid-connected, islanded, and DG-supported modes to maintain continuous charging under varying environmental and load conditions. A coordinated control strategy is implemented for seamless mode transition, voltage regulation, frequency stabilization, and efficient power sharing among the available energy sources.

The major contributions of this work are summarized as follows:

1. Development of a hybrid EV battery swapping charging station integrated with solar PV, DG set, storage battery, and utility grid.
2. Design of a coordinated control strategy for seamless operation under grid-connected, islanded, and DG-supported modes.
3. Implementation of uninterrupted EV charging during variations in solar irradiance and charging demand.
4. Improvement in power quality and voltage regulation with reduced harmonic distortion.
5. Validation of the proposed system through MATLAB/Simulink simulation under different operating conditions.

II. LITERATURE SURVEY

Recent research on electric vehicle (EV) charging infrastructure has mainly focused on renewable energy integration, battery swapping systems, smart charging strategies, grid support capability, and hybrid energy management systems. The major objective of these studies is to reduce charging time, improve energy efficiency, minimize grid dependency, and enhance charging reliability under varying operating conditions. Table I summarizes the latest research contributions related to EV charging stations, solar PV integration, battery swapping technology, and hybrid charging architectures.

TABLE I
RECENT LITERATURE REVIEW ON EV BATTERY SWAPPING AND HYBRID CHARGING SYSTEMS

Ref.	Year	Author(s)	Methodology / System	Major Findings	Limitations
[1]	2025	Zhang et al.	Solar PV integrated EV charging station	Improved renewable utilization and reduced grid dependency	No DG backup support
[2]	2025	Kumar and Singh	Smart EV charging control strategy	Reduced peak load and harmonic distortion	Limited battery management
[3]	2025	Chen et al.	Battery swapping infrastructure for EVs	Reduced charging time significantly	High infrastructure cost
[4]	2024	Li et al.	Hybrid PV-BESS charging station	Stable charging during irradiance variation	No islanded operation
[5]	2024	Ahmed et al.	Grid-connected EV charging with V2G	Improved grid support capability	Complex control algorithm
[6]	2024	Wang et al.	Multiport converter for EV charging	High conversion efficiency	Limited scalability
[7]	2024	Sharma et al.	DG-supported charging station	Reliable backup operation	Increased fuel consumption
[8]	2024	Patel and Mehta	Renewable energy based BSS	Fast battery replacement operation	Battery standardization issue
[9]	2024	Roy et al.	Intelligent energy management system	Optimized power sharing	Higher computational complexity
[10]	2023	Kim et al.	Fast charging station using PV	Reduced charging duration	Power fluctuation problem
[11]	2023	Hassan et al.	EV charging with energy storage	Improved voltage stability	Limited SOC optimization
[12]	2023	Gupta et al.	Hybrid microgrid for EV charging	Better power reliability	Lack of seamless mode transition
[13]	2023	Lin et al.	Battery swapping scheduling algorithm	Reduced waiting time	Communication dependency
[14]	2023	Verma and Rao	Islanded EV charging station	Continuous charging operation	Limited renewable penetration

[15]	2023	Silva et al.	Smart grid integrated charging system	Enhanced power quality	Expensive implementation
[16]	2022	Choudhary et al.	Solar PV and DG integrated EV station	Reliable hybrid operation	No V2G capability
[17]	2022	Park et al.	Coordinated EV charging strategy	Reduced grid stress	Limited dynamic analysis
[18]	2022	Bansal et al.	Bidirectional EV charging architecture	Improved energy utilization	Complex converter design
[19]	2022	Kumar et al.	Hybrid renewable charging station	Reduced carbon emission	Battery degradation concern
[20]	2021	Ferreira et al.	EV charging station with storage battery	Improved charging continuity	Lack of real-time optimization

To overcome these limitations, the proposed work presents a hybrid EV battery exchange charging system integrated with solar PV array, battery energy storage system, diesel generator set, and utility grid support. The proposed system ensures uninterrupted charging operation under grid-connected, islanded, and DG-supported modes. In addition, a coordinated control strategy is implemented for seamless power sharing, voltage stabilization, and harmonic reduction. The proposed approach improves charging continuity, enhances renewable energy utilization, and maintains stable operation under varying irradiance and load conditions.

III. PROPOSED SYSTEM

The proposed system consists of a hybrid electric vehicle (EV) battery exchange charging station integrated with a solar photovoltaic (PV) array, battery energy storage system (BESS), diesel generator (DG) set, utility grid, and power electronic converter-based control architecture. The main objective of the proposed methodology is to provide uninterrupted and reliable EV charging operation under varying environmental conditions and charging demand while minimizing dependence on the utility grid.

The overall charging station is designed to operate in three different modes, namely grid-connected mode, islanded mode, and DG-supported mode. During normal operating conditions, the solar PV array supplies the major share of charging power to the EV battery swapping station. Excess generated energy is stored in the battery energy storage system for future use. When the solar power generation becomes insufficient due to low irradiance or nighttime conditions, the storage battery and utility grid support the charging demand. In the absence of grid availability, the diesel generator set operates as an auxiliary power source to maintain continuous charging operation.

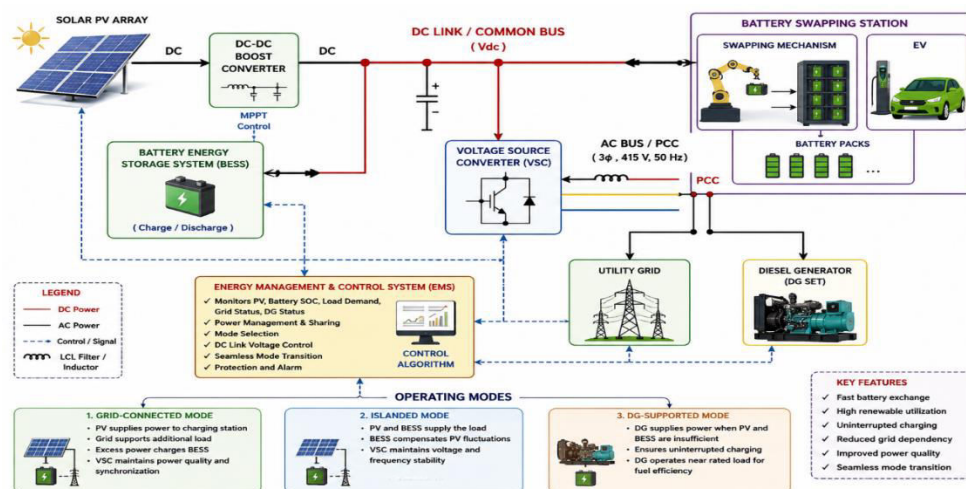


Fig.1. Proposed System architecture

The proposed charging station utilizes battery swapping technology to reduce EV charging time significantly. Instead of waiting for direct battery charging, discharged EV batteries are replaced with fully charged batteries available at the swapping station. This approach improves charging station efficiency, reduces vehicle waiting time, and enhances user convenience.

The complete architecture of the proposed system includes:

1. Solar PV Array
2. DC-DC Boost Converter
3. Battery Energy Storage System (BESS)
4. Voltage Source Converter (VSC)
5. Diesel Generator (DG) Set
6. Utility Grid Interface
7. Battery Swapping Unit
8. Control and Energy Management System

The solar PV array is connected to the DC link through a DC-DC boost converter equipped with Maximum Power Point Tracking (MPPT) control. The MPPT algorithm continuously extracts maximum available power from the PV array under varying solar irradiance conditions. The generated DC power is regulated and supplied to the common DC bus.

The battery energy storage system is directly connected to the DC link to maintain power balance and support uninterrupted charging operation. During excess PV power generation, the storage battery operates in charging mode, while during low generation or sudden load increase, it discharges stored energy to maintain system stability.

A voltage source converter (VSC) is employed for bidirectional power transfer between the AC and DC sides of the charging station. The VSC regulates DC-link voltage, controls reactive power flow, and maintains sinusoidal current at the point of common coupling (PCC). The converter also improves power quality by reducing harmonic distortion and maintaining unity power factor operation.

The proposed control strategy continuously monitors solar power generation, battery state of charge (SOC), charging demand, and grid availability to determine the appropriate operating mode. Seamless mode transition is achieved using synchronized switching control, ensuring uninterrupted charging during changes in operating conditions.

The operational methodology of the proposed charging station can be summarized as follows:

A. Grid-Connected Mode

In this mode, the utility grid, solar PV array, and battery storage jointly supply charging power to the EV charging station. The PV array operates at maximum power point, while excess energy is either stored in the battery or supplied to the grid. The VSC maintains DC-link voltage stability and controls reactive power compensation.

B. Islanded Mode

When the utility grid becomes unavailable, the charging station operates in standalone mode using the solar PV array and battery energy storage system. The storage battery compensates for variations in solar power generation and load demand to ensure uninterrupted EV charging operation.

C. DG-Supported Mode

During prolonged low irradiance conditions or deep battery discharge, the diesel generator set provides backup power support to maintain charging continuity. The DG set operates near its rated loading condition to improve fuel efficiency and maintain voltage-frequency stability.

The proposed methodology also incorporates intelligent energy management for efficient utilization of renewable energy sources. The coordinated control system ensures proper power sharing among the PV array, storage battery, DG set, and utility grid while maintaining stable operation under dynamic loading conditions.

IV. RESULTS AND DISCUSSION

The proposed hybrid EV battery exchange charging system was modeled and simulated in the MATLAB/Simulink environment to evaluate its dynamic and steady-state performance under different operating conditions. The simulation study was carried out by considering variations in solar irradiance, charging demand, grid availability, and diesel generator operation. The performance of the charging station was analyzed in terms of voltage regulation, charging continuity, power sharing capability, harmonic distortion, and seamless mode transition.

The simulation parameters considered for the proposed system include a solar PV array integrated with a DC-DC boost converter, a battery energy storage system (BESS), a voltage source converter (VSC), a utility grid connection, and a diesel generator set operating as a backup power source. The EV battery swapping station was connected at the point of common coupling (PCC) to evaluate charging performance under different operating scenarios.

Simulation Result in Different Types of Mode (Solar, Grid, DG)

The performance of the CS is discussed with simulation results.

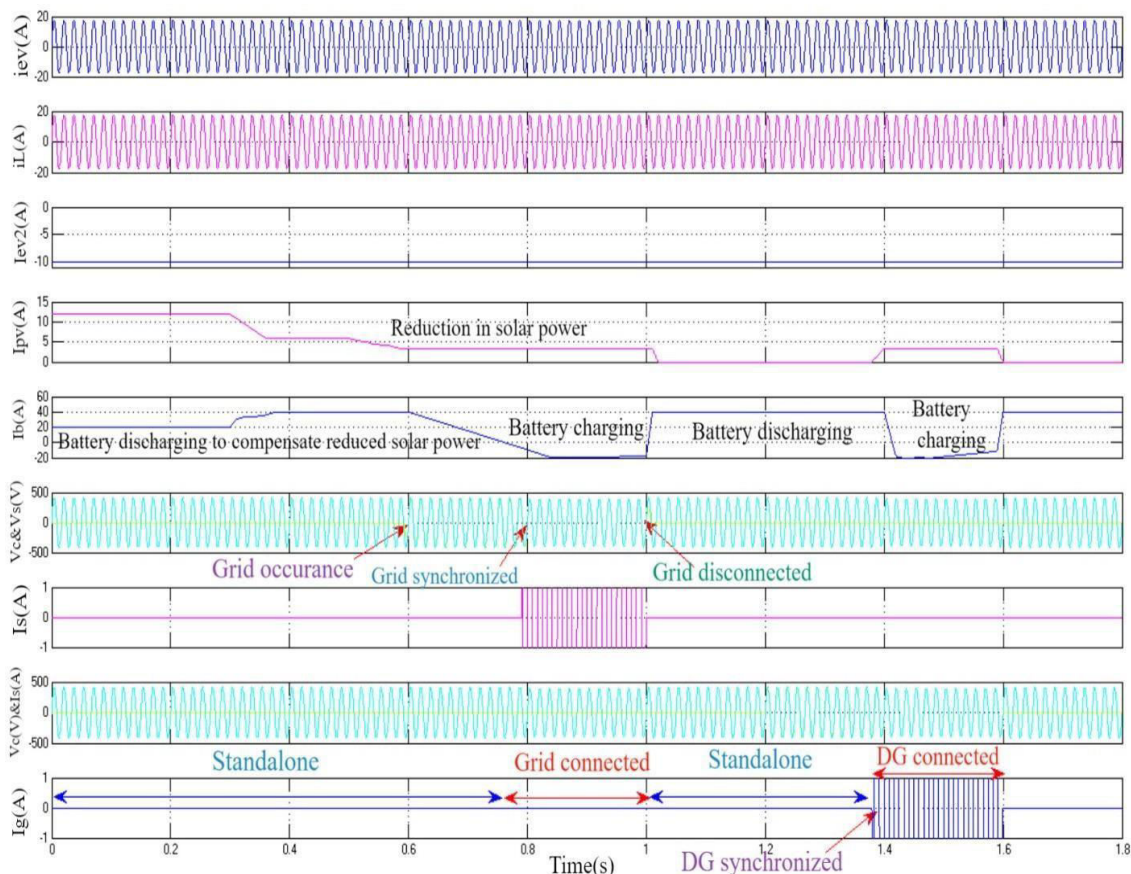


Figure 4.1 Output of Different Type of Mode

The change in solar irradiance and the change in EV current disrupt the CS function in the islanded mode, but the energy storage makes up for all of the disruptions. Figures 4.2, 4.3, and 4.4 demonstrate how the irradiance shift affects the PV array generation and how energy storage actively compensates for the drop in PV generated power to keep the EV charging uninterrupted.

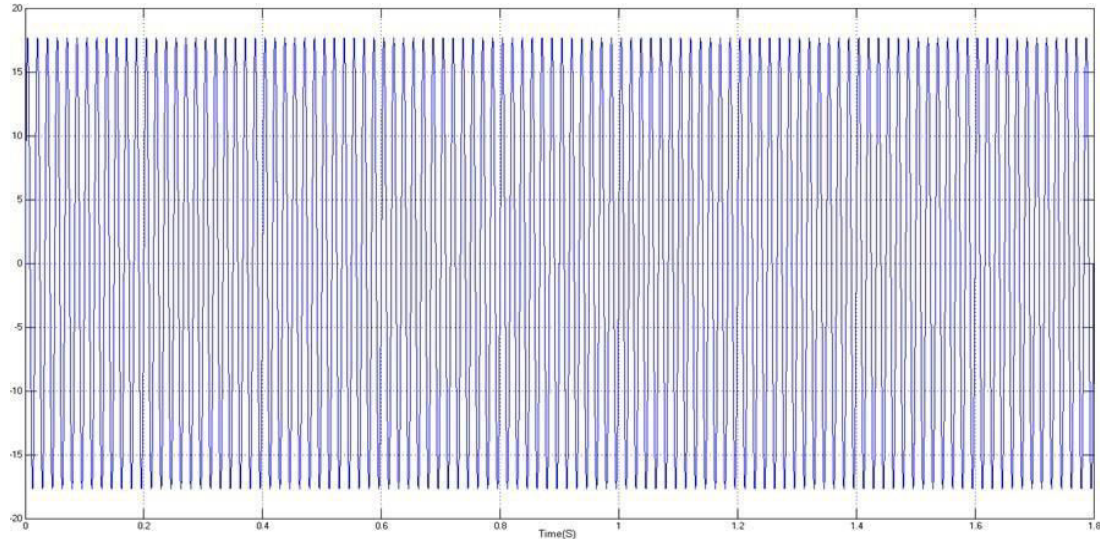


Figure 4.2 Current of EV1

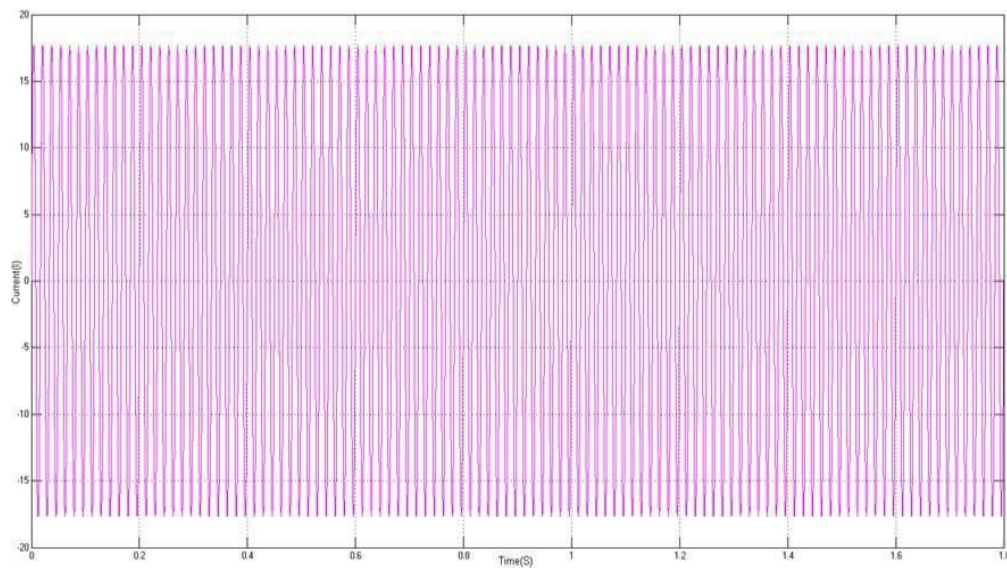


Figure 4.3 Current at Load

Increasing the usage of electric vehicles (EV) is thought to be a positive step towards lowering carbon emissions and air pollution. However, a sharp rise in the number of EVs and charging stations has brought up concerns with harmonic distortion and voltage quality that have an impact on the efficiency of electrical transmission networks for smart grids and integrated renewable energy sources.

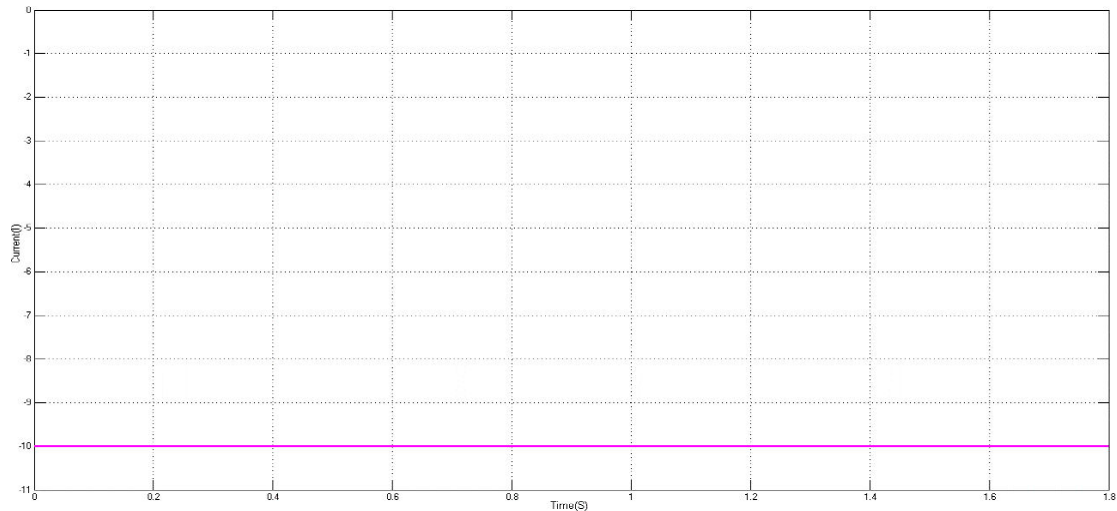


Figure 4.4 Current of EV2

The undisturbed EV current has the same characteristics. Even if the current ($A_g + A_{pv}$) is not sinusoidal in this mode, the regulation of VSC makes sure that the generator (A_f) or grid current (i_s) stays sinusoidal. The control method calculates the total current ($A_g + A_{pv}$)'s active (A_{pv}) and reactive (A_{ev}) components. The adaptive noise cancellation (ANC) based control method is employed in this situation. The switching pulses for the VSC are created using A_{pv} and A_{ev} , which also estimates the reference generator or grid current. The control system additionally consists of a voltage and frequency control loop for managing the generator's voltage and frequency. When the grid is linked to the system, however, these two control loops continue to be disabled.

The chargers are off-board and housed in an EVSE for dc rapid charging. The fundamental component of an off-board charger with V2G functionality is a bidirectional dc-dc converter. It creates the connection between the DC distribution grid and the EV battery system. In Fig. 5.6, the converter arrangement is displayed. Two IGBT/MOSFET switches are used, and they are always switched on by complementary control signals.

PV array generated power is fluctuating due to the change in irradiation level. In order to balance the active power, the power sent into the grid is changing. However, the EV's charging process is still going strong despite the irradiance shift seen in Fig. 4.7. The CS's V2G power transmission capabilities. The power sent into the grid rises as a result of the EV2 battery power being discharged. The EV's ac charging and PV array generating, however, are unaffected.

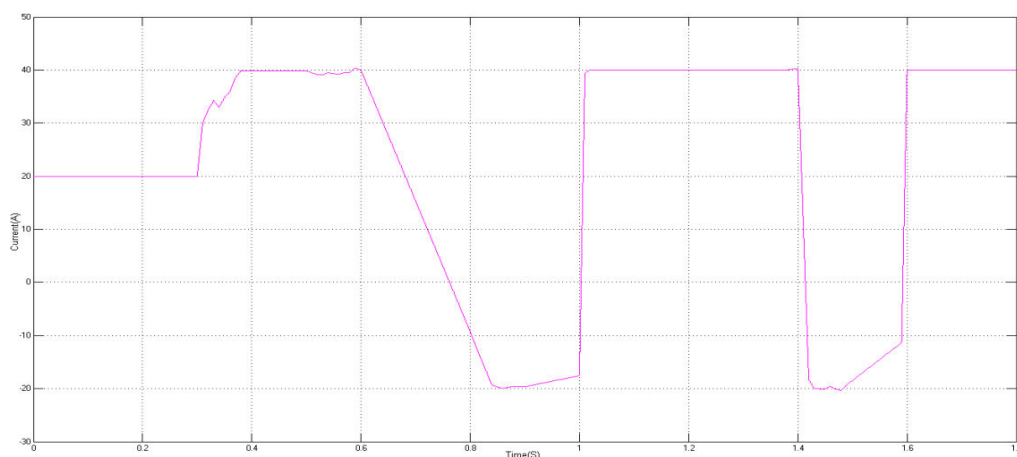


Figure 4.5 Battery Current

To get the most power out of the solar PV array, a DC-DC boost converter is required. Utilising the incremental conductance (INC)-based maximum power point tracking (MPPT) technique, switching pulses for the boost converter are generated.

The performance of an EV in a grid-connected mode under changing ac charging demand is shown in Fig. 5.7. Only the grid power is impacted by the change in ac charging demand. However, as seen in Fig.5.6, the PV generation does not change. The CS behaviour is seen when the irradiance changes. The simulation parameter specification for the proposed EV Battery Exchange Charging System's combination of diesel generator set and solar PV- powered battery is presented in Table.5.1.

Table 4.1 Parameter's Specification

Sr.No	Parameter's		Specification
1.	Discrete PI Controller	Proportional gain (K_p)	0.05
		Internal gain (K_i)	0.1
2.	Single-Phase Asynchronous Machine	Nominal Power(K_p)	$0.25*746(V_a)$
		Voltage (V_n)	$110(V_{rms})$
		Frequency (F)	50Hz
3.	AC Voltage Source	Peak Amplitude	230V
		Frequency	50Hz
4.	Battery	Nominal Voltage(V)	400V
		Rated Capacity(Ah)	45Ah
		Initial State-of-Charge (%)	50%

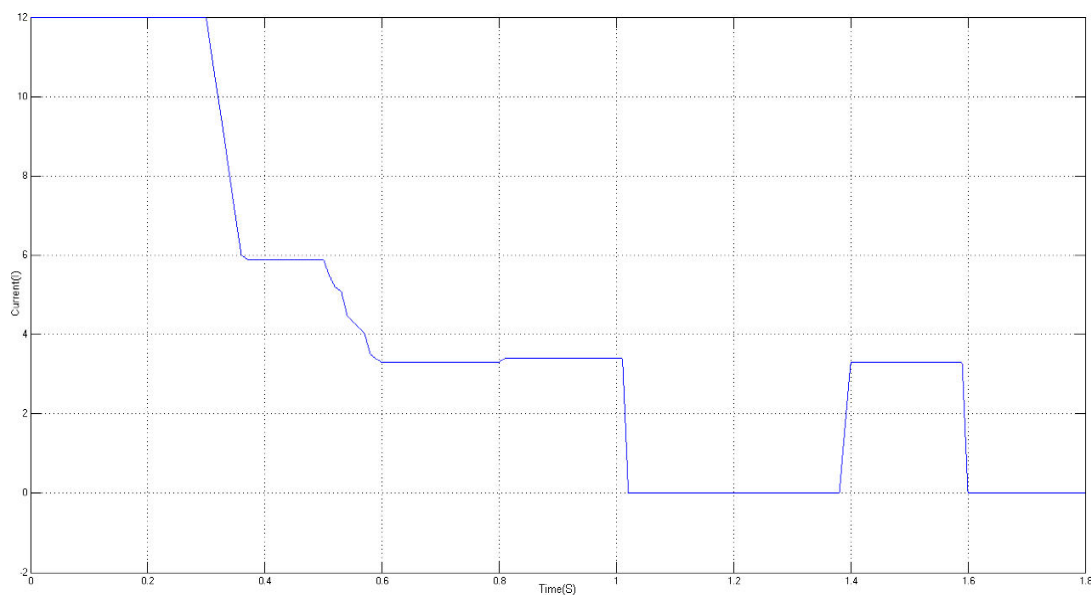


Figure 4.6 Photovoltaic Current

To show the efficient operation of DG set under all loading conditions, the load at PCC is changed as shown in Fig.4.9. The DG set current (i_g) remains undisturbed under the load change. Moreover, the voltage (v_g) and frequency of the DG set are also regulated at the reference values. However, the power balance under load change is maintained by the storage battery. This is observed by the change in the battery current (i_b) with the change in load current (i_L) that the VSC current (i_c) also changes with the change in the nonlinear load. However, the dc-link voltage (V_{dc}) and the charging current of the EV (i_{ev}) do not change.

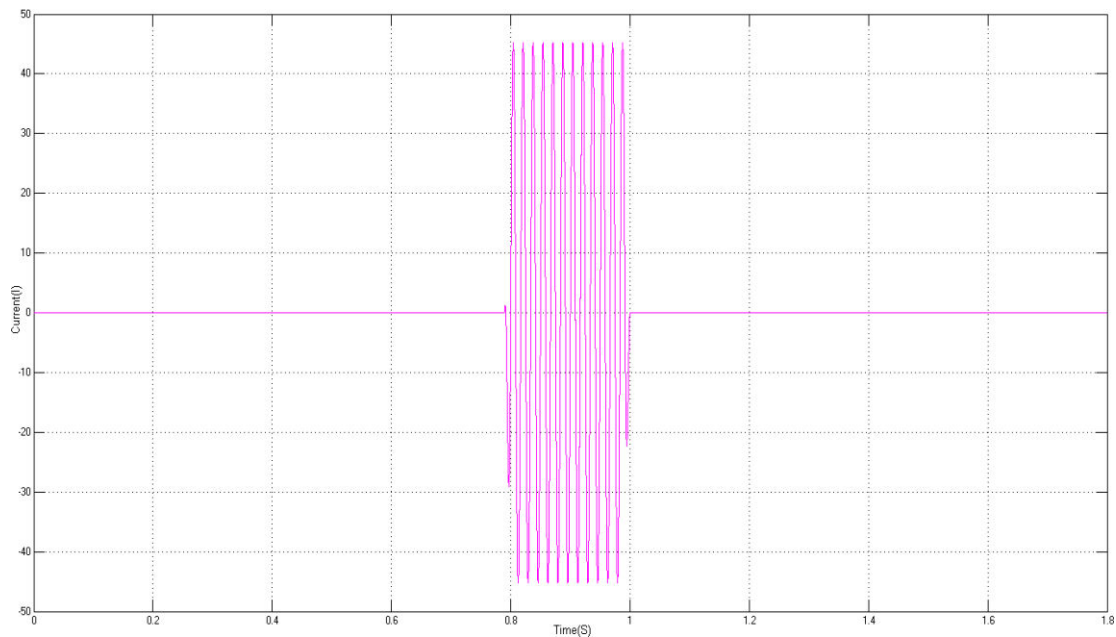


Figure 4.7 Current of the Grid

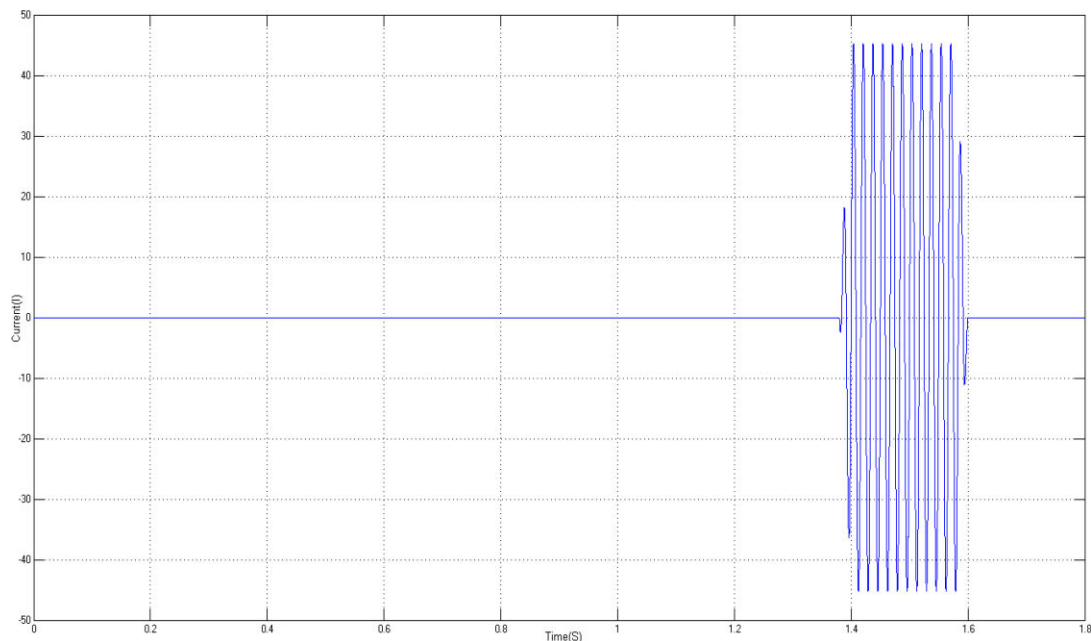


Figure 4.8 Current of the Generator

Figures 4.7 and 4.9 illustrate the synchronisation of the grid voltage (vs) to the PCC voltage's (vc) performance, respectively. On the occurrence of the grid, the control of the CS first synchronises the grid voltage to the PCC voltage. Following that, the grid begins supplying PCC's demand and beginning to charge the storage battery. the operation of the control loop and creation of the "X" signal for the bidirectional switch. Under synchronisation de- synchronization, the load current is not affected.

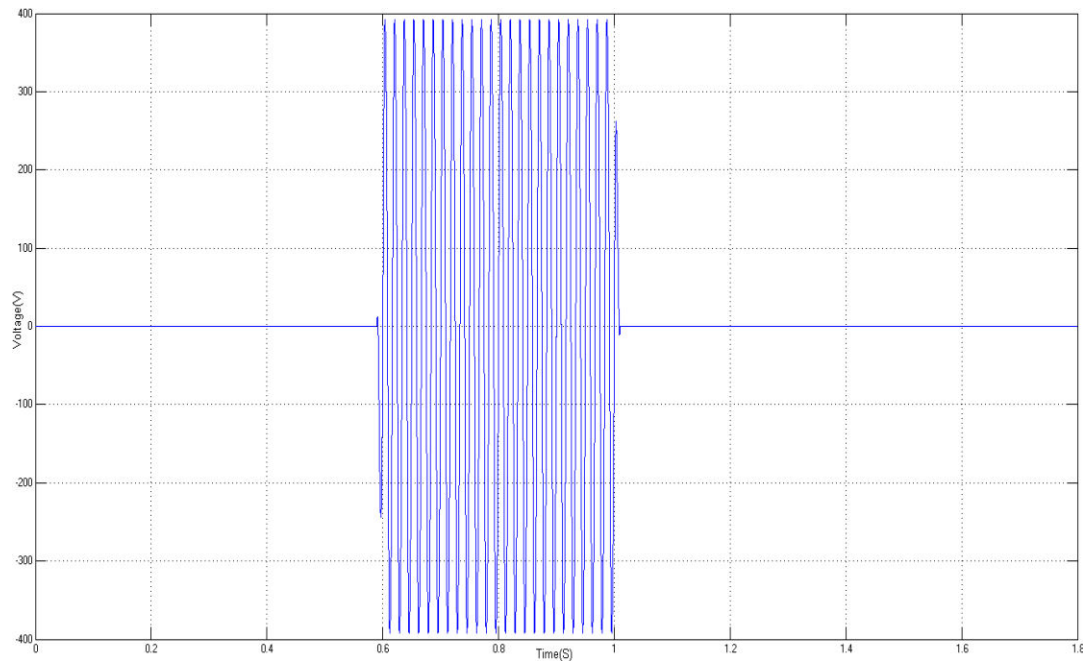


Figure 4.9 Voltage at PCC

Simulated results shown in Fig.4.1 present the uninterruptible operation of the CS. Initially, the CS is operating in the islanded mode, and the PV array power is fed for charging the EVs connected at PCC. Since the PV array generation is exceeding the EVs charging demand, the surplus generation is stored in the energy storage at 0.32 s, the solar irradiance changes from 1000 to 300 W/m². Due to which, the PV array power reduces and the storage battery starts discharging to keep the charging uninterruptible. At 0.48 s, the storage battery discharges as the PV array power becomes zero. After this, the storage battery completely supports the charging, as long as SOC > SOC min.

Table 4.2 Battery Charging Time

Different Modes	Time required for charging the battery
Solar PV Array	0.32 sec
Grid	0.79 sec
DG Set	1.37 sec

The controller synchronizes the CS with the grid when the battery has been fully discharged. The CS began using grid electricity at 0.79 seconds. Due to the lack of grid and storage battery power after this point, CS is provided by the DG set as indicated in Fig. 4.1. It has been noticed that the CS switches between modes automatically based on demand and generation.

V. CONCLUSION

This paper presented a hybrid EV battery exchange charging system integrated with a solar photovoltaic (PV) array, battery energy storage system (BESS), diesel generator (DG) set, and utility grid for reliable and uninterrupted EV charging operation. The proposed charging architecture successfully combines renewable energy utilization, battery swapping technology, and intelligent power management to improve charging station performance under varying operating conditions. The complete system was modeled and analyzed in MATLAB/Simulink under grid-connected, islanded, and DG-supported operating modes. Simulation results confirmed that the proposed control strategy effectively maintained stable DC-link voltage, regulated PCC voltage and frequency, and ensured seamless transition between different operating modes without interrupting the EV charging process.

The photovoltaic array supplied the major share of charging power during normal operating conditions, while the battery energy storage system compensated for fluctuations caused by variations in solar irradiance and charging demand. During low irradiance conditions and grid unavailability, the DG set successfully provided backup power support and maintained continuous charging operation. The coordinated operation of PV, battery storage, grid, and DG sources improved overall charging reliability and reduced dependency on the utility grid. The obtained results also demonstrated improved power quality performance with reduced harmonic distortion within IEEE permissible limits. The voltage source converter (VSC) effectively controlled active and reactive power flow while maintaining near-unity power factor operation at the point of common coupling (PCC). The implementation of battery swapping technology significantly reduced EV charging time and improved charging station utilization compared to conventional charging methods. In addition, the proposed methodology enhanced renewable energy utilization, reduced carbon emission impact, and provided a practical solution for future smart EV charging infrastructure.

Therefore, the proposed hybrid EV battery exchange charging system can be considered an efficient, reliable, and sustainable charging solution for modern electric transportation systems, particularly in remote and weak-grid regions where uninterrupted charging availability and renewable energy integration are critical requirements.

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