Electrical Vehicle Charging Station by Using Integrated Solar Pv, Battery, and Disel Generator System

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Abstract

A EV charging station integrates a solar PV array, battery energy storage (BES), a diesel generator (DG) set, and the grid to ensure uninterrupted charging. It prioritizes solar and battery power, switching to the grid or DG set when needed.The DG operates at 80-85% load for maximum efficiency, while the system regulates voltage and frequency without a mechanical governor. It maintains a unity power factor (UPF) even under nonlinear loads and synchronizes the PCC voltage with the grid or generator. Additionally, the station supports vehicle-to-grid (V2G), vehicle-to-home (V2H), and vehicle-to-vehicle (V2V) power transfers, enhancing efficiency. Its performance is validated using MATLAB/Simulink simulations.

INTRODUCTION

Electric vehicles (EVs) are a clean and efficient mode of transportation, with global adoption expected to reach 100 million by 2030. However, sustainable charging requires electricity from renewable sources rather than fossil fuels, which only shift emissions from vehicles to power plants.

Solar photovoltaic (PV) energy is the most practical renewable option for EV charging due to its widespread availability. Wind and hydro energy are also useful but depend on location. While renewable energy-based charging stations are ideal, they require efficient energy management to handle multiple power sources. This work presents a smart EV charging station that integrates solar PV, battery storage, and a diesel generator (DG) set. It ensures continuous charging by automatically switching between power sources. Key features include:

Seamless mode switching between solar, battery, grid, and DG power. Vehicle-to- vehicle (V2V) and vehicle-to-grid (V2G) power transfer for better energy use. Improved power quality, maintaining a stable power supply.

Efficient DG operation, running at 80-85% load for fuel savings.

Smart energy management, preventing battery overcharging and optimizing solar use.

The system i tested using MATLAB/Simulink, proving its reliability in real-world scenarios. This solution supports a sustainable and efficient EV charging network for the future.

What is MATLAB ?

MATLAB (MATrix LABoratory) is a powerful computational tool widely used in electrical engineering for simulation, analysis, and system design. It provides a high-level programming environment with extensive toolboxes for power systems, signal processing, control systems, and machine learning. With its matrix-based structure, MATLAB efficiently handles circuit analysis, power flow studies, fault analysis, and optimization in electrical networks. Integrated with Simulink, it enables dynamic modeling and simulation of electrical systems, including renewable energy integration, electric vehicle charging, and power electronics. Its ability to visualize data, analyze signals, and design controllers makes it an essential tool for electrical engineers in both research and industrial applications.

Why MATLAB Technology is important?

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LITERATURE SURVEY

The integration of battery storage, solar photovoltaic (PV) systems, and diesel generators (DG) in electric vehicle (EV) charging stations plays a crucial role in enhancing sustainability, reliability, and energy efficiency. This survey explores key aspects such as renewable energy integration, battery technologies, and diesel backup to ensure uninterrupted charging during grid failures or periods of low solar generation. It examines system optimization strategies, economic feasibility, environmental impact, and regulatory considerations to assess the viability of hybrid EV charging stations. Additionally, case studies provide insights into real-world implementations, highlighting both opportunities and challenges in this field. Future trends focus on advancements in smart grid integration, vehicle-to-grid (V2G) technology, and improved control mechanisms for seamless energy management. By addressing these factors, hybrid charging stations can contribute to a more resilient and sustainable EV infrastructure, supporting the widespread adoption of electric mobility.

EXISTING SYSTEM

The conventional approach to EV charging primarily relies on grid-powered charging stations, which depend entirely on grid electricity for operation, including peak demand periods and emergency situations. While some charging stations integrate renewable energy sources such as solar photovoltaic (PV) systems, they often lack battery storage and diesel generator backup. This absence of energy storage and backup solutions reduces their reliability and resilience, making them vulnerable to grid failures and fluctuations in solar energy generation. As a result, these limitations hinder the continuous and efficient operation of EV charging infrastructure, emphasizing the need for hybrid energy solutions to enhance sustainability and reliability.

PROPOSED SYSTEM

The proposed approach introduces a hybrid EV charging station that integrates solar photovoltaic (PV) systems, battery storage, and diesel generators to enhance reliability, sustainability, and operational efficiency. Solar PV panels serve as the primary energy source, harnessing renewable energy to charge EVs and store excess power in batteries for use during periods of low solar generation or peak demand. Diesel generators act as a backup power source, ensuring uninterrupted operation during extended grid outages or insufficient renewable energy availability. An intelligent energy management system, supported by advanced optimization algorithms, dynamically regulates energy distribution, prioritizing renewable sources while minimizing reliance on grid electricity and diesel fuel. This hybrid system significantly improves the resilience and sustainability of EV charging infrastructure, reducing greenhouse gas emissions and dependency on fossil fuels. While initial investment costs may be required for equipment and installation, long-term operational savings from reduced grid electricity consumption and optimized fuel usage enhance its cost- effectiveness. Additionally, potential revenue from EV charging services further strengthens the economic viability of this solution, making it a practical and sustainable advancement in modern EV charging infrastructure

SOFTWARE

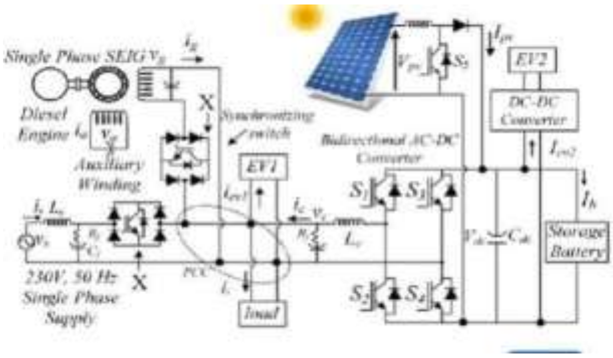
Operating System: Windows 11 RAM Used: 16GB
Software Used: MATLAB 2016a
Simply, this report discuss that the Solar PV arrays are strategically installed to capture solar energy, which is then converted into electrical power for charging EVs and replenishing the battery storage. The battery storage system serves as a crucial buffer, storing excess solar energy for use during periods of low solar irradiance and significant demand. Additionally, a diesel generator provides backup power to ensure uninterrupted charging operations during extended periods of adverse weather conditions or high demand

METHODOLOGY

The implementation of a hybrid EV charging station involves the integration of solar PV, battery storage, and diesel generators to ensure reliable and sustainable power supply. The site selection process considers factors such as energy demand, solar potential, grid connectivity, space availability, environmental impact, and cost- effectiveness. Solar panels convert sunlight into electricity, which is either used directly for charging or stored in batteries for later use. Lithium-ion batteries serve as an energy buffer, ensuring continuous power supply during periods of low solar generation. Diesel generators act as backup power sources, providing stability during grid outages or extended low renewable energy availability.

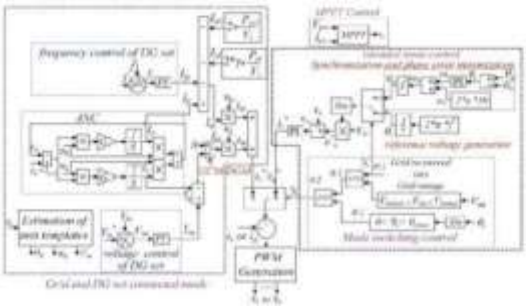
A single-phase grid system, managed through synchronizing switches and H-bridge configurations with Insulated Gate Bipolar Transistors (IGBTs), ensures smooth power distribution. Filtering circuits, such as RLC filters, enhance power quality by reducing harmonics and voltage fluctuations. Additionally, a DC-DC boost converter regulates voltage levels, optimizing the charging process by efficiently managing energy flow between the storage system and EVs. This hybrid system enhances reliability, minimizes dependence on grid electricity, reduces greenhouse gas emissions, and ensures a cost- effective approach to sustainable EV charging infrastructure.

TOPOLOGY OF CHARGING STATION



The charging station uses solar PV, a battery, a diesel generator, and grid power to charge EVs and supply connected loads. The solar PV is connected through a boost converter, and the battery is linked directly. The grid, generator, EV, and load are connected on the AC side. A ripple filter ensures smooth current flow, while capacitors support the generator. A synchronizing switch controls the connection between the grid and generator for reliable operation.

CONTROL STRATEGIES



Control of vsc in isolated mode

In islanded mode, the Charging Station (CS) works without grid support, ensuring continuous AC and DC charging of Electric Vehicles (EVs) and solar power generation. DC charging and solar power are managed by the battery, but AC charging needs a separate controller for the Voltage Source Converter (VSC) since there is no external voltage reference. The islanded controller creates an internal voltage reference of 230V at 50Hz. This reference is compared with the converter's voltage, and a Proportional-Integral (PI) controller reduces the error to generate the required current. A hysteresis controller then adjusts this current and generates gate signals for the converter, ensuring smooth operation of the CS in islanded mode.

$$i_c^*(s) = i_c^*(s-1) + z_{pv}\{v_{ce}(s) - v_{ce}(s-1)\} + z_{iv}v_{ce}(s)$$

Control of vsc in dg set or grid connected mode

In grid-connected mode, the controller manages the power exchanged with the grid, while in DG setconnected mode, the DG set runs at constant power for better fuel efficiency. In both cases, the controller compensates for the EVs' harmonic and reactive current demands by estimating the reference current. For grid- connected mode, only the active part of the EV current is used, while for DG set-connected mode, both active and reactive parts are considered. An adaptive notch cancellation (ANC) method extracts the EV's fundamental frequency current, and a sample- andhold logic helps determine active and reactive currents at each zero crossing. This ensures efficient power control in both modes.

$$I_{sp} = I_p - I_{ef2} - I_{pf}$$

$$I_{sq} = 0$$

In grid connected mode, only active current of EV is considered and the reactive current is considered zero for achieving unity power factor operation. However, in DG set connected mode, both active and reactive current components of EV are used. Now, total active and reactive current in DG set connected mode is as,'

$$I_{sp} = I_p - I_{ef2} - I_{fp} - I_{pf}$$

$$I_{sq} = I_{vq} - I_q$$

This system manages power flow between an electric vehicle (EV), solar panels, a battery, and a grid (or generator) by controlling currents: the EV's active and reactive currents handle its power exchange, a variable γ directs solar power between charging the battery and feeding the grid based on battery charge level, and signals like Ief2, Ipf, Ifp, and Ivq ensure stable voltage and frequency, all regulated by a hysteresis controller for precise current matching.

$$i_s^* or\ i_g^* = I_{tp} \times u_p + I_{tq} \times u_q$$

DG Set Voltage and Frequency Control

The DG set's voltage and frequency are controlled
using decoupled control of the VSC. Here, frequency is regulated by active power, while voltage is controlled by reactive power. Two PI controllers are used—one for voltage and one for frequency regulation.

$$I_{vq}(s) = I_{vq}(s-1) + z_{vp}\{V_{me}(s) - V_{me}(s-1)\} + z_{vi}V_{me}(s)$$

Where Vme=Vm *-Vm and the zvi and zvp are the PI controller gains. Similarly, the discerate expression of the frequency PI controller is as,

$$I_{fp}(s) = I_{fp}(s-1) + z_{fp}\{f_e(s) - f_e(s-1)\} + z_{fi}f_e(s)$$

Essentially, the system uses "smart adjusters" (PI controllers) to keep the DG set's frequency and voltage steady. When the system is connected to a stable power grid, the grid itself handles the frequency and voltage, so the "smart adjusters" on the DG set don't have to do anything and their adjustments become zero **Control of EV2** To charge an Electric Vehicle (EV) connected to a DC link, a DC-DC converter uses a two-stage process called Constant Current/Constant Voltage (CC/CV) charging. First, the EV charges at a constant current until it's almost fully charged. Then, it switches to constant voltage to top off the battery. This ensures safe and efficient charging. Two "smart adjusters" (PI controllers) manage this process: one to control the voltage and another to control the current, with the voltage controller providing the target current for the current controller.

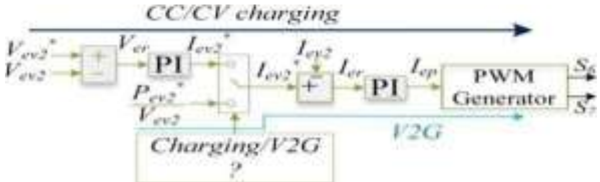


Fig 5.2. EV2 control for CC/CV charging and V2G power transfer

$$I_{ev2}^*(s) = I_{ev2}^*(s-1) + z_{evp}\{V_{er}(s) - V_{er}(s-1)\} + z_{evi}V_{er}(s)$$

The EV's charging is managed by "smart adjusters." One adjuster checks the battery's voltage and figures out the right charging current. Another adjuster then uses that target current, along with the actual current, to control a switch that delivers the power, ensuring the battery charges safely and
correctly expressed as

$$d_{ev}(s) = d_{ev}(s-1) + z_{ep}\{I_{er}(s) - I_{er}(s-1)\} + z_{ei}I_{er}(s)$$

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A "smart adjuster" controls the battery current. For sending power back to the grid, the battery's discharge is based on a set power level. This power level tells the system how much to discharge.

Control of synchronization and switching

To ensure smooth transitions between different operating modes (like switching from running on its own to connecting to the grid or a generator), the charging station needs a smart way to change modes. First, it measures the phase difference

between the two voltage sources it needs to connect. Then, a "smart adjuster" (PI controller) adjusts the charging station's voltage frequency until both voltages are in sync. This "smart adjuster" uses the phase difference and its settings (zpa and zia) to make these adjustments. The system also checks certain conditions to decide when to switch modes. Once everything is aligned, a signal (X='1') is sent to close a switch, connecting the charging station to the new power source without disrupting the charging process.

$$\Delta\omega(s) = \Delta\omega(s-1) + z_{pa}\{\Delta\theta(s) - \Delta\theta(s-1)\} + z_{ia}\Delta\theta(s)$$

ADVANTAGES

- Cost Efficiency
- Improved Power Quality
- Reduced Grid Strain
- Reduced Transmission Losses
- Reduced Noise Pollution

APPLICATIONS

Urban and Rural EV Charging Infrastructure:

Provides sustainable charging solutions for diverse locations, addressing the increasing demand for EV charging.

Residential and Commercial Buildings:

Enables integration of EV charging with on-site renewable energy generation and energy storage. o Facilitates V2G applications for home energy management.

Grid Stability and Ancillary Services:

Supports grid frequency and voltage regulation through V2G capabilities. o Provides active power filtering to improve grid power quality.

Remote and Off-Grid Locations:

Offers reliable EV charging in areas with limited or no grid access, utilizing solar PV and DG sets.

Emergency Power Supply:

EV batteries can act as emergency power supply, through V2H or V2G technologies

EXPERIMENTAL RESULTS

Proposed Designed Model

Below are the figures of result of simulation model of solar energy battery and diesel generator, load {EV1 current, EV2 current, load, Vc & Vs of grid, Vg &Vs of diesel generator} and simulation of output of grid connected mode and diesel generator
connected mode

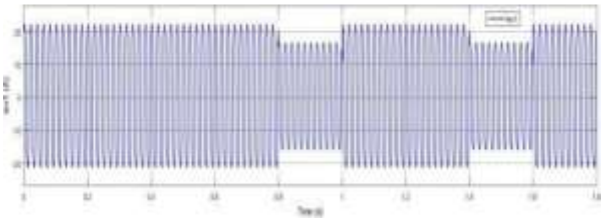

FIG1, Simulation result of EV1 Current

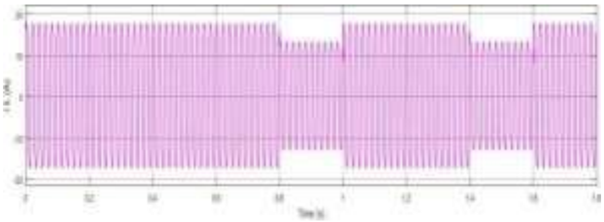

FIG2, Simulation result of Load

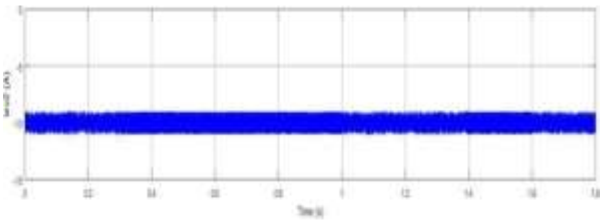

FIG3, Simulation result of EV2 current

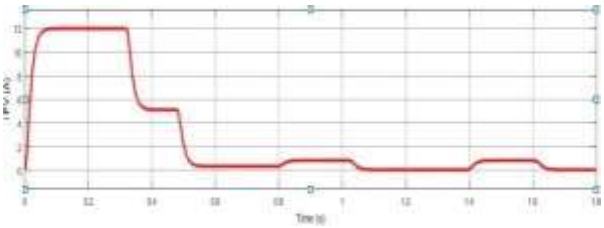

FIG 4 Simulation result of Solar Energy

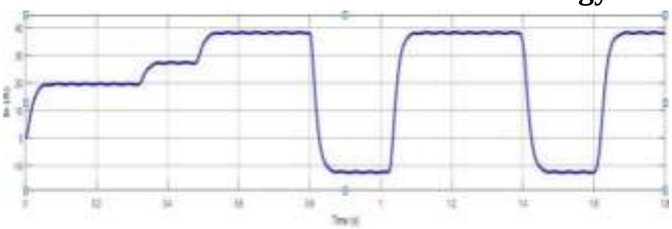

FIG5, Simulation result of Battery FIG:1.1 Combined

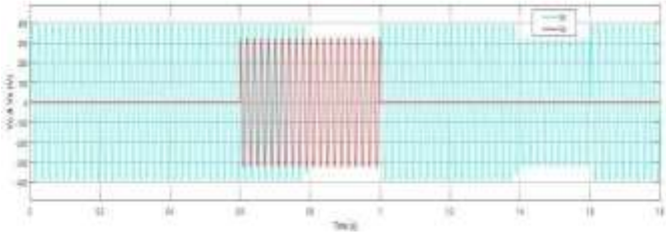

FIG6, Simulation result of Vc & Vs for Single phase grid

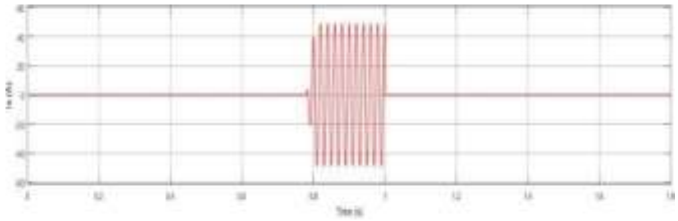

FIG7, Simulation output for grid connected mode

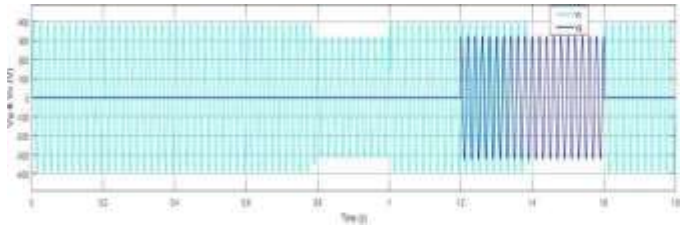

FIG8, Simulation output of Vg, Vc for Diesel

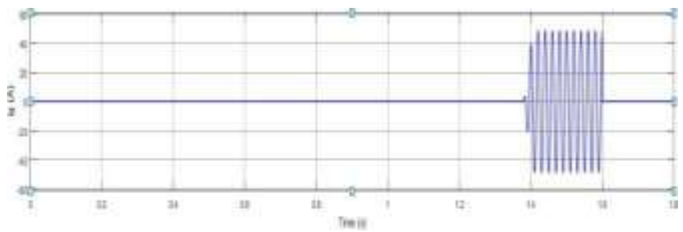

FIG9, Simulation output of Ig for DG connected mode

CONCLUSION

An implementation of PV array, storage battery, grid and DG set based charging station has been realized for EV charging. The presented results have verified the multimode operating capability (islanded operation, grid connected and DG set connected) of the CS using only one VSC. Test results have also verified the satisfactory operation of charging station under different steady state conditions and various dynamics conditions caused by the change in the solar irradiance level, change in the EV charging current and change in the loading. The operation of charging station as a standalone generator with good quality of the voltage, has been verified by the presented results. Whereas, test results in DG set or grid connected mode, have verified the capability of ANC based control algorithm to maintain the power exchange with the grid at UPF or the optimum loading of the DG set. Moreover, the islanded operation, grid connected and DG set connected operations along with the automatic mode switching have increased the probability of MPP operation of the PV array and optimum loading of DG set along with increasing the charging reliability. The compliance operation of the charging station with voltage and current THD always less than 5% verifies the effectiveness of the control. Form the above mentioned point, it can be concluded that this charging station with the presented control have the capability to utilize the various energy sources very efficiently and provides the constant and cost effective charging to the EVs.

FUTURE SCOPE

Renewable Energy Integration: Combining solar PV and battery storage allows for clean, renewable energy to be used for charging EVs, reducing carbon emissions and reliance on fossil fuels

Energy Security: The inclusion of a diesel generator provides backup power during periods of low solar generation or high demand, ensuring continuous operation and reliability of the charging station.

Cost Savings: By utilizing solar power and battery storage during peak sunlight hours, the need to rely on grid electricity or diesel generator usage is minimized, leading to potential cost savings in the long term. **Scalability and Flexibility:** Such a system can be easily scaled up or down depending on the charging station's needs and can be deployed in various locations, including remote areas where grid access is limited.

Resilience to Grid Outages: During grid outages or emergencies, the charging station can continue to operate independently, providing essential services and supportto EV owners.

Environmental Impact: Overall, the integration of renewable energy sources reduces the carbon footprint associated with charging EVs, contributing to environmental sustainability and combating climate change.

Additionally, advancements in technology, such as improved solar panels, more efficient batteries, and cleaner diesel generators, will further enhance the viability and effectiveness of these charging stations. Integration with smart grid technologies and demand-response strategies can optimize energy usage and grid interaction, maximizing the benefits of the system while minimizing its environmental impact. Furthermore, as governments and organizations continue to prioritize clean energy and decarbonization efforts, there may be incentives and support programs available to encourage the development and deployment of such hybrid charging stations.

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