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Implementation of a Sustainable EV Charging Station Powered by Solar PV and Battery with Grid Integration

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Abstract: Determined to further develop network power quality, this study presents an electric vehicle charging station that is communicated with a lattice associated photovoltaic cluster and battery energy capacity. This study appraises the unit layouts (UTs) and reference framework flows by examining the positive arrangement parts (PSCs) of the three stage matrix voltages. Through a bidirectional buck-support converter, the dc association between the EV and BES is laid out. Electric vehicles get power from sunlight powered chargers when the sun is straight above. Right when the EV station draws power from the framework over the course of the evening. Associating an EV charging station to the framework influences the voltage at the place of normal association with synchronizes with the lattice voltages. To come by a reasonable result under differing dynamic circumstances, the model is tried and refined.

Key Words: Electric Vehicle (EV), Charging Station, Renewable Energy, Grid Integration, Simulation, Energy Management, Grid, Battery, etc.

1. Introduction

The need for better fuel economy and a further reduction in greenhouse gas emissions is driving the automotive industry to undergo a comprehensive transformation toward vehicle electrification, leading to the introduction of plug-in hybrid electric vehicles (PHEVs) and electric vehicles (EVs), collectively referred to as plug-in electric vehicles (PEVs). The electrical powertrain of current and next-generation PEVs consists of an energy storage system connected to a propulsion machine via an inverter. Additionally, an external battery charger is an essential component of the vehicle's powertrain.

In most PEVs, a bidirectional DC/DC converter is employed between the battery and the propulsion machine inverter. This converter plays a key role in boosting the battery voltage and efficiently managing power delivery or absorption during cruising, acceleration, and regenerative braking. In the conventional architecture, the bidirectional DC/DC converter operates solely during propulsion, while a separate AC/DC converter is used for battery charging. Regardless of the converter topology, this setup involves two

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distinct power electronic converters for two separate operation modes.

To enhance efficiency and reduce size, weight, and cost, this study proposes integrating the charger with the existing bidirectional DC/DC converter used during driving. Driven by fossil fuel depletion and environmental concerns, EV research is advancing, though consumer adoption depends heavily on addressing key issues like charging time. This dissertation aims to develop fast-charging solutions to accelerate EV adoption.

Furthermore, An EU study found that road transport accounts for over 70% of CO_2 emissions in the sector and about 28% of total emissions. To reduce greenhouse gases, many developed countries promote EV adoption through incentives like tax breaks, purchase subsidies, free public parking, and highway access.. Electric vehicles have many advantages over ordinary vehicles:

- **Zero emissions:** Electric vehicles emit no CO_2 or NO_2, making them environmentally friendly, though battery production can slightly impact their overall carbon footprint.
- **Simplicity:** EVs have fewer moving parts, making them simpler, quieter, and cheaper to repair due to the absence of components like a clutch, gearshift, and cooling circuit.
- **Reliability:** EVs are more reliable due to fewer, simpler components and are not affected by vibrations, fuel corrosion, explosions, or engine wear.
- **Cost:** EVs have lower maintenance and energy costs compared to traditional gas-powered vehicles, making them more economical per kilometre.
- **Comfort:** There are no tremors or engine noise while you ride in an electric vehicle, making it a more pleasant option.

2. Literature Review

Study on Electric Vehicles in India Opportunities and Challenges: Over the years, the exploitation and pollution of natural resources have created the need for renewable and environment-friendly products. One of these products is Electric Vehicles. Electric Vehicles are the replacement for petroleum-based vehicles. They are one of the emerging technologies as well as eco-friendly and viable. The replacement of internal combustion engines with electric engines will reduce pollution to a great extent and be profitable to consumers. Many countries around the globe have implemented this technology and are contributing towards amelioration of the environment. We are going to see the opportunities and challenged faced in India over implementing electric vehicles.

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Literature Review of Electric Vehicle Technology and its Applications: This paper reviews the technical background of electric vehicle technology and its applications. A number of important concepts frequently used in this field are explained, and the technical details, including the theoretical principles, are given alongside practical systems pertaining to several kinds of electric charging piles. It critically appraises a number of state-of-the-art research progresses in this field developed within the last ten years. Finally, it points out the future potential research directions regarding electric vehicle technology and its applications, especially of charging techniques. By reading this review paper, readers will not only grasp a technical background of electric vehicle technology, but also gain a full picture of the research field.

3. Proposed System

A portable power supply equipped with a dual-active-bridge (DAB) converter for power factor correction (PFC) has been developed. A highly efficient grid-connected onboard charger for battery charging has also been introduced. This onboard charger is simpler and more efficient than traditional dual-stage chargers, as it performs charging in a single stage. However, it is mainly used for low-power applications. Additionally, an electric vehicle charging station has been developed, where all EVs are charged using a combination of solar panels and the electrical grid.

3.1 Voltage Source Converter (VSC):

Voltage source converters (VSCs) play a key role in AC-DC conversion, receiving power from a DC solar array and converting it into three-phase AC, which is then supplied to the grid via a static transfer switch (STS). Real-world voltage sources include batteries, cells, and generators. Advanced FACTS devices use VSCs for programmable voltage injections in AC networks. This study proposes an off-board EV charging station powered by solar energy and integrated with a Battery Energy Storage (BES) system. It manages power flow between the PV array, BES, EV, and grid. When solar energy is available, it charges the EV and feeds excess to the grid, while dedicated DC converters ensure efficient transfer. The BES stores surplus energy for use during grid outages or when solar generation is unavailable, maintaining reliable EV charging.The key features of the present work are as follows.

i. Electric vehicle (EV) battery charging is done using the PV array, with any excess electricity being sent to the grid and BES.
ii. When there is no PV source available, the BES charges the EV battery. This

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ensures that the grid is not overloaded and that as little electricity is traded as possible.

iii. The PV array is directly linked at the dc connection in this architecture. This leads to an increase in the system's overall efficiency.

iv. Fourthly, since the regulation of voltage source converters (VSCs) handles EV charging and discharging, nonlinearities are injected into the grid.

v. The system's capacity to automatically and smoothly transition between grid disconnection and reconnection modes of operation.

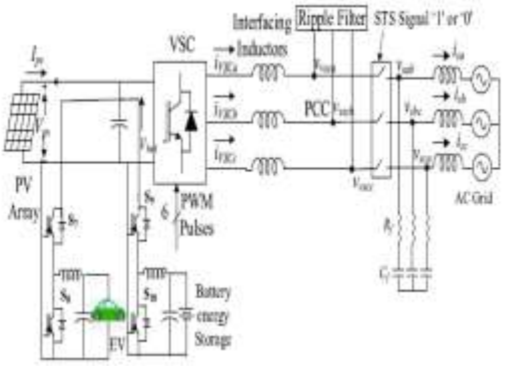


Fig 1. System topology.

As shown in Fig 1, the BES-enabled EV charging station supports bidirectional power flow between the PV array, BES, EV, and grid via a Voltage Source Converter (VSC). Independent bidirectional DC converters manage EV and BES charging/discharging at the common DC link. The VSC connects to the grid through interface inductors and syncs via a Static Transfer Switch (STS). Peak shaving is achieved using BES, though it raises system cost. The converter reduces losses by efficiently managing power flow from BES to the EV battery.

3.2 Control approach

The main purpose of the system is the EV charging. In case the grid is not available, there maining power is used for the charging of the BES. If required, either EV or BES or both are discharged to the grid.

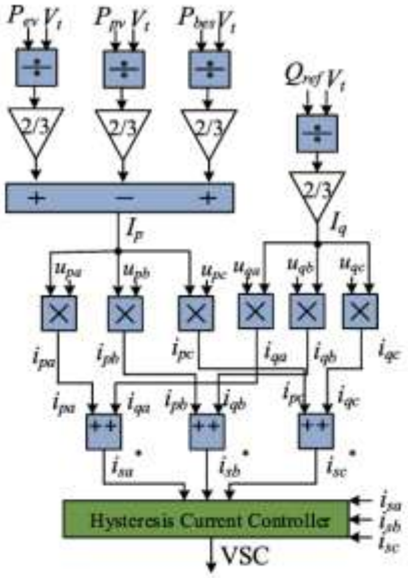


Fig 2. GC control.

The control is classifiedas:1)MPPT control; 2)grid connected(GC) mode control; 3)synchronization and standalone mode(SM) control ; 4)BES control; and 5) EV control. The three phase voltages(vsa, vsb, and vsc) are transformed to α–βdomain using Clark's transformation

$$\begin{pmatrix} v_{s\alpha} \\ v_{s\beta} \end{pmatrix} = \begin{pmatrix} 1 & -\frac{1}{2} & -\frac{1}{2} \\ 0 & \frac{\sqrt{3}}{2} & -\frac{\sqrt{3}}{2} \end{pmatrix} \begin{pmatrix} v_{sa} \\ v_{sb} \\ v_{sc} \end{pmatrix}. \qquad (1)$$

The over all transfer function from Fig.2 is attained as

$$v_{p\alpha\beta} = \frac{a\omega}{(s+a\omega)^2+\omega^2}\begin{bmatrix} (s+a\omega) & -\omega \\ \omega & (s+a\omega) \end{bmatrix}\begin{bmatrix} v_{s\alpha} \\ v_{s\beta} \end{bmatrix}.$$

The PSCs are estimated from controller output obtained in (2)by using inverse Clark's transformation

$$\begin{pmatrix} v_{pa} \\ v_{pb} \\ v_{pc} \end{pmatrix} = \frac{3}{2}\begin{pmatrix} \frac{2}{3} & 0 \\ -\frac{1}{3} & \frac{\sqrt{3}}{3} \\ -\frac{1}{3} & -\frac{\sqrt{3}}{3} \end{pmatrix} \times \begin{pmatrix} v_{s\alpha} \\ v_{s\beta} \end{pmatrix}. \qquad (3)$$

(b) EV battery charging/discharging control algorithm. The amplitude of terminal voltage (Vt) is computed using phase voltages as

$$V_t = \sqrt{\frac{2}{3} \times \left(v_{pa}^2 + v_{pb}^2 + v_{pc}^2\right)}$$

Where vpa, vpb, and vpc are PSCs. The in-phase UTs are computed from PSCs and terminal voltage as

$$u_{pa} = \frac{v_{pa}}{V_t}, \quad u_{pb} = \frac{v_{pb}}{V_t}, \quad u_{pc} = \frac{v_{pc}}{V_t}.$$

Like wise, quadrature UTs are evaluated as depicted in The reference grid currents obtained are subtracted from actual grid currents. The error obtained is given to hysteresis current controller and VSC gate pulses are obtained

3.3. A grid-connected PV array and battery energy storage interfaced EV charging station

A grid-connected PV array and battery energy storage-based EV charging station provides a sustainable and efficient solution for clean transportation. Solar energy powers EV charging, with excess energy stored in the BESS for use during low solar availability. The grid serves as a backup when solar and battery sources fall short, and surplus energy can be fed back to the grid when generation exceeds demand. This setup enhances energy reliability, reduces fossil fuel reliance, eases grid load during peak times, and supports carbon reduction and smart grid initiatives.

3.4 Objectives of a Grid-Connected PV Array and Battery Energy Storage Interfaced EV Charging Station

The main objectives of a grid-connected PV array and battery energy storage-based EV charging station are to deliver a reliable, efficient, and eco-friendly power supply for electric vehicles. By harnessing solar energy, the system reduces dependence on grid electricity and fossil fuels, cutting carbon emissions and supporting clean energy goals. The integrated BESS ensures continuous power during low solar output and peak demand, while optimizing energy flow between the PV array, battery, EVs, and the grid. It also enables bidirectional energy transfer, allowing surplus power to support grid stability and promote decentralized energy generation, aligning with sustainable mobility and smart grid development.

3.5 Applications of a Grid-Connected PV Array and Battery Energy Storage Interfaced EV Charging Station

- **Urban EV Charging Stations**: Provides clean and efficient charging infrastructure in cities to support the growing number of electric vehicles.
- **Commercial & Industrial Zones** – Powers EV fleets in warehouses, factories, and business parks while reducing peak demand charges.
- **Public Transportation Hubs** – Supports electric buses and taxis with sustainable charging at bus depots, railway stations, and airports.

4. Simulation Model and Results

Advancements in battery capacity and fast charging technology have led to the development of more efficient EV charging methods. Emerging options like mobile charging stations and inductive pads show promise but remain limited in use. A major hurdle has been the lack of standardized protocols across manufacturers, prompting the industry to push for standardization by 2015. The Society of Automotive Engineers (SAE) defined three charging levels: Level 1 (120V AC) for slow charging, Level 2 (240V AC) for moderate speeds, and Level 3 (480V DC or higher), or supercharging, which can recharge up to 80% of a battery in about 30 minutes. Charging time ultimately depends on battery size, power supply, and charger-vehicle compatibility.

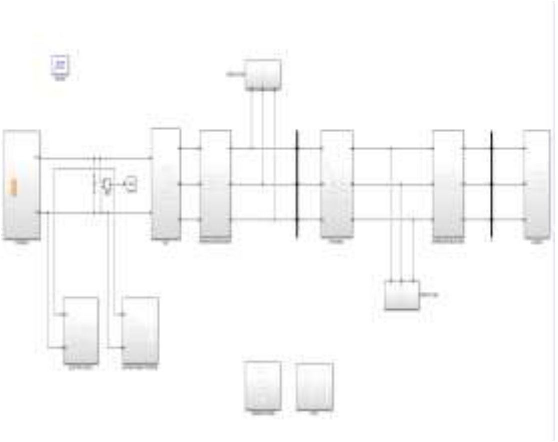


Fig 3: Simulation of BES charging & Discharging Control

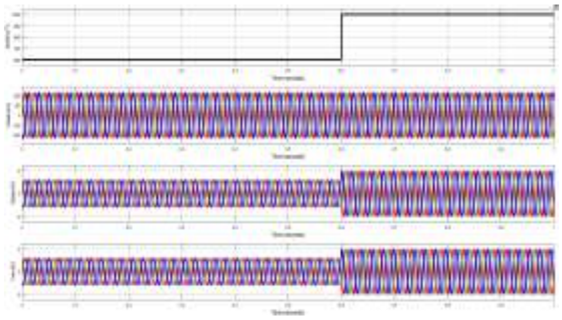


Fig 4. Irr, Vs abc, ISabc, Ivsc

The figure 4 illustrates the dynamic response of a grid-connected EV charging station under changing solar irradiance. At around 0.6 seconds, a step increase in irradiance occurs, simulating a rise in sunlight. While the three-phase voltage remains stable and balanced, the source and grid currents increase in amplitude, indicating a higher power contribution from the PV system.

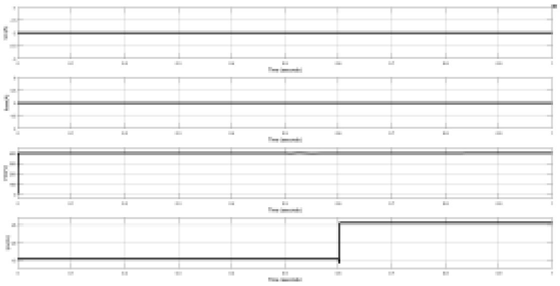
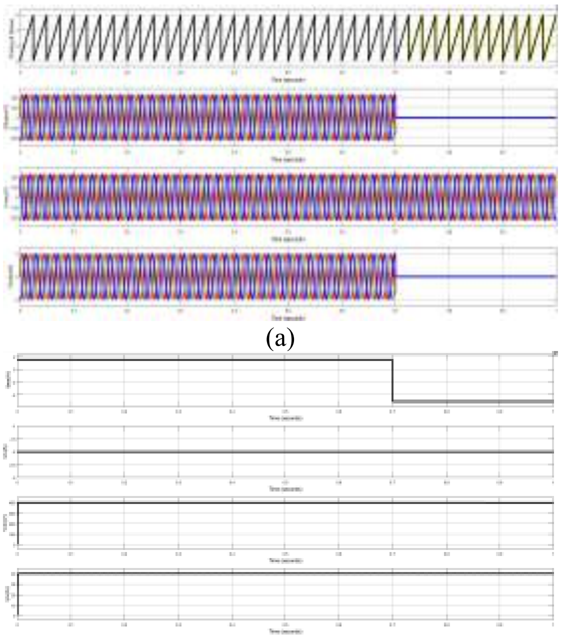


Fig 5. Simulated response of EV charging station under variation of PV insolation.

The simulation demonstrates that the EV charging station maintains stable operation (voltage and battery behavior) despite variation in PV insolation**,** with only the PV current responding to the change, indicating effective power management and system stability.

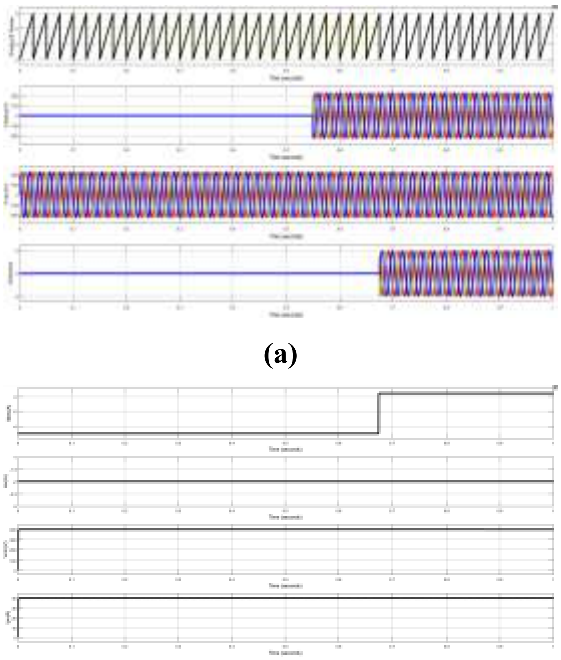


(a)

(b)

Fig 6.(a) Simulated performance at (b) grid Disconnection.

The figure 6 illustrates the response of a grid-connected EV charging station during a grid disconnection at around 0.7 seconds. Prior to disconnection, all parameters remain stable, indicating normal operation. After the disconnection, the battery current drops, showing reduced interaction with the grid, while PV current, inverter output, and DC voltage remain steady. This demonstrates the system's ability to maintain voltage regulation and uninterrupted EV charging through effective control and energy storage support, even during grid outages.



(a)

(b)

Fig 7. (a) Simulated performance at (b) grid reconnection.

The figure 7 illustrates the EV charging station's response during grid reconnection at around 0.7 seconds. Before reconnection, the system operates stably in standalone mode. Upon reconnection, the battery current (Ibess) increases, indicating resumed grid interaction, while PV current, inverter output, and DC voltage remain steady. This demonstrates a smooth

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and reliable transition back to grid-connected mode, ensuring continuous and stable EV charging.

5. Conclusion & Future Scope

Here we exhibit the charging station that is based on PV arrays and uses BES. Results from tests conducted under a variety of dynamic conditions including intermittent PV isolation with a BES in floating, compensatory, and continuous power grid modes have shown that EV charging stations may operate with enhanced power quality. There has also been much research on the system's reaction to BES system changes and disposals.

Future Scope: India's push for electric vehicle (EV) adoption is driven by the dual goals of reducing greenhouse gas emissions and cutting oil dependency. Vision 2030 outlines an ambitious roadmap to achieve large-scale EV integration, requiring strategic planning and swift action to overcome associated challenges. With global environmental commitments and growing pressure to transition to cleaner energy, India must act decisively. The future of EVs in the country looks promising, supported by technological advancements, government incentives, and increasing consumer interest in sustainable mobility solutions.

- The development of more efficient, lighter, and less expensive batteries that use rare earth elements is a continuous endeavor.
- To make electric vehicle batteries more environmentally friendly, renewable energy sources should be used for charging and recycling technology should be improved.

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