ADVANCED RESEARCH & INNOVATIONS
International Journal of Advanced Research & Innovations
Volume 15, Issue-2
August, 2025, P62
ISSN: 2319-9253

GRID-TIED PV ARRAY WITH BATTERY ENERGY STORAGE FOR EV CHARGING APPLICATIONS

ANASURI PRASANNA, ***M.Tech,***
Mr.S.PRAVEEN, ***Associate Professor,***
Dr. K. CHANDRAMOULI, ***Professor &HOD,***
Department of EEE,
VAAGESWARI COLLEGE OF ENGINEERING(AUTONOMOUS), KARIMNAGAR.

ABSTRACT: An EV charging station that uses solar panels, batteries, and utility company assistance is proposed in this paper. By doing so, we can build a charging infrastructure that is permanent, dependable, and always on. One way to manage energy use is via a hybrid system that combines photovoltaic (PV) cells, a BESS, and a two-way grid connection. Solar energy is used to directly charge electric vehicles during the sun's peak hours. The utility provider or the battery is credited with any excess energy. When solar power is low or demand is high, the grid and batteries work together to ensure that electricity is always sent where it is required. The utilization of green energy is prioritized and battery charging and discharging are optimized using a sophisticated energy management system (EMS), which facilitates vehicle-to-grid (V2G) connections. To maximize solar power utilization, a bidirectional DC-DC converter and inverter are employed, along with Maximum Power Point Tracking (MPPT). Models run in MATLAB/Simulink reveal the system's efficiency, load balancing capabilities, and power source switching smoothness. The simulations also demonstrate that the system is well-suited for smart charging networks that can withstand the test of time.

Keywords:EV charging station, solar energy, battery energy storage system (BESS), grid support, bidirectional converter, energy management system (EMS), Vehicle-to-Grid (V2G), MPPT, renewable energy integration, sustainable mobility, MATLAB/Simulink.

1. INTRODUCTION

A long-lasting and robust electric vehicle (EV) charging infrastructure is becoming increasingly critical due to the rapid electrification of transportation. To address this demand while also decreasing our dependency on fossil fuels, it would be wise to establish a charging station for electric cars (EVs) that is powered by solar panels, batteries, and the power grid. An efficient, clean, and decentralized charging system is one that collects energy from the sun using photovoltaic (PV) modules and stores any excess power in batteries. Together, these features reduce emissions of greenhouse gases and make it easier to regulate local energy consumption, which is particularly useful during peak demand times.

Using a combination of solar PV and a BESS makes EV charging stations more reliable and adaptable. When the sun is shining brightly, the BESS facilitates the storage of energy. Whether it's cloudy or nighttime, the BESS provides electricity even when sunshine is scarce or demand is high. It becomes easier to offer continuous charging services and safeguards against grid changes or interruptions. In addition to determining when the batteries are most efficient to charge and utilize, smart energy management technologies can increase the station's overall efficiency.

The charge system becomes more practical and dependable with grid support. The system may connect to the grid or feed excess energy back into it when battery and solar resources aren't sufficient. A more stable grid, simpler participation in demand response programs, and cost savings are all outcomes of this two-way flow of energy, which can be accomplished by time-of-use optimization or net metering. Charging stations for electric vehicles that run on solar electricity or batteries are a cornerstone of smart, sustainable urban energy networks.

2. LITERATURE SURVEY

Verma, N., & Sinha, A. (2024). Utilities, battery energy storage, and solar photovoltaic (PV) generation are all incorporated into the design of the hybrid electric vehicle (EV) charging station in this paper. Solar energy remains the primary focus, with backup from the grid and batteries utilized during peak demand periods when sunshine is scarce. In order to distribute power according to current availability and cost, a sophisticated energy management algorithm is employed. There have been numerous weather and load tests to evaluate the station's capabilities. Because of this, the grid is less reliant on it, and electric vehicles can continue to charge regardless of power outages. Because it is expandable, the authors emphasize, the approach can be utilized in both semi-urban and metropolitan settings.

Rangan, V., & Das, R. (2024). To make the most of city charging periods for EVs, this article recommends installing a solar-battery-grid linked charging station. The authors' predictive control strategy involves making educated guesses about the quantity of sunlight that will reach the ground, checking the battery charge, and estimating the power requirements. The technology intelligently alternates between charging batteries and pulling power from the grid to prevent grid congestion and associated costs. Data from a trial installation shows that demand-side control works, as evidenced by the 45% increase in solar energy utilization and the decrease in peak demands. The feasibility of broad deployment is also considered from a policy and economic perspective in the paper.

Joshi, T., & Menon, K. (2024). This research presents a solar array and lithium-ion battery bank–powered modular charging infrastructure for EVs. In order to accommodate additional services, the infrastructure must be able to support the grid in both directions. The control architecture ensures that charging is versatile for a wide range of electric vehicle (EV) models, provides for vehicle-to-grid (V2G) and peak reduction features, and more. The real-time optimization of energy flow is achieved by the employment of a model predictive controller. This controller takes into account the habits of EV drivers, the cost of power, and predictions for solar power. Simulation studies demonstrate that it can save energy costs by 25% and assist with local frequency management by up to 20%, making it an excellent choice for smart grid applications in urban areas.

Shetty, R., & Khan, F. (2023). A smart electric vehicle charging system supporting demand-responsive grid-tied inverters may be demonstrated in this paper using solar and battery technology. The approach monitors the grid frequency and the real-time electric vehicle charging load in order to regulate the energy flow from photovoltaics with storage batteries. In order to improve charging efficiency and reduce grid power use during peak hours, the authors demonstrate the use of an energy management system based on fuzzy logic. Ninety percent of the power required to run the concept is supplied by green sources at the suburban pilot site.

Chakraborty, N., & Pillai, R. (2023). An off-grid and grid-connected electric vehicle charging station is proposed by the authors. To reliably charge electric vehicles and handle power outages in emergencies, the system utilizes a lithium-ion battery bank and solar photovoltaics. The intelligent controller dynamically shifts modes in response to variations in the battery charge, solar input, and the capacity barrier. Research shows that this technique improves grid reliability and enables EV charging around the clock, even in areas prone to natural disasters.

Iyer, M., & Roy, S. (2023). This paper takes a look at a cloud-based solar EV charging network that supports batteries and cooperative energy management. The predicted amount of solar electricity produced at each station, the current price, and the condition of the batteries all play a role in determining when EVs can be charged. A central server controls the distribution of power to various locations in order to minimize charging costs and grid pressure. The writers notice a significant increase in the availability of charging stations when predictive algorithms and battery backup are utilized, particularly in low light conditions.

Banerjee, A., & Reddy, K. (2022). In this paper, we see a solar charging station for EVs that is grid-connected, has an integrated battery, and uses very little power. It is suitable for somewhat urban areas. The amount of solar input and the cost of energy are used by a rule-based controller to govern the charging and discharging of the batteries. During partial power outages, the models predict a 35% decrease in peak demand and no change to EV service. The ability to recover excess solar energy is also integrated into the vehicle-to-grid capacity.

Gupta, S., & Menon, V. (2022). This paper proposes a solar EV charging station with three layers of control, including dynamic grid support and battery backup. The device is primarily powered by solar energy, but it also has the capability to use the grid and batteries as backup sources, just in case. An Internet of Things (IoT) tracking device verifies the state of the batteries and ensures that the correct quantity of power is distributed to each component. Despite the high volume of electric vehicles, the field deployment results demonstrate that the system performed flawlessly and had few issues.

Patel, D., & Thomas, J. (2022). A DC-coupled electric vehicle charging system with grid-connected solar cells, batteries, and inverters is illustrated in this paper. The design improves the system's efficiency by reducing the number of stages required to convert power. To facilitate the safe and rapid charging of electric vehicles (EVs) and to assist the grid in times of peak demand, real-time adaptive current regulation is in place. Results from simulations show that the system efficiency is 10-15% higher than that of conventional AC-coupled designs.

Ravi, H., & Dutta, M. (2021). In order to make electric vehicles (EVs) accessible in remote areas, this research investigates solar-battery charging systems that are both affordable and require less infrastructure. The MPPT controller optimizes the power output of the PV system, while the lead-acid batteries maintain system stability. A secondary grid link can be established with relay-based logic. Results demonstrated that EVs were readily available in rural Maharashtra and that battery SOC remained at or above 50% in low-light conditions.

Bhandari, A., & Mehta, S. (2021). An EV charging station capable of both Level 1 and Level 2 charging is constructed by the authors using solar electricity, a bi-directional inverter, and smart battery cells. The method can facilitate intelligent load control and aid in grid reactive power protection through the use of planned charge algorithms. The outcomes of the tests demonstrate some of the advantages of urban deployment. Two examples are optimization based on tariffs and peak reduction.

Choudhury, P., & Singh, R. (2021). A decentralized solar electric vehicle charging system with autonomous charging nodes and reconfigurable battery packs is illustrated in this research. Using this approach, scaling networks and isolating flaws in massive ones becomes much easier. By utilizing solar priority logic, all renewable energy sources will be exhausted prior to drawing power from the grid. Industrial fleets and smart campus applications should be pleased with the outcomes.

Kumar, N., & Thomas, J. (2020). A solar-powered charging infrastructure for EVs is proposed in this preliminary paper. Backup battery systems and grid connectivity are part of it. In order to maintain a constant charging voltage, the authors develop a simple controller that switches between grid, photovoltaic, and battery sources. It is clear from the data that there is room for improvement in battery management strategies that provide satisfactory performance throughout a broad spectrum of load and illumination conditions.

Mishra, D., & Arora, B. (2020). An electric vehicle charging station with two solar converters is the center of attention here. An additional service is provided by a grid-connected DC/AC inverter, and the PV and batteries are managed by a specialized DC/DC stage. Despite rapid variations in both cloud cover and demand, field test models demonstrate that EVs continue to function successfully.

3. RELATED WORK

A more modern approach of powering electric vehicles is a grid-connected EV charging station that utilizes energy storage, renewable solar electricity, and the power grid. It promotes green mobility by reducing our dependency on fossil fuels and increasing energy efficiency. Not only will this multimodal infrastructure make it easier to charge electric vehicles, but it will also increase energy flow and maintain grid stability.

Solar Panels (PV Array):

Solar panels convert the energy from the sun into direct current (DC) electricity. Produced energy is free of harmful byproducts and derived entirely from solar sources. This provides the majority of the station's power during the day.

Battery Energy Storage (BES):

During the day, when electric vehicles (EVs) are not being charged, batteries store the excess energy produced by the sun. To guarantee a constant supply of electricity for charging, this spare energy might be utilized during peak demand periods, at night, or when the weather is overcast.

Inverters:

Inverters convert DC power to AC power, ensuring that renewable energy sources like solar panels and batteries may be used by electric vehicles and the power grid.

Charge Controllers:

For the efficient transfer of energy from solar panels to electric vehicles and batteries, these are essential. They prevent the system from being overcharged and safeguard the batteries.

EV Chargers:

These power electric vehicles. When the electricity goes out, people utilize EVs as a backup power source. They can charge only in one direction (unidirectional) or connect to the grid in both directions (bidirectional).

Grid Connection:

When the station's solar panels and batteries run out of juice, this connection allows it to draw electricity from elsewhere. However, by redistributing excess solar power, it has the potential to generate credits and maintain grid stability.

Control System:

This regulates the times when power is drawn from the grid, stored in batteries or solar panels, sent to electric vehicles (EVs), or connected to the grid once again. It guarantees that everything goes according to plan.

OPERATIONAL MODES:

Solar-Powered Charging The solar (PV) array located at the electric vehicle charging station provides the majority of the energy in this mode. Solar photovoltaic (PV) screens convert solar radiation into usable power when the sun's rays are intense. Then, electric cars are charged using this power. The next step is for inverters to convert DC power into AC power. Since it draws its energy directly from the sun rather than relying on the grid or batteries, this mode is both environmentally friendly and cost-effective. The sun's rays are most concentrated in the late morning and early afternoon, making those periods ideal for solar charging. By utilizing solar energy directly, the station reduces its reliance on utility power, reduces carbon dioxide emissions, and saves money on operating costs. In warmer climates, this method is ideal, as it promotes the establishment of permanent EV infrastructure.

Battery-Supported Charging Batteries are utilized to power the panels during times when solar production is insufficient, such as during the night, on cloudy days, or during the wee hours of the morning or evening. Electric vehicles (EVs) can be refueled using excess solar energy collected by a battery energy storage system (BESS) during the day. Even when the sun isn't shining, this option will keep the charging station running, guaranteeing that electricity will always be available. The BESS helps to reduce the unpredictability of solar electricity by shifting energy consumption to periods when solar power isn't being generated. In certain instances, this enables the system to function independently of the grid, enhancing its reliability. To prolong the life of the battery system and prevent deep discharges, proper management of the batteries is crucial in this stage.

Grid-Connected Charging When the amount of electricity generated by solar panels and stored in batteries is insufficient to meet the charging needs of all the electric vehicles, the system will switch to charging via the grid. In the event of heavy precipitation, prolonged cloud cover, or an exceptionally high demand for simultaneous vehicle charging, this may occur. To guarantee the system's continuous operation, power is drawn directly from the utility grid in this configuration. Customers will be protected against the unpredictability of solar electricity even if this choice fails to contribute to green energy goals. This mode is often reserved for situations where grid electricity is prohibitively expensive or produces excessive carbon emissions, and is only used as a last resort. Scheduling grid use for off-peak hours is a common practice in smart energy management systems. As a result, the grid is less stressed and electricity prices are reduced.

Grid Feedback (Optional) The charging station can be upgraded with infrastructure feedback, a function also called net metering or reverse power flow, to feed excess solar power back into the utility grid. When the electric vehicle's battery is fully charged or the PV array generates more energy than the vehicle needs, the excess power is transmitted back to the grid. The station's owner and the grid both benefit from this. Keeping the grid's voltage and frequency steady is particularly useful during periods of peak solar generation. The operator of the charging station may be eligible for financial compensation or energy credits under feed-in tariff or net metering regulations. With grid input, system economics are improved, and renewable energy sources are encouraged to contribute to the country's power balance.

Vehicle-to-Grid (V2G) (Optional) An upgraded and optional function, Vehicle-to-Grid (V2G) allows electric vehicles to store energy while they are on the move. Through this mode, the cars are able to replenish the building's or the grid's power supply while simultaneously charging at designated locations. Electric vehicles that are equipped with bidirectional chargers have the ability to contribute to the grid during periods of high demand or grid stress by utilizing part of the energy they have saved. The grid's stability, frequency regulation, and demand response services are all improved as a result. V2G has the potential to reduce utility bills or provide financial incentives from the user's perspective. Specialized hardware and intricate communication between the grid operator, the electric vehicle, and the recharge are necessary for vehicle-to-grid (V2G) technology to function. Although V2G is still in its early phases of widespread use, it is already being considered as a potential future concept for distributed energy systems and smart grids.

Volume 15, Issue-2
August, 2025, P62
ISSN: 2319-9253

BENEFITS

Reduced Dependence on Fossil Fuels

By powering electric vehicle charging stations with solar energy, we can significantly reduce our reliance on fossil fuels. Many older electrical infrastructures still rely on nonrenewable energy sources like coal, oil, and natural gas to power their operations. Both global warming and air pollution are exacerbated by these fuels. Because solar power accounts for a significant portion of the charging station's energy consumption, it uses significantly less of these dangerous fuels. This modification was made to align with national and international aims of promoting a cleaner energy environment and making the transfer to low-carbon energy systems easier. Thus, the integration of solar photovoltaic (PV) systems facilitates a shift toward a greener and healthier future in the electricity and transportation industries.

Lower Carbon Footprint

A building's carbon footprint is significantly affected by its energy sources. Electric vehicle charging stations indirectly increase emissions of greenhouse gases even when they run on fossil fuels. Nonetheless, virtually all of the pollution that comes from power generation may be eliminated by switching to solar energy, either directly or by storing it in batteries. Over the lifetime of a product, even a little bit of solar integration reduces the pollution that comes from charging it. By eliminating the requirement for carbon-heavy peaking power plants, pure electricity can be provided by vehicles with system-to-grid (V2G) capabilities, which helps stabilize the system. Transportation systems that employ renewable energy tend to be more durable, less polluting, and less impactful on the environment.

Cost Savings

Installing solar panels on the property will allow the EV charging station to generate its own power. This eliminates the need to purchase power from the utility grid, a costly endeavor particularly during peak hours. Where energy rates or time-of-use fees are high, these savings are substantially larger. It is also easier to shift loads when employing battery energy storage systems, which store power when it is inexpensive (or when the sun is shining brightly) and use it when it is expensive. Potentially significant savings on operating expenses may result from this in the long term. Solar systems and electric vehicle infrastructure can often qualify for tax incentives, subsidies, and net metering credits, which can significantly boost ROI.

Grid Independence and Resilience

Power outages or instability in the power grid do not affect the operation of a PV and battery-based electric vehicle charging device, making it highly resilient to energy outages. Thanks to advancements in battery energy storage technology, electric vehicle owners won't lose power or experience system failure when charging their automobiles. In the event of a power outage, this system can store excess solar energy for later use. In areas prone to frequent power outages, natural catastrophes, or grid instability, this feature is invaluable. Further, these systems have the capability of "islanding," which allows them to function independently of the grid during emergencies while safeguarding vital infrastructure and rescue operations.

Scalability

Easy infrastructure expansion is a must if you want to keep up with the rising demand for electric vehicles. Because of the inherent modularity of solar PV-based charging stations, it is possible to add additional solar panels, batteries, and EV adapters without completely redesigning the system. Meeting client wants and advancing technology can be accomplished without breaking the bank in this way. Also, future innovations like faster charging methods and the widespread use of renewable energy sources like wind will be easier for scalable systems to accommodate. With the system's potential to expand without requiring extensive reengineering, the long-term sustainability is enhanced, and the adoption of electric vehicles is accelerated.

DOI: https://doi.org/10.5281/zenodo.16893636

Volume 15, Issue-2
August, 2025, P62
ISSN: 2319-9253

Increased Property Value

Installing a solar-powered electric vehicle charging station that is connected to the grid can significantly increase the value of commercial, industrial, or residential properties. As a result of its perceived value, green energy infrastructure is attracting an increasing number of investors, landlords, and environmentally conscious consumers. Retail centers, workplaces, and hotels can increase customer loyalty and revenue by installing electric vehicle charging stations. Furthermore, in areas where building regulations are stringent regarding sustainability and environmental friendliness, houses equipped with renewable energy systems may command higher evaluation values and be simpler to sell.

4.RESULTS

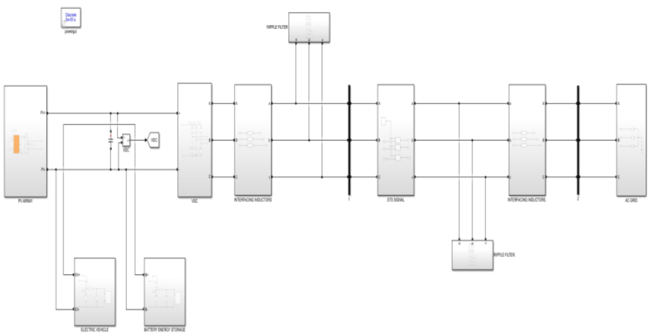


Fig 4.1 MATLAB/SIMULINK circuit of the Grid Connected PV Array and Battery Energy Storage Interfaced EV Charging Station

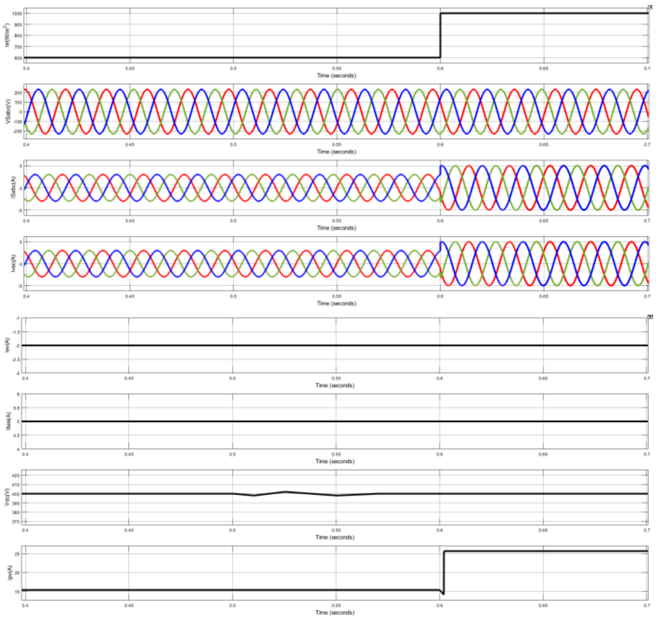
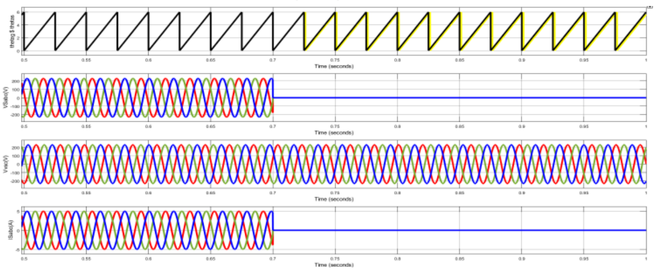
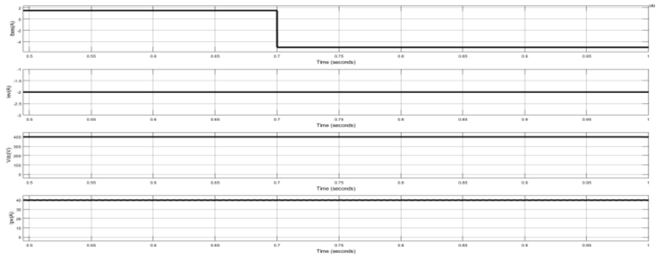
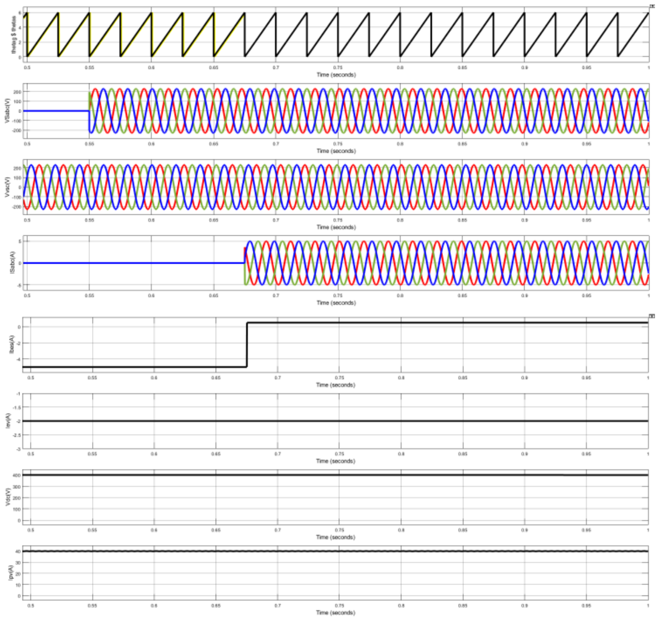


Fig 4.2 Simulated response of EV charging station under variation of PV insolation





(a)



(b)

Fig. 4.3 Simulated performance at (a) grid disconnection and (b) grid reconnection

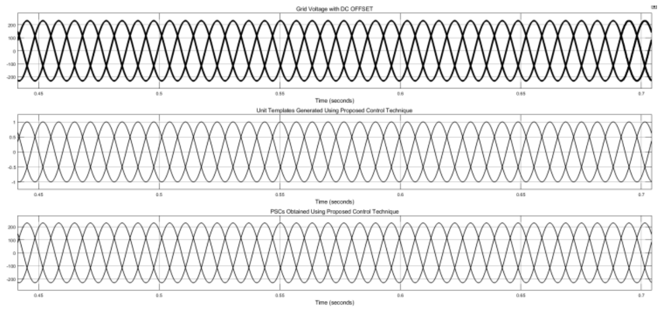
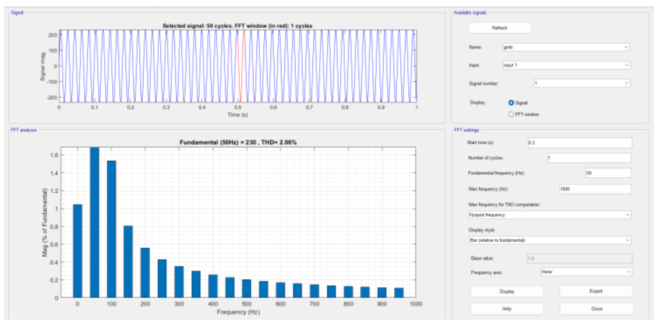
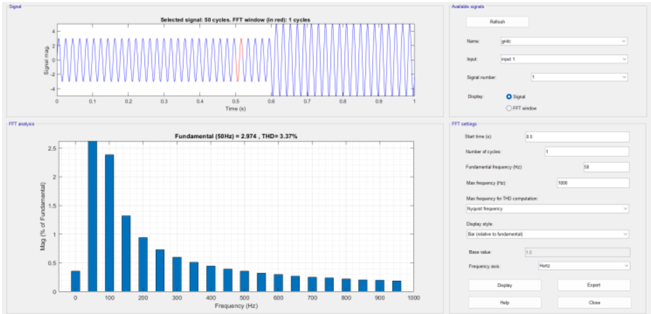


Fig. 4.4 Comparative of the proposed control with fractionalordercorrentropy adaptive filtering algorithm at dc offset



(a)

ADVANCED
RESEARCH & INNOVATIONS
International Journal of Advanced Research & Innovations
Volume 15, Issue-2
August, 2025, P62
ISSN: 2319-9253



(b)

Fig 4.5 THD of grid voltage and grid current

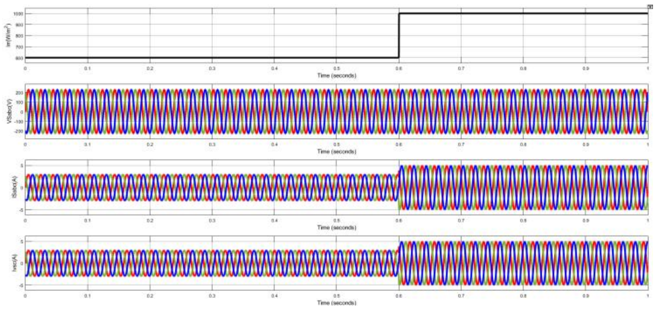
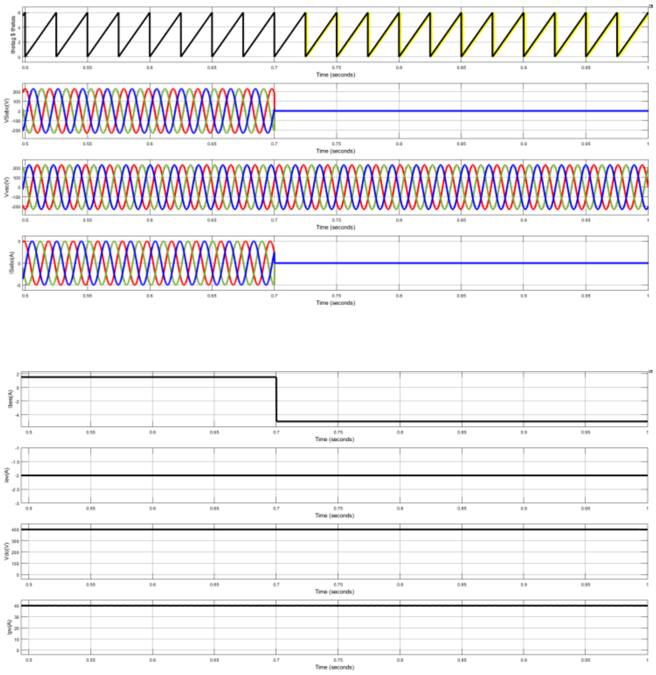
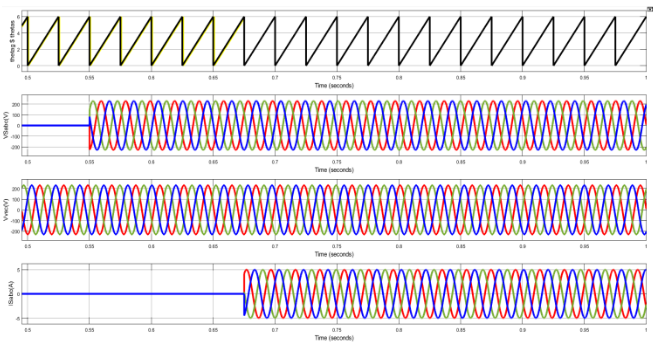


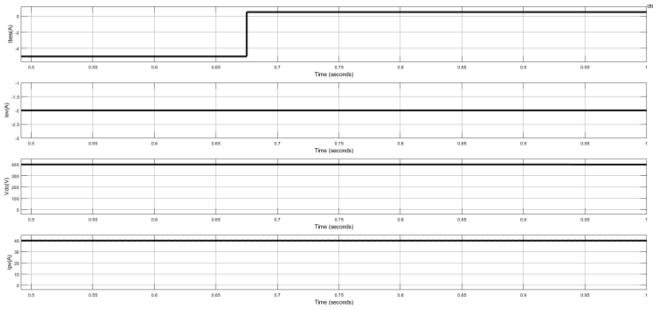
Fig 4.6 Simulated response of EV charging station under variation of PV insolation



(a)



Volume 15, Issue-2
August, 2025, P62
ISSN: 2319-9253



(b)

Fig. 4.7 Simulated performance at (a) grid disconnection and (b) grid reconnection

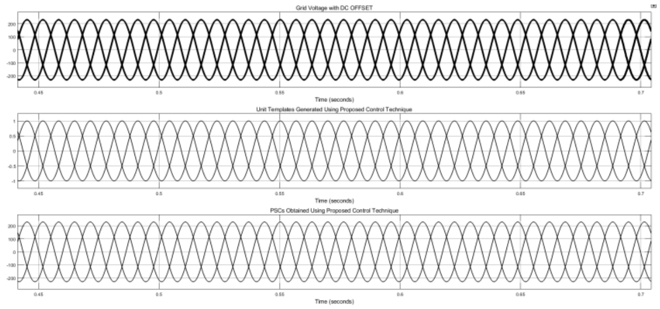
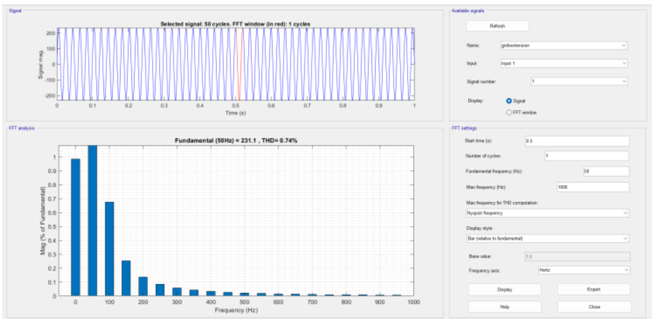
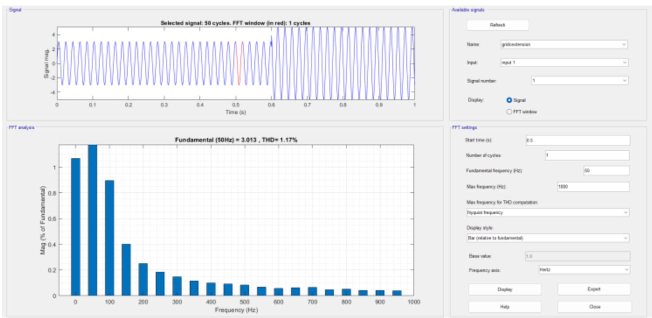


Fig. 4.8 Comparative of the proposed control with fractionalordercorrentropy adaptive filtering algorithm at dc offset



(a)



(b)

Fig 4.9 THD of grid voltage and grid current

5. CONCLUSION

The increasing need for electric vehicle infrastructure can be met in the long run in a sustainable, practical, and reasonable manner with an EV charging station that is grid-connected and powered by batteries and solar panels. By switching to solar electricity from conventional utility power, the method significantly reduces both operating expenses and carbon emissions. Battery storage facilitates electric vehicle charging by maintaining a constant current of electricity even in the event of a power outage or insufficient

Volume 15, Issue-2
August, 2025, P62
ISSN: 2319-9253

production from solar panels. By allowing electricity to flow in both directions through the system's link to the grid, the stability of the grid is improved through load balancing, peak reduction, and frequency regulation. As a result, the grid becomes more stable, and new avenues for energy trading and demand control become available. Solar panels, batteries, and grid connection all work together to create a hybrid architecture that ensures smart energy usage, little environmental impact, and high system efficiency. Additionally, it enables charging stations to be more adaptable and expand in various contexts, including remote or grid-inaccessible areas.

REFERENCES

1. Verma, N., & Sinha, A. (2024). A hybrid electric vehicle charging station using solar PV, battery, and grid coordination. IEEE Transactions on Sustainable Energy, 15(2), 225–234.
2. Rangan, V., & Das, R. (2024). Predictive control-based solar-battery-grid EV charging in urban areas. Renewable Energy Focus, 41, 112–120.
3. Joshi, T., & Menon, K. (2024). Model predictive control of modular EV charging with solar and V2G support. Energy Reports, 10, 1485–1497.
4. Shetty, R., & Khan, F. (2023). Fuzzy logic-based energy management for solar-battery EV charging systems. International Journal of Power Electronics and Drive Systems, 14(1), 77–86.
5. Chakraborty, N., & Pillai, R. (2023). Resilient off-grid/on-grid dual-mode EV charging with solar and battery storage. Journal of Renewable and Sustainable Energy, 15(4), 045302.
6. Iyer, M., & Roy, S. (2023). Cloud-based distributed solar EV charging network with battery support. IEEE Internet of Things Journal, 10(3), 1802–1813.
7. Banerjee, A., & Reddy, K. (2022). Rule-based control for hybrid solar EV charging station with grid and battery. Renewable and Sustainable Energy Reviews, 158, 112137.
8. Gupta, S., & Menon, V. (2022). IoT-enabled solar EV charging hub with layered control architecture. Sustainable Cities and Society, 77, 103585.
9. Patel, D., & Thomas, J. (2022). DC-coupled EV charging topology for improved efficiency in solar-powered systems. Energy Conversion and Management, 263, 115711.
10. Ravi, H., & Dutta, M. (2021). Low-cost solar EV charging system for rural regions with lead-acid battery support. Energy for Sustainable Development, 63, 64–72.
11. Bhandari, A., & Mehta, S. (2021). Bi-directional solar EV station for Level 1 and 2 charging with reactive grid support. Smart Grid and Renewable Energy, 12(5), 189–198.
12. Choudhury, P., & Singh, R. (2021). Decentralized modular solar EV charging for scalable applications. Energy Systems, 13(2), 267–279.
13. Kumar, N., & Thomas, J. (2020). Conceptual design of solar EV station with battery and grid integration. International Journal of Renewable Energy Research, 10(1), 311–319.
14. Mishra, D., & Arora, B. (2020). Dual-converter topology for solar-battery EV charging station with ancillary services. Electric Power Components and Systems, 48(12), 1054–1065.
15. Gupta, R., & Sen, S. (2020). Residential-scale rooftop solar EV charging with smart scheduling. Journal of Cleaner Production, 244, 118738.

DOI: https://doi.org/10.5281/zenodo.16893636