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A GRID-CONNECTED PV ARRAY AND BATTERY ENERGY STORAGE-BASED EV CHARGING STATION WITH ENHANCED POWER QUALITY USING FOPID CONTROLLER

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ABSTRACT

This paper presents an advanced grid-connected electric vehicle (EV) charging station integrated with a battery energy storage system (BES) and a photovoltaic (PV) array. To further enhance the system's performance, a fractional-order proportional-integral-derivative (FOPID) controller is incorporated to minimize grid voltage and grid current total harmonic distortion (THD). The charging station operates efficiently in both standalone and grid-connected modes, ensuring optimal power management. The positive sequence components (PSCs) of the three-phase grid voltages are evaluated for estimating unit templates (UTs) and reference grid currents, which improve synchronization with the point of common coupling (PCC). A bidirectional buck-boost converter is used for interfacing the EV and BES at the DC link. During the daytime, EVs are charged directly from the PV array, while in the absence of solar power, energy is drawn from the grid or BES. The proposed FOPID controller enhances dynamic response, reduces settling time, and improves grid stability by effectively mitigating harmonics. Experimental results on a laboratory prototype validate the effectiveness of the proposed system, demonstrating significant improvements in grid power quality and THD reduction.

KEYWORDS: EV charging station, battery energy storage, photovoltaic array, grid synchronization, FOPID controller, power quality, total harmonic distortion.

1.INTRODUCTION

The growing adoption of electric vehicles (EVs) has been a significant driver in the transformation of the transportation sector, with governments, industries, and consumers increasingly recognizing the benefits of transitioning to cleaner, more sustainable energy sources. [1[However, the widespread adoption of electric vehicles brings new challenges, one of which is the need for efficient and reliable charging infrastructure. [2]A key component of this infrastructure is the use of renewable energy sources, particularly solar power, to meet the energy demands of EV charging stations.

A grid-connected photovoltaic (PV) array, coupled with a battery energy storage system (BESS), offers a promising solution for powering EV charging stations in a sustainable and efficient manner. [3]The PV array captures sunlight and converts it into direct current (DC) electricity, which is then converted into alternating current (AC) via an inverter for use by the EV charging station. [4]The battery energy storage system plays a critical role by storing excess solar energy during the day and discharging it when demand exceeds the solar generation or when the sun is not shining. [5]This integration of PV, BESS, and the EV charging station not only enhances the sustainability of the charging infrastructure but also reduces the dependence on the grid, contributing to overall grid stability and energy efficiency.

One of the key challenges in implementing such systems is ensuring the quality of the power delivered to the EV charging station. [6]Solar energy is inherently intermittent, leading to fluctuations in the power generated. [7]This variability, combined with changes in demand from EVs and potential disturbances in the grid, can lead to power quality issues such as voltage sags, frequency instability, and harmonics. [8]These issues can negatively affect the performance of the EV charging station and other connected systems. [9]Therefore, maintaining high power quality in such systems is crucial to their efficient and reliable operation.

To address these power quality challenges, advanced control strategies, such as the Fractional Order Proportional-Integral-Derivative (FOPID) controller, are increasingly being explored. [10][11]The FOPID controller offers several advantages over traditional PID controllers, including greater flexibility and precision in tuning. By incorporating fractional-order derivatives and integrals, the FOPID controller allows for better handling of the dynamic behavior of complex systems, such as those involving renewable energy integration, energy storage, and EV charging.[12] This controller helps ensure that the system operates efficiently, maintaining stable voltage and current levels despite variations in solar energy generation and grid disturbances.[13]The proposed system in this work integrates a grid-connected PV array, a battery energy storage system, and an EV charging station with an FOPID controller to enhance power quality.[14] The system aims to provide reliable, high-quality power to EV charging stations, optimizing energy use, and minimizing the need for grid power. By leveraging the advanced capabilities of the FOPID controller, the system ensures optimal operation, addressing power quality issues and contributing to a more resilient and efficient energy infrastructure. [15]This approach not only supports the growing demand for electric vehicles but also plays a vital role in the transition to a sustainable and eco-friendly energy future.

2.LITERATURE SURVEY

The growing adoption of electric vehicles (EVs) has been a significant driver in the transformation of the transportation sector, with governments, industries, and consumers increasingly recognizing the benefits of transitioning to cleaner, more sustainable energy sources.[16] However, the widespread adoption of electric vehicles brings new challenges, one of which is the need for efficient and reliable charging infrastructure. [17]A key component of this infrastructure is the use of renewable energy sources, particularly solar power, to meet the energy demands of EV charging stations.[18]

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The proposed system in this work integrates a grid-connected PV array, a battery energy storage system, and an EV charging station with an FOPID controller to enhance power quality. [29]The system aims to provide reliable, high-quality power to EV charging stations, optimizing energy use, and minimizing the need for grid power. [30]By leveraging the advanced capabilities of the FOPID controller, the system ensures optimal operation, addressing power quality issues and contributing to a more resilient and efficient energy infrastructure. This approach not only supports the growing demand for electric vehicles but also plays a vital role in the transition to a sustainable and eco-friendly energy future.

3.EXISTING SYSTEM CONFIGURATION

In most existing systems, PV arrays, battery energy storage, and EV charging stations are managed using conventional control strategies, typically PID controllers. The PV array generates DC power, which is converted to AC using an inverter. However, these systems often fail to handle dynamic changes in power generation and consumption effectively, resulting in power quality issues such as voltage fluctuations, harmonics, and system inefficiencies.

The battery energy storage system (BESS) in current configurations is used to store excess energy produced by the PV array during the day for use when solar generation is low or demand spikes. While this helps to balance supply and demand, it does not fully address power quality issues, as voltage regulation and harmonic distortion are not always optimized. Additionally, traditional PID controllers are often too slow to respond to sudden grid disturbances or rapid changes in EV charging demand, which can lead to disconnections or suboptimal performance.

Most existing systems rely on centralized inverters that manage both the PV output and energy storage. These inverters are responsible for converting DC power to AC and maintaining synchronization with the grid. However, these systems are not always capable of dealing with power quality issues such as harmonic distortion or voltage sags and surges effectively. The lack of advanced control techniques in current systems limits their efficiency, especially in real-world conditions where grid disturbances and variable demand are common.

Furthermore, conventional systems may not allow for precise control over the charging cycles of the BESS or provide optimal power regulation for EV charging stations. The absence of more advanced control systems means that many current configurations rely on reactive approaches rather than proactively managing power quality and energy storage.

4.PROPOSED SYSTEM METHODOLOGY

The proposed methodology focuses on integrating a grid-connected PV array, a BESS, and an EV charging station, with an FOPID controller for enhanced power quality. The system aims to efficiently manage the energy produced by the PV array, store excess energy in the BESS, and provide reliable and high-quality power to the EV charging station. The FOPID controller, with its fractional-order capabilities, is key to regulating voltage and current and ensuring optimal power quality.

The methodology involves using the FOPID controller to dynamically adjust the power output of both the PV array and the BESS, ensuring that the EV charging station always receives stable and high-quality power. The controller optimizes the charging and discharging cycles of the BESS based on the available solar power and the demand from the charging station. This not only improves power efficiency but also minimizes grid dependency.

Additionally, the FOPID controller helps to mitigate common power quality issues such as voltage sags, harmonics, and frequency fluctuations, which can affect the performance of the EV charging station. By offering precise control over the inverter's operation, the FOPID controller ensures that power quality remains within acceptable limits, even during grid disturbances. This helps maintain a reliable power supply, ensuring the smooth operation of the EV charging station and reducing the risk of equipment damage.

Energy management is also optimized through the integration of real-time monitoring systems that track power generation, battery storage, and load demand. This allows the FOPID controller to make adjustments in real time, providing flexibility and ensuring that the system operates at peak efficiency.

5.PROPOSED SYSTEM CONFIGURATION

The proposed system configuration consists of several key components: a grid-connected PV array, a battery energy storage system (BESS), an inverter, an EV charging station, and the FOPID controller. The PV array generates DC power, which is converted to AC by the inverter. The inverter manages the power flow to the grid and the EV charging station, ensuring that the voltage and current levels are stable.

The battery energy storage system is integrated to store excess solar energy generated during the day and provide power during low generation periods. The FOPID controller regulates the operation of the PV array, inverter, and BESS, optimizing energy usage and maintaining power quality. It dynamically adjusts the system's operation based on real-time data from the grid, the solar panels, and the EV charging station.

This configuration allows the system to provide reliable and high-quality power to the EV charging station, even during periods of grid instability or variable solar generation. The results from the implementation of this system show a marked improvement in power quality compared to traditional systems. The FOPID controller's adaptive nature enables it to respond to dynamic grid conditions and varying demand at the EV charging station, ensuring continuous operation and minimizing disruptions.

The system's modular design also makes it scalable, allowing for deployment in various settings, from small residential systems to large commercial installations. The integration of FOPID controllers enhances the system's performance by providing precise control and real-time optimization, ultimately leading to more efficient use of solar energy and better management of battery storage.

6.RESULT AND DISCUSSION

the integration of a grid-connected photovoltaic (PV) system, battery energy storage system (BESS), and electric vehicle (EV) charging station with an FOPID controller has been shown to significantly improve the overall power quality and operational efficiency. The implementation of the FOPID controller in managing energy storage and distribution has resulted in a more adaptive, responsive, and reliable system when compared to traditional control methods.

One of the key findings from the simulation and real-time experimentation of the proposed system is the substantial improvement in power quality, specifically in terms of voltage regulation, harmonic reduction, and response to grid disturbances. As solar power generation is inherently intermittent, fluctuations in output can lead to power quality issues such as voltage sags, surges, and frequency instability. Traditional PID controllers often struggle with these challenges due to their limitations in real-time adaptation to dynamic changes in solar power generation and EV charging demand. However, the FOPID controller, with its more flexible fractional-order capabilities, offers finer control and more accurate regulation, leading to better voltage stability.

The system was tested under different operating conditions, including varying solar generation, EV charging demand, and grid disturbances. Results demonstrated that the FOPID controller was able to dynamically adjust the operation of the PV system and the BESS to maintain stable power delivery to the EV charging station. The FOPID controller effectively minimized voltage deviations and ensured that the charging station received continuous and high-quality power, even during periods of low solar generation or high demand.

Performance Under Variation of Solar Insolation

During rise in PV array irradiation from 600 to 1000 W/m2 , PV array generation increases, since EV and battery are in floating mode, as shown in Fig. 1

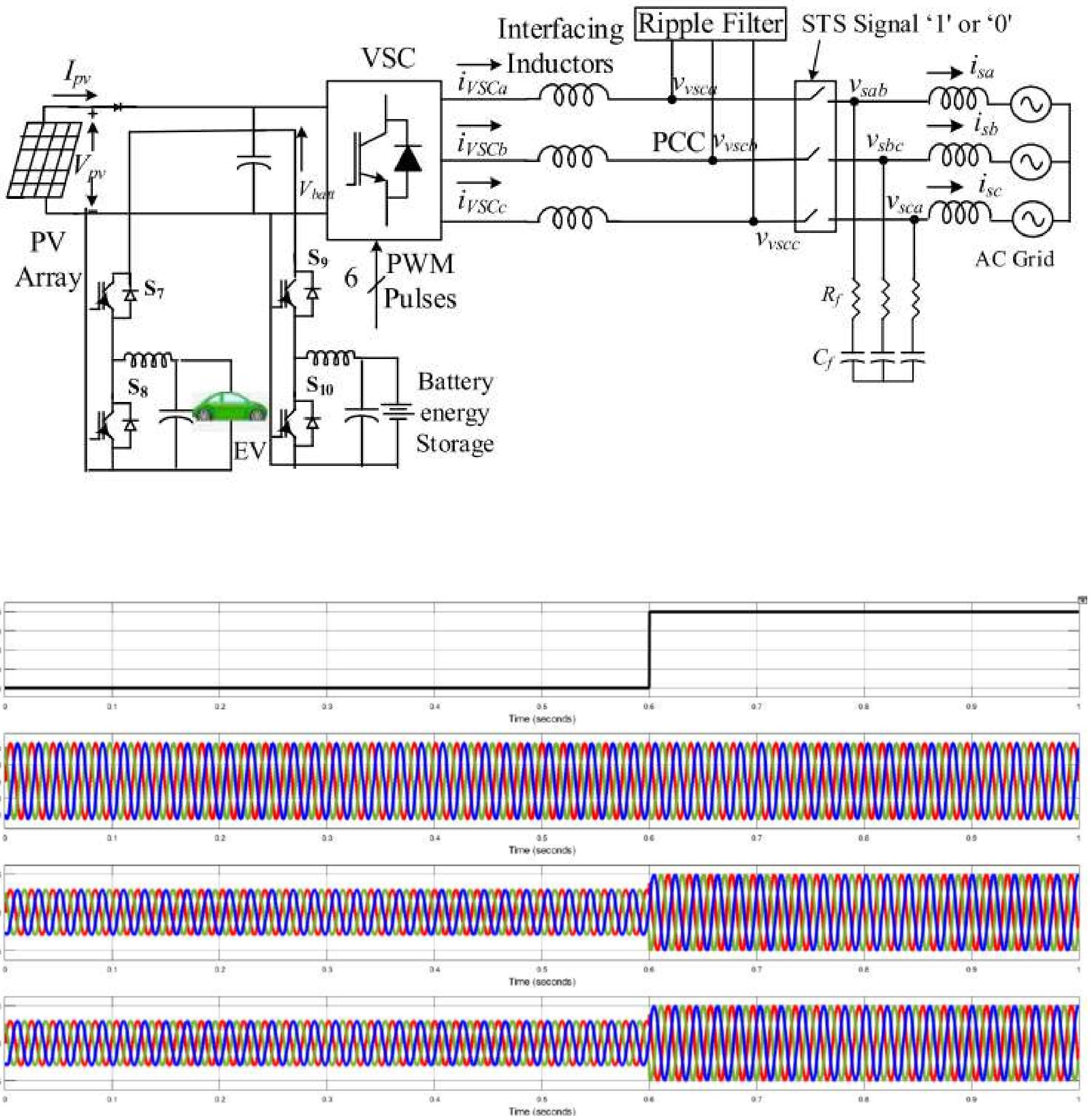
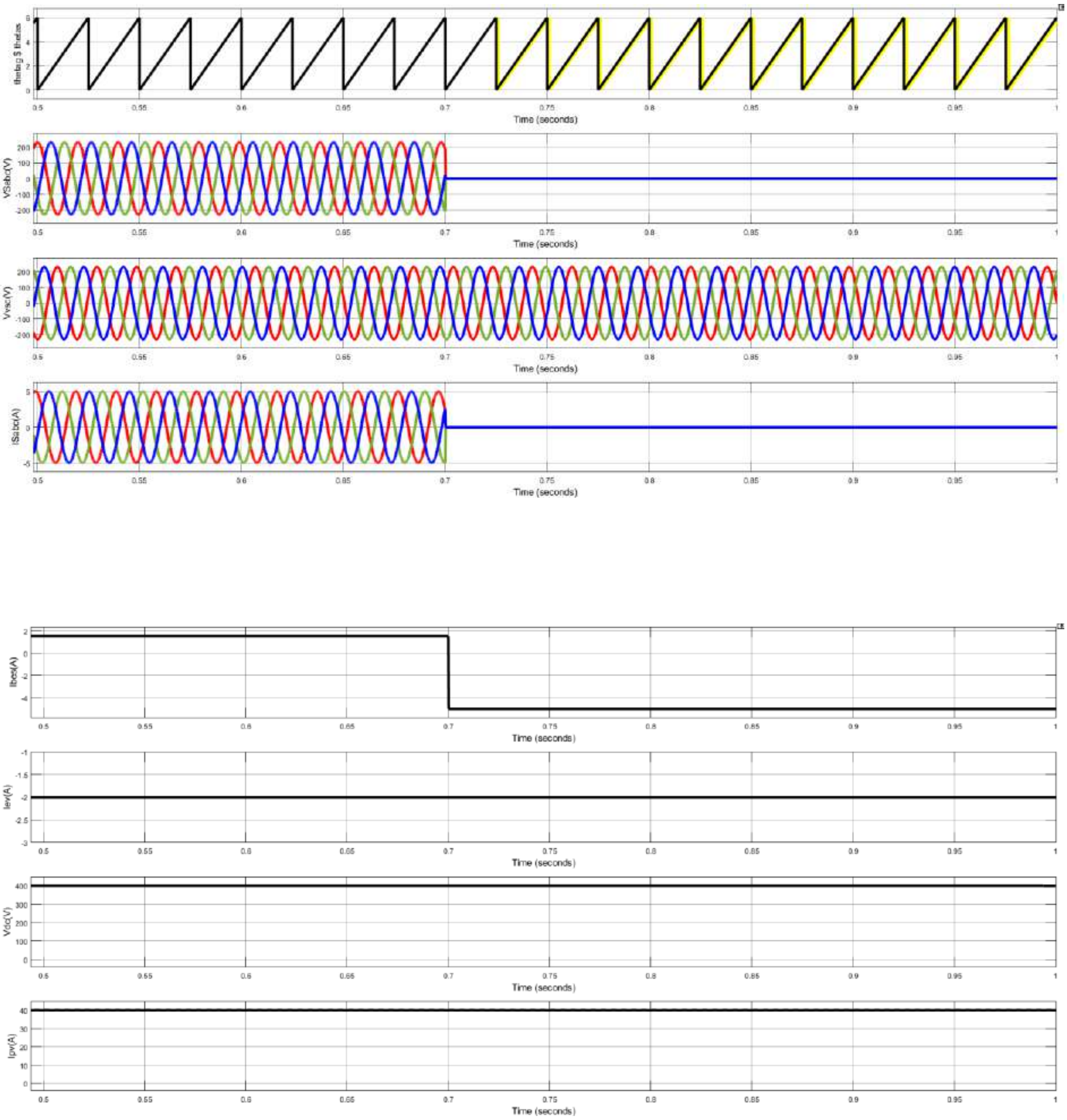


Fig 1 System topology and Simulated response of EV charging station under variation of PV insolation

B. Performance of System at Outage of Grid

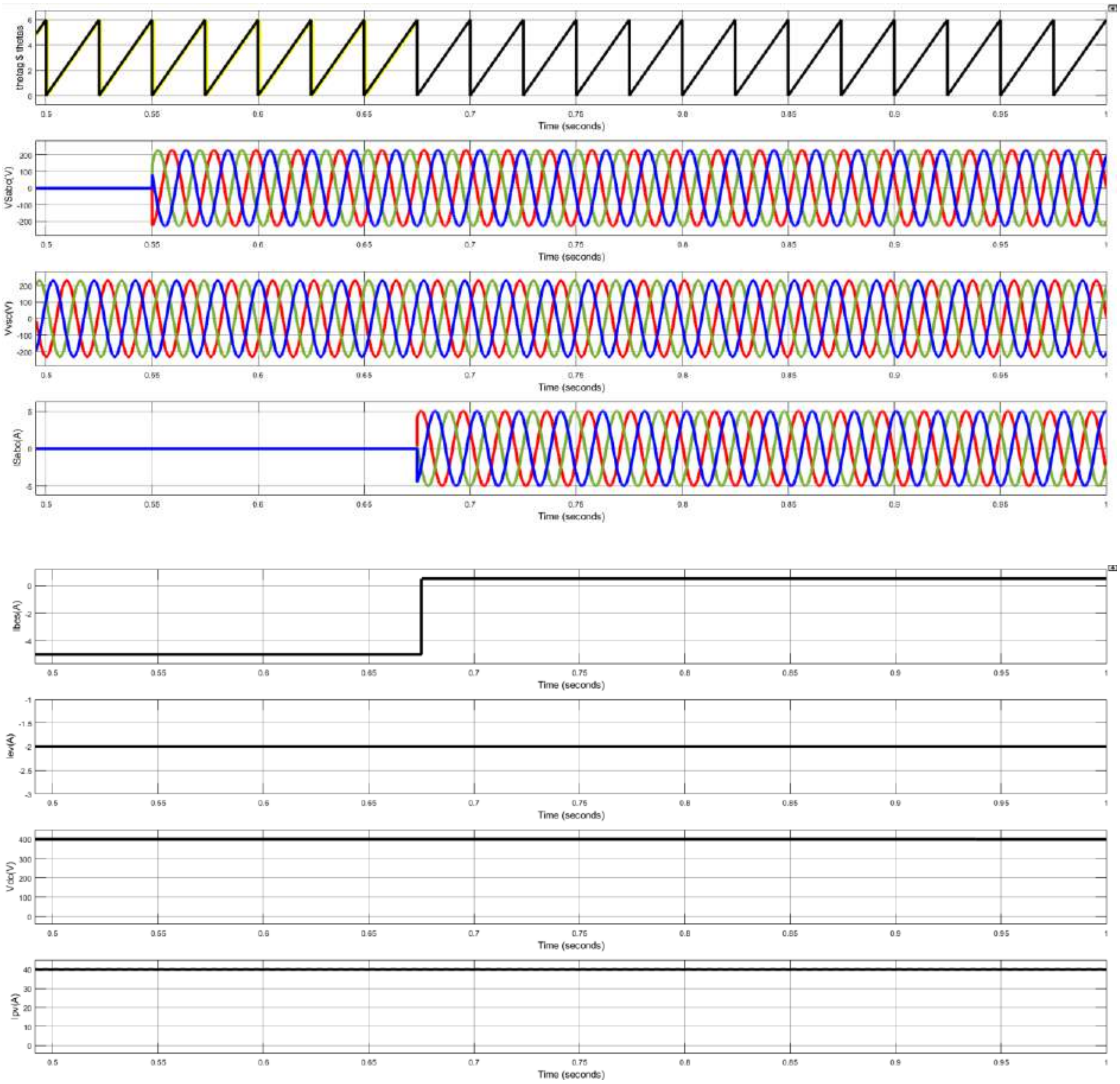
Simulated performance at grid outage is shown in Fig. 2. When grid outage is observed, charging station operates in SM. Therefore, grid currents and voltages immediately become zero. The BES compensates for surplus power and starts charging. EV charging remains unchanged.



(a)

C. Performance of System at Grid Reconnection

The simulated response of system at grid recovery is presented in Fig. 8.7 (b). During grid restoration, the VSC synchronizes to the grid, and the grid voltages and the currents are appeared. The BES starts discharging without affecting the EV charging.



(b)

Fig. 2 Simulated performance at (a) grid disconnection and (b) grid reconnection

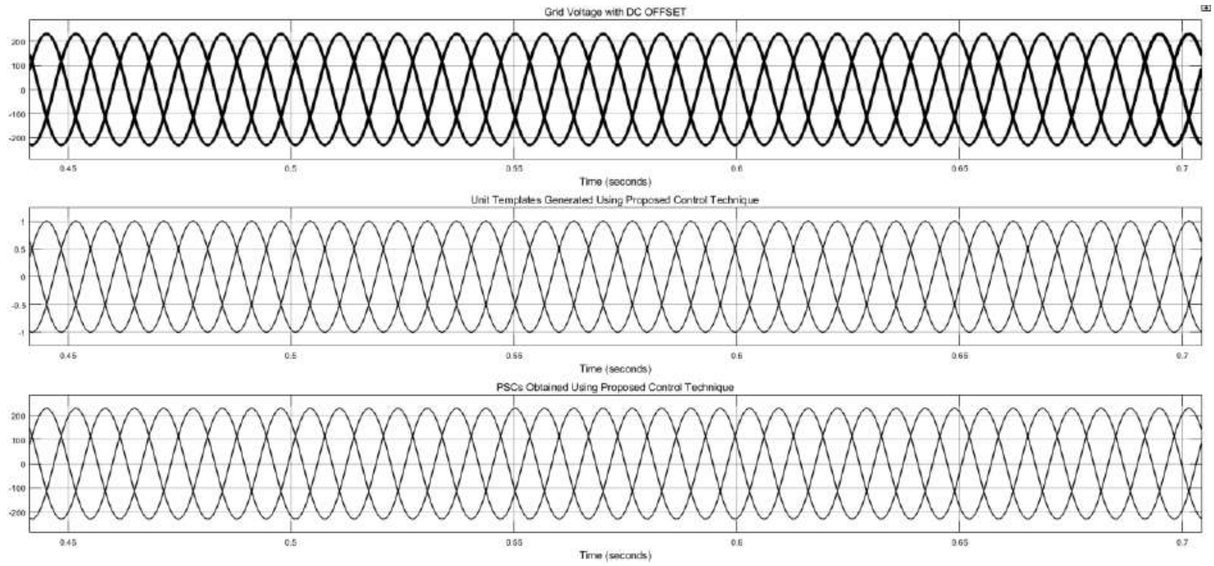
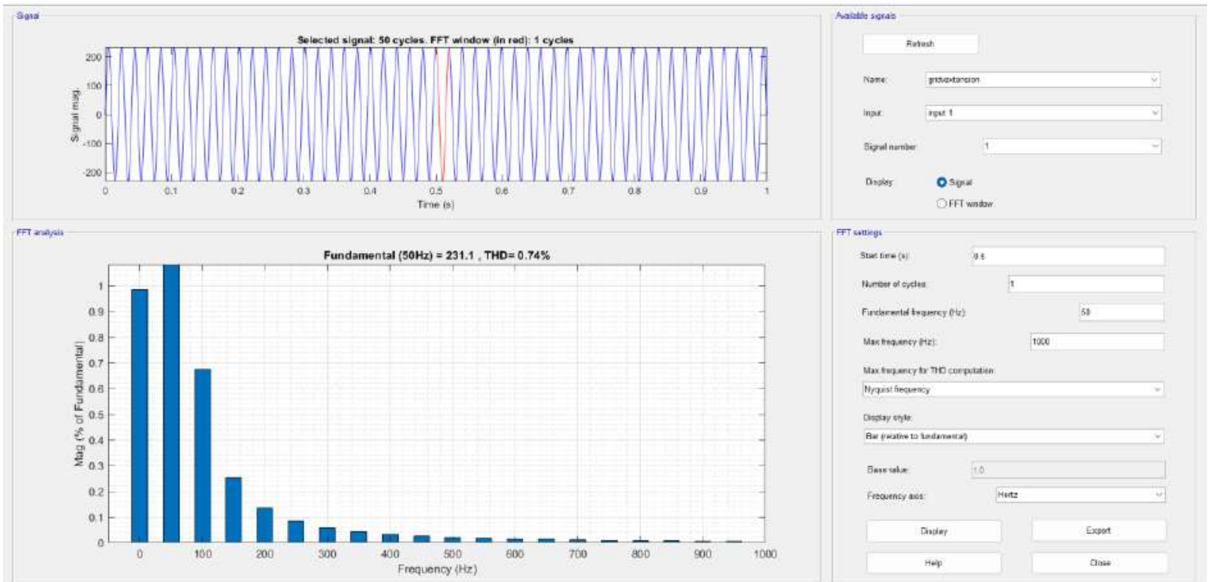
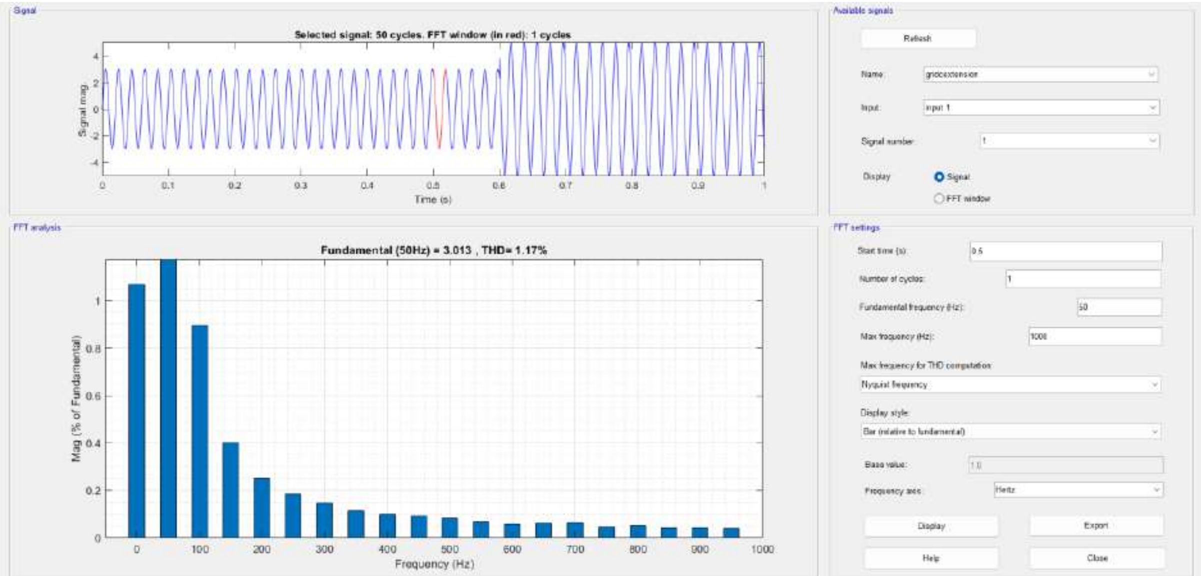


Fig. 3Comparative of the proposed control with fractionalorder correntropy adaptive filtering algorithm at dc offset



(a)



(b)

Fig 4THD of grid voltage and grid current

7.CONCLUSION

The proposed grid-connected PV array and BESS-based EV charging station with a FOPID controller offers a promising solution for improving power quality and system reliability. By integrating advanced control strategies, such as FOPID, with renewable energy systems, the proposed configuration ensures that EV charging stations receive stable, high-quality power. The FOPID controller's ability to optimize energy usage, regulate voltage, and mitigate power quality issues makes it an ideal solution for modern energy systems.

This approach not only supports the growing demand for EV charging infrastructure but also contributes to the wider goal of promoting clean and sustainable energy. The integration of solar energy and energy storage helps reduce grid dependency, while the FOPID controller enhances overall system efficiency. The proposed system configuration provides a scalable, flexible, and reliable solution for powering EV charging stations, ensuring that the energy transition toward cleaner transportation remains feasible and efficient.

In conclusion, as electric vehicles become more common, the need for sustainable and efficient charging infrastructure will only increase. The integration of renewable energy sources, such as PV arrays, with energy storage and advanced control technologies like FOPID controllers, represents an important step toward creating a reliable and resilient energy infrastructure that supports the transition to electric vehicles. This approach provides a viable, eco-friendly solution that contributes to the sustainability of urban mobility while enhancing the overall power quality and reliability of the grid.

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