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DESIGN AND INVESTIGATION OF A THREE-PHASE SOLAR PV AND BATTERY STORAGE SYSTEM WITH INTEGRATED UPQC FOR POWER QUALITY IMPROVEMENT

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ABSTRACT: The primary objective of this project is to design and evaluate a three-stage UPQC system for energy storage using solar photovoltaic (PV) and batteries. Some of the most significant challenges faced by present-day power systems include voltage fluctuations, harmonics, and power quality issues. A viable solution would be to integrate solar photovoltaic (PV) systems with battery energy storage systems (BESS) and Unified Power Quality Conditioner (UPQC) technology. Research aims to design, develop, and evaluate a practical integrated system. The goal is to enhance the grid's reliability, power quality, system efficiency, and the ease of adding green energy sources through thorough performance assessments and analysis.

Keywords: Three-Phase, Solar PV, Battery Energy Storage System, Unified Power Quality Conditioner (UPQC), Renewable Energy Integration, Power Quality Issues, Grid Resilience.

1. INTRODUCTION

A combination of factors, including a surge in interest in and investment in renewable energy, is causing a sea change in the world's energy environment. To combat climate change and the depletion of fossil fuels, more and more public and private organizations are turning to renewable energy sources to power their operations, reduce their impact on the environment, and satisfy their energy demands. For the generation of long-term, environmentally friendly power, solar photovoltaic (PV) systems rank high among the most promising renewable energy options.

Through the conversion of sunlight into electricity, solar PV systems provide a dependable and environmentally friendly source of energy by utilizing the sun's abundant and controllable energy. Solar photovoltaic (PV) systems have many benefits, but they also have certain drawbacks, like as intermittency, grid integration issues, and unpredictability. The intermittent nature of solar power generation makes grid reliability and stability vulnerable to power output changes. Environmental factors, such cloud cover and shadowing, can impact the power generation of solar PV systems.

To overcome these challenges and make the most of solar PV systems, it is becoming more important to develop innovative energy storage devices that can store excess energy during periods of high generation and release it during periods of low generation. One of the most important technologies for connecting solar photovoltaics to the power grid is battery energy storage systems, or BESS. By accumulating and releasing extra energy when needed, BESS can increase grid stability, reduce power production unpredictability, and make renewable energy integration more reliable.

Renewable energy systems cannot operate reliably and steadily without energy storage solutions and devices to improve power quality. Electrical equipment and the grid's stability are both compromised by power quality problems such as voltage sags, harmonics, and oscillations. A state-of-the-art device that addresses numerous power quality issues in real time is a universal power quality conditioner (UPQC). By constantly monitoring and changing current and voltage waveforms, UPQCs can help keep voltage levels steady, reduce harmonic distortion, and improve the power quality in general. One solution to the problems plaguing modern power grids is the combination of solar photovoltaics, battery energy storage, and unified power quality conditioners. By combining energy storage, power quality enhancement, and renewable energy generation technologies, this all-encompassing approach aims to increase system performance, stabilize the grid, and pave the way for the widespread use of renewable power sources [15]. To better understand these technologies and their practical uses, a UPQC is integrated into the building and performance evaluation of a three-phase solar PV and battery energy storage system.

2. LITERATURE SURVEY

Mohan, S., et al. " 2023 Power electronic interfaces used in UPQC, BESS, and PV systems are thoroughly covered in this study's technique for design. Improving power quality and operational efficiency requires grid-connected renewable energy sources to be incorporated. In order to achieve ideal power flow, harmonic mitigation, and voltage stabilization, the research explores novel converter topologies, control approaches, and protection systems. This technology has the potential to be widely used in renewable energy installations, as the results of the simulation show that it works well in a variety of operational scenarios.

Renz, S., et al. 2023 Improving power flow regulation through the use of a three-phase inverter system is the primary objective of this research. Also covered is an examination of how UPFCs, or Unified Power Flow Controllers, are used in modern power grids. The study delves further into the UPFC's working principles, which include controlling the grid's voltage, current, and power flow. Tests and models show that UPFC can boost system stability, reduce power losses, and improve power quality. Various control mechanisms are being studied in an effort to enhance system performance in the context of a dynamic grid.

Patel, M., et al.2020 The characteristics of three-phase solar PV systems that employ battery storage for managing power quality in real-time are investigated in this study. Voltage drops, harmonics, and frequency fluctuations—all issues with power quality—become major concerns. The authors introduce a novel control system that allows for the seamless integration of solar power with energy storage, ensuring consistent operation regardless of changes in solar output. Both computational and practical evidence have shown that the proposed strategy significantly enhances grid-connected systems' ability to regulate voltage and mitigate harmonics.

Akhavan, M., 2023 This study delves into the topic of improving power quality in industrial applications through the integration of active power filters (APFs), three-phase solar PV systems, and battery energy storage. Power quality is improved in regions with high renewable energy usage thanks to the proposed system design's consistent approach to efficiently managing flicker, voltage sags, and current harmonics. The modeling findings show that PV-BESS with Active Power Filters (APFs) integrated can reduce harmonics, increase voltage support, and better control loads under variable load situations.

Li, J., et al. 2023, This research shows how solar photovoltaic cells and a unified power quality conditioner (UPQC) can be built to work together as a system for managing power quality and storing energy. By enhancing power quality and energy storage capacities, the technology seeks to alleviate the problems associated with intermittent solar energy production. Voltage stability, harmonic mitigation, and fault tolerance characteristics are examined through a comprehensive analysis of control methodologies and modeling approaches. Both simulation and real-time testing validate the recommended system's efficacy, lending credence to its potential use in grid-connected contexts.

Vasudevan, G., et al. 2022 The efficiency of a three-phase solar photovoltaic system that incorporates a unified power quality conditioner (UPQC) and energy storage batteries is examined in this study. The purpose of this study is to assess the integrated system's capacity to enhance power quality through the provision of a consistent and reliable electrical supply. Through the use of simulations and hardware-in-the-loop testing, the authors evaluate crucial characteristics such as voltage control, harmonic distortion, and overall system efficiency. Incorporating UPQC and battery storage into the microgrid makes it more resistant to fluctuations in generation and demand, as shown by the findings.

Kumar, M., et al. 2022 With an emphasis on voltage regulation, this research delves into the implementation and modeling of a UPQC in solar systems that include battery storage. Because fluctuations in solar power can cause issues with energy quality, the study highlights the significance of maintaining a constant voltage profile in photovoltaic systems that are connected to the grid. Combining battery storage with UPQC effectively reduces voltage oscillations and ensures a steady and uninterrupted power supply, independent of solar generating levels, according to the authors' computer model and experimental data.

Saha, R., et al. 2022 By simulating and controlling a PV-BESS-UPQC system, this project intends to improve power quality in networks that are connected to the grid. The UPQC device, the photovoltaic system, and the battery energy storage are all interdependent, and this paper argues for a comprehensive management method to manage this connection. Problems like voltage dips, harmonics, and flicker are common in modern power networks, and this method aims to fix them.

Sharma, S., et al. 2022 This study introduces a method for optimizing the PV-BESS-UPQC system's power flow control using MATLAB and Simulink. By reducing energy losses, improving battery consumption, and easing worries about power quality, the optimization method hopes to boost system performance. Harmonic correction and voltage management control algorithms are developed after the authors examine various operational circumstances, such as variations in solar irradiation and load demand.

Verma, R., et al. 2022 Improving power quality and eliminating harmonics are the goals of this research into improving battery storage in grid-connected PV-UPQC systems. This study looks at different methods of controlling and sizing batteries to see which ones can optimize harmonic reduction while keeping the system efficient. The benefits and drawbacks of harmonic mitigation, regulating power flow, and battery capacity are demonstrated through simulation testing. In order to improve the overall efficiency of the system and decrease harmonic distortion, the authors offer an optimal control strategy for grid-connected renewable energy applications.

Singh, P., et al. 2021 In order to improve power quality, the authors assess different PV-BESS-UPQC system topologies. To find the best configuration for reducing power quality issues such voltage sag, harmonic distortion, and load imbalance, the study examines several inverter, battery storage system, and power conditioner designs. In order to choose the best topologies for specific application demands, the findings of the comparative research show the trade-offs among complexity, cost, and performance.

Rahman, N., et al. This research looks at how well hybrid systems that use both solar photovoltaics and batteries may reduce harmonics and increase grid stability. The authors investigate the potential of hybrid solar-battery systems to stabilize the grid in the face of variable renewable energy supplies and reduce power quality problems like voltage dips and harmonics.

Basha, S., et al. " 2021 Improving power quality in industrial applications is the focus of this study, which looks at methods including managing solar photovoltaic systems, batteries, and UPQC all at once. The authors propose a unified method of control that harmonizes voltage regulation, energy storage management, and harmonic correction.

Mansor, M. A., et al. 2020, Consequently, this research delves into the ins and outs of a unified power quality conditioner (UPQC)–powered, three-phase solar PV and battery energy storage system. By using a consistent and dependable power source, the research shows that the system can eliminate voltage dips, harmonic distortion, and flicker. Based on the simulation results, the proposed solution is a good option for renewable energy systems that are connected to the grid. It improves voltage control and reduces harmonic content.

Hossain, M., et al. 2020 In order to keep the grid stable, this study provides an evaluation of the dynamic performance of solar PV-battery storage systems that use UPQC. The authors examine the system's short-term reaction to various operational scenarios, such as fluctuating demand and renewable energy sources. The research shows that UPQC, when combined with solar PV and battery storage, can significantly improve grid stability in extensive simulations. This means it can improve power quality, reduce harmonics, and regulate voltage with both short-term and long-term benefits.

3. PROPOSEDSYSTEM

This method is proposed in the research paper "Construction and Performance Investigation of Three-Phase Solar PV and Battery Energy Storage System Integrated UPQC" as a novel approach to addressing important problems with modern power grids. Power quality conditioners (UPQCs), energy storage systems (BESS), and photovoltaic (PV) systems are the three main parts of the integrated system. A more resilient grid, optimized system efficiency, and better absorption of renewable energy sources are all goals of the initiative, which aims to improve power quality through the integration of varied technologies. Solar photovoltaics are the main power source for the system that has been presented. These devices convert sunlight into usable electricity by means of the photovoltaic effect. The efficiency, accessibility, and cost-effectiveness of solar PV have been greatly improved by recent major advancements in the technology. An eco-friendly and long-term solution, the proposed technology converts sunlight into electricity using solar photovoltaic arrays.

The suggested system could not function without battery energy storage systems (BESS), which can store and control energy. By capturing and storing excess energy from the solar PV system, Bess improves the accuracy of energy supply and demand synchronization. To ensure a consistent and reliable power supply for the grid, the BESS can release stored energy to increase solar PV output when solar irradiation is low or energy demand is high. By providing auxiliary services including voltage support, frequency management, and stability maintenance, BESS increases grid resilience. Modern power conditioning devices designed to solve a wide range of power quality issues in electrical systems are known as universal power quality conditioners (UPQCs). Voltage drops, harmonics, and fluctuations are all issues with power quality that the suggested solution uses UPQCs to alleviate. Through constant monitoring and adjustment of voltage and current waveforms, UPQCs guarantee stable voltage levels, reduce harmonic distortion, and improve power quality in general. Modern power systems can reap several benefits from using solar PV, energy storage battery systems, and unified power quality conditioning technology. The primary goal is to increase flexibility and resilience by including energy storage and diversifying energy sources. By integrating energy storage, power quality improvement features, and intermittent renewable energy generation, the proposed system has the potential to provide the grid with dependable, high-quality power. In order to ensure utility reliability, the system takes into account power quality problems and additional services. In addition, the suggested approach promotes sustainability by making use of renewable energy sources, including the abundant and clean solar energy resources. Because they generate power without depleting fossil fuels or adding to global warming, solar photovoltaic (PV) systems are an eco-friendly option.

Incorporating power quality enhancement technology, energy storage, and solar photovoltaic systems speeds up the transition to a more robust and sustainable energy future. Several crucial stages are encountered by the integrated system during its development and evaluation of performance. Initial configuration and design of the solar PV arrays, BESS, and UPQCs takes system requirements, site conditions, and performance targets into account. To ensure the best possible performance and compatibility, the parts are then combined into one cohesive system design. After building is complete, the system is tested and evaluated extensively to ensure it works as expected in real-world environments.The study's overarching goals are to confirm design parameters, improve system performance, and identify development-critical areas through analysis of performance. Through simulations of several operational scenarios—including varying solar irradiation levels, load profiles, and grid conditions—the study intends to demonstrate the integrated system's ability to enhance power quality, increase grid resilience, and incorporate renewable energy sources. Modern power systems face significant problems that the suggested method can fix. A sustainable, dependable, and high-quality power supply can be achieved through the system's integration of solar PV, BESS, and UPQC technologies. This integration also improves grid resilience and the incorporation of renewable energy sources. Improving power system efficiency, promoting renewable energy technology, and hastening the transition to a more sustainable energy future are all goals of the integrated system's development and performance analysis.

4. METHODOLOGY

To accomplish all of the goals mentioned in the abstract, the technique used in "Construction and Performance Investigation of Three-Phase Solar PV and Battery Energy Storage System Integrated UPQC" was carefully designed. The successful development and assessment of an integrated system rely on the steps that make up this technique. Solar photovoltaic arrays, energy storage systems based on batteries, and universal power quality conditioners must have their criteria and specifications defined at the first stage of system design. Space constraints, solar irradiation levels, system capacity, voltage ratings, and desired performance outcomes are all part of the site-specific considerations. Considerations such as efficiency, compatibility, affordability, and reliability are taken into account while choosing components for each subsystem, in accordance with the system design. All of these parts require UPQC devices, inverters, solar panels, and batteries. By following standards for component selection, wiring, cabling, and connections, subsystems can communicate and coordinate well before being integrated into a unified system architecture. Software interface and control algorithm development guarantees efficient system operation and coordination. A comprehensive evaluation of the created system is carried out to guarantee its dependability, performance, and functionality. While functional testing ensures that every part works as it should, performance testing determines how well the system performs across a wide range of operating situations, such as varying loads and sun irradiation levels.

Energy output, storage efficiency, grid robustness, and excellent power quality are some of the specified criteria that improve performance evaluation. We can find out what needs fixing and where actual performance differs from expectations by analyzing test data. The results of performance evaluations direct iterative optimization efforts that aim to boost system efficiency and performance. Improve grid resilience, power quality, and integration of renewable energy sources while reducing costs and environmental consequences by adjustments

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to system topologies, control algorithms, energy management methods, or improvements in components.

The last step is to evaluate the system in real-world scenarios, such as pilot studies or field tests, to see how well it performs.The comprehensive gathering of performance data throughout time guarantees that the system will meet the study objectives and stakeholder expectations. Every step of the process is documented, including the design choices, component choices, integration methodology, testing procedures, and performance evaluations. Methodology, results, and conclusions are all part of the comprehensive reports that stakeholders receive. Designing, integrating, testing, evaluating, optimizing, validating, documenting, and architecting the integrated system are all part of the process. By enhancing power quality and encouraging the use of renewable energy, this methodology aims to accomplish the study objectives of making modern power systems more resilient.

5. RESULTS AND DISCUSSION

One must read the "Building and Performance Investigation of Three-Phase Solar PV and Battery Energy Storage System Integrated UPQC" and pay close attention to the discussion and findings sections in order to understand how well the integrated system achieves the set goals. Critical insights into operation, efficiency, and possible repercussions are provided by comprehensive data analysis and interpretation, which has a tremendous effect on grid resilience, power quality improvement, and the integration of renewable energy sources.

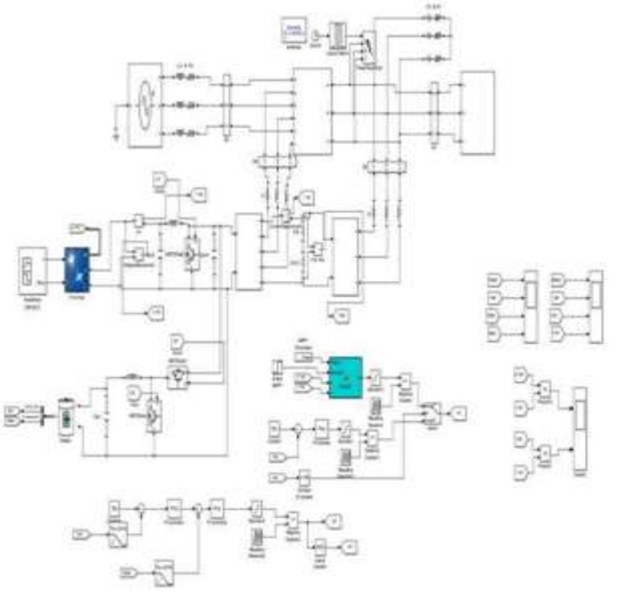

Fig1.Simulation Diagram

Starting with a review of the system's ability to generate solar energy, the data shows how well the PV arrays work to transform sunshine into electricity. An insightful evaluation of the system's ability to generate energy can be derived from data collected over time and under different conditions. Researchers can measure variables including ambient temperature, shading effects, and sun irradiation levels to determine the system's total energy output and its temporal fluctuations.

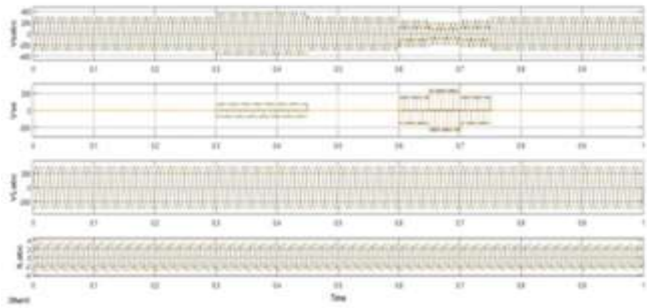

Fig2.Three phase Load Current and Load Voltage

In order to determine the BESS's ability to discharge and store energy as needed, its effectiveness is also evaluated. By meticulously monitoring charge/discharge cycles, energy efficiency, and battery health parameters, the research team collects substantial data on Bess's storage capacity, charging and discharging rates, and overall performance. Researchers are looking into the system's potential to improve grid stability and resilience, its capacity to provide

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ancillary services like frequency control and voltage support, and more.

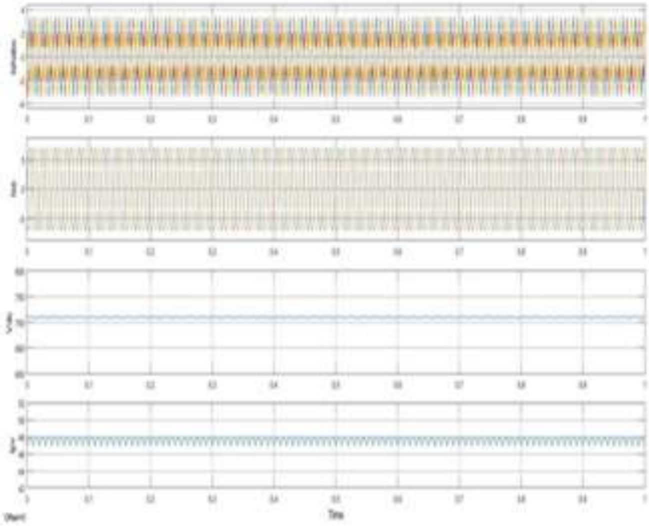

Fig3.Current at PV and voltage DC OUTPUT voltage

Assessing how well the system communicates with the UPQC is a crucial part of the findings and analysis. Test results and real-world data show that the UPQC fixes power quality problems by reducing voltage dips, harmonics, and fluctuations.

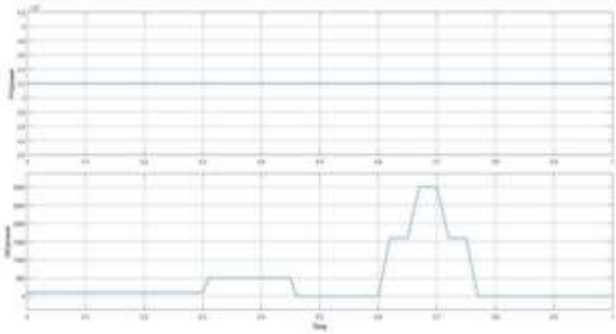

Fig4.PV power and DC power

The results show that the system can handle real-world scenarios well, like managing energy storage, incorporating renewable energy sources smoothly, and making the grid more resilient.

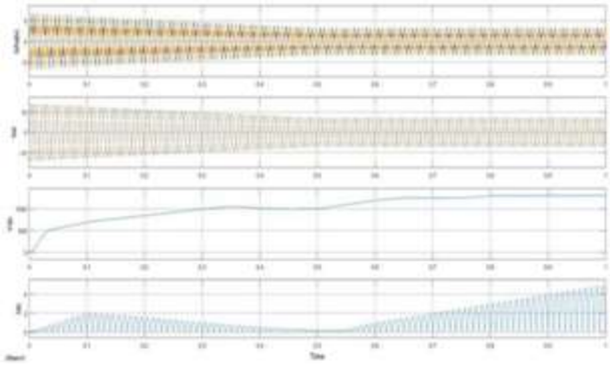

Fig5.DC voltage and current

Implications for grid resilience, power quality improvement, and renewable energy integration are also included in the studies. We take a look at the main findings and highlight how important they are for reaching the research goals.

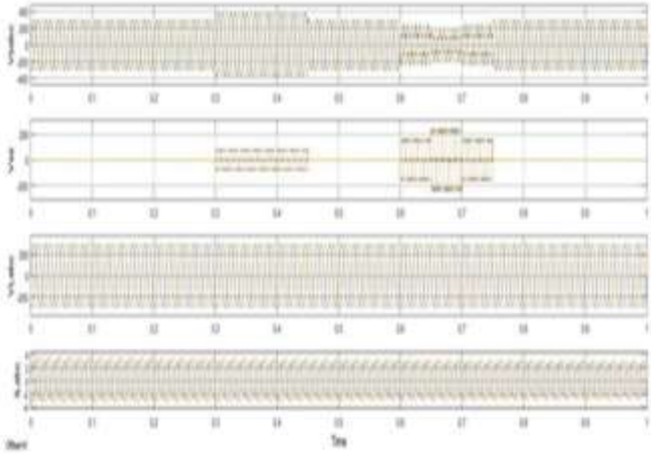

Fig6.Load currents and load voltages

The discussion delves further into the broader ramifications of the integrated system, taking into account the evolving energy scene and the transition to a more sustainable and resilient power grid.

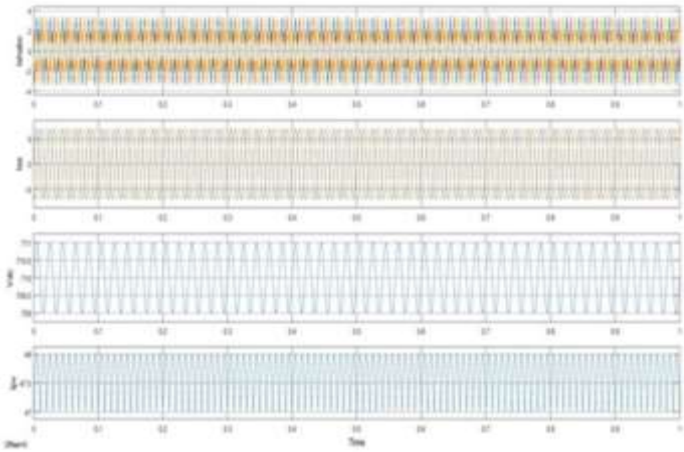

Fig7.PV currents and DC voltages

Additionally, the argument considers the integrated system's repeatability and scalability in light of cost-effectiveness, technical feasibility, and regulatory limitations.

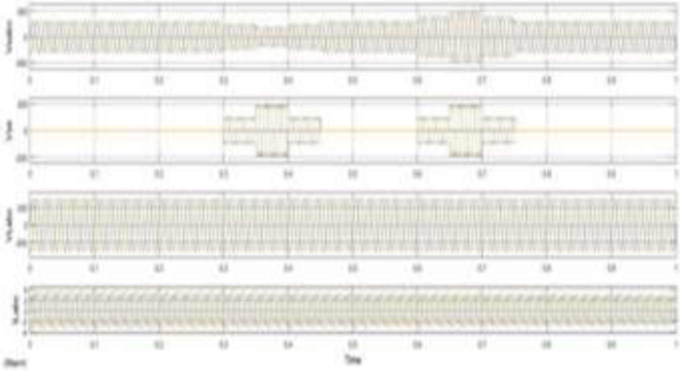

Fig8.Load currents and load voltages

Domains such as power electronics, grid integration methods, solar photovoltaic technologies, and battery storage systems are examined in this study.

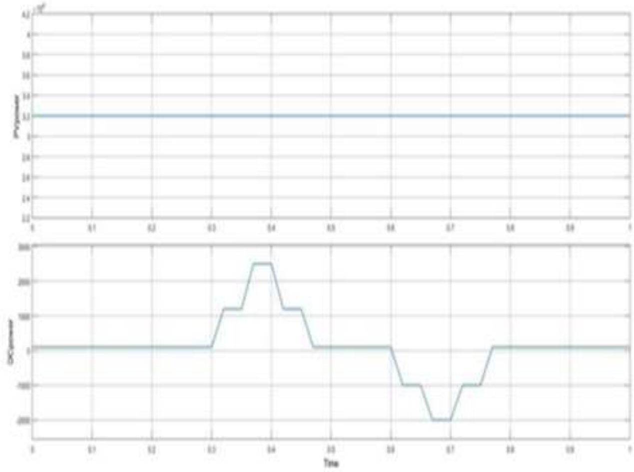

Fig9. DC power and PV power

The effectiveness of the UPQC-integrated three-phase solar PV and battery energy storage system is further investigated in the part devoted to findings and discussion. Improving grid resilience, power quality, and the ability to integrate renewable energy sources can be achieved through analyzing the system's performance indicators, debating the important results, and evaluating their repercussions.

6. CONCLUSION

Complex power quality challenges, including harmonics, voltage surges and sags, and voltage interruption, have been studied in relation to the design of a three-phase UPQC under imbalanced and distorted voltage grid situations. The UPQC gains active power capacity when the BESS and PV are integrated. The ability to supply and absorb PV active power is the main benefit of merging BESS with UPQC. The limited availability of renewable energy sources, which aren't always trustworthy because of the damage they do to the environment, can be reduced with the help of a BES.

Lastly, one may make the case that UPQC in conjunction with BESS and PV could be a viable alternative to traditional distributed generation methods for improving power quality in modern distribution systems. The steady supply from the PV-Bess system keeps the DC-link voltage constant. As a result, it may make the DC-link voltage control approach easier. The reference voltage and current are efficiently generated by the shunt and series APF compensator through the use of STF-UVG technology for phase synchronization. The UPQC is built separately from the PLL components to ensure system stability and a power factor close to unity. Because of this, voltage and current can be effectively reduced in reaction to grid conditions. The offered method confirmed that the grid current harmonics were in accordance with the IEEE 525 standards. Lastly, it must be stressed that the suggested approach may improve the grid power system's overall efficiency.

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