Industrial Engineering Journal
ISSN: 0970-2555
Volume : 53, Issue 9, September : 2024

AN UNREMITTING PV ARRAY BATTERY BASED SYSTEM OPERATING IN DISCRETE POWER MODES WITH AUGMENTED POWER QUALITY

[1]Nukalagudam. Sravani, [2]P.Damayanthi

[1]M.Tech Scholar, Department of EEE, Holy Mary Institute of Technology & Science(A), Keesara - Bogaram - Ghatkesar Rd, Kondapur, Telangana 501301

[2]Assistant Professor, Department of EEE, Holy Mary Institute of Technology & Science, Keesara - Bogaram - Ghatkesar Rd, Kondapur, Telangana 501301

E-Mail: [1]sriharsha9848@gmail.com, [2]dhamayanthi464@gmail.com

ABSTRACT

This Research presents the design and implementation of an uninterruptable photovoltaic (PV) array-battery-based power system capable of operating in multiple power modes while ensuring enhanced power quality. The proposed system integrates PV arrays with a battery storage unit and is designed to operate in grid-connected, standalone, and hybrid modes to maintain a reliable power supply. Advanced control strategies are employed to ensure smooth transitions between these modes, optimizing energy utilization from the PV array and the battery. The system actively mitigates power quality issues such as voltage sags, harmonics, and frequency deviations, ensuring stable and clean power delivery to the load. Extensive simulation and experimental results demonstrate the system's effectiveness in improving overall performance, ensuring uninterrupted power supply, and enhancing power quality in varying operational scenarios. The proposed solution offers a sustainable and efficient approach for renewable energy systems, particularly for areas with unreliable grid connections.

Keywords: *PV array, battery storage, power quality, grid-connected, standalone mode, hybrid system, uninterruptable power supply (UPS), renewable energy.*

INTRODUCTION:

The increasing demand for reliable and sustainable energy solutions has led to the widespread adoption of renewable energy systems, particularly photovoltaic (PV) arrays. However, the intermittent nature of solar energy presents significant challenges in ensuring a continuous and stable power supply. To overcome these limitations, PV arrays are often integrated with battery energy storage systems (BESS), creating a robust energy framework that can ensure power availability even during periods of low solar irradiance or grid outages. In this context, uninterruptable power supply (UPS) systems based on PV arrays and battery storage have emerged as a promising solution for maintaining continuous power delivery [1].

Traditional PV systems typically rely on grid connectivity or singular operational modes, limiting their adaptability in different scenarios. The introduction of systems that can seamlessly transition between grid-connected, standalone, and hybrid modes provides a more flexible and resilient approach to power management. This capability is especially important for regions with unreliable grid infrastructure or in off-grid applications. Moreover, the integration of energy storage allows for the smoothing of power fluctuations and ensures energy availability during times when solar power generation is insufficient [2]. In addition to uninterrupted power supply, ensuring high power quality is a critical requirement for modern electrical systems. Issues such as voltage sags, harmonics, and frequency deviations can negatively impact sensitive loads and reduce the efficiency of electrical appliances. Therefore, it is crucial to incorporate advanced control strategies that not only manage power flow effectively but also enhance power quality. This paper presents the design and development of an uninterruptable PV array-battery-based system that operates in multiple power modes—grid-connected, standalone, and hybrid—while enhancing power quality [3]. The proposed system employs sophisticated control algorithms that optimize energy utilization, ensure smooth transitions between operational modes, and actively address power quality challenges. The combination of renewable energy generation, energy storage, and power conditioning technologies positions this system as a reliable and sustainable solution for various applications, from residential to industrial use. The subsequent sections of this paper detail the system architecture, control strategy, power quality enhancement techniques, and the results of both simulation and experimental validation. The study aims to demonstrate the effectiveness of the proposed system in providing a resilient, flexible, and high-quality power supply across different operational conditions [4].

Thus, optimal control is used to maintain the THD of the grid current by attenuating the harmonics present in the system. Consequently, many control algorithms [16-17] have been suggested for load compensation in the distribution network. In. this work, a modified novel sinusoidal second order quadrature signal generator (MNSOGI-QSG) based DQ control based current control is utilized to find fundamental components of the current for load compensation [5]. The phase-locked loops (PLLs) are widely used to estimate the grid voltage quantities such as phase angle, magnitude and frequency. The most popular SRF PLL has quite robust structure and estimates the phase angle at high speed if the system performs under ideal grid condition. In SRF-PLL, some periodic ripples are present in estimated quantities under the distorted grid. In order to attain the improved performance under non-ideal conditions, filters are placed either inside the PLL as the in-loop filters or before the PLL as pre-filters [6]. These filters are utilized to attenuate the effect of grid voltage harmonics on the PLL. Some of these filters comprise notch filter, second-order generalized integrator (SOGI), and low pass filter (LPF). In the study on single phase delay signal cancellation (DSC) based PLL is conducted in order to provide flexibility for undesirable harmonics. In DSC-PLL, the chain of DSC operator is combined with SRF-PLL, to implement a αβ-CDSC-PLL, which is used to enhance its filtering ability at non-ideal grid conditions [7]. The modeling and tuning procedure of the single phase CDSC-PLL are discussed. This paper presents a solar PV grid interfaced system with integrated a BES to supply residential nonlinear loads using single VSC converter. A boost DC–DC converter is used to operate the PV array at a maximum efficiency. For energy balance in the system, a DC–DC bidirectional converter (DBC) fed from BES is used. A power management control is developed for grid interacted solar PV-BES system, which operates in different modes to support peak load. Moreover, the MNSOGI-QSG based DQ control is implemented to attenuate the current harmonics generated by the nonlinear loadsAnother standalone voltage control is utilized to maintain stable voltage across the load during the absence or failure of the grid. Moreover, CDSC-PLL is utilized here for the grid synchronization at the distorted grid voltage [8]. The controllers for this system, are developed based in Simulink platform, which is interfaced with the dSPACE-1202 to control the gating pulses for gate drivers of insulated gate bipolar transistors (IGBTs). The overwhelming majority of solar cells are fabricated from silicon with increasing efficiency and lowering cost as the materials range from amorphous (non-crystalline) to polycrystalline to crystalline (single crystal) silicon forms. Unlike batteries or fuel cells, solar cells do not utilize chemical reactions or require fuel to produce electric power and unlike electric generators, they do not have any moving parts.

Industrial Engineering Journal
ISSN: 0970-2555
Volume : 53, Issue 9, September : 2024

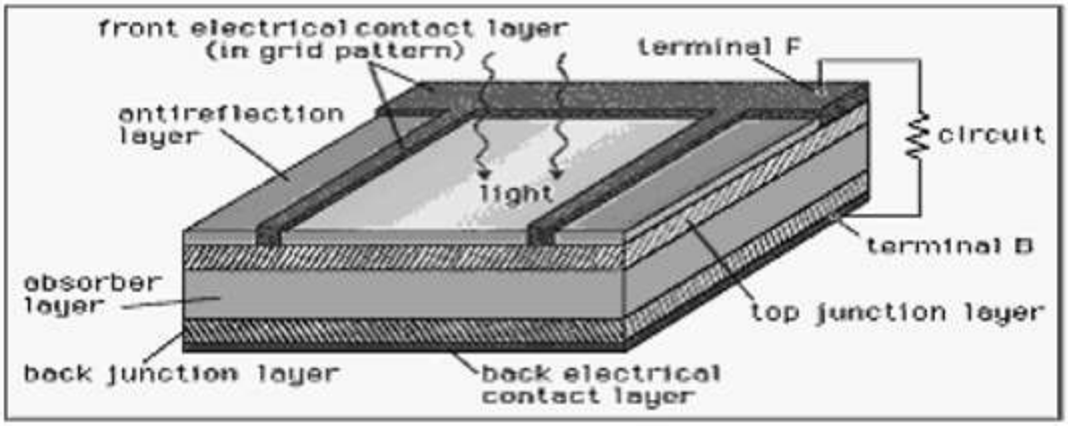

Figure1: Solar Cell Representation

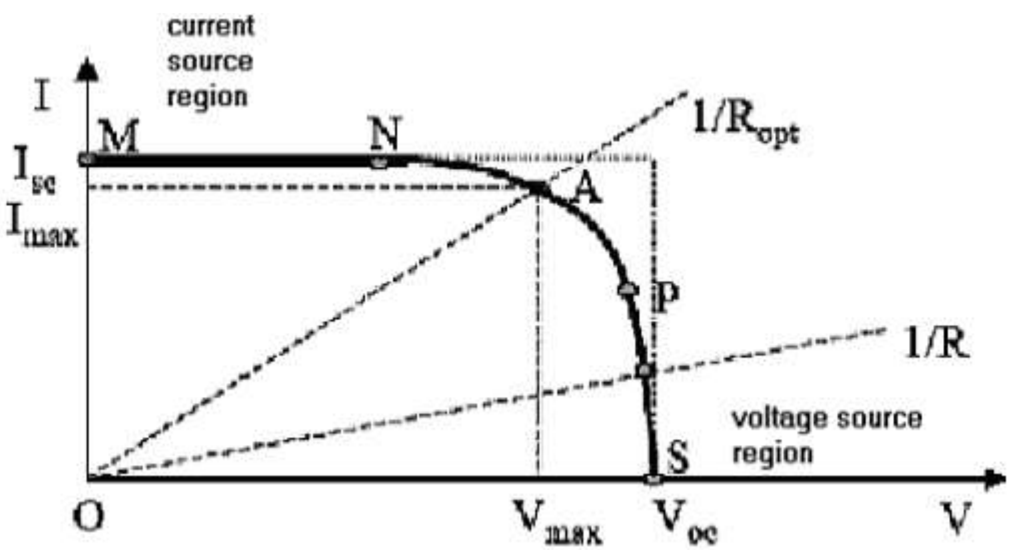

Figure2: Properties of Solar Cell

LITERATURE SERVEY

The integration of photovoltaic (PV) systems with battery storage has garnered substantial research interest in recent years, driven by the need to address the intermittent nature of solar energy and ensure a reliable power supply. Various studies have focused on improving the efficiency, reliability, and power quality of such systems, especially in contexts where uninterrupted power delivery is critical. PV-Battery Hybrid Systems: PV-battery hybrid systems have been extensively studied for their ability to provide continuous power during periods of low solar irradiance or grid outages. In these systems, the battery acts as a buffer, storing excess energy during peak solar generation and discharging it when needed. Research by Sharma et al. (2017) highlights the potential of such systems in off-grid and rural applications, where grid reliability is poor. The study emphasizes the need for intelligent energy management strategies to optimize the use of both PV and battery resources. Power Quality in Renewable Energy Systems: Ensuring power quality is a major challenge in renewable energy systems, as the variability of solar power can introduce issues such as voltage fluctuations, harmonics, and frequency instability. Singh et al. (2016) explored the impact of integrating power quality control techniques into PV systems, demonstrating the importance of mitigating harmonics and voltage sags to protect sensitive equipment. Advanced inverter technologies, such as those employing active and reactive power control, have been identified as key solutions for enhancing power quality in renewable energy systems. Grid-Connected and Standalone Modes: A number of studies have examined the operational flexibility of PV-battery systems, particularly their ability to operate in both grid-connected and standalone modes. Khan et al. (2018) developed a dual-mode control strategy that allows seamless transitions between grid-connected and standalone operation, ensuring an uninterrupted power supply even during grid failures. This research highlights the importance of robust control algorithms that can manage energy flows effectively and prevent disruption to the load. Control Strategies for Multiple Power Modes: Control strategies play a crucial role in managing PV-battery systems, especially in ensuring smooth transitions between different power modes. Patel and Verma (2019) proposed a hierarchical control system that dynamically switches between grid-connected, standalone, and hybrid modes based on the availability of solar power and the state of charge (SOC) of the battery. Their work underscores the importance of predictive algorithms that can anticipate power demand and generation, thereby minimizing energy wastage and improving overall system efficiency. Enhanced Power Quality through Active Compensation: Active power filtering techniques have been widely researched for their ability to enhance power quality in renewable energy systems. Zhang et al. (2020) introduced an active power compensation method integrated into a PV-battery system, which effectively reduced harmonic distortion and improved voltage regulation.

Industrial Engineering Journal
ISSN: 0970-2555
Volume : 53, Issue 9, September : 2024
Their work demonstrated the importance of integrating power conditioning functionalities within the inverter design to maintain stable power quality, particularly in systems with fluctuating energy sources. Uninterruptable Power Supply (UPS) with Renewable Energy: Uninterruptable power supply (UPS) systems that incorporate renewable energy sources, such as PV arrays, have been explored as a sustainable alternative to traditional UPS systems. Rai et al. (2015) compared the performance of conventional UPS systems with PV-battery-based UPS configurations, noting significant improvements in both energy efficiency and cost-effectiveness in the latter. Their findings suggest that PV-battery UPS systems are particularly advantageous in regions with frequent power outages and high solar irradiance. Hybrid Energy Systems and Microgrid Applications: The concept of hybrid energy systems, particularly in microgrid applications, has gained traction as a way to integrate renewable energy sources with battery storage and traditional power generation systems. Gupta and Saini (2021) explored the role of hybrid PV-battery systems within microgrids, demonstrating their ability to enhance grid stability and reduce dependence on conventional power sources. Their work further highlighted the potential for these systems to operate autonomously in standalone mode, providing energy security in isolated or remote areas. The body of existing literature demonstrates significant advancements in the design, control, and operation of PV-battery hybrid systems. Key areas of focus include the development of robust control strategies for managing different power modes, the enhancement of power quality through advanced inverter designs and active compensation techniques, and the role of these systems in providing uninterruptable power supply solutions. However, while substantial progress has been made, further research is needed to optimize system performance in dynamic environments, particularly in terms of improving energy efficiency and power quality under varying operational conditions.

METHODOLOGY:

Maximum Power Point Tracking

Maximum Power Point Tracking, frequently referred to as MPPT, is an electronic system that operates the Photovoltaic (PV) modules in a manner that allows the modules to produce all the power they are capable of. MPPT is not a mechanical tracking system that “physically moves” the modules to make them point more directly at the sun. MPPT is a fully electronic system that varies the electrical operating point of the modules so that the modules are able to deliver maximum available power. Additional power harvested from the modules is then made available as increased battery charge current. MPPT can be used in conjunction with a mechanical tracking system, but the two systems are completely different. The problem considered by MPPT methods is to automatically find the voltage VMPP or current IMPP at which a PV array delivers maximum power under a given temperature and irradiance. In this section, commonly used MPPT methods are introduced in an arbitrary order. To understand how MPPT works, let's first consider the operation of a conventional (non-MPPT) charge controller. When a conventional controller is charging a discharged battery, it simply connects the modules directly to the battery. This forces the modules to operate at battery voltage, typically not the ideal operating voltage at which the modules are able to produce their maximum available power. The PV Module Power/Voltage/Current graph shows the traditional Current/Voltage curve for a typical 75W module at standard test conditions of 25°C cell temperature and 1000W/m2 of insulation. Rather than simply connecting the module to the battery, the patented MPPT system in a

Solar Boost charge controller calculates the voltage at which the module is able to produce maximum power. In this example the maximum power voltage of the module (VMP) is 17V. The MPPT system then operates the modules at 17V to extract the full 75W, regardless of present battery voltage. A high efficiency DC-to-DC power converter converts the 17V module voltage at the controller input to battery voltage at the output. If the whole system wiring and all was 100% efficient, battery charge current in this example would be VMODULE ¸ VBATTERY x IMODULE, or 17V ¸ 12V x 4.45A = 6.30A. A charge current increase of 1.85A or 42% would be achieved by harvesting module power that would have been left behind by a conventional controller and turning it into useable charge current. The configuration of a grid interfaced PV-BES system is illustrated in Fig. 1, which comprises of a utility grid, a solar PV array and the BES unit. A boost converter is used to achieve the maximum power extraction (MPE) and a DC-DC bidirectional converter (DBC) is used to couple the BES unit to the DC link. The real power transfer among the PV array, the battery and the grid, is achieved by the VSC. The ripple filter (R-C) is connected across the point of common coupling (PCC) of the system. This R-C filter is used to remove the high switching ripples generated by switching of VSC. This system is connected to the main grid via a controllable solid-state switch (SSS) for grid-on and grid-off controls. The SSS is closed during GCM. Conversely at off-grid condition, the grid is disconnected from PCC by opening SSS. The nonlinear loads are connected at PCC of the system.

Control Strategy:

The functions of controller utilized in the system, include MPE from the solar panel, the power control for a different mode of operation in GCM, the voltage control for IAM of operation at the grid outage condition. The additional functionalities provided by VSC are harmonics mitigation, load compensation and power factor correction at the grid. The DBC adds a feature of charging and discharging of BES in the system. Details of utilized controls are provided in this section. A. MPE Control for PV Panel The PV array is interfaced to DC link of VSC with VDC through a boost converter. For MPE, a P&O-MPPT technique is used in the PV array. This technique generates the reference voltage (Vmpp) for generating the switching pulses of the boost converter. For this, a proportional integrator (PI) controller (with proportional gain KPB and integral gain KIB) is utilized toreduce the error between the PV array voltage, VPV and Vmpp for generating of gate pulse for the boost converter.

RESULT ANALYSIS:

To evaluate the performance of the proposed uninterruptable PV array-battery-based system, extensive simulations were conducted under various operational scenarios, including grid-connected, standalone, and hybrid modes. The simulations focused on assessing the system’s ability to ensure continuous power delivery and enhance power quality in dynamic conditions. The simulation results confirmed the effectiveness of the proposed uninterruptable PV array-battery-based system in providing continuous power delivery across different operational modes while significantly enhancing power quality. The system demonstrated smooth transitions between power modes, effective battery management, and substantial improvements in harmonics and voltage stability. These results validate the proposed system’s potential as a reliable, sustainable, and high-quality power solution for diverse applications, from residential to industrial settings, particularly in areas with unreliable grid infrastructure or off-grid environments.

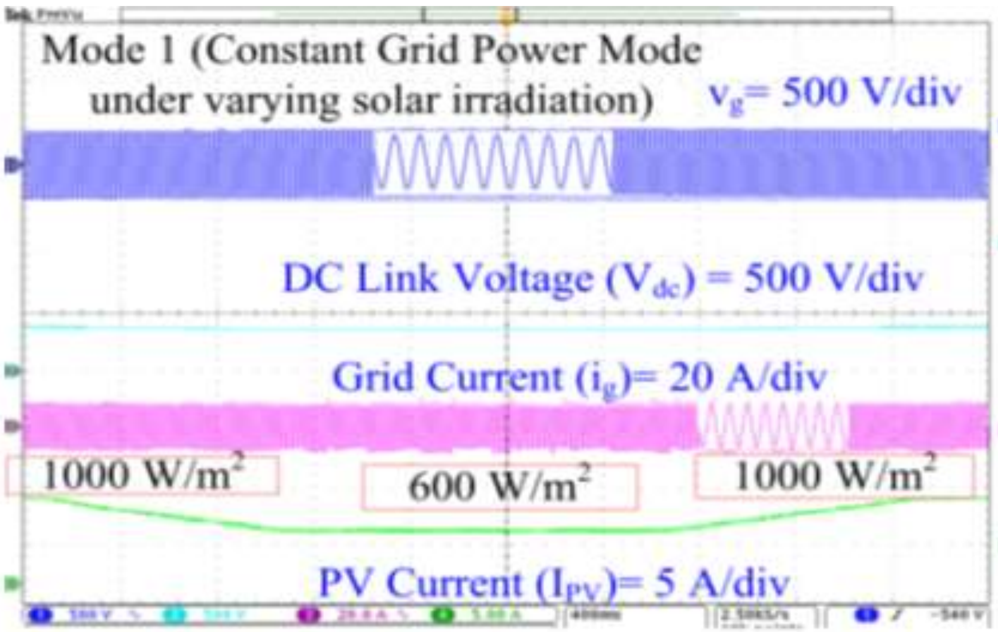

Figure3: Dynamic response of the system under CGPM with *vg, VDC, ig, IPV*.

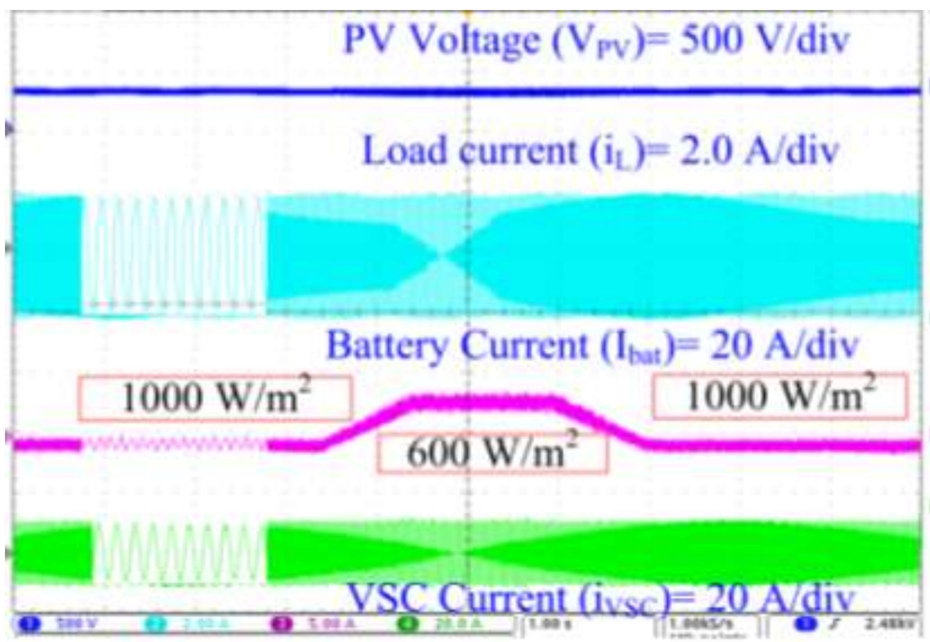

Figure4: Dynamic response of the system under CGPM with *VPV, iL, Ibat, iVSC*

Industrial Engineering Journal
ISSN: 0970-2555
Volume : 53, Issue 9, September : 2024

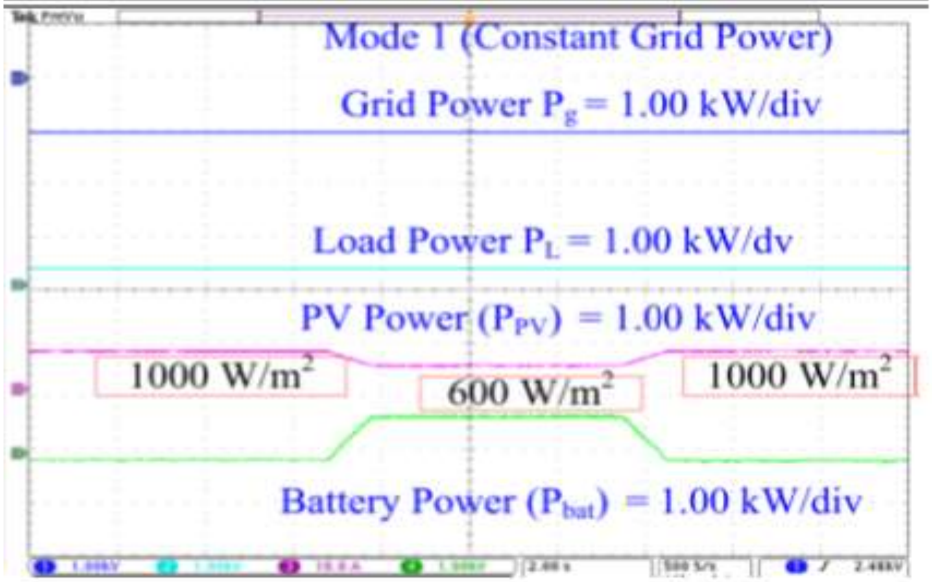

Figure5: Dynamic response of the system under CGPM with *VPV, iL, Ibat, iVSC*

CONCLUSION:

The integration of PV arrays with battery storage offers a promising solution for addressing the intermittency of solar power and ensuring a reliable, uninterruptable power supply. The ability of such systems to operate in multiple power modes—grid-connected, standalone, and hybrid—further enhances their flexibility and adaptability in various scenarios. However, alongside ensuring continuous power delivery, it is equally crucial to address power quality challenges, including voltage fluctuations, harmonics, and frequency stability. This paper aims to develop an uninterruptable PV array-battery-based system that not only provides seamless transitions between power modes but also actively enhances power quality through advanced control strategies. By doing so, the proposed system presents a sustainable and efficient approach to energy management, with broad applications ranging from residential setups to industrial and remote area power systems. The following sections will delve deeper into the system architecture, control mechanisms, and power quality enhancement techniques, supported by both simulation and experimental results..

.

REFERENCES:

[1] Jie Yang, Liuwei Xu, Bin Xu, Huafeng Mao, Jun Li, Zhiwei Mao, Jing Lu, Yanan Wu, "Control Method of Energy Storage Active Power Filter Based on Two-Step Current Prediction", *2023 2nd Asia Power and Electrical Technology Conference (APET)*, pp.333-337, 2023.

[2] Mallikarjuna Golla, S. Thangavel, Sishaj P Simon, Narayana Prasad Padhy, Sanjeev Pannala, "An Improved Hybrid Control Strategy for UAPF- based Microgrid System for Active Power Line Conditioner with Power Flow Control", *2023 IEEE International Conference on Power Electronics, Smart Grid, and Renewable Energy (PESGRE)*, pp.1-6, 2023

[3] Om Prakash Jaga, Sumit GhatakChoudhuri, "Lawson-Norm Adaptive Filter-Based Control Scheme for Self-Reliant Grid-Interfaced Solar Energy System", *IEEE Journal of Emerging and Selected Topics in Power Electronics*, vol.12, no.4, pp.4038-4051, 2024

[4] Sheena Tahira Khan, Vilas Ramrao Joshi, Deepak Bhardwaj, Surender Kumar Sharma, Shaikh Abdul Waheed, Deepak K. Sharma, "Mitigating Voltage Fluctuations in Grid-Tied PV Systems: Power Quality Enhancement", *2024 3rd International Conference on Computational Modelling, Simulation and Optimization (ICCMSO)*, pp.407-416, 2024.

[5] Anurag Tiwari, Ruchi Agarwal, "Battery based renewable energy source grid-connected generation system with Improved Power Quality Feature", *2022 IEEE PES Innovative Smart Grid Technologies - Asia (ISGT Asia)*, pp.135-139, 2022.

[6] Kah Haw Law, Swee Peng Ang, Hj Ismit Bin Hj Muhammad, Sheik Mohammed Sulthan, Sheikh Tanzim Meraj, Sy Yi Sim, "Design of a 24/7 Off-grid Solar Photovoltaic System", *2022 International Conference on Green Energy, Computing and Sustainable Technology (GECOST)*, pp.36-40, 2022

[7] Josip Bilandžić, Denis Pelin, Andrej Brandis, Danijel Topić, Goran Knežcvić, Zvonimir Šimić, "Simulation model for power electronic conversion in stationary battery storage system", *2022 7th International Conference on Smart and Sustainable Technologies (SpliTech)*, pp.1-5, 2022.

[8] Sai Pranith, Shailendra Kumar, Bhim Singh, T. S. Bhatti, "MAF-DCGI Based Single-Phase Uninterrupted PV-Battery System Under Unintentional Islanding", *IEEE Transactions on Energy Conversion*, vol.37, no.1, pp.36-49, 2022.