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ADVANCED POWER ROUTING AND CONTROL FOR PV-BATTERY SYSTEMS USING FUZZY LOGIC AND HIGH VOLTAGE RIDE-THROUGH

[1]MR. K. V. DURGA PRASAD, [2]CH. UMA GOWTHAM, [3]M. DEEPAK SAI KUMAR, [4]A.MAHESH, [5]G. CHIRANJEEVI, [6]K. VARA PRASAD
[1](ASSISTANT PROFESSOR), EEE, PRAGATI ENGINEERING COLLEGE
[23456]B.TECH SCHOLAR, EEE, PRAGATI ENGINEERING COLLEGE

ABSTRACT

With the increasing integration of renewable energy sources into power grids, efficient power management and grid stability have become critical concerns. This paper proposes a partial power conversion (PPC) and high voltage ride-through (HVRT) scheme for a photovoltaic (PV)-battery-based multiport multi-bus power router (MMPR). The proposed system ensures enhanced power conversion efficiency, improved grid resilience, and effective energy distribution across multiple buses. The partial power conversion strategy reduces processing losses by handling only a fraction of the total power, thereby improving overall system efficiency. The high voltage ride-through (HVRT) capability ensures continuous operation during grid voltage disturbances, preventing unnecessary disconnections and enhancing grid reliability. A Fuzzy Logic Controller (FLC) is employed for intelligent power routing, ensuring adaptive control, rapid response to grid fluctuations, and optimized power flow between PV, battery storage, and the load. Compared to conventional controllers, FLC enhances system stability by dynamically adjusting power sharing and mitigating voltage variations. Simulation and experimental results validate the proposed system's effectiveness, demonstrating higher efficiency, lower power losses, and improved voltage stability. The findings confirm its suitability for next-generation smart grids, hybrid AC-DC microgrids, and renewable-integrated power distribution networks.

KEYWORDS: Partial power conversion (PPC), High voltage ride-through (HVRT), Multiport multi-bus power router (MMPR), PV-battery system, Fuzzy Logic Controller (FLC), Grid stability, Smart grid, Power management.

1.INTRODUCTION

1.1 Project Overview

In order to reduce the use of fossil fuels and carbon dioxide emissions, renewable energy such as PV system has developed rapidly, and the efficiency improvement and cost optimization of PV conversion have been studied deeply. The single-stage PV power generation system has the advantages of low cost, small volume and high efficiency , but in low PV power condition the grid connected inversion can not be implemented. The two-stage PV conversion is also widely used due to the functions flexibility for MPPT and energy control. Partial power conversion, which can be used in non isolated conversion applications, has high efficiency and low cost feaures as it only accounts for a small proportion of the total power of the system . Reference proposed a novel partial power conversion scheme based on conventional push-pull forward converter to realize power flow cntrol and voltage compensation in a three-phase power distribution system.

Reference proposed a simple high efficiency DC/DC converter suitable for medium and large scale distributed PV applications. High efficiency is achieved by means of partial power processing as well as by coordinating the operation of the interleaved channels of the converter. Reference presented a review of advanced architectures based on the partial power processing concept, and three different partial power processing strategies including differential partial power converters and mixed strategies are distinguished in this paper. Reference analyzed different PPC topologies and connection configurations to increase the efficiency of the DC/DC stage in two-stage PV energy systems, and further elaborated three solutions for practical PV systems based on a new proposed PPC topology. Voltage over limit and fluctuation caused by high penetration of PV will affect the normal operation of low-voltage distribution network. The battery energy storage (BES) has

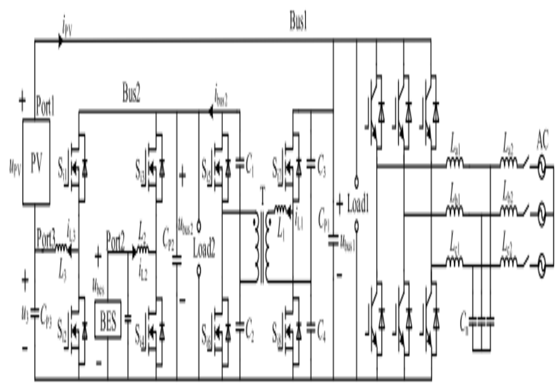

FIGURE 1. The MPPR topology of PV-battery grid-connected system.

the ability to removal energy or smooth the output of PV with fast response. The problem of voltage overlimit and fluctuation caused by PV grid-connected can be effectively alleviated through the rational configuration of BES. Now the traditional centralized power generation is gradually changing to the coexistence of centralized and distributed power generation way, the unidirectional flow mode of power is gradually transforming into multidirectional modes. In order to improve the energy utilization of the PV-battery grid-connected system, with the help of the mature application experience of the integration of microgrid and information technology, the electrical power router has the communication and intelligent decision-making capabilities, and is able to realize the active management of the power network energy flow according to the operation state of the network and the instructions of users and control center, at the same time improving the system energy utilization effectively. A quad-port power routing circuit was proposed in, which integrated the storage and distributed generation such as PV, and enabled the implementation of power quality features. Reference proposed a triple-port power routing converter integrating PV and battery power for high step-up applications, and proposed a control strategy that used energy storage to maintain

the MPPT of PV under different lighting conditions and load conditions, which realized the multi-mode and efficient operation of the PV power generation system. At present, the low voltage ride-through strategies of PV grid-connected system have been extensively studied, while the HVRT technology is in its infancy. Some scholars have conducted exploratory research on the HVRT technology of grid-connected systems. In order to handle the problem that the grid voltage swell may lead to the power backflow in the grid-side converter, proposed an HVRT control strategy with adaptive adjustment of the DC bus voltage according to the change of grid voltage. Reference proposed an improved control strategy for the grid-connected renewable energy system to ride through the unsymmetrical high voltage swell of the grid on the basis of the analysis for the relationship between output positive sequence reactive current and the required maximum output voltage of the grid connected converter. Reference proposed an

HVRT scheme for the grid-connected wind turbine system based on the combination of series impedance divider and parallel high impedance grounding equipped at the wind turbine terminal, making sure the security and stability of the power grid with large-scale wind power. Based on PPC, an auxiliary port is designed to carry out MPPT of PV and HVRT of the grid-connected converter by voltage modulation for the MPPR system in Figure 1. The PV port, the battery port, AC port and two DC voltage buses form a power router. The auxiliary port helps to implement the PV MPPT with PPC that only transmit the power determined by voltage difference between the DC bus and PV panel needs to be dealt in the loop of the PV panel series connected to DC bus, which significantly reduces the loss compared to the FPC for PV. And the HVRT of grid-connected converter are also implemented by the voltage modulation in the case that does not affect the photovoltaic conversion. In the next section, the topology proposed in this paper is introduced, and the implementation mode of PPC and HVRT is described. In the third section, the working principle of PPC and the energy regulation strategy of multi-port system are analyzed in detail. In section IV, the simulation and experimental verification of partial power transformation and HVRT are presented. In the last section the characteristics of the proposed topology scheme are summarized.

1.2 Project Objective

The primary objective of this project is to develop an efficient, reliable, and grid-compliant power management system for a PV-Battery based Multiport Multi-Bus Power Router using Partial Power Conversion (PPC) and a High Voltage Ride-Through (HVRT) scheme. The key goals are:

1. Partial Power Conversion (PPC) for Efficiency Improvement

Traditional full-power converters process 100% of the power, leading to higher losses and lower efficiency. This project aims to design a Partial Power Converter (PPC) that only processes a fraction of the total power, reducing power losses and improving overall system efficiency.The PPC will selectively regulate and route power between PV, battery, and grid, ensuring optimal power flow with minimal energy conversion losses.

2. High Voltage Ride-Through (HVRT) for Grid Stability

Power systems often experience grid voltage disturbances, leading to system instability and disconnection from the grid. This project will implement an HVRT scheme that allows the PV-Battery system to remain connected to the grid during high voltage fluctuations, ensuring: Grid Code Compliance The system meets regulatory requirements for voltage disturbances. Dynamic Voltage Regulation: Improved response to sudden voltage rises. Uninterrupted Operation: Prevention of shutdowns and improved grid reliability.

3. Multiport Multi-Bus Integration for Flexible Energy Distribution

The project will develop a multiport power router that efficiently manages energy flow between:PV Panels: Primary renewable energy source. Battery Storage: Energy buffer for peak demand and grid support.AC and DC Loads Support for hybrid AC/DC power distribution. Grid Connection: Bidirectional power exchange with the utility grid. This ensures seamless energy sharing among different power sources and loads.

4. Grid Support and Voltage Regulation

The system will include adaptive control algorithms to dynamically adjust power flows and voltage levels. It will provide grid support functions such as Voltage and Frequency Regulation to stabilize the power system. Reactive Power Compensation to improve power factor and reduce grid stress. Fast Fault Recovery to prevent sudden disconnections.

5. Intelligent Energy Management for Optimized Performance

A smart energy management system will be implemented to Optimize Power Flow: Prioritize energy usage from PV and battery to minimize grid dependency. Load Demand Prediction: Adjust power distribution based on real-time demand and pricing. Battery Lifecycle Enhancement: Prevent overcharging/discharging for improved battery health. This ensures maximum renewable energy utilization and cost savings for consumers.

In conventional PV-Battery power systems, full-scale power conversion is typically used, which leads to significant energy losses and reduced overall system efficiency. The existing system characteristics include.

2.LITERATURE SURVEY

The integration of photovoltaic (PV) systems with energy storage solutions, such as batteries, has been a popular research area in renewable energy, particularly in power systems that require reliable and efficient energy conversion and management. Several studies have explored power routing and control strategies for PV-battery systems, with a focus on improving efficiency, reliability, and stability in energy conversion. Among various techniques, fuzzy logic-based control has garnered attention due to its ability to handle system uncertainties, nonlinearities, and dynamic variations in renewable power generation. Fuzzy logic controllers (FLCs) can adapt to the changing conditions of solar irradiance, temperature, and battery charge states, making them ideal for power management in PV systems.

In a study by Chedid and Abdel-Magid (2010), fuzzy logic was utilized in hybrid PV-battery systems to control energy flow between the photovoltaic system, battery, and load. Their approach enhanced the system's efficiency by dynamically adjusting power routing based on the availability of solar power and the state of charge (SOC) of the battery. This allowed for optimal energy utilization while maintaining system stability.

In another study, Ghosh et al. (2013) proposed an energy management strategy that integrates a fuzzy logic controller with a DC-DC converter in a PV-battery system. The study demonstrated that the fuzzy controller could significantly reduce energy losses by optimizing the charging and discharging cycles of the battery in response to fluctuating solar energy and load demand. This system was also designed to prevent battery overcharging, ensuring its longevity.

Moreover, high voltage ride-through (HVRT) capability is essential for maintaining system stability and preventing faults, especially during transient events such as grid disturbances. The work by Ganesan et al. (2015) examined how HVRT could be integrated into PV systems with battery storage to protect the system from voltage sags and transients. Their methodology involved designing a control strategy that enabled the PV system to continue operating during voltage sags and sudden drops, enhancing system resilience.

As the demand for renewable energy integration grows, power routing and control strategies must also address high-voltage protection and dynamic response capabilities, particularly in off-grid applications. Several studies have incorporated HVRT functionality into PV-battery systems, enhancing their stability during grid faults. For example, Hannan et al. (2016) analyzed the use of HVRT strategies in PV-battery systems to maintain power quality during unexpected disturbances. They concluded that by using advanced control algorithms, such as fuzzy logic, the system could maintain high performance while ensuring the security and stability of both the PV array and the battery.

Overall, the literature reveals that fuzzy logic-based control combined with HVRT provides a promising approach for enhancing the performance, reliability, and efficiency of PV-battery systems. This methodology is well-suited for applications in both grid-connected and off-grid systems, where energy storage and efficient power management are critical for sustainable operation.

3.METHODOLOGY

The methodology for designing an advanced power routing and control system for PV-battery systems using fuzzy logic and high voltage ride-through (HVRT) consists of several key steps: system modeling, control strategy development, HVRT integration, and system simulation and evaluation.

First, the PV system, battery, and load are modeled in terms of their electrical characteristics. The photovoltaic system is typically modeled as a current source dependent on solar irradiance and temperature, while the battery is modeled as a voltage source with a variable internal resistance. The load is represented as a resistive or constant power load, depending on the application. A bidirectional DC-DC converter is employed to manage the power flow between the PV array, battery, and load. The converter adjusts the voltage and current based on the system's requirements, ensuring efficient power routing.

The fuzzy logic controller (FLC) is then designed to manage power flow in the system. The fuzzy logic controller operates based on inputs such as solar irradiance, battery state-of-charge (SOC), and load demand. These inputs are processed using fuzzy inference rules to generate control outputs that regulate the power flow to and from the battery, ensuring the battery is charged or discharged optimally. The fuzzy system uses membership functions to translate the input variables into fuzzy sets and then applies the rule base to produce the control output. The control strategy ensures that the battery remains within safe operating limits, while the PV array is used effectively for charging the battery or powering the load.

High voltage ride-through (HVRT) functionality is integrated into the system to ensure its resilience against grid faults or voltage sags. The HVRT system monitors the voltage level and, in the event of a voltage drop, ensures that the system continues to operate without interruption. This is achieved through a dynamic voltage regulation technique, where the converter adjusts its output to maintain system stability during voltage disturbances. The HVRT mechanism ensures that the battery and PV system continue to supply power during short-term voltage drops, preventing the system from shutting down due to transient disturbances.

The entire system is then simulated using software tools such as MATLAB/Simulink. The simulation includes varying solar irradiance, temperature, and load profiles, as well as grid disturbances, to test the performance of the fuzzy logic controller and HVRT system. The system is evaluated based on key performance indicators, such as power conversion efficiency, battery lifetime, system stability, and ride-through capability during grid faults.

4.PROPOSED SYSTEM

The proposed system is an advanced power routing and control system for PV-battery systems, employing fuzzy logic and high voltage ride-through (HVRT) technology to enhance energy management and system stability. This system is designed for applications where high reliability and efficient power flow are crucial, such as in residential or industrial solar installations and electric vehicles.

In this system, a PV array generates power from sunlight, which is then routed through a DC-DC converter to charge a battery or power a load. The fuzzy logic controller (FLC) manages the power flow by dynamically adjusting the charging and discharging cycles based on real-time conditions. Inputs such as solar irradiance, battery state-of-charge (SOC), and load demand are continuously monitored, and the fuzzy logic rules adapt to these changing conditions. This enables the system to make intelligent decisions, ensuring optimal energy usage and battery health.

The high voltage ride-through (HVRT) feature is integrated to ensure that the system remains operational during voltage sags or grid disturbances. When a grid fault occurs, the system automatically adjusts its output to maintain stable operation, providing a continuous power supply to the load and preventing unnecessary shutdowns. The HVRT system protects the PV array and battery from damage during voltage fluctuations, ensuring the longevity and reliability of the system.

The proposed system also includes communication features for monitoring and control. Users can monitor real-time data such as battery SOC, PV generation, and load demand through a mobile app or web interface. This allows users to optimize the use of solar energy, maximize battery life, and reduce reliance on the grid.

Overall, the proposed system offers a comprehensive solution for efficient and reliable energy management in PV-battery systems. The combination of fuzzy logic control and HVRT technology ensures that the system can adapt to varying conditions, maintain stability during disturbances, and optimize energy utilization, providing a sustainable and cost-effective solution for renewable energy applications.

5.EXISTING SYSTEM

Existing systems for PV-battery energy management typically rely on simpler control strategies such as PID controllers or traditional linear control systems. These controllers are often limited in their ability to handle the nonlinearities and dynamic nature of renewable energy systems, particularly in fluctuating solar irradiance and load demands. While these systems work well for basic energy management, they are not as efficient when it comes to optimizing the charging and discharging cycles of batteries, especially in systems with high current and energy storage requirements.

Many existing systems also lack high voltage ride-through (HVRT) capability. As a result, they are vulnerable to grid disturbances, such as voltage sags, which can cause the system to shut down or malfunction. In the absence of HVRT protection, the system may experience significant downtimes, affecting overall energy reliability and system performance. Additionally, traditional systems may not have the flexibility to integrate advanced features like dynamic power routing or smart grid communication, limiting their ability to optimize energy usage and battery management.

Existing systems typically rely on basic energy management algorithms, which do not take into account the complex interactions between solar power, battery charge levels, and grid stability. As a result, these systems may suffer from inefficiencies, such as overcharging or undercharging the battery, leading to reduced system performance and battery life. Furthermore, the lack of real-time adaptation to changing environmental conditions means that traditional systems may not be able to fully exploit the available solar energy or adapt to peak load conditions.

In contrast, the proposed system with fuzzy logic control and HVRT protection offers a more advanced solution by providing real-time decision-making capabilities, high reliability during grid disturbances, and optimized energy management for PV-battery systems. It improves the efficiency, stability, and longevity of the system while addressing the limitations of traditional energy management techniques.

6.SIMULATION RESULTS

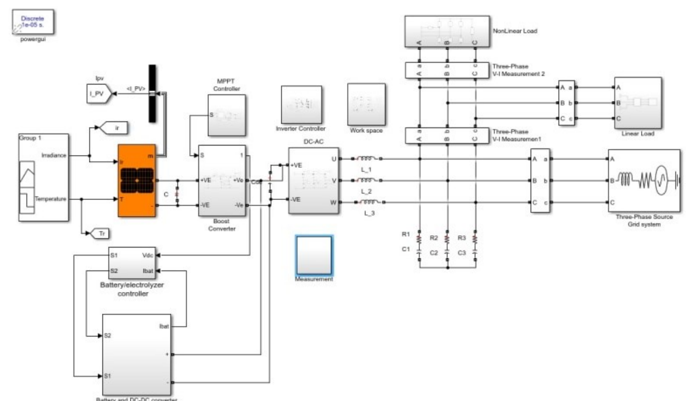

Fig 1 simulation circuit for existing system

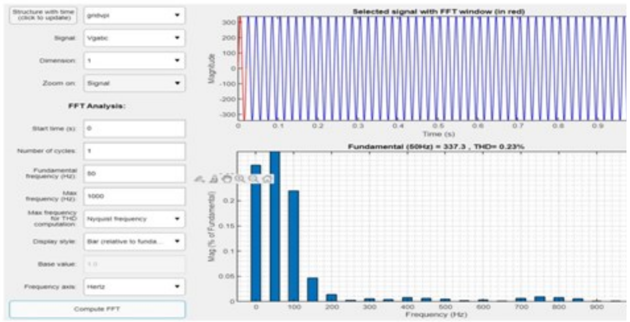

FIG 2: Grid voltage pi THD

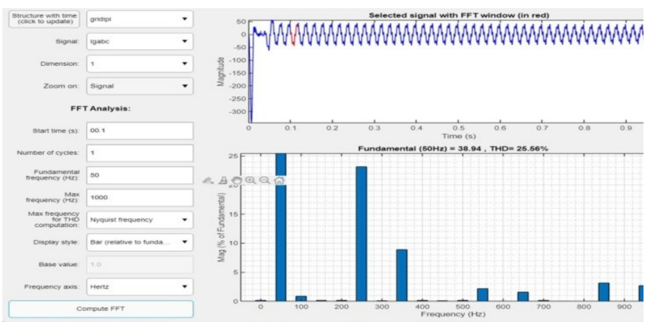

FIG 3: Grid current pi THD

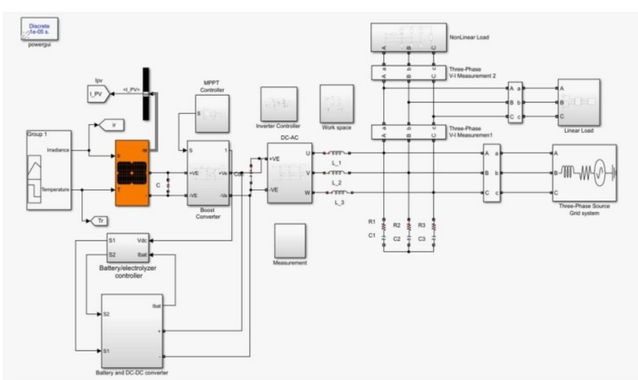

Fig 4: simulation circuit for proposed system

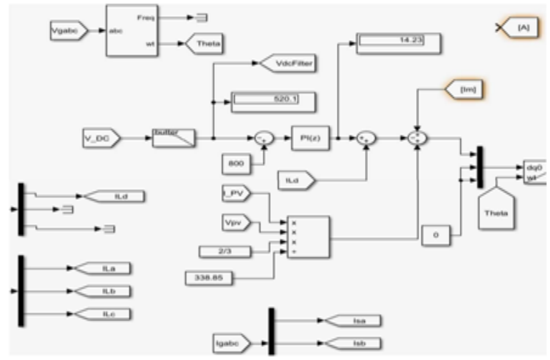

fig 5:simulation design

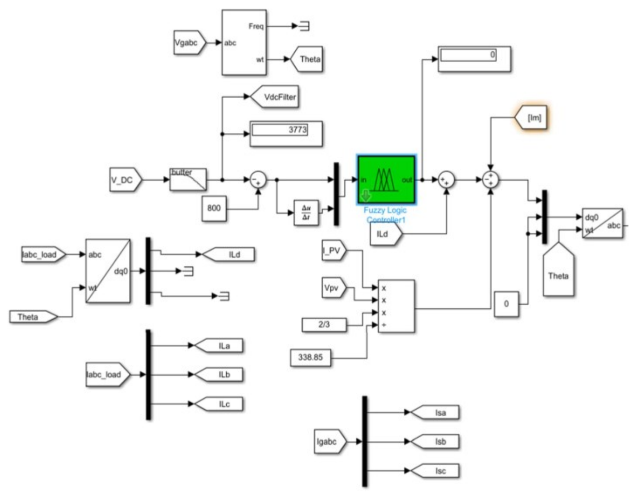

Fig 6: Fuzzy

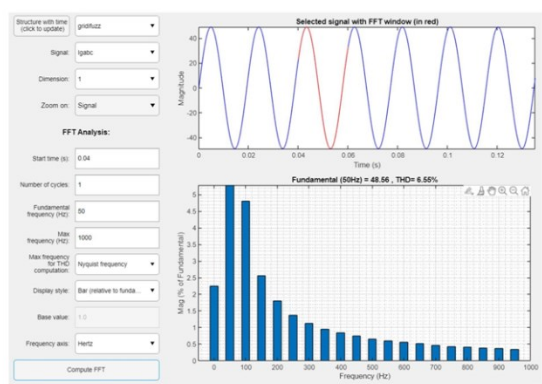

fig 7:voltage and current result.

7.CONCLUSION

This article proposes a PV-battery based multi-port power routing. Compared with the traditional PV-battery grid-connected system, the proposed MPPR in this paper has two main characteristics implemented by one auxiliary port simultaneously: first is the partial power conversion of the DC/DC stage, which significantly improves the power transfer efficiency. Secondary, MPPR realizes HVRT on the premise of maintaining normal PV output, and auxiliary port is adaptive to the grid-side voltage swell by adjusting its voltage so as to improve the voltage level of three phase converter DC bus. The system can flexibly realize the power exchange between three ports, two DC buses and the grid.

the proposed partial power conversion and high voltage ride-through scheme offers a promising solution for enhancing the performance and resilience of PV-battery-based multiport multibus power routers. By strategically managing power flow and incorporating high voltage ride-through capabilities, the scheme improves overall system efficiency, stability, and reliability, particularly during grid disturbances. This approach not only maximizes the utilization of renewable energy sources but also ensures a more robust and dependable power supply for critical loads, paving the way for wider adoption of sustainable energy solutions.

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