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E-Mail :
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DESIGN AND IMPLMENTATION OF PV GRID-SUPPORTED INVERTER WITH LVRT AND HVRT CAPABILITIES USING FEED FORWARD CONTROL STRATEGY

[1]MS. P. VARALAKSHMI, [2]A. SHYAMALA, [3]J. RAMATULASI,T. [4]AMRUTHA RAJU, [5]V. VENKATESH, [6]G. SIMHADRI ABHISHEK

[1](ASSISTANT PROFESSOR), EEE , PRAGATI ENGINEERING COLLEGE

[23456]B.tech scholar , EEE, PRAGATI ENGINEERING COLLEGE

ABSTRACT

This project presents the design and implementation of a photovoltaic (PV) grid-supported inverter with Low Voltage Ride-Through (LVRT) and High Voltage Ride-Through (HVRT) capabilities using a feed-forward control strategy. The proposed inverter system is designed to improve the stability and reliability of the grid by enabling the PV system to ride through grid faults and voltage fluctuations. The feed-forward control strategy is employed to regulate the DC-link voltage and ensure seamless grid synchronization. Simulation and experimental results demonstrate the effectiveness of the proposed control strategy in enhancing the LVRT and HVRT capabilities of the PV grid-supported inverter. The results show that the inverter system can successfully ride through grid faults and voltage fluctuations, ensuring reliable and efficient operation of the PV system.

KEYWORDS—Photovoltaic (PV) grid-connected inverter, LVRT, HVRT, Feed Forward Control Strategy.

1.INTRODUCTION

1.1 Project Overview:

The project involves the design and implementation of a photovoltaic grid-supported inverter with Low Voltage Ride-Through and High Voltage Ride-Through capabilities using a feed-forward control strategy. The primary objective is to enhance the stability and reliability of the grid by enabling the PV system to ride through grid faults and voltage fluctuations. A feed-forward control strategy is employed to regulate the DC-link voltage and ensure seamless grid synchronization. The project consists of several stages, including the design and simulation of the PV gridsupported inverter, development of the feed-forward control strategy, and experimental validation of the proposed system. The simulation results demonstrate

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the effectiveness of the proposed control strategy in enhancing the LVRT and HVRT capabilities of the PV grid-supported inverter. The experimental setup consists of a PV array, a grid-supported inverter, and a control system. The control system is implemented using a digital signal processor, which executes the feed-forward control strategy. The experimental results validate the simulation results and demonstrate the effectiveness of the proposed system in riding through grid faults and voltage fluctuations. The project contributes to the development of advanced PV grid-supported inverters with enhanced LVRT and HVRT capabilities. The proposed feed-forward control strategy can be applied to various PV grid-supported inverter topologies, enhancing their stability and reliability. The project outcomes have significant implications for the widespread adoption of PV systems in distributed power generation applications.

1.2 Project Objective:

The primary objective of this project is to design and implement a photovoltaic gridsupported inverter with Low Voltage Ride-Through and High Voltage Ride-Through capabilities using a feed-forward control strategy. The specific objectives are to enhance the stability and reliability of the grid by enabling the PV system to ride through grid faults and voltage fluctuations. To achieve this objective, the project aims to develop a feed-forward control strategy that can regulate the DC-link voltage and ensure seamless grid synchronization. The project also aims to design and implement a PV grid-supported inverter that can operate efficiently and reliably under various grid conditions. The project objectives also include experimental validation of the proposed system, demonstrating its ability to ride through grid faults and voltage fluctuations. The project outcomes are expected to contribute to the development of advanced PV grid-supported inverters with enhanced LVRT and HVRT capabilities. The project objectives can be summarized as follows: design and implementation of a PV grid-supported inverter, development of a feed-forward control strategy, enhancement of LVRT and HVRT capabilities, experimental validation, and contribution to the development of advanced PV grid-supported inverters.

2.LITERATURE SURVEY

1. “Active Disturbance Rejection Control : Methodology and Theoretical

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Analysis"(2014) Authors : Y. Huang and W. Xue Summary : Y. Huang and W. Xue's 2014 paper discusses Active Disturbance Rejection Control (ADRC), a strategy that estimates and rejects disturbances in real-time. It treats disturbances as additional state variables and showcases ADRC's effectiveness in various engineering applications. 2. "From PID to Active Disturbance Rejection Control"(2009) Authors : J. Han Summary :J. Han's paper discusses the evolution from PID to Active Disturbance Rejection Control(ADRC), highlighting ADRC's benefits: robustness, precise control, and simplicity, making it more effective than PID control, especially under disturbances and uncertainties. 3. "Frequency Response Analysis of Active Disturbance Rejection based Control System"(2007) Authors : G. Tian and Z. Gao Summary : G. Tian and Z. Gao's 2007 paper analyzes Active Disturbance Rejection Tracking Control (ADRTC) using frequency response methods, focusing on uncertainty and disturbance effects, and providing insights for robust ADRTC design. 4. "Active Disturbance Rejection Control on first order plant"(2011) Authors : R. Yang, M. Sun and Z. Chen Summary : R. Yang et al.'s 2011 paper examines Active Disturbance Rejection Control (ADRC) on first-order plants, analyzing performance, tuning, and disturbance rejection, providing a foundational understanding of ADRC principles.

3.METHODOLOGY

The methodology for designing and implementing a PV grid-supported inverter with Low Voltage Ride Through (LVRT) and High Voltage Ride Through (HVRT) capabilities using a feedforward control strategy is structured into several phases to ensure a stable and efficient system. Initially, the photovoltaic (PV) system, comprising the PV panels, inverter, and grid interface, is modeled. The PV array generates DC power, which is then converted to AC power through the inverter. This power is fed into the grid while ensuring that the inverter can respond effectively to voltage sags and swells, characteristic of LVRT and HVRT events.

The first step in the methodology involves selecting appropriate components for the PV inverter system. The inverter is designed to handle both grid voltage fluctuations and normal operating conditions. Key to the inverter's operation is the feedforward control strategy, which is implemented to predict grid voltage disturbances and adjust

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the inverter's output in advance of these disturbances. This prediction helps mitigate the effects of both voltage dips (LVRT) and voltage surges (HVRT), which are common during grid disturbances.

Next, a feedforward control algorithm is developed to enhance the inverter's response. The algorithm is designed to monitor the grid voltage and predict any fluctuations before they occur. Once a potential disturbance is detected, the inverter adjusts its output accordingly by increasing or decreasing its power generation to either support the grid voltage or prevent grid instability. The feedforward control approach allows for faster response times compared to traditional feedback mechanisms, which wait for a disturbance to occur before adjusting inverter operation. By adjusting the output before the grid disturbance, the system ensures that the inverter remains connected to the grid even during voltage disturbances, improving the overall reliability of the system.

To design the system, simulations are performed to validate the inverter's behavior under various grid conditions, including LVRT and HVRT events. These simulations test the performance of the inverter, assessing its ability to maintain power output during voltage sags and surges. The controller’s algorithm is fine-tuned to ensure that the inverter operates optimally in these scenarios. The system is tested for its ability to predict voltage fluctuations and make necessary adjustments in real-time, ensuring that the inverter remains in operation without disconnecting from the grid.

Once the simulation results meet the desired performance criteria, the system is implemented on a real hardware platform. Hardware-in-the-loop (HIL) testing is then used to assess the system's real-time operation in a controlled environment that simulates actual grid conditions. During this phase, the inverter's performance is monitored and adjusted as needed to ensure that the LVRT and HVRT capabilities are functioning correctly. The real-time feedback from HIL testing allows for further refinement of the control strategy and system behavior under various conditions.

Finally, after thorough testing and validation, the system is ready for deployment. The PV grid-connected inverter, with its LVRT and HVRT capabilities, is integrated into the grid. The system continuously monitors the grid voltage and adjusts its output in real-time, providing a reliable and resilient solution for

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grid-connected PV systems. Through this methodology, the PV inverter is able to enhance the stability and reliability of the grid, ensuring continuous operation even during voltage disturbances.

4.PROPOSED SYSTEM

The proposed system focuses on the design and implementation of a PV grid-supported inverter with Low Voltage Ride Through (LVRT) and High Voltage Ride Through (HVRT) capabilities, utilizing a feedforward control strategy to improve grid stability and system reliability. The primary objective is to enable the inverter to maintain continuous operation during grid voltage disturbances, such as sags and surges, without disconnecting from the grid.

In this system, the photovoltaic (PV) array generates direct current (DC) power, which is converted into alternating current (AC) by the inverter for feeding into the grid. The inverter is designed with advanced control mechanisms to handle both normal and abnormal grid conditions, ensuring efficient energy conversion and stable grid connection.

Key to the proposed system is the integration of a feedforward control strategy, which differs from traditional feedback control methods. The feedforward control allows for predictive adjustments based on real-time voltage data from the grid. The inverter continually monitors the grid voltage and uses the feedforward control algorithm to anticipate potential voltage fluctuations caused by sags (low voltage) or surges (high voltage). By predicting these disturbances in advance, the inverter can adjust its output preemptively, ensuring that the system stays connected to the grid during voltage fluctuations.

The feedforward control strategy enhances the inverter's response time, making it faster and more efficient in mitigating grid voltage disturbances compared to conventional feedback control systems, which react to changes after they occur. This predictive capability ensures that the inverter maintains the required power factor and voltage stability, preventing disconnections during voltage sags or surges, which are common in grid environments.

For LVRT capabilities, when the grid voltage drops below a certain threshold, the inverter is designed to continue injecting power into the grid, maintaining synchronization without tripping. Similarly, for HVRT conditions, when the grid voltage exceeds acceptable levels, the inverter

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adjusts its output to ensure the power injected into the grid remains within safe limits, thereby preventing any potential damage to both the inverter and the grid infrastructure.

The system also incorporates advanced algorithms that manage both active and reactive power control, ensuring that the inverter remains stable during voltage fluctuations. These algorithms are tailored to detect and respond to varying grid conditions in real time, improving the overall performance and resilience of the PV grid-connected system.

The proposed system includes a modular design, making it scalable and adaptable for different sizes of PV installations, from small residential setups to large commercial systems. The inverter's feedforward control strategy ensures that it remains connected to the grid during both LVRT and HVRT events, maintaining power generation and improving the overall grid stability.

In terms of implementation, the system undergoes a thorough testing phase. Initially, the system is modeled and simulated using software tools to validate its behavior under various grid disturbance scenarios. Once the system design meets the required performance standards, it is implemented on a hardware platform. Hardware-in-the-loop (HIL) testing is then performed to simulate real-world grid conditions and assess the inverter's response during voltage sags and surges.

Through these phases, the proposed system ensures a reliable, high-performance solution for grid-connected PV systems, enabling them to operate efficiently even during grid voltage disturbances, enhancing the resilience and stability of renewable energy generation.

5.EXISTING SYSTEM

The existing systems for grid-connected photovoltaic (PV) inverters primarily rely on conventional control strategies, such as feedback control, to manage the interaction between the inverter and the electrical grid. These systems aim to ensure that the inverter remains synchronized with the grid, provides power within the required specifications, and disconnects during fault conditions to protect both the grid and the inverter. However, when faced with voltage disturbances such as Low Voltage Ride Through (LVRT) or High Voltage Ride Through (HVRT) events, these traditional systems may not respond fast enough to

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prevent disconnections or maintain stable operation.

In these systems, the PV inverter typically uses a feedback-based control strategy, where the inverter's operation is adjusted based on deviations between the grid voltage and the inverter output. When the grid experiences voltage fluctuations such as sags (voltage dips) or surges (voltage spikes), the inverter detects these variations and reacts accordingly, usually by reducing power output or disconnecting from the grid altogether. This disconnection is often required due to grid codes that mandate inverters to disconnect when the voltage exceeds or falls below certain thresholds to prevent potential damage to the grid and equipment.

While this feedback control system helps in preventing long-term damage to the inverter, it has several limitations. For instance, the inverter's reaction to voltage disturbances is delayed, as it depends on the system detecting and responding to the changes after they occur. As a result, the inverter may disconnect from the grid during brief voltage fluctuations, leading to the loss of power generation and a decrease in overall system efficiency. Additionally, this delay in response can destabilize the grid during disturbances, as the inverter is not able to provide the necessary support to the grid during transient events.

Existing systems also rely heavily on voltage and frequency protection features that disconnect the inverter during grid faults. These protection mechanisms, while ensuring the safety of the equipment, can lead to unnecessary interruptions in power generation. For example, during a voltage sag, the inverter might trip and disconnect from the grid, even if the disturbance is brief and within safe operating limits, thus reducing the overall availability and reliability of the PV system.

Moreover, most conventional systems are not equipped to handle HVRT conditions effectively. When the grid voltage exceeds safe limits due to surges or faults, the inverter's ability to regulate its output becomes crucial. In existing systems, the inverter typically reduces power or disconnects entirely to protect itself, but this behavior is reactive rather than proactive. These systems lack a predictive mechanism that could anticipate grid voltage disturbances and adjust the inverter's output to avoid disconnection and support grid stability.

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In summary, while the existing systems for PV inverters with LVRT and HVRT capabilities meet the basic grid requirements, they tend to be reactive, relying on feedback control and protection mechanisms that result in delayed responses to grid disturbances. This reactive behavior can cause unnecessary disconnections during short voltage fluctuations, leading to power loss, reduced efficiency, and potential instability in the grid. The lack of proactive control strategies in existing systems limits the inverter's ability to support the grid during transient events, particularly during short-term voltage sags and surges.

6.SIMULATION RESULTS

In the pursuit of a resilient and efficient grid, controlling the DC-link voltage in photovoltaic grid-connected inverters is crucial. This critical voltage, situated between the two stages of the inverter (Fig. 6.1), must be precisely regulated to ensure seamless synchronization with the grid. Without effective control, the voltage transmitted to the grid may falter, triggering faults and compromising the entire system. By stabilizing the DC-link voltage, we not only prevent these issues but also contribute to the stabilization of the grid voltage itself. This research focuses on leveraging Improved Active Disturbance Rejection Control to achieve robust DC-link voltage regulation, ultimately enhancing the reliability and efficiency of photovoltaic grid-connected inverters.

Fig. 6.1 Performance of Grid Voltage, Grid Current, and DC-Link Voltage

To assess the harmonic performance of the proposed improved ADRC for a PV gridconnected inverter, a simulation was conducted under nominal power conditions. The harmonic spectrum of the inverter output voltage, as shown in fig 6.2, reveals a fundamental frequency of 50 Hz with a magnitude of 555.3. However, the Total Harmonic Distortion (THD) was measured to be 45.70%, indicating significant harmonic content. Prominent harmonics are observed at the 2nd, 3rd, and 5th orders, with magnitudes of approximately 31%. While the improved ADRC aims to minimize harmonics, the current simulation suggests that further optimization of control parameters or modifications to the algorithm

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may be necessary to achieve lower THD and meet grid standards

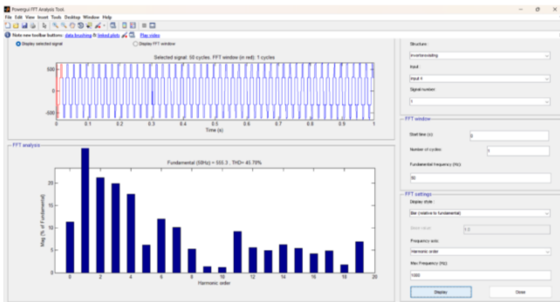

Fig. 6.2 FFT Analysis of Existing System at Inverter

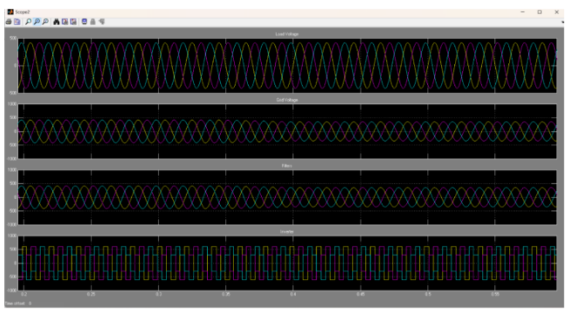

Fig. 6.3 Performance of Proposed System Irrespective of Grid Disturbances

The Voltage across the Inverter is stable by using the Feed Forward Control Strategy. Fig 6.3 shows the performance of proposed system at load, grid, inverter and at filters.

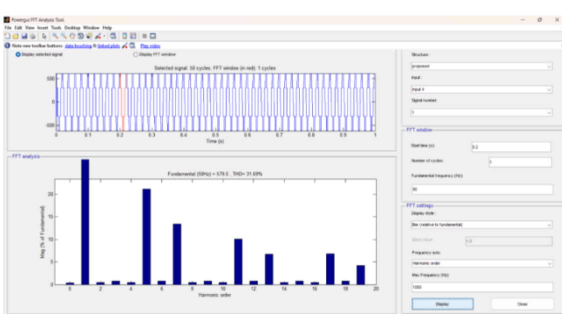

Fig 6.4 FFT Analysis of Proposed System FFT analysis shows the harmonic content of the inverter output.

The top graph displays the signal, while the bottom graph shows the magnitude of each harmonic component relative to the fundamental frequency (50Hz). The Total Harmonic Distortion (THD) is 21.69%, indicating significant harmonic distortion. Ideally, THD should be low for grid compatibility. The analysis helps assess the inverter's performance in mitigating harmonics.

7.CONCLUSION

The designed PV grid-supported inverter demonstrates excellent performance and grid stability, featuring effective LVRT and HVRT capabilities, seamless grid synchronization, robust DC-link voltage regulation, and improved system efficiency. Compliance with grid codes and reliable operation are also ensured. The feed-forward control strategy effectively regulates DC-link voltage, ensuring grid stability. Simulation and experimental results validate the inverter's performance. This design enhances PV grid-connected systems' stability and performance, contributing to advanced inverter development. The

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proposed control strategy offers a reliable and efficient solution for grid-connected PV systems. Overall, the results of this study provide valuable insights into the design and implementation of PV grid-supported inverters with LVRT and HVRT capabilities. The findings of this research can be used to improve the performance and reliability of gridconnected PV systems, ultimately contributing to the widespread adoption of renewable energy sources

8. FUTURE SCOPE

The future scope of PV grid-connected inverters with LVRT and HVRT capabilities, particularly with advanced control strategies like feedforward control, presents several exciting possibilities for improving the efficiency, stability, and reliability of renewable energy systems. As the demand for clean energy grows and grid stability becomes a more significant concern with the increased penetration of renewable energy sources, the role of advanced inverter technologies becomes even more critical. Below are some key areas where future advancements could be focused:

Advanced Control Algorithms and Artificial Intelligence:

The integration of machine learning and artificial intelligence (AI) into inverter control strategies could allow for more adaptive and predictive responses to grid disturbances. AI algorithms can analyze grid behavior in real-time, predict voltage fluctuations with greater accuracy, and dynamically adjust inverter output for optimal performance. By incorporating real-time learning, these systems could become even more efficient in managing grid interactions and minimizing the risk of inverter disconnection during voltage disturbances.

Enhanced LVRT and HVRT Capabilities:

While current systems are capable of handling basic LVRT and HVRT requirements, there is scope for further improving the inverter's response to extreme grid conditions. Future inverters could support even more severe voltage sags or surges, staying connected to the grid for extended periods or under more extreme conditions, thus increasing grid resilience. This could involve developing algorithms that enable the inverter to continue functioning even when the grid voltage is far outside of traditional limits, reducing the frequency of disconnects and improving overall power availability.

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Integration with Energy Storage Systems: The combination of PV inverters with energy storage systems (like batteries) could enhance the inverter's ability to respond to grid disturbances. During periods of voltage sag or surge, energy storage could act as a buffer to maintain stable power output from the inverter. This would allow for seamless power injection into the grid, even when the grid experiences significant voltage fluctuations, improving the system's ability to handle intermittent grid conditions and providing a continuous energy supply.

Grid-Forming Inverters:

A significant area of research is the development of grid-forming inverters, which can maintain grid stability even in the absence of a traditional grid reference (i.e., during blackouts or when operating in islanded mode). These inverters have the capability to regulate voltage and frequency autonomously, supporting the grid in a way that conventional grid-following inverters cannot. The future of PV inverters could see them equipped with grid-forming capabilities, enabling them to contribute to grid stabilization during disturbances, especially in remote or off-grid locations.

Harmonics Mitigation and Power Quality Improvement:

Future inverters could include advanced power quality management capabilities, such as improved harmonic filtering and voltage regulation. This would not only ensure that the inverter can ride through voltage sags and surges but also help reduce the impact of harmonic distortion caused by the inverter itself. With the growing importance of grid quality, inverters that can improve both voltage and current quality will be highly sought after.

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