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Multimode Inverter Control Strategy for LVRT Capability Enhancement In Grid Connected Solar PV System

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Abstract

The multimode inverter control strategy for enhancing low-voltage ride-through (LVRT) capability in grid-connected solar PV systems. The strategy aims to address the challenges associated with grid disturbances and ensure stable operation of the PV system. The proposed approach includes multiple operating modes for the inverter, allowing seamless transition between grid-connected and standalone modes during grid faults. The control strategy incorporates a dynamic voltage regulation scheme to maintain voltage stability and prevent system instability during LVRT events. Additionally, advanced control techniques, such as proportional-integral resonant (PIR) control and hysteresis control, are employed to achieve precise current and voltage regulation. The proposed strategy offers improved fault ride-through capability and grid synchronization performance, enabling uninterrupted power supply and minimizing the impact of grid disturbances on the PV system. Through simulation studies and experimental validation, the effectiveness and feasibility of the proposed control strategy will be evaluated. The outcomes of this project can contribute to the reliable integration of solar PV systems with the grid, promoting renewable energy utilization and grid stability.

***Keywords:* Active and reactive power control, Low-voltage ride-through (LVRT), Fault ride-through (FRT), Grid disturbances, Stable operation, Multiple operating modes, Seamless transition, Dynamic voltage regulation, Proportional-integral resonant (PIR) control, Hysteresis control, Improved fault ride-through capability, Grid synchronization performance, Uninterrupted power supply, Grid integration, Renewable energy utilization, Grid stability.**

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I. INTRODUCTION

The multimode inverter control strategy aims to enhance the low-voltage ride-through (LVRT) capability of grid-connected solar PV systems. By incorporating multiple operating modes and a dynamic voltage regulation scheme, the strategy enables seamless transition between grid-connected and standalone modes during grid faults, ensuring stable operation of the PV system. Advanced control techniques, such as PIR control and hysteresis control, are employed to achieve precise current and voltage regulation, maintaining optimal power generation and grid synchronization performance. The proposed strategy offers improved fault ride-through capability, minimizing the impact of grid disturbances and ensuring uninterrupted power supply. Through extensive simulation studies and experimental validation, the effectiveness and feasibility of this control strategy will be evaluated, contributing to the reliable integration of solar PV systems with the grid and promoting renewable energy utilization while maintaining grid stability.

II. LITERATURE SURVEY

2.1 Review on the MPPT Techniques and LVRT Requirements for Different Grid Codes Concerning PV System Integrated to Electric Power Network

Low voltage ride through capabilities is one among many of the unexplored challenges in integrating photovoltaic (PV) systems into the power grid. This paper presents a comprehensive review for several control techniques to assure the LVRT capability of grid feeding converters. Along with that, various methods of MPPT techniques used in PV system and LVRT requirements for Grid connected PV system is presented. LVRT is an essential attribute of PV inverters that allows them to remain connected with the grid during short-term disturbances in the grid voltage.

2.2 Fault Ride Through for Solar Photovoltaic and Wind-Turbine Integrated Distribution Network: A Systematic Review

The purpose of this paper is to provide a systemic review on fault ride through (FRT) capabilities. As there are multiple types of power system faults, where each type has different effect on the power quality, faults types along with their effects on the power quality are firstly highlighted for better understanding of the FRT capabilities. The FRT techniques along with its types are then introduced. Furthermore, the most common renewable energy sources where FRT techniques are implemented are discussed. Recent Improvement methods for FRT are highlighted and summarized. The protection devices used to detect and isolate faults are lastly introduced, where the paper is then concluded.

2.3 Improving performance of LVRT capability in single-phase grid-tied PV inverters by a model-predictive controller

New interconnection standards for Photovoltaic systems are going to be mandatory in some countries. Such that the next generation of PV should support a full range of operation mode like in a power plant and also support Low-Voltage Ride-Through capability during voltage sag fault. Since the voltage sag period is short, a fast dynamic performance along with a soft behavior of the controller is the most important issue in the LVRT duration. Recently, some methods like Proportional Resonant controllers, have been presented to control the single-phase PV systems in LVRT mode. However, these methods have had uncertainties in respect their contribution in LVRT mode. In PR controllers, a fast dynamic response can be obtained by tuning the gains of PR controllers for a high bandwidth, but typically the phase margin is decreased. Therefore, the design of PR controllers needs a tradeoff between dynamic response and stability. To fill in this gap, this paper presents a fast and robust current controller based on a Model-Predictive Control for single-phase PV inverters in other to deal with the LVRT operation. In order to confirm the effectiveness of the proposed controller, results of the proposed controller are compared with the classical PR controller. They are also implemented in a 1 kW single-phase transformer less Highly Efficient and Reliable Inverter Concept inverter.

2.4 New Trends in the Control of Grid-Connected Photo voltaic Systems for the Provision of Ancillary Services

The gradual displacement of conventional generation from the energy mix to give way to renewable energy sources represents a paradigm shift in the operation of future power systems: on the one hand, renewable technologies are, in general, volatile and difficult to predict; and on the other hand, they are usually connected to the grid through electronic power converters. This decoupling due to power converters means that renewable generators lack the natural response that conventional generation has to the imbalances between demand and generation that occur during the regular operation of power systems. Renewable generators must, therefore, provide a series of complementary services for the correct operation of power systems in addition to producing the necessary amount of energy. This paper presents an overview of existing methods in the literature that allow photovoltaic generators to participate in the provision of ancillary services, focusing on solutions based on power curtailment by modifying the traditional maximum power point tracking algorithm.

2.5 Classification and Detection of Faults in Grid Connected Photovoltaic System

An integration of distributed generations (DGs) to the utility grid has raised the need for good power quality, safety operation and islanding protection of the grid interconnection. This paper presents the classification and detection of faults in a distributed generation, particularly photovoltaic (PV) grid-connected system. The initial step in fault detection of PV system is recognition, investigation and classification of all possible faults that maybe occur in the system. The classification, simulation and discussion of all possible faults in both AC and DC side of PV system are presented, where 100 kW array connected to a 25 kV grid via a DC-DC boost converter and a three phase three-level Voltage Source Converter (VSC).

2.6 Control of Transformer less Inverter-Based Two-Stage Grid-Connected Photovoltaic System Using Adaptive-PI and Adaptive Sliding Mode Controllers

To enhance the move towards a sustainable society, the solar Photovoltaic (PV) industry and its applications are progressing at a rapid rate. However, the associated issues need to be addressed when connecting PV to the grid. Advanced and efficient controllers are required for the DC link to control the second harmonic ripple and current controllers to inject quality active and reactive power to the grid in the grid-connected PV system. In this paper, DC-link voltage, active power, and reactive power are successfully controlled in stationary reference using Adaptive-PI (A-PI) and Adaptive-Sliding Mode Controller (A-SMC) for a 3-kW single-phase two-stage transformer less grid-connected inverter. A Resonant Harmonic Compensator (RHC)-based Proportional Resonant (PR) controller is employed in the current-controlled loop. The magnitude, phase, and frequency information of the grid voltage are provided by Second-Order General Integral (SOGI)-

based PLL that has harmonic immunity, fast-tracking accuracy, and a rapid-dynamic response. MATLAB®/Simulink®/Simscape R2017b were used for the test bench implementation. Two scenarios were considered: in the first case, the input PV power feedforward loop was avoided, while in second case, it was included. The feedforward loop of input PV power improved the overall system dynamics. The results show that the designed controller improves both the steady-state and dynamic performance as compared with a proper-regulated PI-controller. The proposed controllers are insensitive to active and reactive power variations, and are robust, stable, faster, and fault tolerant, as compared to controllers from prior studies.

III. WORKING PRINCIPLE OF THE PROPOSED SYSTEM

3.1 Block Diagram of the proposed system

- PV Array: The solar photovoltaic array captures sunlight and converts it into electrical energy.
- Inverter: The inverter is the key component responsible for converting the direct current (DC) generated by the PV array into alternating current (AC) suitable for grid connection. In this project, the inverter is equipped with advanced control capabilities.
- Grid: The electrical grid represents the utility's power distribution system to which the solar PV system is connected.
- Control Canter: The control centre encompasses the various control strategies and algorithms, which are integral to this project. It manages the operation of the inverter and ensures that it operates in different modes for grid support and power quality control.
- Energy Storage: Energy storage systems (ESS) are included to store excess energy generated by the PV array. These systems can discharge stored energy during grid disturbances, further enhancing grid stability.

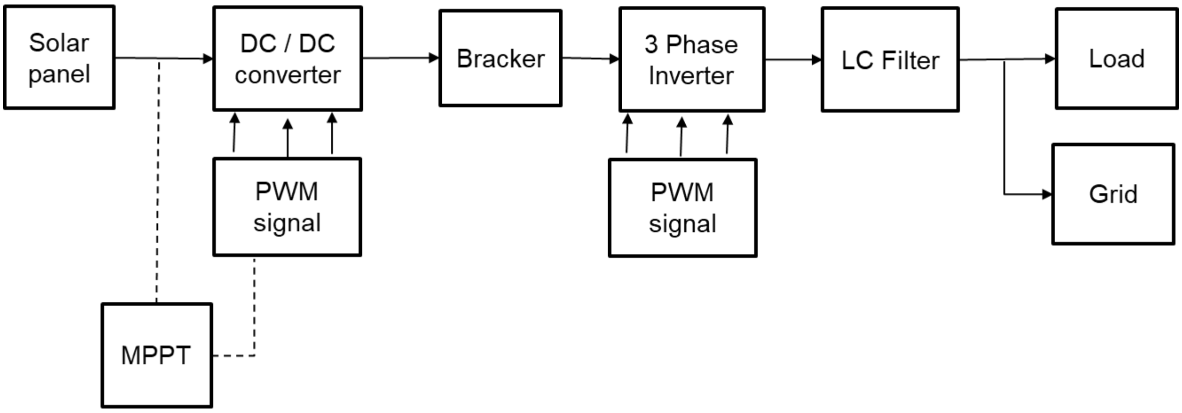

Figure 1: Block diagram of the proposed system

3.2 Hardware Components of the Proposed System

The following list represents the proposed system's key hardware components. 1)Solar Panel, 2) SEPIC Converter, 3) MOSFET, 4) Capacitor, 5) Resistor, 6) Voltage Regulator (7850), 7) Transformer, 8) Gate Drive IC - FAN7392, 9) SEPIC Gate Drive IC - Opto-coupler, 10) Gate Driver, 11) Microcontroller, 12) Crystal Oscillator, 13) LED, 14) Diode

Components Used:

Table 1: Components Used

COMPONENTS	QUANTITY	OPERATING VALUE
Solar panel	1	10W
MOSFET	7	n-type,12V
Capacitor	Required	-
Inductor	Required	-
Resistor	Required	-
Voltage regulator 7850	1	12V-5V
Transformer	2	230V/12V
Gate drive ic-FAN7392	3	12V
SEBIC gate device IC -opto coupler	1	12V
Microcontroller-PIC16F877A	1	5V
Crystal oscillator	1	-

Led	Required	-
Diode	Required	-

Solar Panel: Solar panels are the primary energy source in the system. They convert sunlight into electrical energy using photovoltaic cells. Their output voltage and current are crucial parameters for the inverter.

SEPIC Converter: A SEPIC (Single-Ended Primary Inductor Converter) is used to efficiently manage the power generated by the solar panels. It allows for voltage step-up or step-down, optimizing power transfer to the inverter.

MOSFET (Metal-Oxide-Semiconductor Field-Effect Transistor): MOSFETs are electronic switches used in the inverter circuit to control the flow of electrical current. They play a key role in converting DC power from the solar panels to AC power for the grid.

Capacitor: Capacitors store and release electrical energy as needed, helping to stabilize voltage and current in the inverter circuit.

Inductor: Inductors are used to filter and smooth the current in the circuit, reducing harmonics and ensuring the quality of the power output.

Resistor: Resistors are used for various purposes, such as voltage division and current limiting, to control the behavior of the circuit.

Voltage Regulator (7850): Voltage regulators maintain a stable output voltage, which is important for ensuring the quality of the power delivered to the grid.

Transformer: Transformers are used to step up or step down the voltage as necessary before feeding power into the grid.

Gate Drive IC - FAN7392: This IC provides the necessary drive signals to control the MOSFETs efficiently, ensuring smooth switching and optimal power conversion.

SEPIC Gate Drive IC - Opto-coupler: Opto-couplers are used for electrical isolation and signal transmission between the control circuitry and the power circuit, enhancing safety and reliability.

Gate Driver: The gate driver is essential for controlling the MOSFETs by providing the right signals and ensuring proper switching.

Microcontroller - PIC16F877a: The microcontroller is the brain of the system, responsible for executing the control strategy for the inverter. It processes data from sensors and issues commands to regulate the inverter's operation.

Crystal Oscillator: The crystal oscillator generates a precise clock signal for the microcontroller, ensuring accurate timing for control functions.

LED: LEDs can be used for status indicators, helping with system monitoring and diagnostics.

Diode: Diodes are used for various purposes, such as blocking reverse current and protecting components from damage.

IV. EXPERIMENTAL RESULT AND ANALYSIS

4.1 Simulation Diagram

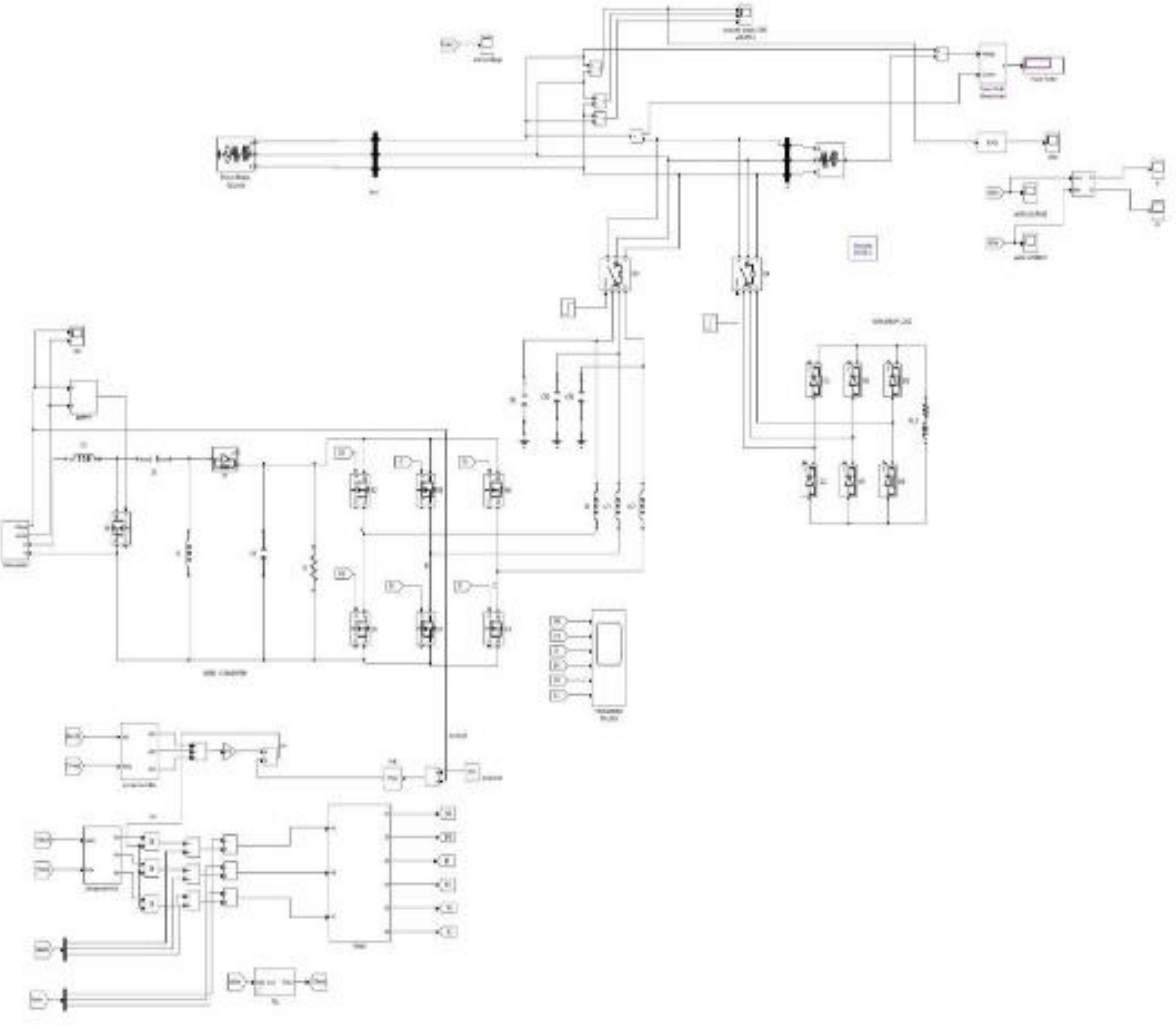

Figure 2: Simulation Diagram

4.2 Simulation Result

SOLAR PANEL OUTPUT VOLTAGE & CURRENT

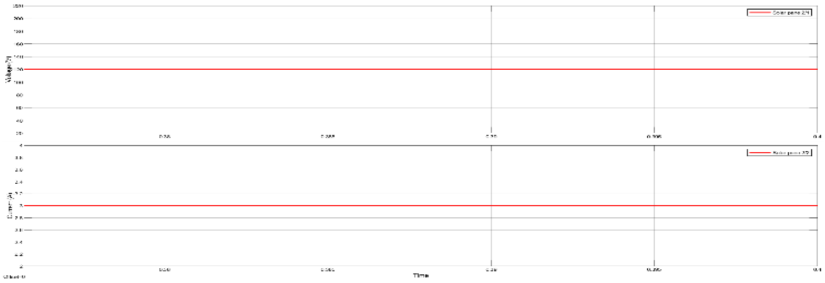

Figure 3: Solar Panel Output Voltage & Current

TRIGGERING PULSES

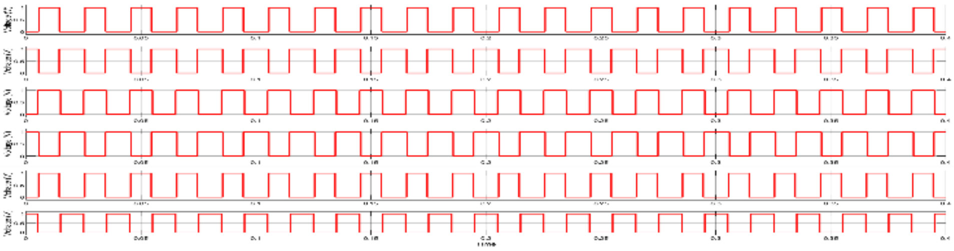

Figure 3: Triggering Pulses

LOAD VOLTAGE

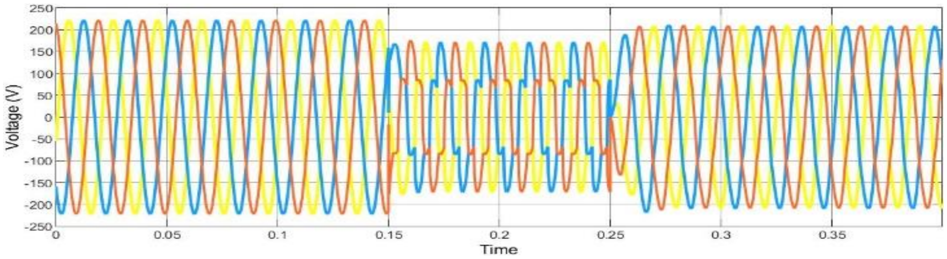

Figure 3: Load Voltage

LOAD CURRENT

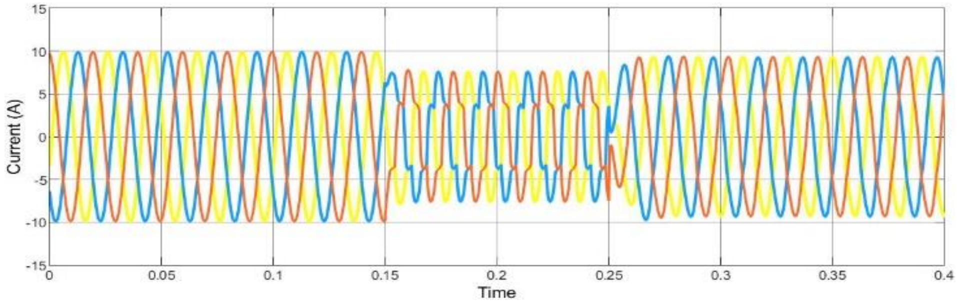

Figure 3: Load Current

PHASE TO PHASE LOAD VOLTAGE

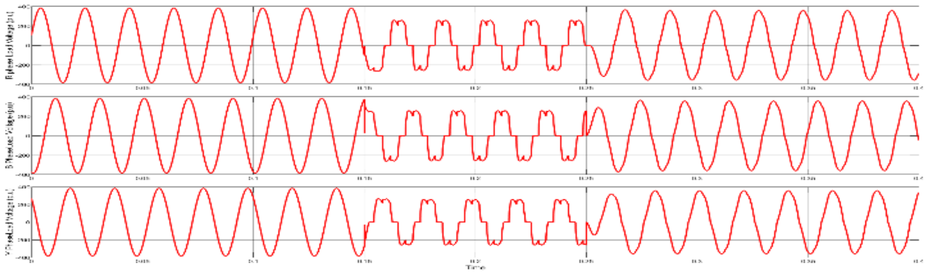

Figure 3: Phase To Phase Load Voltage

SAG

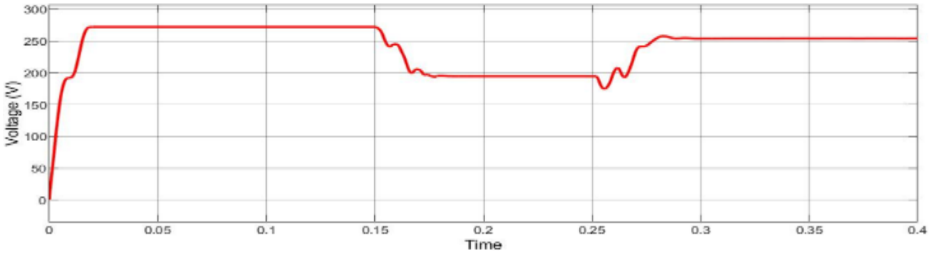

Figure 3: Sag

REACTIVE POWER(Q)

Figure 3: Reactive Power(Q)

REAL POWER(P)

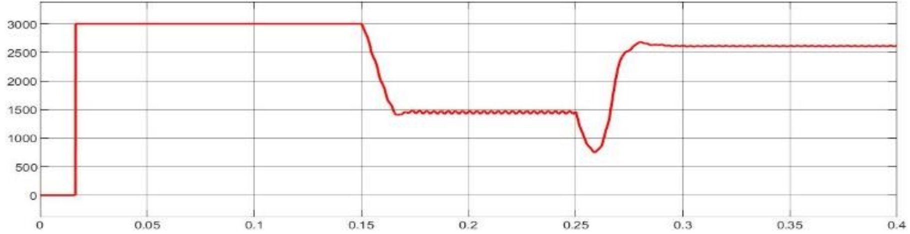

Figure 3: Real Power(P)

4.3 HARDWARE

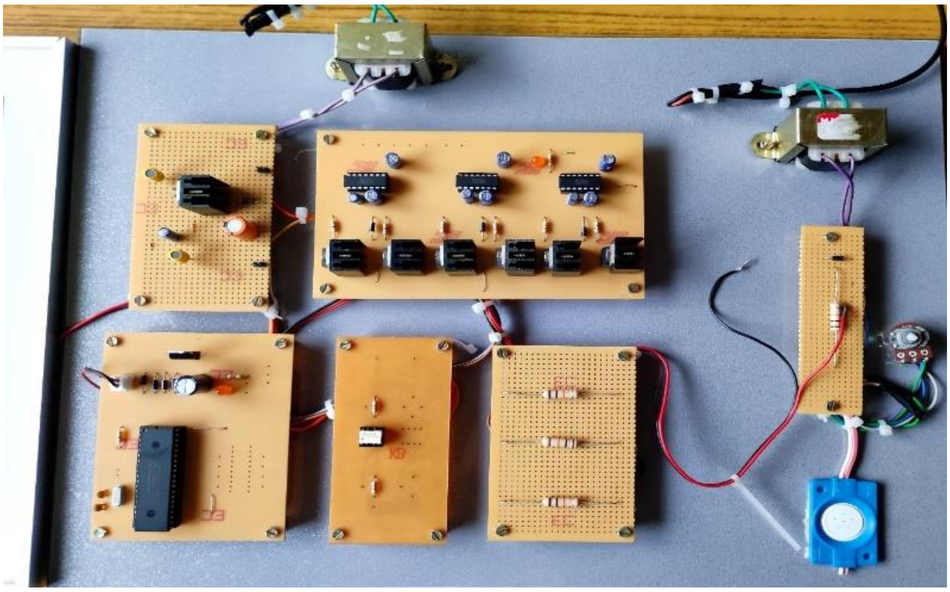

Figure 3: Hardware

HARDWARE RESULT

SOLAR OUTPUT

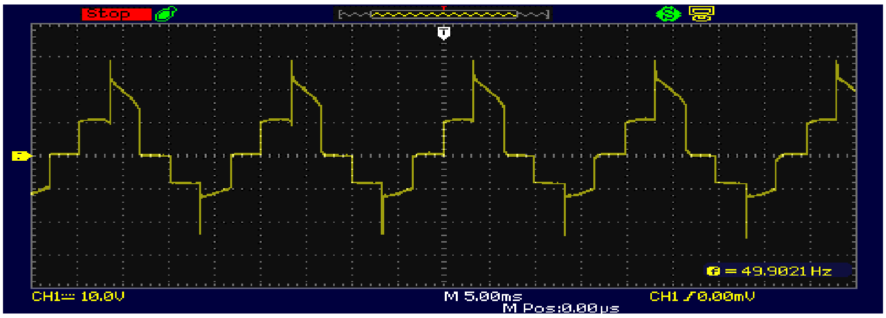

Figure 3: Solar Output

SOURCE TO DRAIN

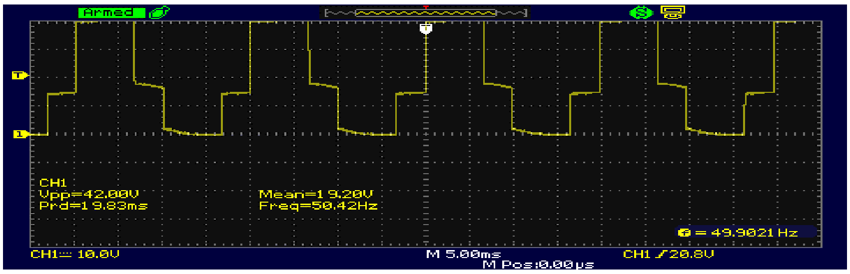

Figure 3: Source To Drain

SINGLE PHASE

Figure 3: Single Phase

TRIGGER PULSE

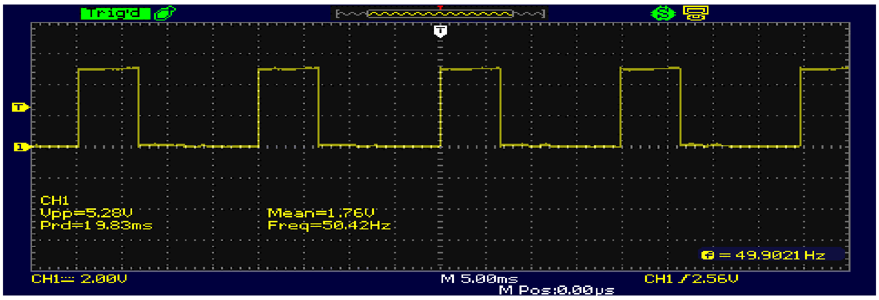

Figure 3: Trigger Pulse

3 PHASE SUPPLY

Figure 3: 3 Phase Supply

GRID

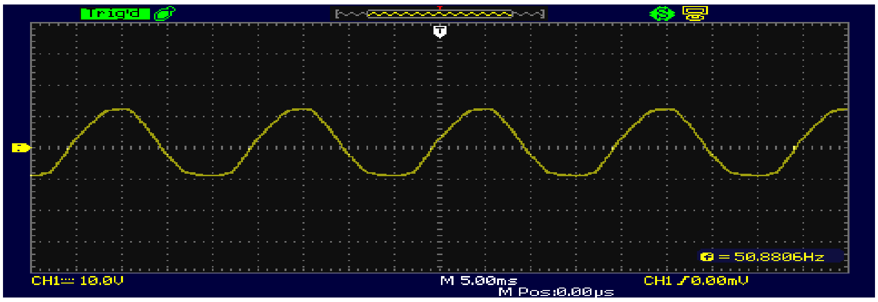

Figure 3: Grid

INJECTION OUTPUT (AFTER ERROR CORRECTION)

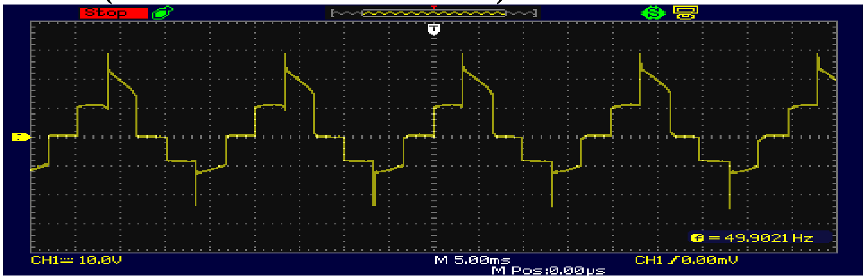

Figure 3: Injection Output (After Error Correction)

BEFORE INJECTION (LOAD SIDE)

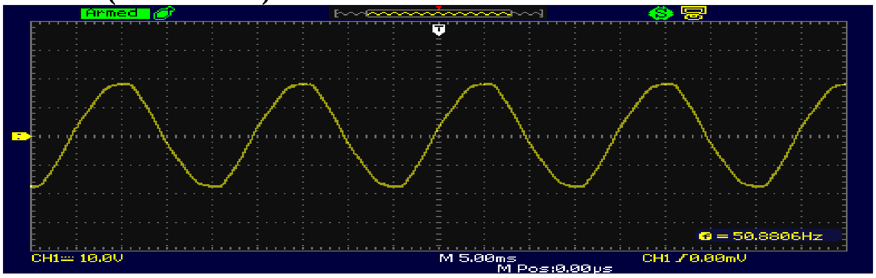

Figure 3: Before Injection (Load Side)

V. Conclusion

The paper highlights the importance of LVRT capability in grid-connected solar PV systems, as it ensures the stability and reliability of the grid during voltage fluctuations. The proposed control strategy utilizes the multimode operation of the inverter to enhance the system's LVRT capability. The research paper provides a detailed analysis of the experimental results, including the performance of the system under different operating conditions and voltage disturbances. The analysis helps in understanding the effectiveness of the control strategy and its impact on the system's LVRT capability.

VI. Future Improvements

Future improvements can contribute to the ongoing enhancement of the multimode inverter control strategy for LVRT capability in grid-connected solar PV systems. By addressing various aspects such as energy storage integration, advanced control algorithms, fault detection, hardware improvements, real-time monitoring, and system-level optimization, the LVRT capability can be further enhanced, ensuring the stability and reliability of the grid during voltage fluctuations or disturbances.

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