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Control of Three Phase PV Inverter Fed through Flyback Converter

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ABSTRACT: As this refers a comprehensive control scheme for a three-phase inverter fed isolated DC-DC converter system integrated with a photovoltaic (PV) module. In the characteristics of PV module structure, Peturb and Observe (P&O) MPPT algorithm is employed to optimize the maximum power tracking efficiency of power conversion using DC-DC converter through three-phase inverter that having wide range of advantages of in high voltage and power generation applications. This implements a grid-connected three-phase inverter with the power flow capabilities. The inverter is an effective power electronic interface for renewable energy systems. The voltage and current controllers are designed with consideration for the dq reference frame. The system incorporates a PV array, DC-DC converter, phase-locked loop (PLL) technique, unipolar switching in the inverter stage and a LCL filter which includes Voltage Source Converter (VSC) are aimed at control of voltages and currents during grid integration. By the controllers, aligning and synchronizing the grid electrical parameters with output parameters, this control strategy ensures seamless power transfer while minimizing grid disturbances and harmonics by improving the efficiency of the grid.

KEYWORDS: DC-DC converter, Flyback converter, maximum power point tracking, three phase inverter, grid connected inverter, phase locked loop (PLL), LCL filter, unipolar voltage switching.

I. INTRODUCTION

The continuous consumption of fossil fuels has caused the fossil fuel deposit to be reduced and has adversely affected the environment depleting the biosphere and cumulatively adding to global warming. With the non-renewable sources becoming increasingly deficient, solar power provides a likely replacement for the non-renewable resources. Due to the energy shortage, the integration of renewable energy sources to the electricity grid becomes a interested topic nowadays. The number of renewable energy sources and distributed generators are increasing very fast which also brings some threats to the power grid. In order to maintain or even to improve the power supply reliability and quality of the power system with distributed generation, it is necessary to have some new strategies for the operation and management of the electricity grid. Modern power electronic technology is an important part in distributed generation and the integration of the renewable energy to the power grid. It is widely used in the grid-based system.

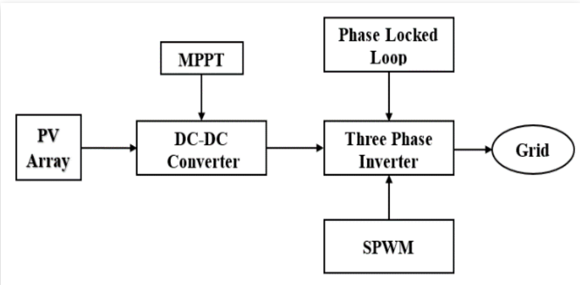

Figure 1: Block Diagram

PV module generates energy and provide DC current. This power injection to the grid is performed through DC-AC inverters. Solar PV cells have nonlinear characteristics. Its efficiency is very low and the DC power output varies with solar irradiation and ambient temperature. The power output of the solar PV module in terms of MPPT produces maximum power. The I–V (current–voltage) and P-V (Power-Voltage) characteristics of photovoltaic module is non-linear and it indicates that there exist only one point where the module delivers maximum power with increased efficiency. The energy from the PV array is transferred to the grid through a power electronic converter. The inverter allows the control of amplitude, frequency and phase of the generated voltage.

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Grid-connected inverters are designed according to the norm of power quality and grid synchronization. One of the well-known techniques is the SPWM, which enables a constant switching frequency, being less complex for the design of the output filters. One of the basic requirements for grid-connected inverters is the synchronization of the injected current with the grid voltage, which is performed by the Phase-Locked Loop (PLL) algorithm, since it is possible to obtain the phase angle information. This information is also used for voltage and current transformation in the dq reference frame. This paper is focused on the implementation of a grid-connected three-phase inverter system or a Voltage

Source Converter (VSC). Finally, this paper is focused on the implementation of a PV array, DC-DC converter, phase-locked loop (PLL) technique, unipolar switching in the inverter stage and a LCL filter are intended for control of voltages and currents during grid integration a grid-connected three-phase inverter system with the design of the control system in d-q reference frame as shown in the block diagram.

II. SYSTEM MODELLING

A. PV CELL

The modelling of solar photovoltaic (PV) cell can be done as both current and voltage source, hence the series as well as parallel both combinations are possible in solar cell, but the solar cell characteristic is more similar to current source. The current-voltage and power-voltage characteristic of a solar cell is shown in figure 2. From the above figure it can be clearly seen that there is only a single point in the P-V curve, from where we can get maximum power. Hence, for obtaining maximum power from the cell, the operating voltage and current should be corresponding to the maximum power point.

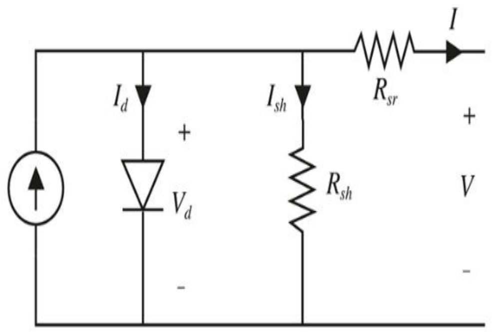

Figure 2: PV Cell

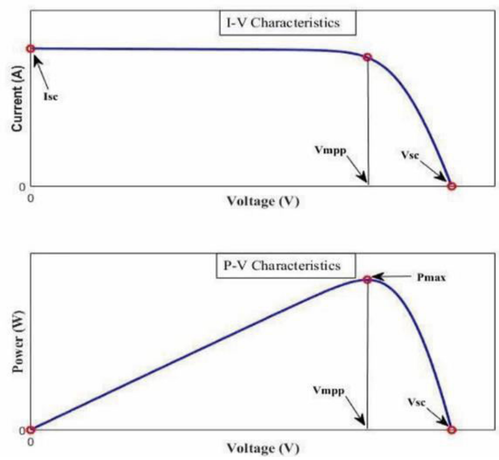

Figure 3: I-V and P-V characteristics of solar cell

B. FLYBACK CONVERTER

The Flyback converter is an isolated DC-DC switching converter [2]. The Flyback converter topology is shown in Fig.4. When the switch S is turned on by the pulse of PWM, there is no transfer of energy to load but it stores in primary winding. So, the current flows through the primary winding. When switch is turned off, energy stored in the transformer in the form of magnetic field provides an induced voltage and energy transferred to load. The input voltage [3] and voltage across the inductor are in series and collectively charge the output capacitor (C_{out}) to a voltage higher than input voltage.

C. THREE PHASE INVERTER

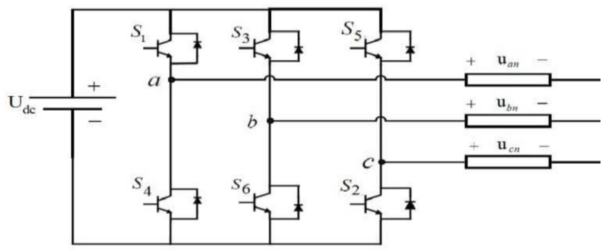

Figure 4: Three Phase Inverter

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| Volume 11, Issue 2, March 2024 |

Three phase inverter converts dc source into three phase ac output. This conversion is achieved through a power semiconductor switching topology. In this topology, gate signals are applied at 60-degree intervals to the power switches, creating the required 3-phase AC signal. The fundamental principle behind its operation involves the use of three individual inverter switches, with each switch is dedicated to one of the three output phases. To generate a balanced and synchronized ac output waveform, these switches are precisely controlled by using PWM technique of Unipolar voltage switching.
Each switch operates at specific intervals, ensuring that only one switch is active at every 60-degrees of the basic output waveform. In essence, a 3-phase inverter is a crucial component for efficiently converting DC power into three-phase.

III. CONTROL STRATEGY

A. VOLTAGE AND CURRENT CONTROL THROUGH STATIONARY AND ROTATORY FRAMES

The control system in the dq reference frame reduces the number of plants to be controlled from three to two, in comparison with the abc frame, allowing to control the active (P) and reactive (Q) power flow between the grid and the inverter. The control system in the dq reference frame tracks constant reference signals, enabling the accurate regulation of electrical variables with linear controllers. The PI control system can reduce the error in steady state to zero, when it follows constant references. Some of the advantages of the control in dq reference frame incomparison with the control in the and abc reference frames are: the control and filtering of DC magnitudes is most simple than the control of AC magnitudes, using linear controllers in this system allows to uncouple the control by active and reactive power. The current control systemin the dq reference frame enables to regulate P and Q, modifying the phase angle and amplitude of line current with respect to the grid voltage measured at the PCC. Moreover, this current control system protects the system against overcurrent.

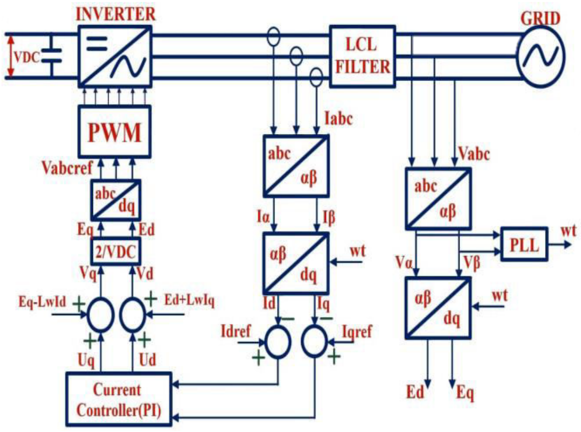


Figure 5: Control diagram in dq reference frame

This control strategy regulates phase and frequency by synchronizing with the grid voltages and currents, modifying the direct (d) and quadrature (q) components in rotating frame. The measurements of the grid currents are transformed to the dq reference frame. Subsequently, these transformed signals are compared to the desired reference parameters. The result of these comparisons is processed by PI controllers. Control signals are transformed to the abc reference frame, in turn these are used to generate the PWM signal. The synchronization of the inverter and grid needs the PLL [4] system. The information of the phase angle of the grid is provided by the PLL.
In this work, the control loops for the component d and q are implemented using proportional-integral (PI) controllers.

B. LCL FILTER

The inverter is the most common power electronic converter used to connect the renewable energy sources to the utility grid. However, the high frequency switching of semiconductors can cause the harmonic injection to the grid. Since grid filter reduces the harmonic injection to the utility grid. LCL filters consists of two inductors and one capacitor per branch. The attenuation of the LCL filter is-60dB/dec for the higher order harmonic to the resonant frequency [6].

IV. METHODOLOGY

The model encompasses a comprehensive control scheme designed for a sophisticated system comprising a three-phase inverter, an isolated DC-DC converter, and a photovoltaic (PV) module. Central to this scheme is the implementation of the Perturb and Observe (P&O) Maximum Power Point Tracking (MPPT) algorithm [1] within the PV module structure. This algorithm optimizes the efficiency of power conversion by continually adjusting the operating point of the PV module to track the maximum power available from the solar source. This optimization is particularly beneficial in high voltage and power generation applications where maximizing efficiency is paramount.

The system architecture integrates a grid-connected three-phase inverter [5], which serves as a crucial power electronic interface for PV systems. The inverter is equipped with power flow capabilities, enabling seamless integration with the grid. To ensure smooth and efficient power transfer, voltage and current controllers are designed within the frame of the dq reference frame. This allows for precise control and alignment of grid electrical parameters with the output parameters of the system. Several key components contribute to the effective operation of the system. The inclusion of a phase-locked loop (PLL) technique aids in synchronizing the system's output with the grid, ensuring stable and reliable performance during grid integration. Additionally, the utilization of unipolar switching in the inverter stage enhances efficiency and reduces switching losses. A crucial aspect of grid integration is the mitigation of disturbances and harmonics to maintain grid stability and reliability. To address this, a LCL filter, incorporating a Voltage Source Converter (VSC), is employed with the grid connected inverter.

V. MATHEMATICAL MODELLING OF PHASE LOCKED LOOP

Two-phase Stationary Frame

Vds=u1Cos0°+u2Cos120°+u3Cos240°

Vqs=u1Sin0°+u2Sin120°+u3Sin240 °

Two-phase Sychronous rotating frame

Vdr=u3*u1+u4*u2

Vqr=-u4*u1+u3*u2

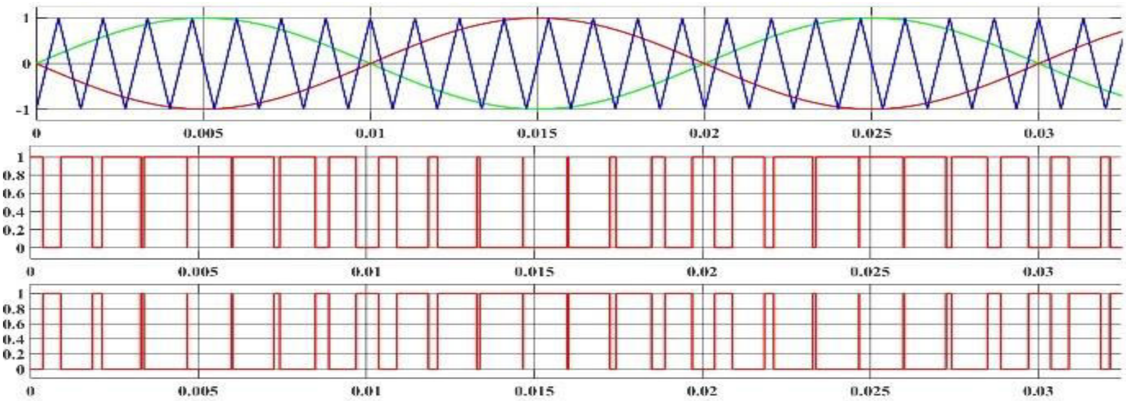
Three phase voltage equations

Va= u(1)

Vb= -0.5*u(1) + u(2)*0.866

Vc= -0.5*u(1) - u(2)*0.866

VI. SIMULATIONS RESULTS



Generation of Unipolar Voltage Switching

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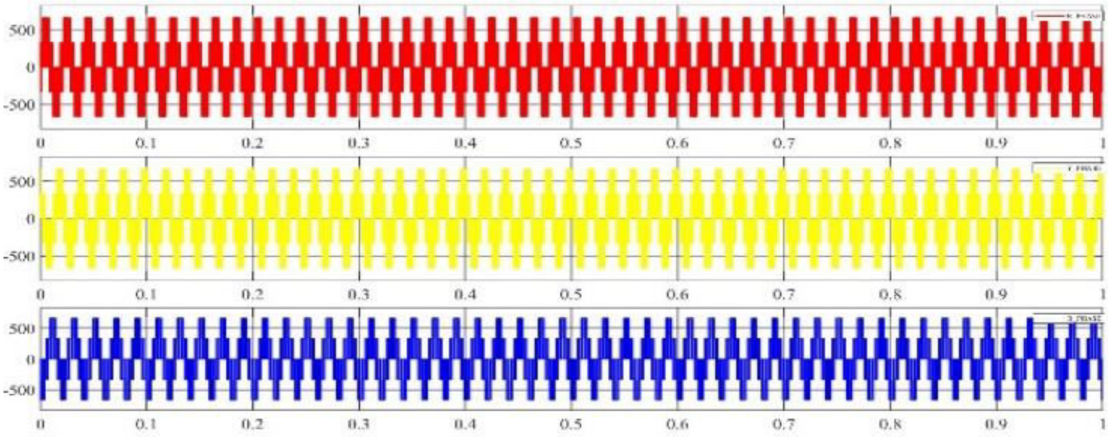
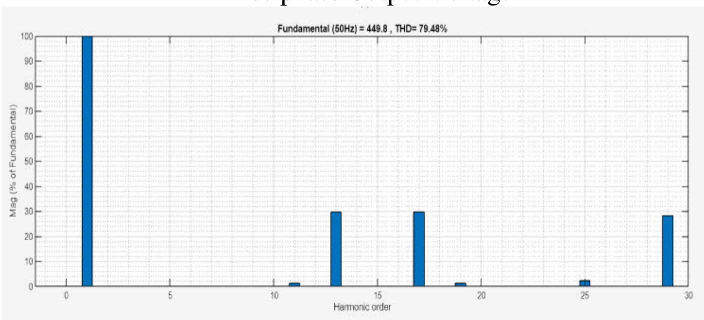
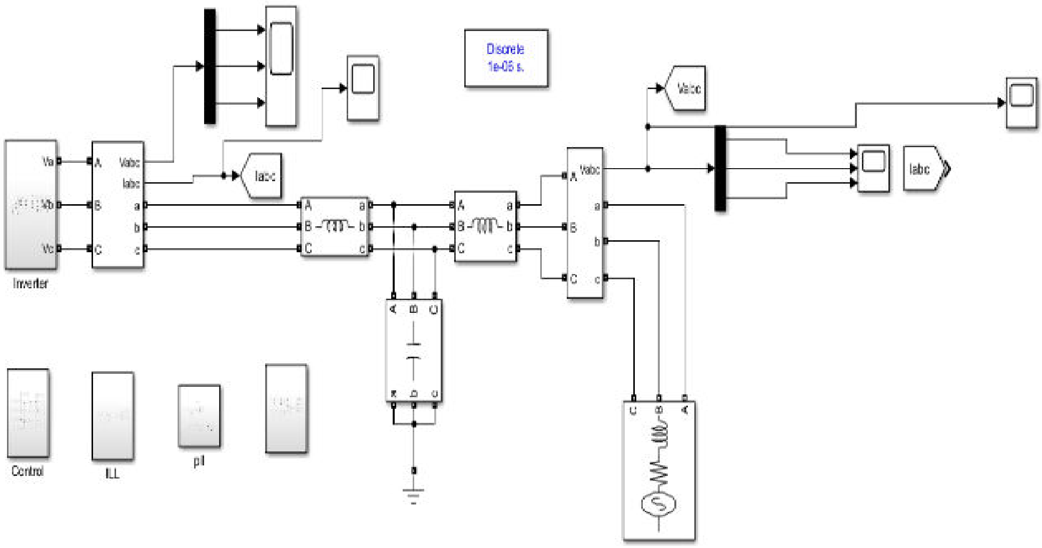
Three-phase Inverter with unipolar voltage switching



Three phase Output Voltage



Harmonic Spectrum for three-phase inverter with increased Modulation Index



Grid connected three-phase inverter

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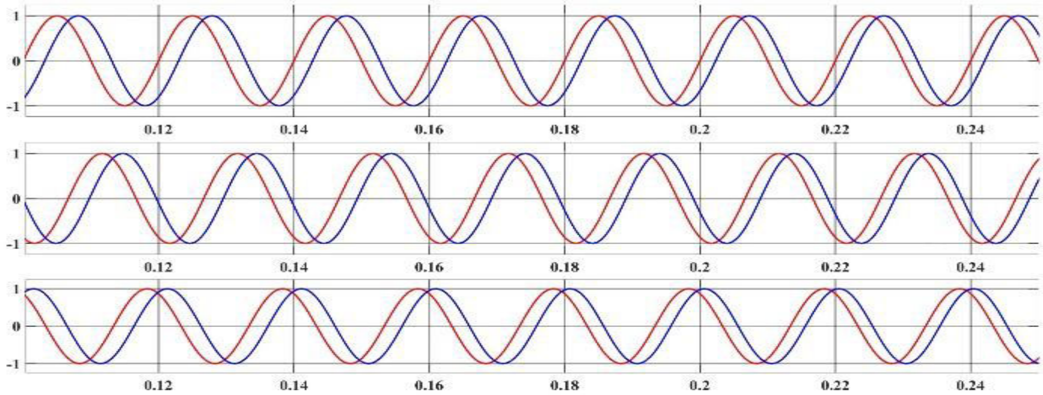

Synchronized Inverter Output Voltages with Grid

VII. CONCLUSION

In conclusion, a PV fed three-phase inverter with a real-time control of voltages and currents has been implemented by verifying the various approaches. The linear control system is a simple way to achieve local stability of the system and control of the injected power in presence of small disturbances and changes in the point of operation. The current control system in the dq reference frame allows the independent control of the direct and quadrature current. PI current controllers in the dq reference frame enabled the reduction of the error in steady state to zero. The implementation of Phase Locked Loop system established the phase and frequency synchronization of the voltage generated by the three-phase inverter with the grid voltage. The phase signal supplied by the PLL can be modified, which lets the correction of the phase shift introduced into the system by the LCL network filter. The PLL can assure the synchronization of the three-phase inverter with the grid.

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