

Synchronization of Grid Connected Three Phase Inverter

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Abstract— The synchronization between the grid and inverter is crucial for power sharing. By reconnecting the inverter to the electrical grid, it becomes possible to provide power in grid-off mode. Inverter-interfaced distributed generators (DGs) rely on control methods to drive the power devices in the inverter. A three-phase inverter produces output in terms of voltage, frequency, and phase, which can be matched with the electrical output using control methods. These control methods determine the pulse width modulation (PWM) pulses for driving the inverter. Simulations of the proposed systems with a grid-connected inverter are expressed through a MATLAB SIMULINK Model. Various algorithms generate different PWM pulses for the inverter. The differences between these algorithms are summarized in the results. Finally, the simulation results are analyzed across the load, total harmonic distortion (THD), error in grid voltage, and inverter voltage.

Keywords—Microgrid, Three phase inverter, THD, synchronization.

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1. INTRODUCTION

In the realm of modern technology, the Microgrid is an innovative concept that harnesses the efficient distribution of power flow. Furthermore, in order to ensure the seamless sharing of active and reactive power within the grid, synchronization between components is crucial. This synchronization process plays a vital role in enabling Distributed generators to effectively manage voltage and current fluctuations. Notably, the utilization of algorithms allows for optimal performance of the three-phase inverter in synchronized conditions..

The load capability can be effectively utilized when it operates under the supervision of monitoring conditions. The synchronization algorithm aids in detecting error voltages across the load while reconnecting the inverter with the electrical grid. The islanded mode of the inverter refers to its standalone condition. When the inverter is connected to the grid, it synchronizes the parameters of the electrical grid and distributed generators (DGs). The load voltage or current can be expressed in terms of voltage, frequency, and phase. To enable synchronization and power sharing, it is important to minimize Total Harmonic Distortion (THD) so that frequency changes can occur. These parameters can be controlled by a specific control system with an embedded controller [12].

Relevant Literature is reviewed in second section. Proposed system of synchronization with Grid Connected three phase Inverter is described in Experimentation section.

2. LETRATURE SURVEY

To enhance the efficiency of renewable energy utilization, it is crucial to ensure stability and synchronization with the grid. The utilization of d-q frame for Three-phase voltage-source converters (VSCs) can lead to instability during synchronization. Additionally, the impedance of grid-tied inverters exhibits negative incremental resistance behavior. A comprehensive analysis of this model can be found in reference [1].

In grid connected mode, the implementation of a Phase-Locked Loop (PLL) enables synchronization between the inverter and the grid in terms of phase. The stability of both the grid voltage and the inverter load voltage is assessed using this control method. Furthermore, during grid reconnection after islanded mode, phase and amplitude matching are crucial. Smooth operation is required for a seamless transition from one mode to another during voltage sag [2].

Electric vehicles have the capability to synchronize with both single and three-phase networks. The flexible control of both single and three-phase systems has been successfully demonstrated in both hardware and software [3].

The Amplitude Adaptive Notch Filter (AANF) serves as a modified current control loop synchronization tool. This method simplifies the complexity by eliminating the need for calculating the references reactive component and the harmonic components of currents. To implement this method, voltage and current sensors are utilized in a three-phase manner [4].

The system does not necessitate the use of a static transfer switch on the grid side. Instead, it relies on current and voltage sensors for the inverter, allowing for smooth mode transitions. The system can easily switch between grid mode and stand-alone mode, effectively eliminating transient over current. The response to these strategies is fast and readily available. The output impedance of the power converter is expressed using two frames: Stationary and Synchronous. The Stationary Frame consists of two sequences, namely positive and negative, which are coupled together.

The analysis of low-frequency dynamics caused by impedances and mode variations can be conducted using Synchronous Reference Frame (SRF) PLL methods. The stability of frequency in PLL can be examined in this context [7]. A new variation of SRF-PLL is

the Low-Pass Notch Filter PLL (LPN-PLL), which incorporates the Fast Fourier Transform with PLL. By utilizing a Digital Signal Processor, it offers high performance and robustness against harmonics [8]. Grid-connected photovoltaic (PV) systems designed for three phases in a single-stage manner provide advantages such as reduced complexity, high stability, and maximum efficiency [9].

The small-signal impedance is analyzed using feedback control and PLL in the synchronous reference (d-q) frame. The impedance model provided highlights concerns related to instability and harmonics impedance [10]. There are three conditions that can lead to an increase in switching frequency. Voltage estimation, which is free from noise, is performed across the Point of Common Coupling (PCC). Additionally, distortion can be expressed even without the use of the PLL Algorithm [11]. The hybrid system combines a Proportional Integral controller and a resonant controller. The proposed system offers the potential for harmonics reduction [12].

The reduction of harmonics, feasibility, and reactive power compensation are provided by the Self-Tuning Filter (STF) with a digital signal processor [13]. This article presents the synchronization of AC-DC-AC three-phase unidirectional converters. Mitigation of zero crossing distortion can be achieved through experimentation [14]. The article utilizes control schemes for sharing powers and restoring frequency in a three-phase voltage source inverter. The connection between the grid and microgrid can be established using a defined sync algorithm [15]. In order to minimize common mode voltages, a synchronized pulse width modulation (PWM) method is proposed in this paper. Simulation can be used to experiment with a simple circuit [16].

This paper presents a control strategy that offers operation mode transformation, power quality enhancement, and low total harmonic distortion (THD) as its key features. The experiments conducted in this study demonstrate the excellent performance of the proposed controller [17]. The voltage source inverters (VSIs) are connected in a parallel scheme with reduced rating, and they are controlled using the same algorithm individually. Furthermore, the uncertainties related to delay and parameters have been identified [18].

The synthesis of grid parameters' amplitude and displacement can enable effective regulation. The management of power flow between the grid and Distributed Generation (DG) system is also possible [19]. This study further examines the efficiency, dynamic response, and functionality of a three-phase integrated motor drive and charger [20].

Simulation is used to describe the synchronization of the grid for the charger and charge control. The mathematical model and system functionality are explained in this document [21]. An implementation of the Self-Excited Induction Generator (SEIG) for three phases in both open loop and closed loop is conducted. The control strategy is experimentally tested using the dSPACE DSP platform [22]. The Grid Connected Converters (GCCs) are controlled by a predictive algorithm, allowing for phase current calculation and the attainment of desired amplitude values [23].

Simulation and experimental performance are used to discuss the transient conditions when the Intelligent Connection Agent (ICA), also known as a grid-connected power converter, is connected or reconnected to the mains. This is detailed in reference [24].

The grid interfacing power quality compensator comprises of two inverters, namely series and shunt. The current limiting algorithm allows for the estimation of voltage sag. The effectiveness of this system was tested through simulation and experimental hardware [25]. To enhance reliability, a grid-tied Photovoltaic (PV) system utilizes a current-fed dual-active-bridge (CF-DAB) dc-dc converter and cascaded multilevel inverter [26]. In the context of Permanent-Magnet Synchronous Generator (PMSG), an Adaptive Network-based Fuzzy Inference System (ANFIS) is employed for speed and position estimation [27].

The utilization of inner and external voltage-current loops in the proposed methods proves to be beneficial for interfacing and power sharing. Furthermore, the configuration allows for the possibility of synchronization [28]. By employing the Conservative Power Theory (CPT), it becomes feasible to achieve Master-Slave control of DG interfaced converters. This method takes into account the sharing of current components [29].

3. EXPERIMENTAL MODEL

Figure 1 illustrates the proposed system in a block format. The system consists of three voltage sources, namely V_a_Grid , V_b_Grid , and V_c_Grid , which can be manually adjusted. Similarly, the three-phase inverter generates voltages, $V_a_inverter$, $V_b_inverter$, and $V_c_inverter$, in a three-phase manner. The Point of Common Coupling (PCC) acts as the central component, isolating the two systems. Both units share the same load system, which has a power rating of 1 KW. The PCC facilitates the connection between the three-phase inverter and the grid based on the load requirements. The Control System Algorithm is crucial in this setup as it generates pulses to trigger the power devices in the three-phase inverter. The nature of these pulses is determined by the algorithms, allowing for control over the three-phase inverter. The Powergui block is responsible for configuring the simulation type, simulation parameters, and preferences..

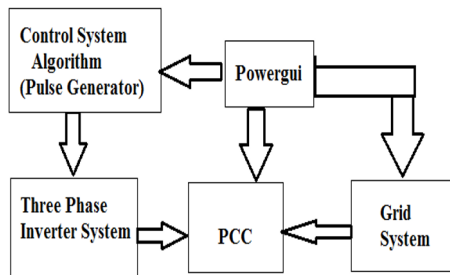


Fig.1. Block Diagram of MATLAB Simulation Model

The initial control algorithm functions by processing two signals: V_{abc_B2} or V_{abc_B3} to PQ_B2 or PQ_B3 , and a step reference signal. These two signals are combined and operated on using a transfer function known as the active power controller. The resulting signal is then passed to the dq0 to abc transformer block, along with a reference signal \sin_cos . The dq0 to abc transformer generates an abc signal, which is then inputted into the hysteresis block along with a unit delayed I_{abc} . Finally, the hysteresis block produces six pulses for the three-phase inverter. The remaining parameters and design remain consistent throughout the entire MATLAB simulation. Control method 1 is depicted in figure 2, and it is utilized for synchronizing two distinct systems, such as the grid and the inverter preferences.

The second algorithm comprises a constant V/Hz control and a discrete SV PWM pulses generator. The voltage control component includes a saturation timer, a discrete rate limiter, a discrete time integrator, and a gain function. Two signals, m (modulation index) and θ (firing angle), are generated. The modulation index should have a value between 0 and 1. In Figure 3, the MATLAB simulation model for Algorithm 2 is presented. The discrete SV PWM pulses generator generates SVPWM (Space Vector Pulse Width Modulation) waves for the switching devices. This generator can generate two switching patterns of pulses for the devices. For the proposed work, switching pattern 1 of SVPWM pulses is selected.

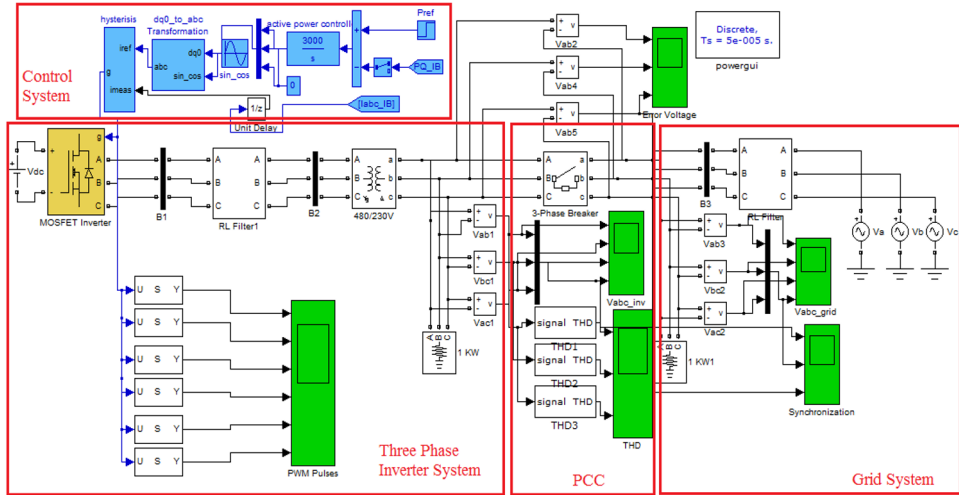


Fig.2. MATLAB Simulation with Method 1.

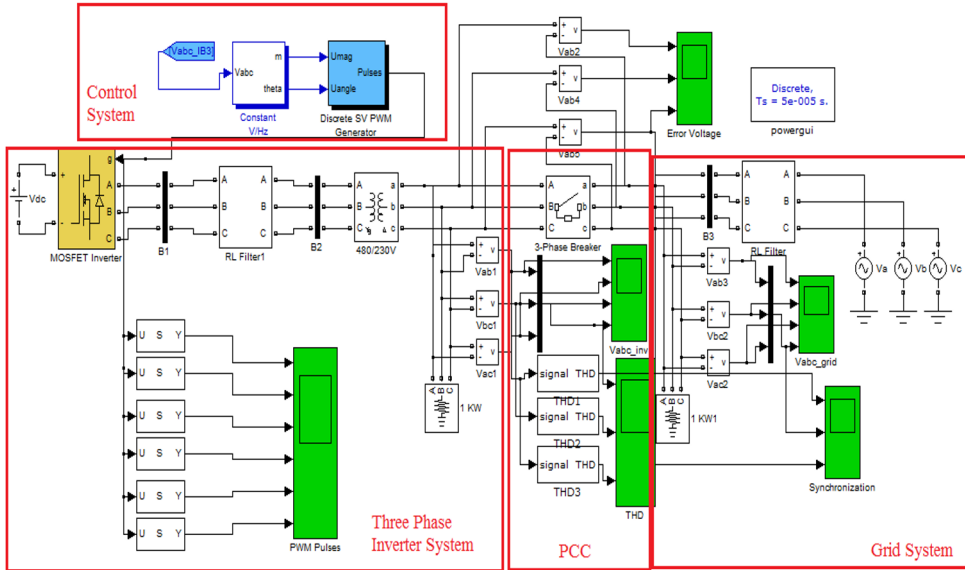


Fig.3. MATLAB Simulation with Method 2.

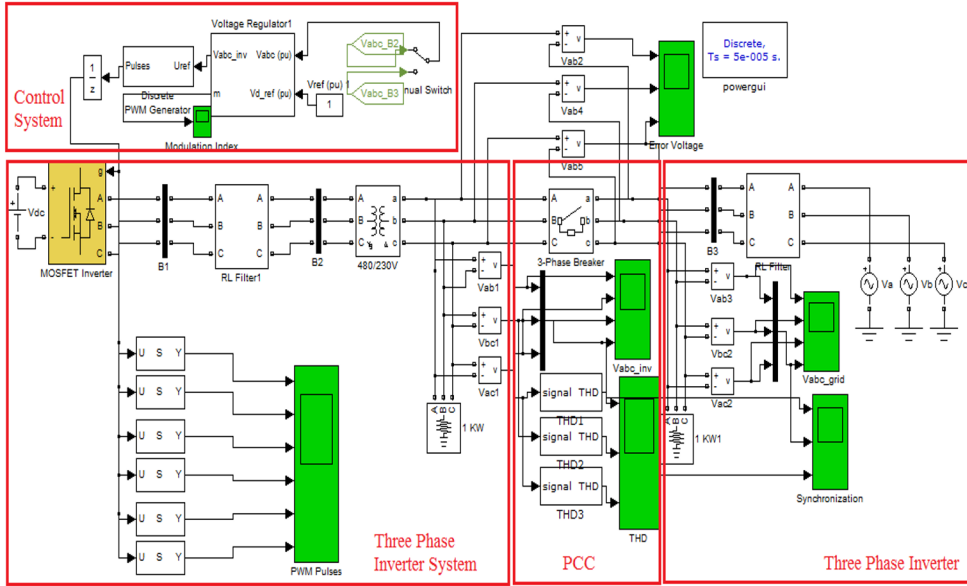


Fig.4. MATLAB Simulation with Method 3.

Third algorithm contains Voltage regulator, Discrete PWM generator and unit delay. Voltage regulator receives the controlled voltage and reference signal (1). Regulated V_{abc_inv} provide to the Discrete PWM generator

The three-phase inverter is responsible for generating pulses. These pulses are then delayed using a unit delay component and fed into the universal bridge. The MATLAB Simulation Model for Algorithm 3 is depicted in Figure 4. A comparison between control algorithms has been conducted, and the selected algorithm will be discussed.

TABLE I
PARAMETERS DIFFERENCE BETWEEN ALGORITHMS

Parameters	Method 1	Method 2	Method 3
Harmonics (THD) (Volts)	0 to 0.325	0 to 0.3	0 to 0.27
Error Voltage (Volts)	-1.12 to 1.12	-1.25 to 1.25	-0.65 to 0.65
Offset (Seconds)	0.05	0.05	0.05

4. CONCLUSION

The synchronization between the three-phase inverter and the electrical grid is essential for the operation of the inverter in both islanded mode and grid-connected mode. When the grid is disconnected from the inverter, it should be able to function independently to provide the necessary power to the respective load. The control algorithm for the three-phase inverter generates PWM pulses that drive power devices according to the requirements. The output produced by the three-phase inverter is used to power the load and should be similar to that of the electrical grid. The error voltage between the grid and

the three-phase inverter can be minimized by adjusting the control mechanism. An embedded system is employed to control the Point of Common Coupling (PCC), ensuring a continuous power supply to the load during grid-off conditions. The implemented synchronization system is simple in structure, easy to operate, convenient to carry, and provides continuous monitoring and real-time display. The harmonics distortion for the control algorithms ranges from 0 volts to 0.325 volts. The error voltages of the control algorithms are available within the range of -1.25 volts to 1.25 volts. The offset parameter lies within the range of 0.067 seconds to 0.05 seconds. By modifying the synchronization system, the affected performance parameters can be reduced.

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