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Asymmetric SPWM used in inverter grid connected

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Abstract - *The overall efficiency of grid-connected photovoltaic power generation systems depends on the efficiency of the DC-into-AC conversion. Therefore, a key consideration in the design and operation of inverters is how to achieve high efficiency with power output. This paper presents a concept of an inverter for grid connected photovoltaic arrays which can synchronise a sinusoidal current output with a voltage grid. Asymmetric PWM inverters can generate power at unity power factor, this approach, based on the active filter is proposed in this work. This method is used in order to correct the phase between the output current and the grid voltage and to maximize the system efficiency in design and control. The functional structure of this system is presented and simulated. Detailed analysis, Simulations results of output voltage and current waveform demonstrate the contribution of this approach to determinate the suitable control of the system. A digital design of a generator SPWM using VHDL is proposed and implemented on an Xilinx FPGA.*

Résumé - *L'efficacité globale des systèmes photovoltaïques connectés au réseau électrique dépend de l'efficacité de la conversion DC-AC. Par conséquent, la considération clé dans la conception et le fonctionnement des onduleurs est de savoir comment adapter un rendement élevé avec une puissance de sortie. Cet article présente le concept d'un onduleur, pour des surfaces photovoltaïques connectées au réseau, afin de synchroniser le courant sinusoïdal avec la tension du réseau. Des onduleurs asymétriques PWM peuvent générer de la puissance pour un facteur de puissance unitaire, approche basée sur un filtre actif, qui est proposé dans ce travail. Cette méthode est utilisée afin de corriger la phase entre le courant de sortie et la tension du réseau et de maximiser l'efficacité de système dans la conception et la commande. La structure fonctionnelle de ce système est présentée et simulée. L'analyse détaillée, les résultats de simulation de la tension de sortie et de l'onde du courant démontrent la contribution de cette approche à déterminer la commande appropriée du système. Une conception numérique d'un générateur SPWM employant le VHDL est proposée et mise en application sur un Xilinx FPGA.*

Keywords: Small grid-connected PV system - Power conditioning - Inverter.

1. INTRODUCTION

With the increasing concern about global environmental protection, the need to produce pollution-free natural energy such solar energy has been drawing increasing interest as an alternative source of energy for the future since solar energy is clean, pollution-free and inexhaustible. In an effort to utilize the solar energy effectively, a great deal of research has been done on the grid-connected photovoltaic generation system [1].

In photovoltaic systems, a grid connected inverter which converts the DC output of the solar modules into the AC electricity, is receiving increased interest in order to generate power to utility. Generally, the grid-connected photovoltaic (PV) system extracts maximum power (MPPT) from the PV arrays providing current to the mains in phase with the sinusoidal voltage of the mains.

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The MPP tracking technique is usually associated with a DC/DC converter [2-4]. When the utility power sources should provide the peak power to the load, the energy provided by PV arrays can alleviate the burden of utility power sources. Power supply reliability and power quality have become important issues for all kind f power electronics including photovoltaic system. Interconnecting photovoltaic system to the utility it is necessary that PV system should met the harmonic standard and the active power supply requirement. The characteristics of the output signal should match the voltage, frequency and power quality limits in the grid. Among these systems, the most common type is the parallel running PV system with the bidirectional power flow to provide unity power factor to the utility line. In grid-connected photovoltaic power generation systems, a DC to AC inverter is employed to transfer the DC energy to grid. For the grid connected inverter is desirable to provide the unity power factor. Usually the inverter is controlled so as to generate the output current in phase -with the grid voltage to achieve the maximum active output power by minimizing the reactive output power. There are various control strategies to control the factor power and fundamental current waveform.

In past years, power conversion systems have been realized using very precise analog IC's controller with complex control methodology to achieve required performances. Owing to analog nature, these systems are difficult to upgrade and modify. Recently, there has been a growing interest in digital controllers, due to their low power consumption and high immunity to noise (temperature changes, components aging,). Moreover digital systems are the most suitable ones to implement sophisticated control schemes and simply interfacing circuits. Among the various advantages of digital approach, design flexibility is the most valuable one, as well as accurate time delay compensation, and IC implementation will be required. So, today, electronic industries and researchers try to develop digital control for power conversion system, using new micro-controller and digital signal processors (DSPs) and VHDL design.

The VHDL design can be easily adapted to different technologies or modified to meet a different application or a new set of specifications, thus providing very fast time-to-market. A voltage source pulse with-modulation SPWM inverter and its control technique are essential to connect them to the utility grid. Sinusoidal PWM is used and a control strategy is proposed. A circuit with a feedback loop is proposed and simulated. A digital design of a generator SPWM which is described using VHDL and implemented on an Xilinx FPGA [8-10].

2. PROPOSED PV INVERTER SYSTEM

The figure 1 shows the circuit diagram of the proposed inverter. The main objective, from this interfacing, is to feed all the collected energy at the PV plant to the AC grid.

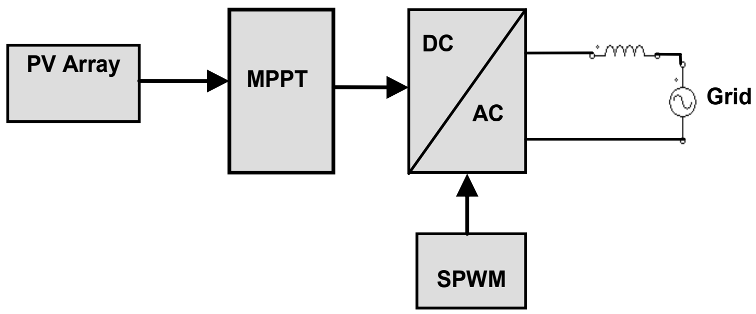


Fig. 1: PV grid connected system

- PV array transform the sun light to electricity.
- MPPT controller, this is used to maximise the power coming from PV array at any atmospheric conditions [2, 3, 5].
- Inverter, this is a device witch transform DC input to an AC output at the same waveforms as the grid line [1, 6, 7].

In the first a basic regarding of the full bridge inverter operation is carried out. The goal is to explain the control of current inverter through the bridge (Fig. 2).

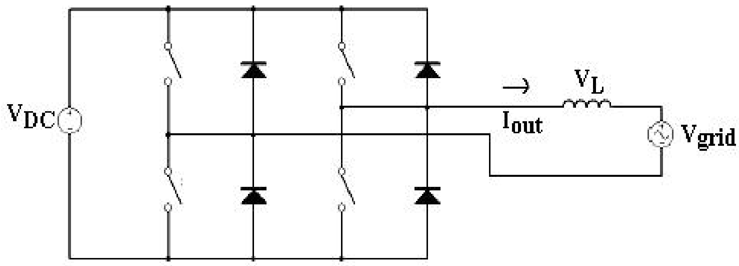


Fig. 2: Inverter grid connected

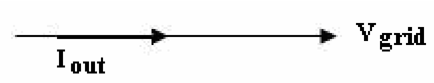
The main specification of the grid connected inverter is that current must be drawn from the PV plant and delivered to the utility grid at unity power factor [5, 6].

Consider the grid connected inverter of Fig. 2, V_{inv} the fundamental component of inverter output, V_L the voltage drop across the link inductor and V_{grid} the utility grid waveform, I_{out} a current drop across the link inductor.

Assuming that the losses are negligible, it is seen that:

$$V_{inv} = V_{grid} + V_L \tag{1}$$

Then:



$$V_{inv} = V_{grid} + j.L.\omega.I_{out} \tag{2}$$

To achieve the unity power factor condition, the current waveform must be in phase from the utility voltage waveform, in vector form this looks like.

The key to controlling this operation is the inverter voltage variable, V_{inv} . From equation (6), is can be written as:

$$I_{out} = \frac{V_{inv} - V_{grid}}{j.\omega.L} \tag{3}$$

The figure 4 shows the difference in phase between the current and utility voltage waveform.

The above phase shows that the magnitude and direction of current flow, therefore power flow can be controlled by the phase shift α and the magnitude of the inverter output waveform.

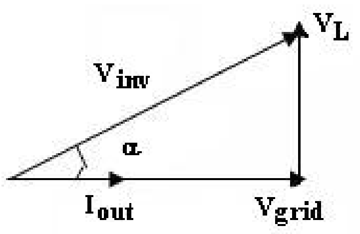


Fig. 3: Magnitude and phase requirement

3. STRATEGIES CONTROL

Several modulation techniques exist for the implementation of DC/AC inverters, for example the sinusoidal PWM. A high-frequency signal is compared with a specific sinusoidal signal with specific frequency. The high-frequency signal is known as carrier or modulator signal. The carrier can be a triangular form generate a train of pulses (PWM) aligned as it's shown in (Fig. 4), this minimizes: noises in the system, ripple current, harmonics distortion acoustic noise. In the SPWM the reference signal is a sinusoidal. The comparison of this signal with a triangular generates the system output (Fig. 4). In order to make the analysis of control PWM it is necessary to define some parameters. The index of amplitude modulation m_a and index of frequency modulation m_f [1, 6].

$$m_a = \frac{V_{ref}}{V_{trig}} \qquad m_f = \frac{F_{trig}}{F_{ref}}$$

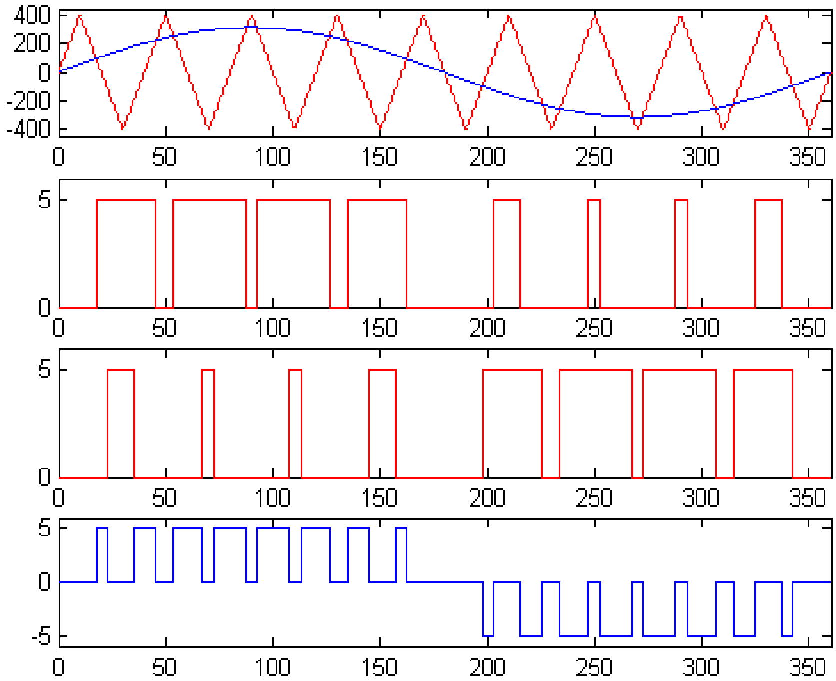


Fig. 4: SPWM modulation

4. SIMULATION OF PV INVERTER SYSTEM

The simulation circuit of PV system it's show in Fig. 5.

The simulation results shows in the Fig. 7, the grid's waveform of voltage and inverter's waveform current, which presents a phase shift between V_{grid} and I_{inv}. In order to correct this phase shift and synchronise the voltage with the current, the active filter based on operational amplifier is introduced.

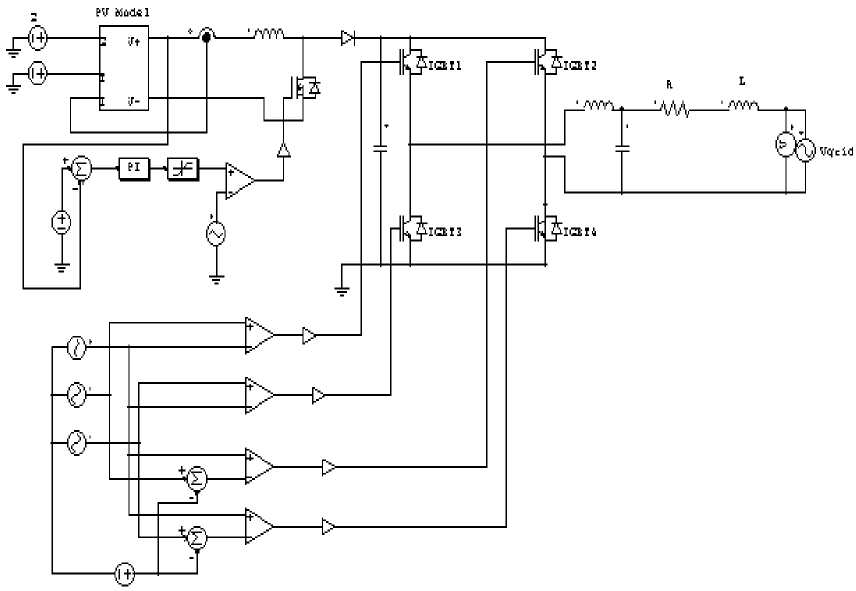


Fig. 5: Block simulation of inverter grid connected

In this case (Fig. 7), the phase between V_{grid} and I_{inv} is equal at 90º. The low-pass filter is used as an active filter, which allows selecting the adequate phase shift at the cut-off frequency in order to improve the power factor. The phase varies in function of cut-off frequency of the filter. It is necessary to put the additional gain to adjust the phase between V_{grid} and I_{inv}.

In order to correct the phase between the grid voltage V_{grid} and the current inverter I_{inv} that injects to grid. Fig. 6 illustrate the simulation scheme for arriving at this goal.

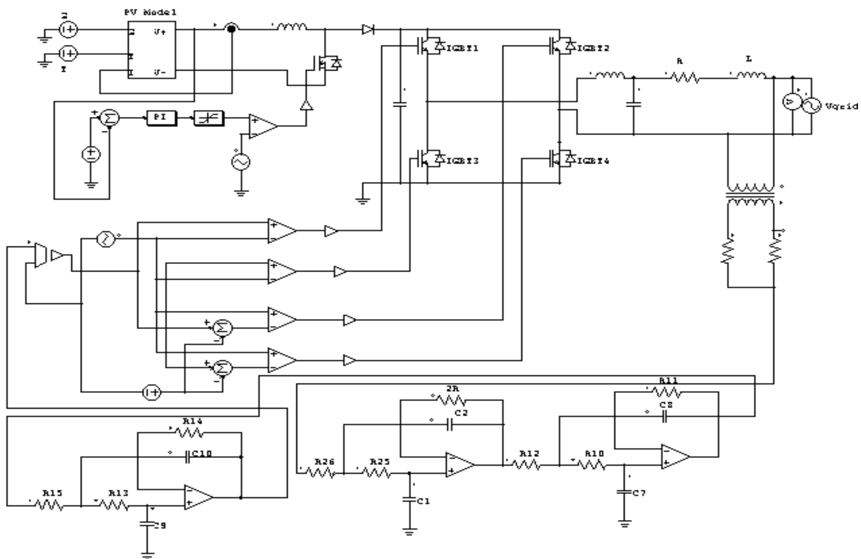


Fig. 6: Block simulation of inverter grid connected with active filter

The simulation results waveforms show in Fig. 7, that the V_{grid} and I_{inv} are in phase and obtained power factor is approximated to unity. These results can determine the reference voltage for the grid inverter control and the circuit with feedback loop.

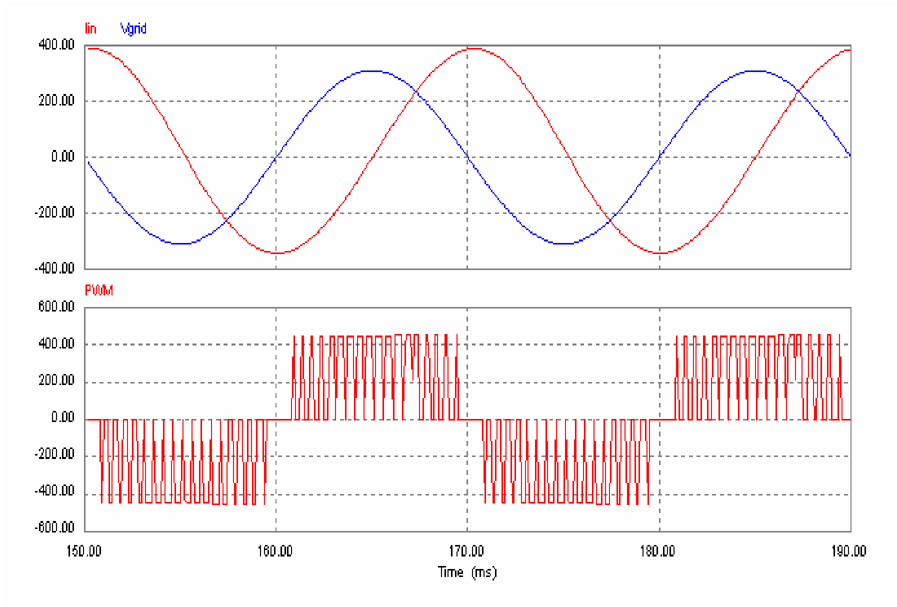


Fig. 7: Open loop simulation results (V_{grid} , I_{inv} , PWM)

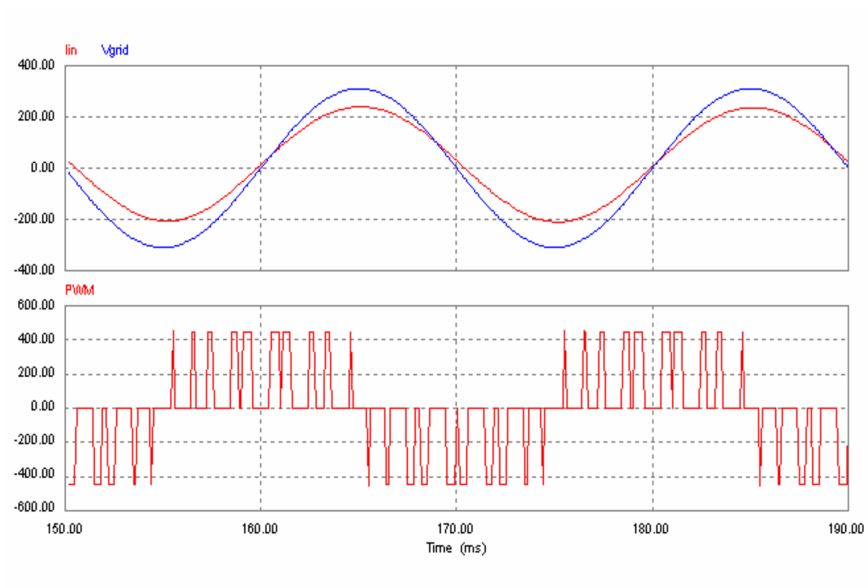


Fig. 8: Closed loop simulation results (V_{grid} , I_{inv} , PWM)

5. DESCRIPTION OF THE DIGITAL MODULE SPWM

From the analogue SPWM shown in Fig. 4, we can find a equivalent digital circuit (Fig. 9), in this equivalent circuit, the triangular signal is generated using the up/down counter of n bits, which is incremented until a maximum value and newly decremented until the minimum value. Determination of the carrier frequency is the first step of design process. The carrier frequency is had been decided 20 kHz. Operating at high frequency is better than the low frequency where the harmonic components could be shifted to high order.

The carrier frequency has the relationship with the clock frequency and the up/down counter. Output counter is compared with the sampled values of the sinusoidal modulating wave, the sin values having first been calculating and may be stored in memory RAM.

The input data in SPWM system will be constant, coming from a memory, which will contain the different values of the discretized sinusoidal signal. The overflow signal of the counter, charges the next constant from the memory for its evaluation. In the Fig. 5, the block diagram of the modulator to be implemented in Xilinx field programmable gate array FPGA is showed. Each one of the blocks has their corresponding VHDL code.

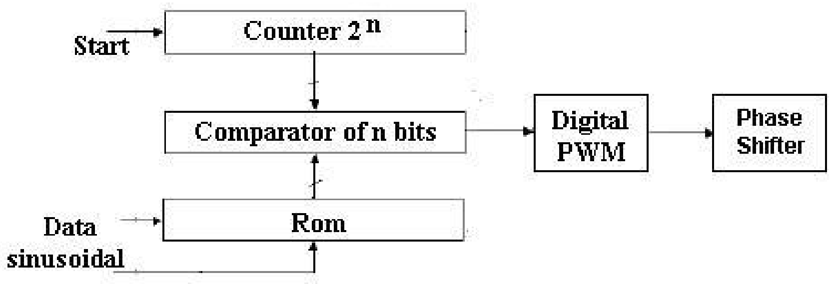


Fig. 9: Equivalent digital circuit to SPWM

A modulator can be unipolar or bipolar, depending on how the comparison between the carrier signal and the reference signal is made, (Fig. 5). The unipolar PWM generates a smaller harmonic content than the bipolar PWM; however, the implementation of an unipolar PWM is much more laborious. At the moment of taking the samples of the sinusoidal signal, should be considered the type of unipolar SPWM, for storing a total of 400 samples. That corresponds to the first 90º of the sinusoidal signal. The rest of the signal is formed reading the table in opposed sense. For the bipolar type, double data should be stored, for avoiding a poor resolution. Other important factor is the modulation index m_a. The modulation index defines the duty cycle of the pulses that form the sinusoidal signal. Typically, the modulation index m_a is always smaller than 1. For this case a multiplier was implemented [8-10].

6. PV INVERTER SYSTEM WITH DIGITAL SPWM

In this paper an strategy control was presented that was simulated and developed in a practical way to control a solar inverter using PWM, with digital control (Fig. 10).

The DC power available at the output of the PV array is converted to AC power using Pulse width modulation (PWM) technique applied to the inverter using FPGA Xilinx. The objective is to obtain PWM signal used to switch the power IGBT's. The inverter under consideration is capable to minimizing the level of the harmonic content.

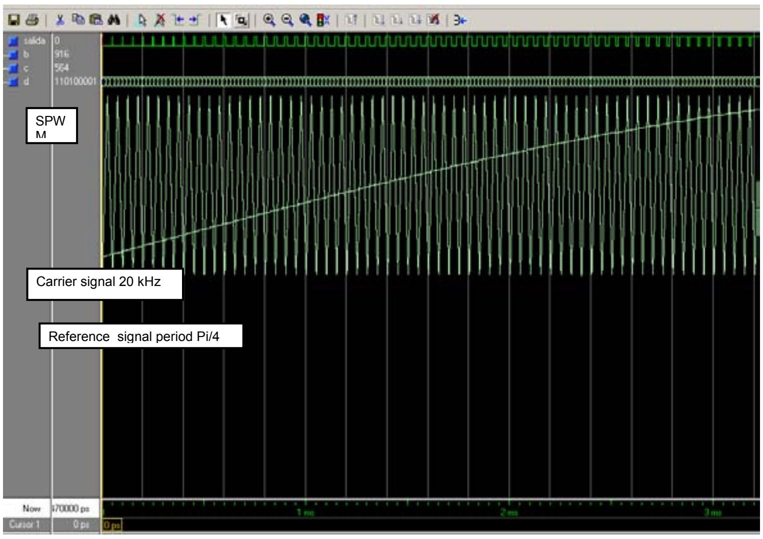


Fig. 10: Illustrates simulation results

It is shown the $\frac{\pi}{4}$ of period of sinusoidal.

7. CONCLUSION

The proposed design of grid connected inverter with asymmetric modulation has been analysed and simulated. Simulations results of output voltage and current waveform demonstrate the contribution of this approach to achieve the maximum active output power by minimizing the reactive output power. The unity power factor and high efficiency with power output are achieved. Using Xilinx FPGA to generate PWM provides flexibility to modify the designed circuit without altering the hardware part. Now we are working on the practical solution of this strategy.

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