A Single-Phase Inverter for PV Systems

K. Souza, S. Daher and F. Antunes
Energy Processing and Control Group – GPEC
Electric Engineering Department
C.P. – 6001 - Campus do Pici – UFC
60455-760 Fortaleza - Ce – Brasil
e-mail: ksouza@gpec.ufc.br

Abstract

This work deals with the design and laboratory implementation of a single-phase inverter for stand-alone or grid connected PV system. The converter is a sinusoidal PWM full-bridge single-phase structure. The sinusoidal switching strategy used provides a grid-compatible output voltage allowing the inverter operation in either stand-alone or grid connected. The structure uses MOSFET as power switches, and the system control signals are generated by a AT89S8252 ATMEL microcontroller-based circuit. Simulation and Experimental results are shown to access the performance of the PV system in a stand-alone operation and also as grid-connected system.

1. Introduction

The solar energy is today a clean and viable source of electricity. It has been used as the main source for electrical loads in rural areas away from the grid or grid-connected in distributed energy production.

Small and medium scale Grid-connected PV systems are being used in large scale in many parts of the world. Although the cost of such systems is still regarded as high, the continuous research in power electronics and in the physics of semiconductors has pointed towards cost reduction of PV systems.

Electricity production from photovoltaic systems has become less costly and more efficient in recent years. This lead to a huge market for off-grid PV power systems for remote areas [1]. Photovoltaic systems are still related to the supply of power to remote areas or rural electrification, small telecommunication devices and satellites. Grid-connected PV system ranging from 10kWp to 500kWp are been installed in several countries, and in some places in large scale [2]. Although the cost of grid connected PV systems is still high, research in power electronics and in semiconductors have played an important role in reducing the cost of PV systems.

Grid-connected PV systems can be of two types: centralised generation or integrated to urban building. In the first case, the photovoltaic plant is located away of urban centers due to the necessity of relatively large areas. On the other hand, systems integrated to urban buildings are located on roofs.

Grid-connected PV systems neither require batteries or to be oversized to attend peak demands because the grid is a large storage energy system. If the PV system generates energy in excess to the residential load, the excess is sold to the grid. When the PV system generates less energy than the value required by the load, the grid supplies the extra value. Grid-connected PV system, due to its modularity, short period between the installation of the plant and the beginning of operation, could be very attractive for the utility [3].

As part of a study to present a simple and cost effective converter for PV systems, this paper deals with the design and laboratory implementation of a static dc-ac converter for grid connected PV system. The converter is made up of a single-phase voltage source inverter (VSI) with sinusoidal PWM strategy. The power converter along with its control strategy changes the PV arrays dc voltage to a grid-synchronous ac voltage. To provide the VSI with low harmonic distortion, a low pass filter has been designed and implemented at the inverter output. The converter uses MOSFET as power switches, and their control signals are generated by an AT89S8252 ATMEL-microcontroller-based circuit. The performance of the converter is analysed by simulation and experimental results for a 100Wp PV. The results are shown for stand-alone and grid connected operation.

2. The PV System

The Fig.1 shows the implemented PV system. The System can be divided in five different blocks: the photovoltaic panel, the single-phase dc/ac converter, the filter, the step up transformer and the grid.

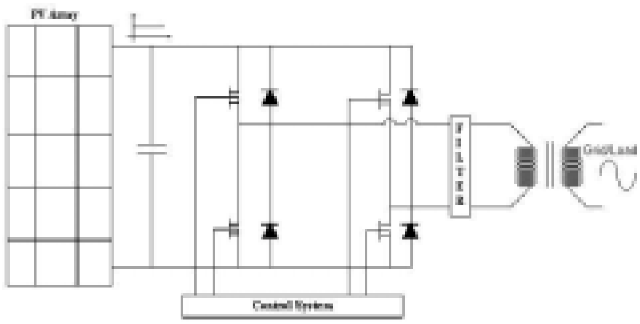

Fig. 1. The Power Electronic Converter

The PV panel is associated in such a way to provide the necessary input voltage to the inverter. The passive filter attenuates the high frequency components of the transformer input voltage. The inverter control is implemented in a microcontroller-based circuit.

3. The DC/AC Converter

DC/AC converters are used to control a power flow from a dc source to an ac source or ac load. In its structure it can be pointed out two basic blocks: the drive signals generation block and the power stage. The drive signals are responsible for the inverter output voltage characteristics. For most the applications it is desired to have a sinusoidal output voltage. Several modulation techniques have been used for a sinusoidal output voltage[5]. The Pulse Width Modulation – PWM technique allows a pulsed voltage at the inverter output making it easier the filtering action of the harmonics at the output voltage. Fig. 02 shows a single-phase inverter structure.

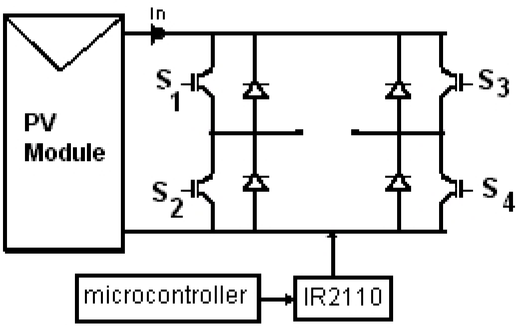

Fig. 02 Single-Phase dc-ac Converter

Two PWM techniques have been studied: The Sinusoidal PWM Technique[4] and the Optimised PWM Technique[6]. It has been decided to use the Sinusoidal PWM technique as a switching strategy for the single-phase inverter. Fig.03, 04 and 05 show the switching pattern for the Sinusoidal PWM strategy.

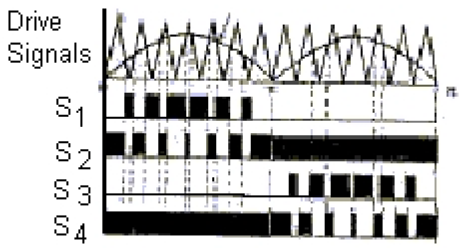

Fig. 03 Gate Drive Signals

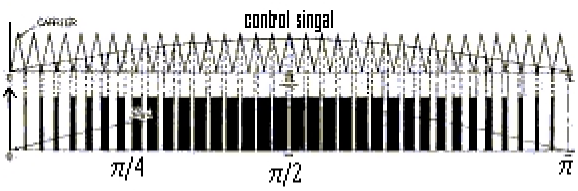

Fig. Fig. 04 Half Period Switching

Fig. 05 Output Voltage Waveform

The single-phase inverter power circuit is seen in Fig.02. Its ac output line voltage is $30V_{rms}$. A 30/220V single-phase power transformer connects the inverter to the grid or the load in case of off-grid operation. Due to the low power capacity of the PV panel, and the low frequency characteristic of the inverter current after the filter, a low frequency transformer has been used.

The inverter characteristics are: Input voltage 48Vcc, inverter output voltage 30Vca. Switches $S_{1,4}$ are power MOSFET IRFP360® and diodes $D_{1,4}$ are power diodes ATP15060K.

The drive signals are generated by a microcontroller-based circuit. The output signals of the microcontroller are the input signals to the IR2110® which drives the four switches of the inverter. The inverter controller is implemented in a AT89S8252 microcontroller with a clock frequency of 24 MHz. Due to this clock frequency the PWM signal switching is limited to 8 kHz.

4. The Output Filter Design

A passive filter has been designed to filter out the harmonic components at the inverter output voltage. At the design stage attention had been paid in reducing the harmonic components at the same time ensuring a good voltage regulation. So, some conditions have been imposed at the design stage:

- The filter cut frequency should be 10 times lower than the power switching frequency;
- The filter cut frequency should be at least 50 times bigger than the fundamental frequency of the output voltage;
- The damping factor is chosen in such a way to guarantee a small displacement between the output voltage and the output current. It has been chosen $\zeta = 0{,}707$.

The passive elements have been determined using the steps below.

a) Cut frequency f_o :

$$f_o = \frac{f_s}{10} = \frac{8KHz}{10} = 800\ Hz$$

b) Damping factor:

$\zeta = 0.7$

c) Filter capacitor:

$$C_f = \frac{1}{4 \cdot \pi \cdot \zeta \cdot f_o \cdot R} = \frac{1}{4 \cdot \pi \cdot 0{,}7 \cdot 800 \cdot 10} = 14{,}2uF$$

d) Filter inductance L_f:

$$L_f = \frac{1}{(2 \cdot \pi \cdot f_o)^2 \cdot C_f} = \frac{1}{(2 \cdot \pi \cdot 800)^2 \cdot 14{,}2u} = 2{,}8mH$$

5. Simulation Results

Before laboratory implementation, the inverter circuit has been simulated. The software used was PSpice®. Fig. 06 shows a simplified version of the Single-Phase DC-AC inverter used for simulation. The Fig. 07 shows the implemented circuit to simulate the PWM switching strategy.

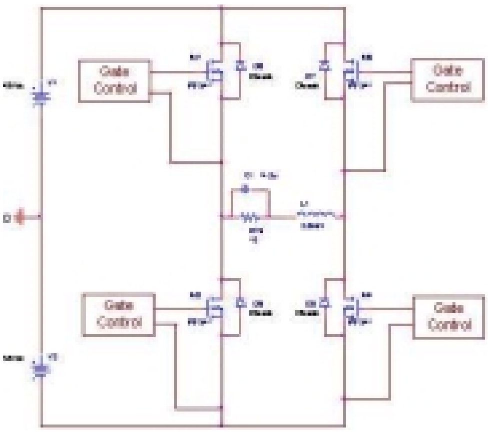

Fig. 06 Single Phase inverter

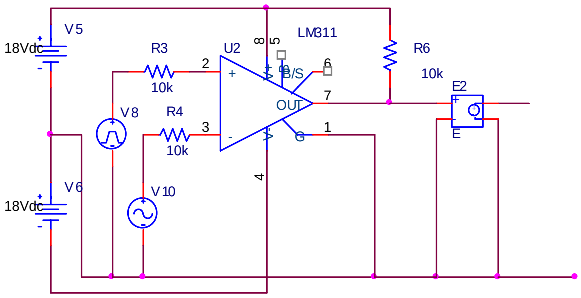

Fig. 07 Gate control circuit

The power sources in Fig.06 were adjusted to have the same value presented by the PV array. The inverter has been designed for the following characteristics: Input voltage established in 48Vcc resulting in a rms output voltage of 30Vac.

The system has been simulated for off-grid operation. Fig. 08 shows the waveform for the output voltage on load with output filter.

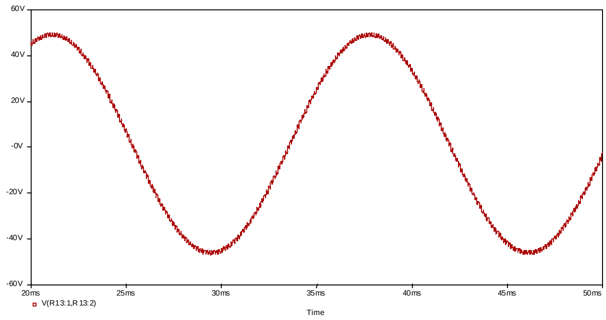

Fig. 08 Output voltage on load with output filter

It can be observed that the output voltage is a sinusoid waveform at the fundamental frequency superposed by a high frequency at the switching frequency. It can be considered that the output voltage is harmonic free. Fig. 09 shows output voltage harmonic spectrum.

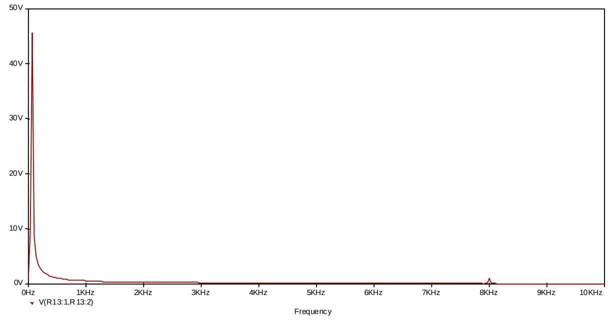

Fig 09 Output voltage harmonic spectrum

Fig 10 shows the output current waveform with a sinusoidal envelope.

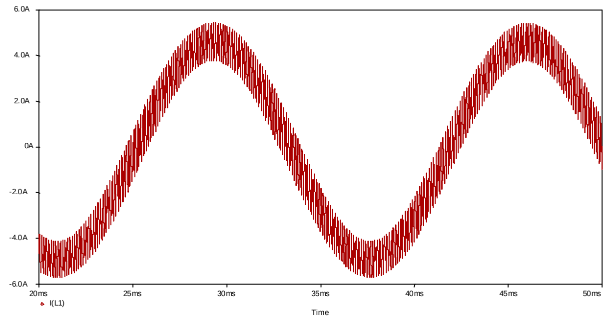

Fig. 10 Output current waveform

6. The Synchronization

In case of grid connected operation it is necessary a synchronization circuit.

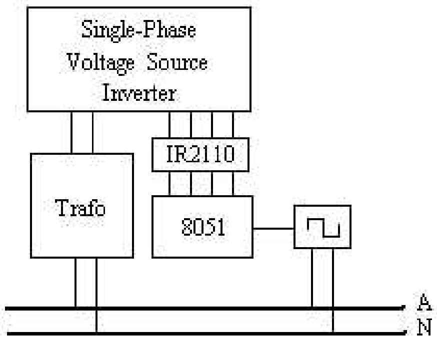

Fig. 11 Connection to the Grid

The Fig.11 shows the single-phase voltage source inverter synchronisation system. The synchronisation circuit is provided by a voltage signal from the phase of the grid which the system is to be connected. At the zero crossing of the voltage of the grid an interruption is set at the microcontroller, then a period of the inverter output voltage is generated synchronised to the grid voltage. This circuit presents a drawback. It requires a very stable grid voltage. In case of a severe voltage sag at the point of commom connection a wrong zero crossing can be seen by the synchronisation circuit.

7. Experimental Results

Some experimental results are shown to demonstrate the performance of the system. The following waveforms are related the inverter. Fig.12 and 13 show the drive signal waveform across power MOSFET switches S_2 and S_1.

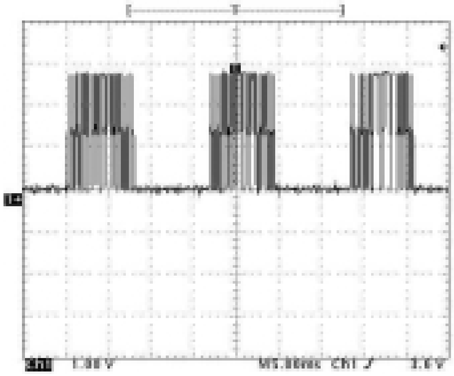

Fig. 12 Microcontroller Generated Drive Signal Waveform (S_2)

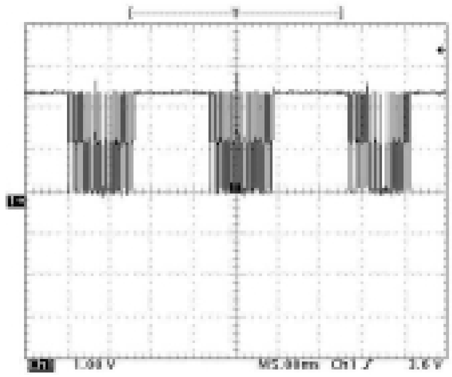

Fig. 13 Microcontroller Generated Drive Signal Waveform (S_1)

It can be seen the sinusoidal switching strategy in operation.

The Fig.14 shows the inverter output voltage V_{AN} at the secondary of the single-phase transformer supplying a resistive load.

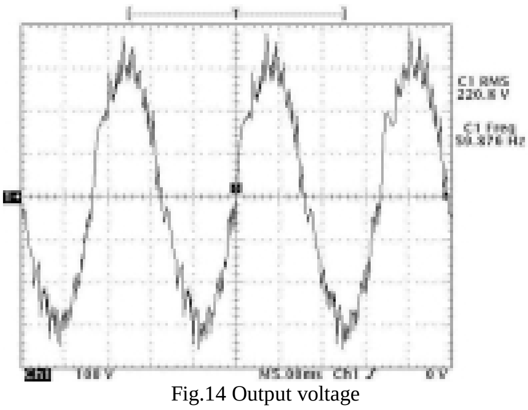

Fig.14 Output voltage

Fig.15 shows resistive load current.

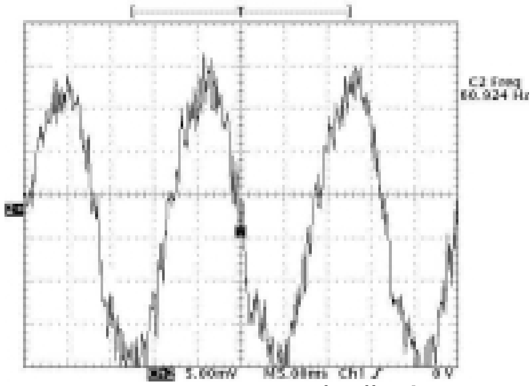

Fig.15 PV system output current for off-grid operation

Fig. 16 shows the PV system output current and voltage for off-grid operation.

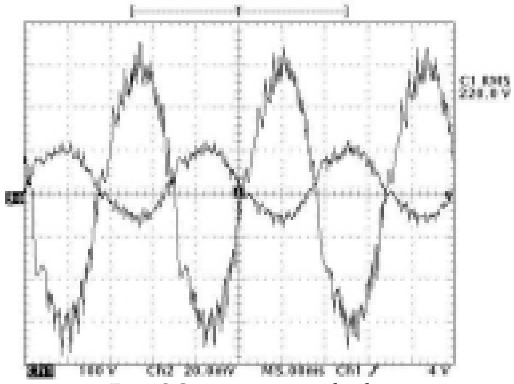

Fig. 16 Output current and voltage

The waveform shown in Fig.17 is related to the PV system connected to the grid, where it is seen the output voltage and current waveforms. The current waveform at the point of common coupling is highly distorted. This situation does not occur for off-grid operation as shown in Fig.16. The distortion presented by the current injected at the grid can be eliminated by a control circuit which imposes a sinusoidal current at the PCC. To attend the utility requirements for harmonic distortion a current controller is been implemented.

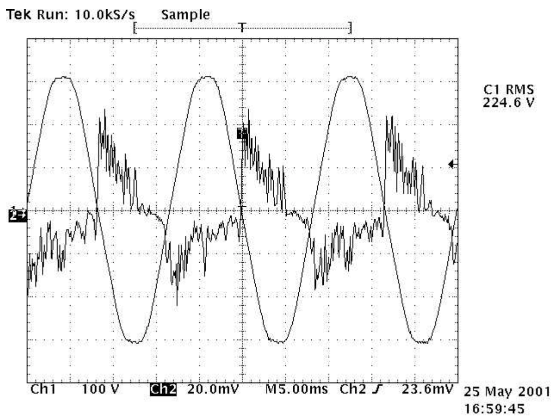

Fig. 17 PV Output voltage and current system connected to the grid.

8. Conclusion

This paper has presented the design and laboratory implementation of a static converter to supply ac load from PV system. The system can also be interconnected to the grid, as part of distributed generation system.

The converter is made up of a single-phase voltage source inverter (VSI) with sinusoidal PWM strategy. The VSI driven by a sinusoidal PWM strategy matches the converter output voltage to the one of the grid.

The system has been designed for 200Wp. The whole system has been implemented in laboratory and the experimental results have been shown to access the performance of the proposed system.

As far as the grid-connected operation, the current at the PCC is highly distorted. The distortion presented by the current injected at the grid can be eliminated by a control circuit which imposes a sinusoidal current at the PCC. To attend the utility requirements for harmonic distortion a current controller is been implemented.

The solar energy available varies considerably during the day, and according to weather conditions. Therefore, the use of a Maximum Power Point Tracker (MPPT) is to be considered. The implementation of the MPPT has not been discussed because it has been presented in [4,6]. Finally, it is important to point out the importance of Power Electronics in the context of renewable energy.

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