

Boost-Half-Boost Photovoltaic System Using SPWM Control and MPPT

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ABSTRACT: The photovoltaic (PV) power generation market, the AC PV module has shown obvious growth. However, a high voltage gain converter is essential for the module's load connection through a DC-AC inverter (or) stand-alone inverter. This paper proposes a load-connected boost-half-bridge photovoltaic (PV) inverter system and its control implementations using microcontroller (PIC16F877A). In order to achieve low cost, easy control, high efficiency and high reliability, a boost-half-bridge DC-DC converter using minimal devices is introduced to interface the low voltage PV module. A full-bridge pulse-width modulated inverter is cascaded with the boost converter. High power factor and very low harmonic distortions are guaranteed under both heavy load and light load conditions. Dynamic stiffness is achieved when load or solar irradiance is changing rapidly. In addition, the dynamic behaviour of the boost-half-bridge DC-DC converter is analyzed; a customized maximum power point tracking (MPPT) method, which generates a ramp-changed PV voltage reference, is developed accordingly. Variable step size is adopted such that fast tracking speed and high MPPT efficiency are obtained. A 54W prototype was fabricated and tested, the relevant features such as high power density, high switching frequency, galvanic isolation and efficiency greater than 90% over a wide output load range.

KEYWORDS: Boost-half- bridge, load-connected photovoltaic (PV) system, maximum power point tracking (MPPT), photovoltaic inverter.

I. INTRODUCTION

Renewable energy sources play an important role in electricity generation. Various renewable energy sources like wind, solar, geothermal, ocean thermal and biomass can be used for generation of electricity and for meeting our daily energy needs. Energy from the sun is the best option for electricity generation as it is available everywhere and is free to harness. On an average the sunshine hour in India is about 6hrs annually also the sunlight shines in India for about 9 months in a year. Electricity from the sun can be generated through the solar photovoltaic module. In this prototype, Maximum Power Point Tracking (MPPT) is used in Photo Voltaic (PV) systems [8] to maximize the photovoltaic array output power, based on the simple and effective P&O algorithm. The final output of the prototype from the 12V DC, 10W solar panel is 230V AC, 54W.

The aim of this research is mainly to design and develop the SPWM switching pulse [6] for single phase full bridge inverter application. The main objectives of this research can be summarized as:

1. To design and implement switching strategy for inverter application, which are simple, reliable, low cost and high efficiency.
2. To develop sinusoidal pulse width modulation switching pulses with bipolar voltage switching using PIC16F877A microcontroller.

To develop a complete prototype of inverter with 54W power rating for photovoltaic application.

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II. BOOST HALF-BRIDGE PV INVERTER

A solar cell (also called photovoltaic cell) is a solid state device that converts the energy of sunlight directly into electricity by the photovoltaic effect. Assemblies of cells are used to make solar modules, also known as solar panels. The energy generated from those solar modules [1], referred to as solar power. A possible implementation of an isolated DC-AC converter, which can be successfully used.

PV cells are semiconductor devices, with electrical characteristics similar to a diode. However, a PV cell is a source of electricity, rather than an electrical load (a diode), and operates as a current source when light energy, such as sunlight, makes contact with it. A PV cell will behave differently depending on the size of the PV panel or type of load connected to it and the intensity of sunlight (illumination)[4]. This behaviour is called the PV cell characteristics. The characteristics of a PV cell are described by the current and voltage levels when different loads are connected. The current in this case is called a short circuit (ISC) current.

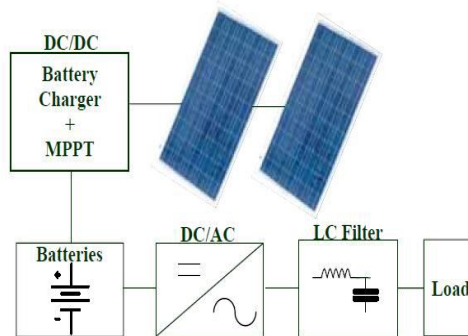


Fig.1. Topology of the Boost-half-bridge PV inverter (source: Grid-connected photovoltaic generation system, IEEE, 2008)

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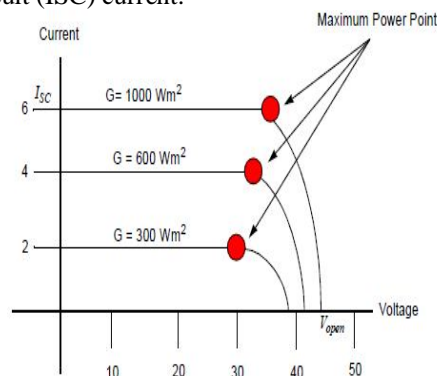


Fig.2. I-V versus illumination (source: A Review of the Single Phase Photovoltaic Module Integrated Converter Topologies with Three Different DC Link Configurations, IEEE, 2008)

Comparisons can be made to the electrical characteristics of different PV cells as these measurements are made at standard test conditions (STC), which are defined as a light intensity of 1000 w/m² and a temperature of 25°C. The light intensity as well as temperature affects the PV cell characteristics. Current is directly proportional to light

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intensity. Voltage also changes with fluctuating light levels, but the change in the voltage is less. Voltage is more affected by changes in the temperature of the PV cell than the current. An increase in cell temperature decreases the voltage and increases the current by a very small amount. It affects an I-V curve. It can be seen that changing (decreasing) the light intensity has a much greater effect than changing (increasing) the temperature. This is true for all commonly used PV materials and the Fig.3.shows the simplified model of a PV cell. The important result of these two effects is that the power of a PV cell decreases when light intensity decreases and/or temperature increases.

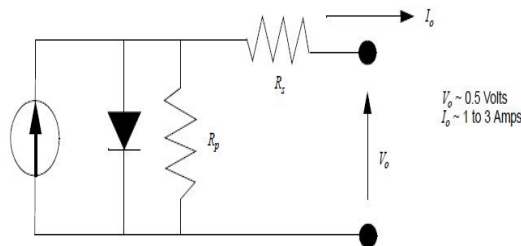


Fig.3. Simplified model of a PV cell (source: A new panel-integratable inverter concept for photovoltaic systems, IEEE, 1995)

III. SOLAR ENERGY CONVERSION

Solar power is a clean renewable energy resource, and will be very important for the future of this planet. Energy from the sun is converted to electrical energy via the photoelectric effect using many photo voltaic cells in a PV panel which is shown in the Fig.4. Power from a PV panel is dc while the utility grid requires ac power. The dc power from the PV panel must be converted to ac power, of a suitable quality, and injected into the grid. This is done using an inverter.

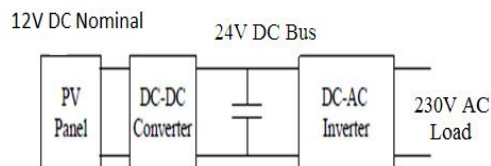


Fig.4. Simplified model of PV inverter

The low DC voltage from the PV panel must first be boosted to 350V DC. This high DC voltage is then suitable for the inverting stage, which injects AC current in phase with the 240V AC load.

IV. PV PANEL SPECIFICATIONS

The converter must be designed to function with a 120W and 60W solar panel. shown below Fig.5. is the I-V curve from the 120W and 60W panels.

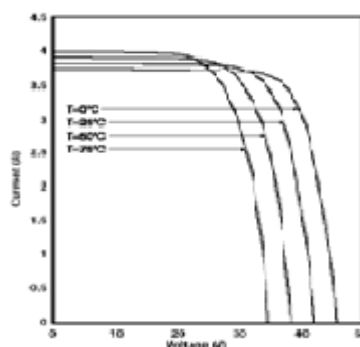


Fig.5. I-V curve for 60W panel

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From the curves it can be seen that the design must handle a maximum short circuit current of 4A, and a maximum open circuit voltage of 45V. It should also be noted that under normal operation, the PV panel voltage can drop down to as low as 10V. For the design it was assumed that the panel will operate at 24V 4A, giving a power output of 96W. These values will be used in the design of the converter.

V. SYSTEM CONTROL ORGANIZATION

A) MAXIMUM POWER POINT TRACKING (MPPT)

Maximum Power Point Tracking (MPPT) is used in Photo Voltaic (PV) systems to maximize the photovoltaic array output power, irrespective of the temperature and irradiation conditions. The dc output power sourced from the solar panel is periodically computed. The following Fig.6. Shows the block diagram of MPPT used in the circuits.

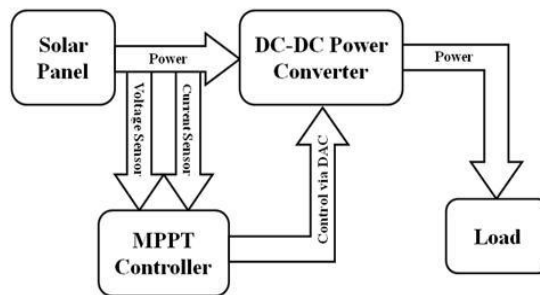


Fig.6. Block diagram of MPPT in the circuits

This is based on any one of the following algorithms,

1. The P&O algorithm
2. The incremental conductance algorithm
3. Ripple correlation method
4. Reduced current sensor method
5. Fuzzy logic control
6. Fractional open circuit voltage or short circuit current
7. Current sweep

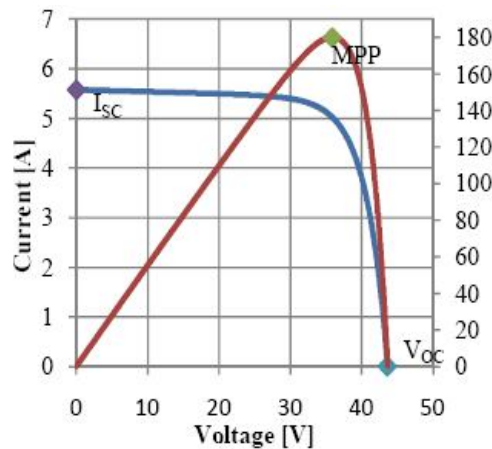


Fig.7. PV panel characteristic curves (source: Maximum Power Point Tracking Techniques, IEEE, 2007)

Among these techniques, the P&O [9] and the incremental algorithms are the most common. These techniques have the advantage of an easy implementation.

If there is an increment in the power, the perturbation should be kept in the same direction and if the power decreases, then the next perturbation should be in the opposite direction. Based on these facts, the algorithm [11] is implemented.

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The process is repeated until the MPP is reached. Then the operating point oscillates around the MPP. A scheme of the algorithm is shown in Fig.8.

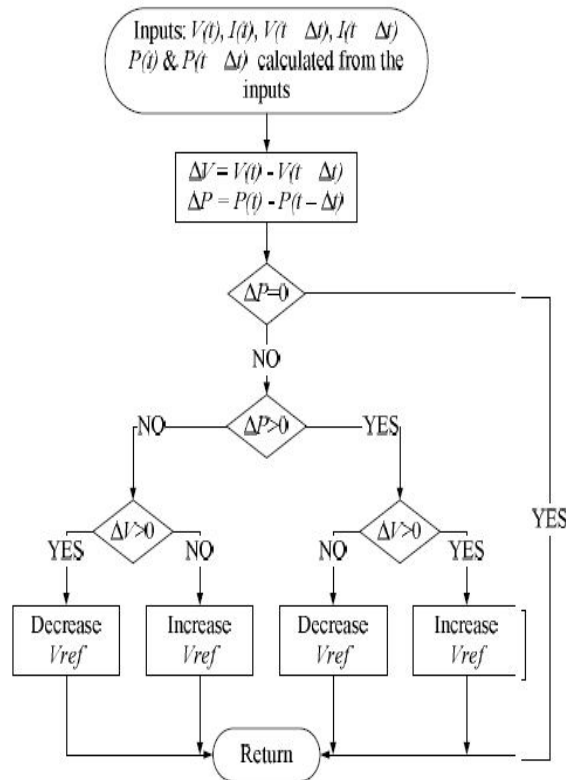


Fig.8. Flow chart for P&O algorithm (source: Grid-Connected Boost-Half-Bridge Photovoltaic Micro inverter System Using Repetitive Current Control and MPPT, IEEE, 2012)

B) MICRO-CONTROLLER

A micro-controller will be used on the dc side to control the boost converter. Most analog control circuits can be implemented in a micro-controller, and micro-controllers are becoming very inexpensive. Using a micro-controller also means that the control implementation is not fixed in hardware, and can be updated in software.

MEMORY ORGANIZATION

There are two memory blocks in each of the PIC16F877A MUC's. The program memory and data memory have separate buses so that concurrent access can occur.

1. A micro-controller is a single integrated circuit, commonly with the following features:
 - a) Central processing unit- ranging from small and simple 4-bit processors to complex 32 or 64-bit processors.
 - b) Volatile memory (RAM) for data storage.
 - c) ROM, EPROM, EEPROM, or Flash memory for program and operating parameter storage.
2. Serial Input/ Output such as serial ports (UATs).
 - a) Other serial communications interfaces like PC, Serial Peripheral Interface and Controller Area network for system interconnect.
 - b) Peripherals such as timers, event counters, PWM generators and watch dog.
 - c) In circuit programming and debugging support.

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C) PWM GATE DRIVE CIRCUIT PULSE WIDTH MODULATOR CONTROLLER (SG3525A)

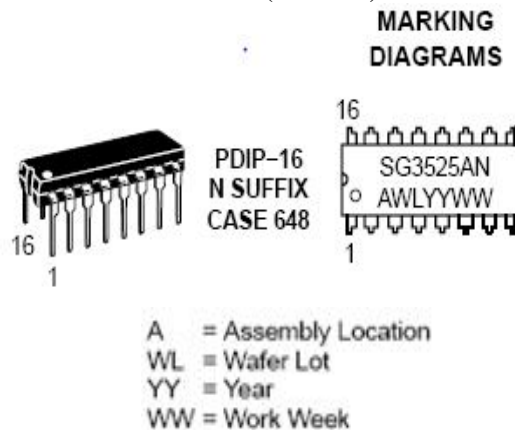


Fig.9. SG3525A packaging

PWM is used in all sorts of power control and converter circuits. Some common examples include motor control, DC-DC converters, DC-AC inverters and lamp dimmers. There are numerous PWM controllers available that make the use and application of PWM quite easy. One of the most popular of such controllers is the versatile and ubiquitous SG3525, whose package is shown in the Fig.9.

SG3525 is used extensively in DC-DC converters, DC-AC inverters, home UPS systems, solar inverters, power supplies, battery chargers and numerous other applications and its block diagram is shown in Fig.10.

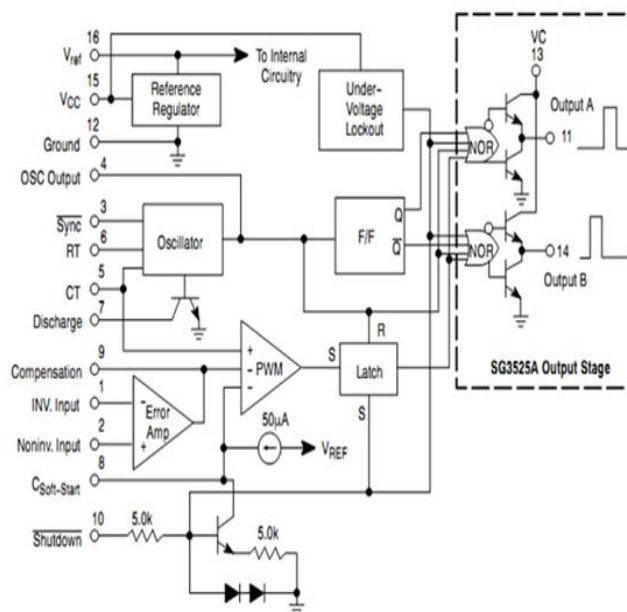


Fig.10. Representative block diagram for SG3525 (source: Development of a Microcontroller-Based, Photovoltaic Maximum Power Point Tracking Control System, IEEE, 2001)

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VI. POWER SUPPLY CIRCUIT

A) VOLTAGE REGULATOR (LM78XX)

The LM78XX series of three terminal positive regulators are available in the To-220/D-PAK package (Fig.3.10) and with several fixed output voltages, making them useful in a wide range of applications. Each type employs internal current limiting, thermal shut down and safe operating area protection, making it essentially indestructible. If adequate heat sinking is provided, they can deliver over 1A output current.[14]-[17]

The internal block diagram of LM78XX is shown in the Fig.11.

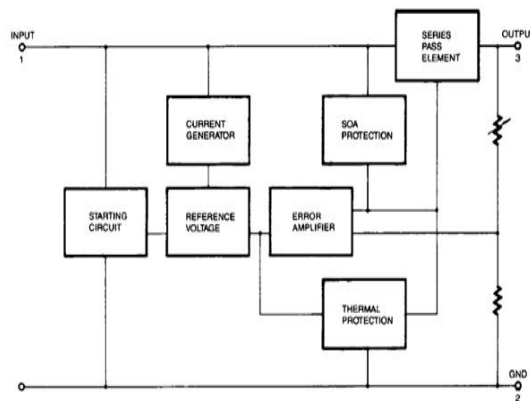


Fig.11. Internal block diagram of LM78XX

B) DC-DC CONVERTER

The DC-DC converter boosts the low DC voltage from the PV panel up to 350V for use by the inverter. The half-bridge boost converter was the chosen topology. The half bridge is a voltage fed converter, while the half bridge dual is a current fed converter. Because the half-bridge dual is boost derived, rather than buck derived it is suited for higher input currents, and higher output voltages, which is ideal for a PV system.

C) FULL-BRIDGE INVERTER

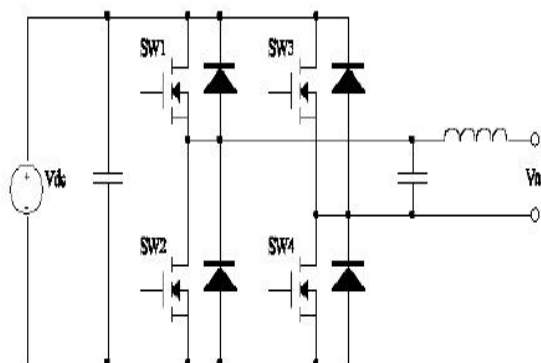


Fig.12. Full-bridge inverter (source: High-performance repetitive control of PWM DC-AC converters, IEEE, 2006)

The Fig 12 is shown Single Phase Full wave Bridge Inverter. The switches are t1, t2, t3 and t4. The switches in each branch is operated alternatively so that they are not in same mode (on /off) simultaneously .In practice they are both off for short period of time called blanking time[5], to avoid short circuiting. The switches t1 and t2 or t3 and t4 should operate in a pair to get the output.

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Table-1 Switching states

T1	T2	T3	T4	V_A	V_B	V_{AB}
ON	OFF	OFF	ON	$\frac{V_s}{2}$	$-\frac{V_s}{2}$	V_s
OFF	ON	ON	OFF	$+\frac{V_s}{2}$	$+\frac{V_s}{2}$	$-V_s$
ON	OFF	ON	OFF	$\frac{V_s}{2}$	$-\frac{V_s}{2}$	0
OFF	ON	OFF	ON	$-\frac{V_s}{2}$	$+\frac{V_s}{2}$	0

The full-bridge inverter will be switched using uni-polar switching, in order to reduce output harmonics. The main relationship between the input and output voltages of the inverter is,

$$V_{out} = m_a V_{bus}$$

Where, V_{out} is the peak value of the output fundamental harmonic.

In practice V_{out} will be the inverter's output voltage, which will be a 50 Hz sinusoidal.

D) SINUSOIDAL PULSE WIDTH MODULATION

In this modulation technique are multiple numbers of output pulse per half cycle and pulses are of different width. The width of each pulse is varying in proportion to the amplitude of a sine wave evaluated at the centre of the same pulse. The gating signals are generated by comparing a sinusoidal reference with a high frequency triangular signal [6]. The rms ac output voltage,

$$V_o = V_s \sqrt{\frac{p\delta}{\pi}} \rightarrow V_s \sqrt{\sum_{m=1}^{2s} \frac{\delta_m}{\pi}}$$

Where, p =number of pulses and δ = pulse width.

The output waveform for the sinusoidal pulse-width modulation is shown in the Fig.14.

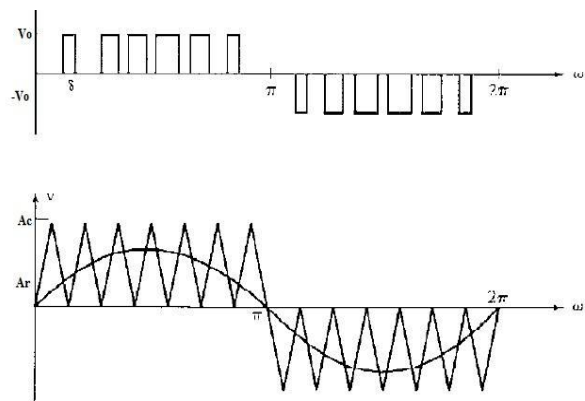


Fig.13.Sinusoidal pulse width modulation

VII. CONCLUSION

A boost-half-bridge inverter for standalone PV systems has been presented in this paper. The operation principles and dynamics of the boost-half-bridge DC-DC converter were analyzed and a customized MPPT control method was

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developed correspondingly. The minimal use of semiconductor devices, circuit simplicity and easy control, the boost-half-bridge PV inverter possesses promising features of low cost and high reliability. High efficiency (97.0%–98.2%) is obtained with the boost-half-bridge dc–dc converter over a wide operation range. Moreover, the current injected to the load is regulated precisely and stiffly. High power factor (>0.99) and low THD (0.9%–2.87%) are obtained under both heavy load and light load conditions. Finally, the customized MPPT method that generates a ramp-changed reference for the PV voltage regulation guarantees a correct and reliable operation of the PV inverter system. The variable step-size technique provides a fast MPPT tracking speed and a high MPPT efficiency ($>99.7\%$). As a result, the proposed boost-half-bridge PV micro-inverter system with its advanced control implementations will be a competitive for grid-connected PV applications.

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