



DESIGN OF A HIGHLY EFFICIENT PURE SINE WAVE INVERTER FOR PHOTOVOLTAIC APPLICATIONS

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Abstract: This paper presents a grid tie inverter for photovoltaic, PV application with a combination switching strategy of sinusoidal pulse width modulation, SPWM. The combination switching strategy will be discussed and the performance of the inverter also will be simulated under grid tie condition in SIMULINK. Besides that, the strategy of sending power into the grid also will be discussed. The input voltage of inverters fluctuates dramatically in distributed generation applications such as in a wind energy system. Yet, a high quality ac output is required for grid interconnection under variable source conditions. Previously developed control strategies mainly focused on improvements under load variations, a dc input of relatively small ripples, etc. This paper proposed a closed-loop sinusoidal PWM control method with real-time waveform feedback techniques for a grid-connected buck-boost inverter. The control-to-output function was derived through steady state modeling based on the power balance condition, which provides an approach when the output cannot easily be characterized in a single-stage buck-boost inverter. The closed loop control model was studied with a newly-invented single stage buck-boost inverter circuit. Simulations verified the method provided fast dynamic response and robustness under large dc voltage variations, non-ideal grid voltage, and component parametric uncertainties. This problem is greatly rectified, that could produce output with higher efficiency of about 97% and reduces the harmonics to a greater extent. To reduce the cost, low frequency transformer is used thus proves to be cost effective. This project proposed a closed-loop sinusoidal PWM control method with real-time waveform feedback techniques. The controlled inverter achieved a low-THD sinusoidal output with a small ac filter and without a dc

link capacitor. Therefore, it is concluded that the proposed method can be a preferred choice for grid connected buck-boost inverters in distributed generation systems.

1. INTRODUCTION

In this early stage of marketing solar electric power systems to the residential market, it is advisable for an installer to work with well-established firms that have complete, pre-engineered packaged solutions that accommodate variations in models, rather than custom designing custom systems. Once a system design has been chosen, attention to installation detail is critically important. Recent studies have found that 10-20% of new PV installations have serious installation problems that will result in significantly decreased performance. In many of these cases, the performance shortfalls could have been eliminated with proper attention to the details of the installation.

Energy crisis are of special attention now a days. A need for power rating inverter is required to smoothly operate electrical and electronic appliances. Most of the commercially available UPS or IPS is actually square wave or quasi square wave inverters. Electronic devices run by this inverter will damage due to harmonic contents. Available sine wave inverters are expensive and their output is not so good. For getting pure sine wave we have to apply sinusoidal pulse width modulation (SPWM) technique. The pulse width modulation inverter has

been the main choice in power electronics because of its simplicity. Sinusoidal pulse width modulation is the mostly used method in motor control and inverter application to generate this signal, triangular wave is used as a carrier signal is compared with sinusoidal wave at desired frequency.

1.SPWM TECHNIQUES FOR BOOST CONVERTERS

Myriads of voltage- and current-mode strategies have devoted to the control of inverters in power electronics. Of those voltage control strategies, space vector modulation (SVM) was widely used in three-phase inverters. However, it requires extensive calculations, thereby limiting the bandwidth of control systems. Function approximation can simplify the execution, but also reduces the accuracy. Some improved SVM methods based on artificial neural networks can reduce computations while still retain accurate results. Random PWM addresses the problems of acoustic noise and radio interference. Optimal switching pattern PWM methods were proposed to either reduce the output filter size or compensate for a non-ideal dc-link voltage. When large disturbances and uncertainties exist, these methods need to be combined with complicated model reference adaptive systems, H_∞ loop-shaping, and fuzzy logic or neural network controllers to track desired trajectories or reference models. Current control strategies, like hysteresis current control (HCC), provide the tightest control of output current in a traditional full-bridge inverter. However, for single-stage buck-boost inverter, the output current usually cannot be directly controlled and these methods introduce lower-order harmonics in the output current. Variable structure control was introduced and applied to power electronics with the strengths of large signal stability and robustness. Although this method is extremely useful for tracking problems, it is not popular due to its theoretical complexity and difficulty in finding a satisfactory sliding surface.

Furthermore, sensing of all state variables and generating of references adds to the cost for a low power inverter system. Single-stage buck-boost inverters can operate under wide dc input voltage ranges and variations, thus presenting a low-cost solution for small wind energy distributed generation systems. This project is intended to establish a simple yet effective control method for such inverters

tolerant of large dc voltage fluctuations and ac grid variations. Specifically, a new closed-loop sinusoidal PWM (SPWM) control method is proposed through the evolution from open-loop, reference feed forward, to closed-loop control analyses. Advantages of this method are demonstrated by simulation of a grid-connected single-stage buck-boost inverter.

2.GRID CONNECTED PHOTOVOLTAIC SYSTEM

The photovoltaic (PV) power generation systems are renewable energy sources that expected to play a promising role in fulfilling the future electricity requirement. The PV systems principally classified into stand-alone, grid connected or hybrid systems. The grid-connected PV systems generally shape the grid current to follow a predetermined sinusoidal reference using hysteresis-band current controller, which has the advantages of inherent peak current limiting and fast dynamic performance. Figure 2.1 shows the schematic diagram of a grid connected PV system. It typically consists of two main parts: the PV array and the power conditioning unit (PCU). The PCU typically includes:

- A Maximum Power Tracking (MPPT) circuit, which allows the maximum output power of the PV array.
- A Power Factor (PF) control unit, which tracks the phase of the utility voltage and provides to the inverter a current reference synchronized with the utility voltage.
- A converter, which can consist of a DC/DC converter to increase the voltage, a DC/AC inverter stage, an isolation transformer to ensure that the DC is not injected into the network, an output filter to restrict the harmonic currents into the network.

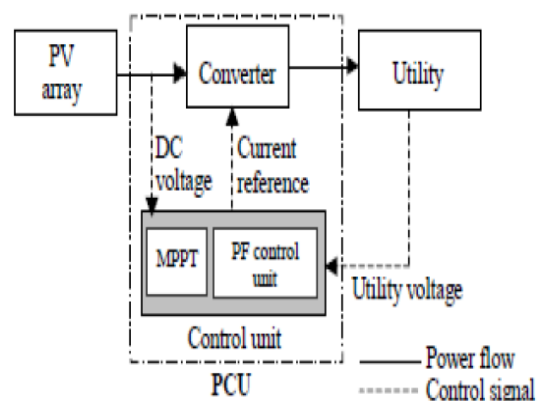


Figure 1 : Schematic diagram of Grid Connected – PV System

3. SINGLE PHASE INVERTER TECHNIQUES

There are two types of single phase inverters i.e. full bridge inverter and half bridge inverter. Half Bridge Inverter: The half bridge inverter is the basic building block of a full bridge inverter. It contains two switches and each of its capacitors has an output voltage equal to $V_{dc}/2$. In addition, the switches complement each other i.e. if one is switched ON the other one goes OFF. Full Bridge Inverter: This inverter circuit shown in Figure 2 converts DC to AC. It is obtained by turning ON and OFF the switches in the right sequence. It has four different operating states which are based on which switches are closed. A low cost, microcontroller-based sinusoidal power source with variable voltage variable frequency (VVVF) is developed. MOSFET H-bridge inverter is used in power source with a standalone LCD as a display system. Sinusoidal pulse width modulation signals are generated for the driver circuit of the inverter.

In sinusoidal pulse width modulation (SPWM), pulses are generated with constant amplitude but having different duty cycles for each period. The developed system has been properly worked for an ac voltage range of 30–80V RMS and a frequency range of 40–70 Hz. The power source is having an incorporated ROM-based LUT which provides desired performance and additional robustness for achieving proposed system capability. The system uses two microcontrollers where one of them microcontroller is used to generate the proposed variable frequency sine wave PWM drive and the other one microcontroller is used for controlling the stand alone LCD display of the developed power source.

A single phase inverter is design and implemented by using IGBT as switch and the output responses are studied. The inverter consists of the control circuit and the power circuit where the control circuit is used to generate the gate pulses to trigger the IGBTs and the power circuit consists of IGBTs and according to the duty cycle of the gate pulses these IGBT's can be turn on and off. The pulse width modulation i.e. PWM technique has been used. Single phase inverters are of three types i.e.

square wave inverter, modified sine wave inverter and pure sine wave inverter. Pulse Width Modulation (PWM) technique is best for sine wave generation.

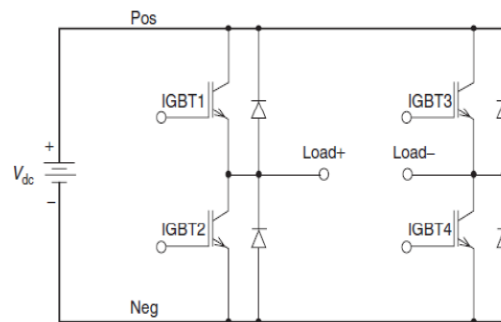
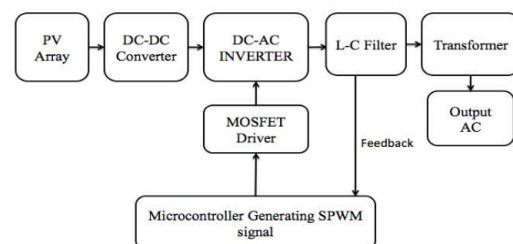


Figure 2 : Single Phase Full bridge Inverter

4. PROPOSED SYSTEM

Figure 3 shows the block diagram of the proposed PV inverter system, the construction of which contains H-bridge configuration closed-loop SPWM technique, DC-DC converter to utilize power between solar panel and inverter, a low frequency



transformer, and passive low pass L-C filter.

Figure 3 : Block Diagram of Proposed PV Inverter System

The proposed single-phase H-bridge inverter was first simulated using PSIM software. Figure shows the schematic diagram of proposed dc-ac PV

system in PSIM. Since H Bridge is bucking mode converter that requires an input voltage higher than the designed output voltage. In this case we employed boost converter between PV array and inverter that step-up PV arrays 24V DC voltage into

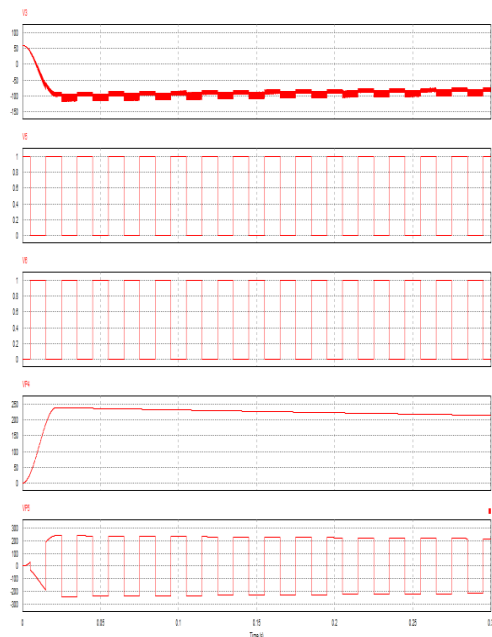


Figure 4: Simulated Output Waveforms

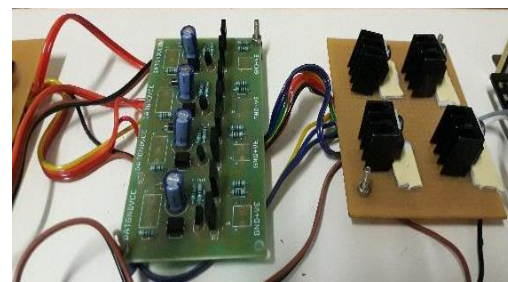
312V DC. This converter topology consists of four MOSFETs, which requires four sets of switching signals. SPWM technique is applied to control the switching of the inverter. Figure 4 shows the simulated output voltage waveform which is non-sinusoidal, distorted, and contains excessive harmonics. Thus, a low pass L-C filter is employed at the output terminal of the inverter to reduce the harmonics. After filtering, we obtained 220V (rms), 50Hz pure sine wave output voltage and current waveform. Based on simulation result a prototype of the proposed PV inverter system has been built and tested in the lab for validation. The Figure 4.4 illustrates the PWM output waveform of H bridge inverter that is later converted to pure sine wave by employing a passive low-pass L-C filter, which eliminates the harmonic components of output waveform and produces a pure sine wave. Figure 5.3

shows the sine wave output voltage across the resistive load.

Therefore, we implemented a closed-loop control scheme by a PIC16F628 microcontroller that senses and provides the necessary output voltage at every point of the distorted curve and makes a correction of those points where the curve is distorted. We termed this as error index of the closed-loop system. Figure 4.4 shows the final pure sine wave output voltage of 220V (rms) of the inverter and First Fourier Transform (FFT). The FFT demonstrates that the fundamental harmonic component lies at 50 Hz and rest of the harmonic components are negligible. After filtering the output voltage, the total harmonic distortion (THD) reduced too much lower level of less than 0.6%.

5.HARDWARE IMPLEMENTATION

This proposed inverter hardware design consists of two major parts: one is control circuit and other is power circuit. In prototype, inverter power circuit consists of four IRF3205 MOSFETs in H-bridge configurations. The inverter circuit divides into high side and low side. The high side gate at the H-bridge requires 10V to 12V more than the driven voltage at the MOSFET. This voltage can be generated with MOSFET gate driver TLP250. TLP250 has high reliability factor and its bootstrap circuit has been accomplished this work and thus to turn on the high-side MOSFET. The bootstrap capacitor voltage rise +V above the high-side emitter,



providing the necessary gate drive voltage.

Figure 5. MOSFET and its driver circuit

In our design the low frequency transformer is employed that was built in such a way so that it acts

as an inductor and the output should have a capacitor which has greater than 250V, and the capacity of the capacitor will depend on the inductance of the transformer. Therefore, the inductance L of transformer and output capacitor should form an L-C passive filter. Thus, the use of transformer's inductance as inductor makes sure to use any extra inductor and thus, it reduced the cost of the system. We used a low frequency transformer that is available in the local market and gives high performances. The transformer is designed to ensure that the flux density in the core of the transformer is maintained considerably high which in fact minimizes the eddy current loss of the transformer. Also, to reduce the price, the inductance of the transformer is used as an inductor in the filter circuit instead of using an additional inductor. Furthermore, aluminium shield has been used above the surface of the transformer to minimize the eddy current loss. If properly turned on, our designed transformer should give 95-97% efficient output.

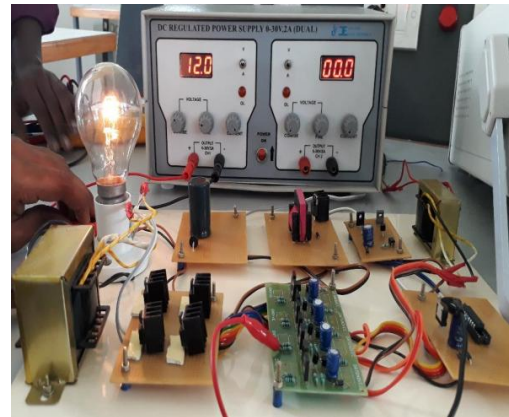


Figure 6 : Filter and low frequency transformer circuit

Figure 7 : Resistive load connected with the inverter circuit

6.CONCLUSION

To demonstrate the inverter a resistive load such as light bulb is connected to it and tested it by giving the supply. Input 9V DC supply produces the output voltage of about 220V AC essential to make the bulb glow brightly. The 9V DC supply is first fed into the boost converter and then H-Bridge inverter which is triggered by the driver circuit using microcontroller. The square wave obtained from the MOSFET (H-Bridge Inverter) then fed into the filter circuit to



convert to pure AC waves with less harmonics using low frequency transformer. Similar to the resistive load, inductive and capacitive loads could also be connected to the device and the power factor factors and its harmonics could be determined that is very efficient when comparing with other inverters.

This paper presents the design and implementation of a pure sine wave inverter for photovoltaic applications. Various advantages exist in the proposed system such as low switching loss, high efficiency, low cost, small size and simple control. Simulation and experimental results of the proposed inverter show that power from PV array can be converted to pure sine wave output voltage of 220V (rms) with a THD below 0.6%, while the FFT analyses confirm that the fundamental harmonic component lies at 50 Hz and higher harmonic components are completely eliminated. Thus it can be concluded that the proposed sine wave inverter is ideal for the photovoltaic power system in residential applications.

7.FUTURE SCOPE

A single-phase transformer less photovoltaic inverter for residential application will be the future scope of this project. The inverter is derived from a boost cascaded with a buck converter along with a line frequency unfolding circuit. Due to its novel operating modes, high efficiency can be achieved because there is only one switch operating at high frequency at a time, and the converter allows the use of power MOSFET and ultra-fast reverse recovery diode. It also features a robust structure because the phase leg does not have a shoot-through issue. And the model indicates that small boost inductance will lead to an increase in the resonant pole frequency and a decrease in the peak of Q , which results in easier control and greater stability. Thus, interleaved multiple phase structure is proposed to have small equivalent inductance; meanwhile, the ripple can be decreased, and the inductor size can be reduced as well. A two-phase interleaved inverter is then designed accordingly.

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