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Solar Power Embedded Based SVPWM Generator for Three Phase Inverter

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***Abstract*—The inverters are the major electronic conversion in the application of renewable energy utilization, variable motor drives and uninterruptible power supply. Most of the inverters utilize Pulse Width Modulation (PWM) technology which has a lot of protection and control circuits. The Sinusoidal based PWM (SPWM) technique has been used to design a single phase inverter in Field Programmable Gate Array (FPGA), which has serious disadvantages or flaws in current flow and range of Total Harmonic Distortion (THD) is high. For utilization of renewable energy sources, modeling of three-phase inverter is completed by using Space Vector based PWM (SVPWM). The experimental results have Attained THD less than 3% which is within tolerable range. The MATLAB and SIMULINK software is used for simulation and analyses purposes.**

Keywords— Inverters; Renewable Energy; PWM; SPWM; SVPWM; THD

I. INTRODUCTION

AC drives are more prevalent than dc drives. It requires high power variable voltage and variable frequency supply. The exploration in pulse width modulation technique has been intensive in the last couple of decades [1]-[6]. These techniques have been used to achieve variable voltage and variable frequency in ac-dc and dc-ac converters. So it is widely used in different fields like variable speed drives (VSD) [2], stable frequency changers (SFC), un-interruptible power supplies (UPS) [1] etc. The major problems faced by the power electronic design engineers are about the reduction of harmonic content in inverter circuits. The classical square wave inverter which is to be used in low or medium power applications suffers from a serious disadvantage such as presence of lower order harmonics in the output voltage. To enhance the harmonics free (distortion free) outputs in high power converter, a PWM control technique may be used.

The major objective of generating high quality sinusoidal signal with an influence of Bit-Stream based PWM technique which is processed by digital logic. Due to the inherent filtering action of the inductive loads and the bandwidth of the current sensors makes the performance metrics to be misleading and hence comparison is difficult. Finally the implementation cost is also high [2].

Traditionally, the DPWM Architecture is implemented for effective synchronization with high resolution in order to avoid the requirements of high frequency clocks. This technique applies ON or OFF duty cycle switching frequency. Low resolution, in this case occurs due to high switching loss [3]. Reduction of harmonics plays the major role in the inverter, so it requires three sinusoidal waves with 120 degree apart as reference signals for three phase inverter. As a result of it, the quality of the signal gradually increases [4]. A pure sinusoidal wave is produced.

Within a classical PWM method, a particular method called generalized scalar PWM approach is used to generate the pulse pattern [5]. In addition to that, the generation of SPWM for inverter with a utilization of solar power is implemented in FPGA for the domestic appliances [6]. PWM switching strategies not only addresses the primary issues like less THD, effective dc bus utilization but also in case of the secondary issues, such as EMI reduction, switching loss, sharpened spreading of Harmonics over the spectrum. Real-time approach of PWM generation can be broadly classified into Triangle Comparison based PWM (TCPWM) and Space Vector based PWM (SVPWM) [7].

In TCPWM approach, it comprises of sine-triangle PWM. In case of three-phase inverter, the reference modulating signals get compared with the common triangular carrier signal to generate PWM pulses. While performing these operations, carrier signal frequency is high when it is compared with modulating signal. It is simple and linear between 0% and 78.5% of six step voltage values, which results in poor voltage performance. In SVPWM technique, a reference signal V_{ref} is sampled with a frequency f_s ($T_s = 1/f_s$). The reference signal may be generated from three separate phase references using the αβγ transformation. It utilizes dc bus voltage more efficiently and generates less harmonic distortion in a three phase voltage source inverter [7]-[8]. The nonlinear loads can be controlled by interfacing renewable sources with grid in single-phase inverter [9]. There is a disadvantage of high ripple current in utility interfaced phase modulated high frequency converter [10]. A sufficient power from renewable sources for various applications in different domains like DSP, is achieved by using Maximum Power Point Tracking (MPPT) algorithm [11], [12]. The vector based PWM can be implemented in different application via supportable new software [13], [14]. Various optimal designs of inverter for solar home can be demonstrated and analyzed as shown in reference [15].

II. SINUSOIDAL PWM FOR SINGLE PHASE INVERTER

Sinusoidal PWM is a type of "carrier-based" pulse width modulation. Modulating PWM uses pre-defined modulation signals to determine output voltages. In SPWM, the modulation signal is sinusoidal, with the peak of the carrier signal always less than the peak of the modulating signal. The purpose of using this technique is to adjust the *dc* or *ac* inverter output voltage amplitude and frequency to a desired value.

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In this case, either MOSFET or IGBT's are used as power inverter switches. The functionality of switching activity performs ON or OFF state switching according to the result of the comparison between a high-frequency, constant-amplitude triangular carrier wave with two low-frequencies (e.g., 50 Hz) of reference sine waves which have adjustable amplitude and frequency. The generated pulse may either positive or negative pulse during each half period of SPWM pulse.

Thus the harmonic content in SPWM pulse can be filtered using LCL filter. Therefore it produces high-power and low-frequency sinusoidal waveform V_o at the output terminals of the *dc* or *ac* inverter.

A. SPWM Signal Generation

The hierarchy level of generating SPWM signal add two reference sine-waves along with one carrier signal. Initially the reference signals get sampled with the constant sampling frequency of 60 Hz. After this operation, the corresponding samples are stored in Lookup Table (LUT) i.e., in internal memory on FPGA. Compare sinusoidal and carrier signal with SPWM control signal which is generated by Direct Digital Synthesis (DDS) technique using high-speed analog comparator. Internal memory reduction is done by Co-ordinate Rotation Digital Computer (CORDIC) algorithm.

B. Architecture of SPWM generation unit

The architecture of the SPWM generation unit is presented in Fig. 1. It is built by using 8-bit fixed-point arithmetic and it consists of five subsystems which include clock generator subsystem, modulation index subsystem, sine carrier subsystem, adjustable amplitude subsystem and comparison subsystem from which SPWM generation algorithm can be implemented.

The values of a sinusoidal wave, mathematically being in the range [−1, 1], have been adapted in the proposed architecture to the equivalent range of [0, 255] with the zero point corresponding to discrete value of *128*. The architecture of SPWM has been synthesized using the VHDL language and its operation has been verified at both low-carrier and high-carrier frequency levels using the ModelSim 6.3g simulator. The major internal signals of the proposed system and the SPWM produces outputs, are fc = 1 kHz, fs = 4 MHz, and M = 0.5 are selected for simulation tests for validation.

A low-carrier frequency has been used for demonstration purposes, since it enables the easy biasing of all SPWM pulses produced within a period of the reference sine wave and the observation of their width. The SPWM output is generated at the intersection of the sinusoidal and triangular waveforms at certain sampling instants. When the value of each sine wave is higher than the triangular wave value, the output pulse is set to logical *1* otherwise logical *0*.

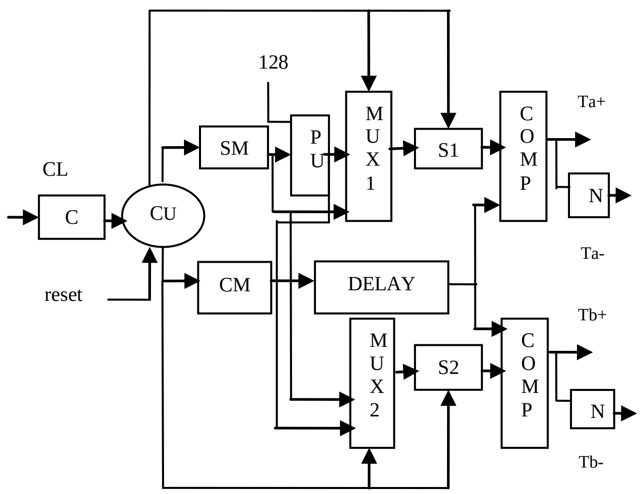

Fig: 1. Architecture of SPWM Generation Unit (SM-Sine Memory, CM-Carrier Memory, CG-Carrier Generator, CU-Control Unit, N-Not, PU-Processing Unit)

III. Proposed Space Vector PWM for Three Phase Inverter

Space Vector Modulation (SVM) was originally developed as vector approach to Pulse Width Modulation (PWM) for three phase inverters. It is a more refinement technique for generating sine wave that provides a higher voltage to the motor with lower total harmonic distortion. The major role of any modulation technique is to obtain variable output having a maximum fundamental component with minimum harmonics. Space Vector PWM (SVPWM) method is an advanced; computation intensive PWM method and is the best techniques for variable frequency drive application. The design and block diagram of three-phase inverter is illustrated in Fig. 2 and Fig. 3 respectively. The basic switching vector generated with respect to reference voltage (V_o) and reference angle (α) is represented in Fig. 4.

The implemented three-phase inverter can be driven by an input source of PV panel of 12 V. A battery of 12 V and 7 amps, such as lithium-ion battery, is used. Using rectifying and filtering circuits, the harmonic content can be reduced and a higher quality signals can be achieved. In case of three-phase inverter, 6 MOSFET switches are used. To drive those switches, six driver circuit are needed for the MOSFET switches. The PIC microcontroller of PIC30F2010, driver IC TLP 250 and MOSFET of the series IRF 840 are used for hardware implementation. The output results can be achieved by using digital oscilloscope (show of three phase inverter waveform) or by connecting a motor to the system (performance analysis).

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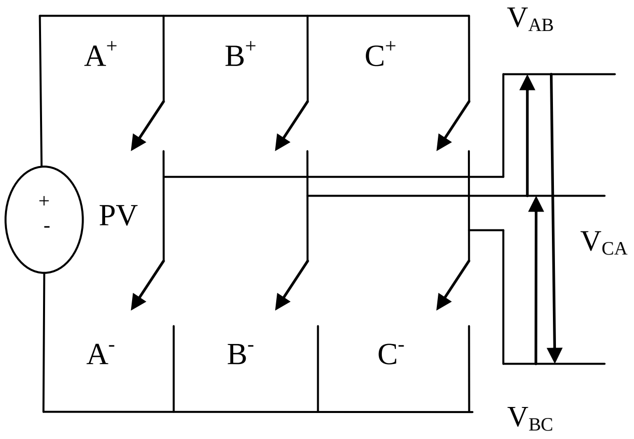

Fig: 2. Design of three-phase inverter

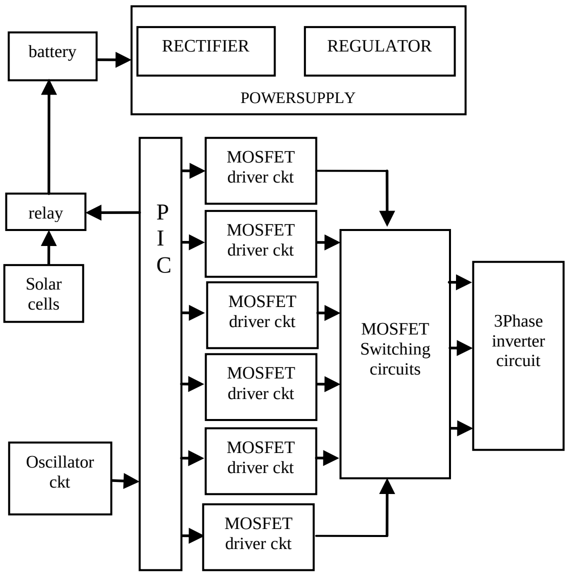

Fig: 3. Block diagram

IV. SIMULATION RESULTS OF SVPWM GENERATOR FOR THREE PHASE INVERTER

The software implementation of SVPWM based three-phase inverter is carried out in MATLAB 7.12.0 and Simulink simulation tool. A relevant Simulink design is depicted in Fig. 5. The simulation result for the Simulink design is illustrated in Fig. 6 through Fig. 11 subsequently.

A. Three Phase Inverter

The switches of three-phase inverter are incorporated from s_1 to s_6 that shapes the output, which are controlled by the switching variables *A, B, C, a, b* and *c*. When an upper switch is switched ON, i.e., when the switches of s_1, s_3 and s_5 are *1*. Then the corresponding lower switches (s_2, s_4, s_6) are turned OFF. Therefore, the switching of ON and OFF state of upper arm switches can be used to determine the output voltage.

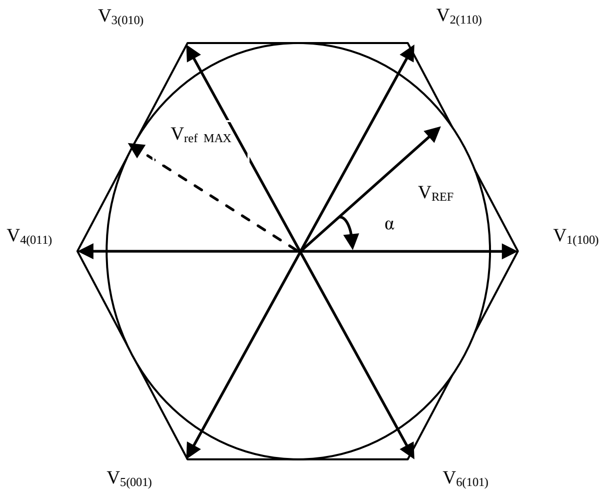

Fig: 4. Basic switching vectors

SVPWM is a unique approach based on space vector representation of the voltages in the α-β plane which is found by Clark's transformation to simplify the parameters of three-phase inverter. SVPWM refers to a special switching sequence of the upper three power transistors of a three-phase power inverter. It generates less harmonic distortion in the output voltages or currents applied to the phases of an AC motor. It also provides more efficient use of *dc* input voltage.

B. PV Panel

A PV module is a packaged and a connected assembly of solar cells. It includes arrays of solar modules, inverter and battery. With a utilization of solar power, *12* volt panel is designed to drive the three-phase inverter. The corresponding VI characteristics for the relevant PV panel get simulated as a function of voltage and current with respect to time.

There are 36 solar cells connected in series-parallel configuration. In that the current controlled source drives the whole circuit.

C. Space Vector PWM

The Space Vector PWM is an efficient technique in motor driving applications. It effectively spreads the harmonics over the entire spectrum range. For implementing the SVPWM, certain parameters are needed such as reference voltage, reference angle and switching vectors (patterns) for the functionality of inverter etc. The generated switching patterns of SVPWM generator triggers the inverter switches to produce 3 phase output.

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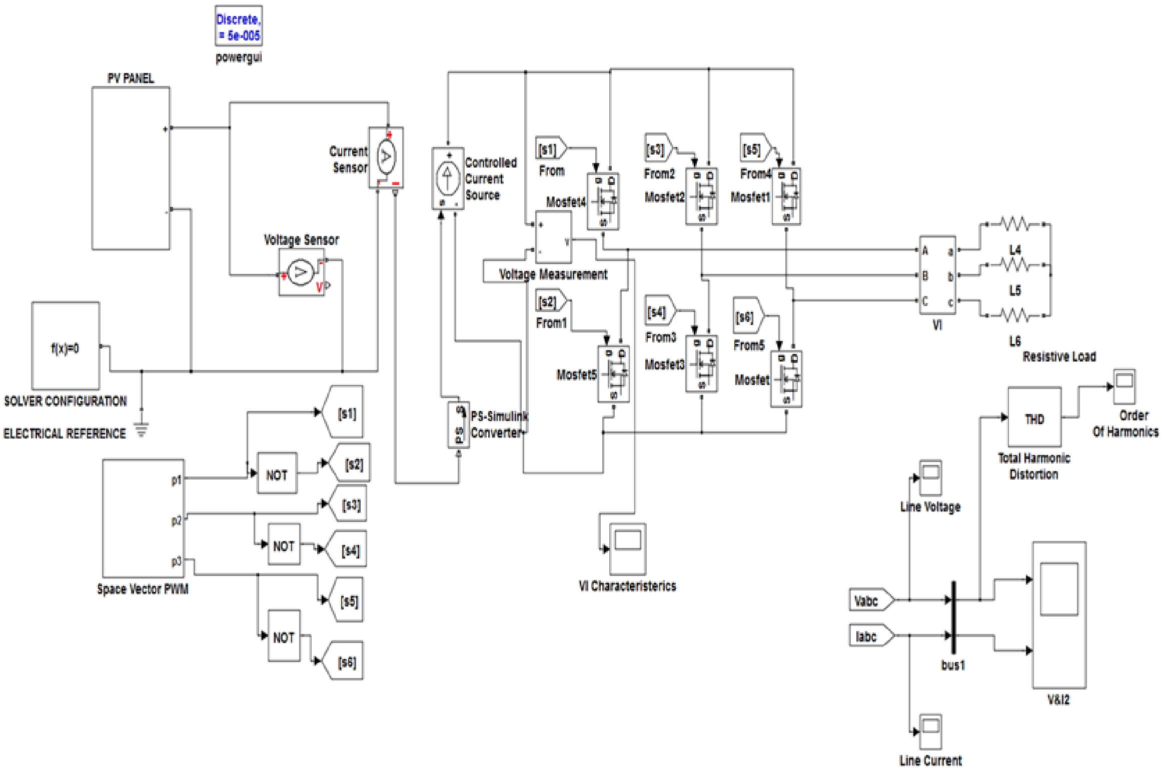

Fig: 5. Simulink Design of SVPWM Generator Based Three Phase Inverter with solar energy utilization

D. Total Harmonic Distortion

For a given inverter, THD plays the important role. The main objective is to reduce the percentage of harmonics and to improve the stability of an inverter. The lower harmonics leads to reduction in heating, emission and core loss in motors. In case of SVPWM technique aims to maintain the limitation of THD percentage less than 3%.

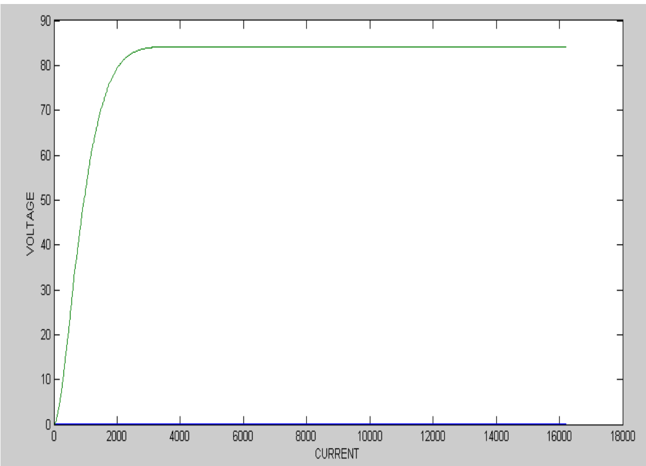

Fig: 6. VI Characteristics

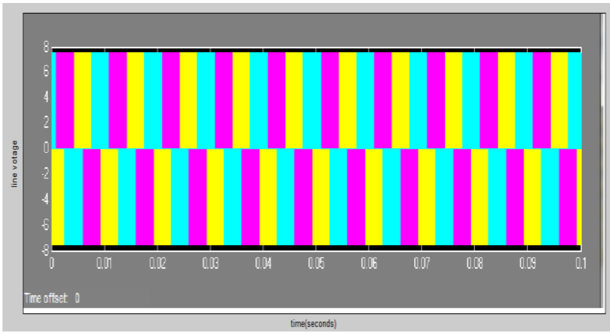

Fig: 7. Line Voltage

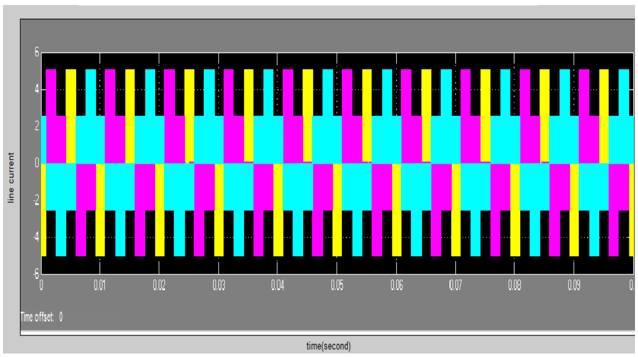

Fig: 8. Line Current

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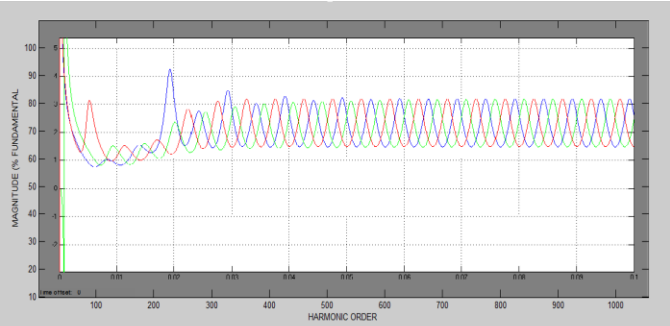

Fig. 9. Order of harmonics

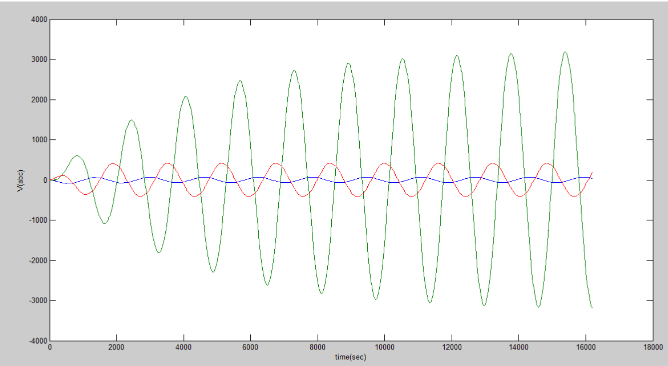

Fig: 10. V_{abc} vs. time

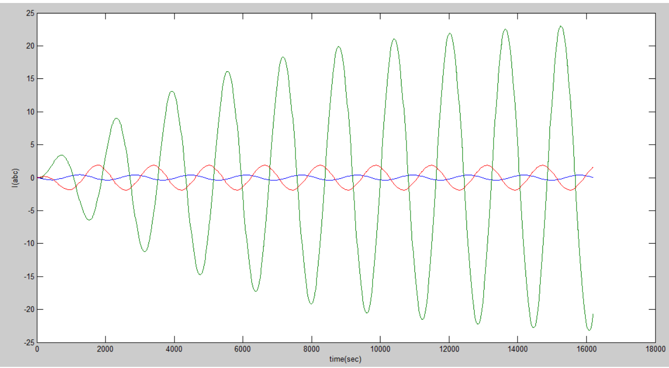

Fig: 11. I_{abc} vs. time

V. CONCLUSION

Space vector modulation technique has become the most popular and important PWM technique for three phase inverters in the application of controlling AC motors. In this paper the analysis of Space Vector PWM for three-phase inverter is presented. The Simulation analysis shows that SVPWM gives enhanced fundamental output with better quality i.e. lesser THD is observed compared to that of other PWM techniques. PWM strategies like SVPWM are implemented in MATLAB and SIMULINK software platforms. The performance is analyzed in comparison to conventional PWM techniques. SVPWM utilize a changing carrier frequency to spread the harmonics continuously to a wider area, hence the peak harmonics are reduced significatnly. The implementation has proven quite improved performance which can be certainly useful for variety of applications.

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