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Performance Analysis of Solar PV and NPC Inverter System Using SVPWM and SPWM Technology

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Abstract: In this paper, comparison of SPWM and SVPWM technique is illustrated with the help of solar PV and NPC inverter system. Novel configuration of a three-level neutral-point-clamped (NPC) inverter is used to convert DC from solar PV to three-phase sinusoidal voltages or currents which will be used to feed the RL load. The strength of the proposed topology lies in a novel, extended unbalance three-level vector modulation technique that can generate the correct ac voltage .The effectiveness of the proposed methodology is investigated by the simulation. Overall the idea behind this paper is to prove how space vector pulse width modulation technique (SVPWM) is more efficient than sinusoidal pulse width modulation (SPWM).

Keywords —SVPWM, SPWM, NPC Inverter, solar photovoltaic (PV), MPPT technique, I & C method, Comparison of SVPWM and SPWM.

I. INTRODUCTION

DUE to the world energy crisis and environmental problems caused by conventional power generation, renewable energy sources such as photovoltaic (PV) and wind generation systems are becoming more promising alternatives to replace conventional generation units for electricity generation. Advanced power electronic systems are needed to utilize and develop renewable energy sources. In solar PV or wind energy applications, utilizing maximum power from the source is one of the most important functions of the power electronic systems. In three-phase applications, two types of power electronic configurations are commonly used to transfer power from the renewable energy resource to the grid: single-stage and double-stage conversion. In the double-stage conversion for a PV system, the first stage is usually a dc/dc converter and the second stage is a dc/ac inverter. The function of the dc/dc converter is to facilitate the maximum power point tracking (MPPT) of the PV array and to produce the appropriate dc voltage for the dc/ac inverter [1]. The function of the inverter is to generate three-phase sinusoidal voltages or currents to transfer the power to the grid in a grid-connected solar PV system or to the load in a stand-alone system. In the single-stage connection, only one converter is needed to fulfil the double-stage functions, and hence the system will have a lower cost and higher efficiency, however, a more complex control method will be required. Inverters are very important power electronics equipment in PV systems. Their major role is to convert DC power into AC power. Furthermore inverter interfacing PV module(s) with the grid ensures that the PV module(s) is operated at the maximum power point (MPPT). Based on the photovoltaic arrays output voltage, output power level and applications, the photovoltaic grid-connected system can adopt different topologies. The remainder of the paper is organized as follows. Section II describes the structure of a three-level inverter. Section III presents detail about SPWM technique. Section IV presents detail about SVPWM technique. Section V describes the simulation and validation of the proposed topology and associated control system. Section VI concludes the paper.

II. STRUCTURE OF THE THREE LEVEL INVERTER

Three level inverter topology, often referred to as Neutral Point Clamped (NPC) inverter. Three level inverters are widely used in several application motor drives, STATCOM, HVDC, pulse width modulation (PWM) rectifiers, active power filters (APFs), and renewable energy applications[1]. The three level inverter offers several advantages over the more common two level inverter. As compared to two level inverters, three level inverters have smaller output voltage steps. In addition, the cleaner output waveform provides an effective switching frequency twice that of the actual switching frequency. Most often the NPC inverter is used for higher voltage inverterS. Multilevel inverter topologies are experiencing increased application in the industrial environment, particularly in high-power drive systems. The main advantages of these inverters are improving quality of voltage waveforms and an increase in the dc-link voltage [5].

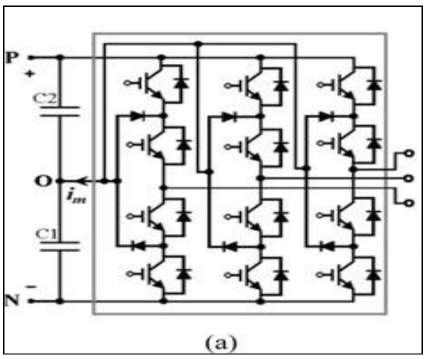

Fig 1: Three level NPC Inverter basic structure

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Fig.1 shows a typical three phase, three-level neutral-point-clamped (NPC) inverter circuit topology. Each leg has four IGBTs connected in series. The converter has two capacitors in the dc side to produce the three-level ac-side phase voltages. The bus voltage is split in two by the connection of equal series connected bus capacitors. Each leg is completed by the addition of two clamp diodes. This topology traditionally has been used for medium voltage drives both in industrial and other applications. Normally, the capacitor voltages are assumed to be balanced, since it has been reported that unbalance capacitor voltages can affect the ac side voltages and can produce unexpected behaviour on system parameters such as even-harmonic injection and power ripple.

NPC three level Inverter has following advantages:

- It provides a cost effective approach.
- High quality output voltage and current waveforms.
- High efficiency design due to decreased switching losses.
- Reduced output filter component size and cost as compared to a two level inverter.
- The field of application of NPC inverters is permanently growing due to their compactness, efficiency, and good performance [6].

III. SPWM TECHNIQUE

SPWM is the most popular technique. In SPWM a digital waveform is generated and the duty cycle is modulated such that the average voltage of the waveform is corresponds to a pure sine wave. SPWM moves the voltage harmonic components to the higher frequencies. The SPWM technique treats each modulating voltage as a separate signal and compared to the common carrier triangular waveform.

The working principle of SPWM includes the following points:

- The frequency of triangular wave is the frequency of PWM.
- Frequency of control voltage controls the fundamental frequency.
- The peak value of control voltage controls the amplitude.

Principle of Sinusoidal Pulse Width Modulation (SPWM):

Generation of the desired output voltage is achieved by comparing the desired reference waveform (modulating signal) with a high-frequency triangular 'carrier' wave as depicted schematically in Fig.2. Depending on whether the signal voltage is larger or smaller than the carrier waveform, either the positive or negative dc bus voltage is applied at the output. Note that over the period of one triangle wave, the average voltage applied to the load is proportional to the amplitude of the signal (assumed constant) during this period. The resulting chopped square waveform contains a replica of the desired waveform in its low frequency components, with the higher frequency components being at frequencies close to the carrier frequency. Notice that the root mean square value of the ac voltage waveform is still equal to the dc bus voltage, and hence the total harmonic distortion is not affected by the PWM process. The harmonic components are merely shifted into the higher frequency range and are automatically filtered due to inductances in the ac system. When the modulating signal is a sinusoid of amplitude Am, and the amplitude of the triangular carrier is Ac, the ratio m=Am/Ac is known as the modulation index. Note that controlling the modulation index controls the amplitude of the applied output voltage. With a sufficiently high carrier frequency (see Fig. 3 drawn for fc/fm = 21 and t = L/R = T/3; T = period of fundamental), the high frequency components do not propagate significantly in the ac network (or load) due the presence of the inductive elements. However, a higher carrier frequency does result in a larger number of switching per cycle and hence in an increased power loss. Typically switching frequencies in the 2-15 kHz range are considered adequate for power systems applications.

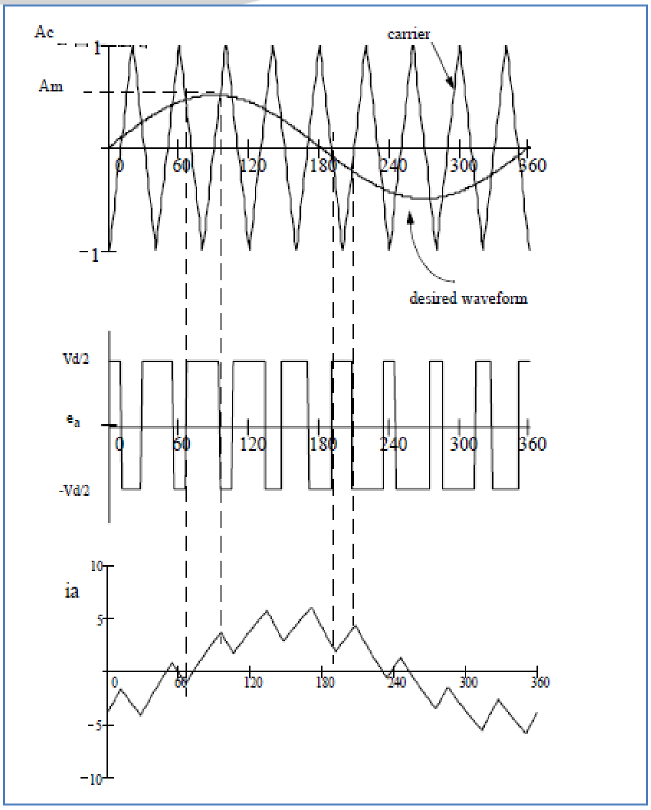

Fig 2: Sinusoidal pulse width modulation

IV. SVPWM TECHNIQUE

In SVPWM applications, a better understanding of the effects of the switching options on the capacitor voltages in the vector space has resulted in many strategies proposed to balance capacitors voltages in the three-level NPC inverter. Space vector modulation (SVM) is an algorithm for the control of pulse width modulation (PWM). It is used for the creation of alternating current (AC) waveforms. There are variations of SVM that result in different quality and computational requirements. One active area of development is in the reduction of total harmonic distortion (THD) created by the rapid switching inherent to these algorithms.

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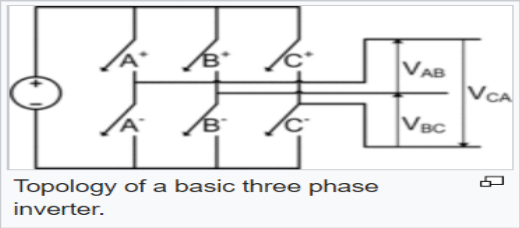

Fig 3: Topology of a basic three phase inverter

A three-phase inverter as shown in fig 3 converts a DC supply, via a series of switches, to AC. The switches must be controlled so that at no time are both switches in the same leg turned on or else the DC supply would be shorted. This requirement may be met by the complementary operation of the switches within a leg. i.e. if A^+ is on then A^- is off and vice versa. This leads to eight possible switching vectors for the inverter, V_0 through V_7 with six active switching vectors and two zero vectors. Note that looking down the columns for the active switching vectors V_{1-6}, the output voltages vary as a pulsed sinusoid, with each leg offset by 120 degrees of phase angle. To implement space vector modulation, 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 α β transformation. The reference vector is then synthesized using a combination of the two adjacent active switching vectors and one or both of the zero vectors[9]. Various strategies of selecting the order of the vectors and which zero vector(s) to use exist. Strategy selection will affect the harmonic content and the switching losses.

Vector	A^+	B^+	C^+	A^-	B^-	C^-	V_{AB}	V_{BC}	V_{CA}	
$V_0 = \{000\}$	OFF	OFF	OFF	ON	ON	ON	0	0	0	zero vector
$V_1 = \{100\}$	ON	OFF	OFF	OFF	ON	ON	$+V_{dc}$	0	$-V_{dc}$	active vector
$V_2 = \{110\}$	ON	ON	OFF	OFF	OFF	ON	0	$+V_{dc}$	$-V_{dc}$	active vector
$V_3 = \{010\}$	OFF	ON	OFF	ON	OFF	ON	$-V_{dc}$	$+V_{dc}$	0	active vector
$V_4 = \{011\}$	OFF	ON	ON	ON	OFF	OFF	$-V_{dc}$	0	$+V_{dc}$	active vector
$V_5 = \{001\}$	OFF	OFF	ON	ON	ON	OFF	0	$-V_{dc}$	$+V_{dc}$	active vector
$V_6 = \{101\}$	ON	OFF	ON	OFF	ON	OFF	$+V_{dc}$	$-V_{dc}$	0	active vector
$V_7 = \{111\}$	ON	ON	ON	OFF	OFF	OFF	0	0	0	zero vector

Fig 4: Eight possible switching vectors for the inverter, V_0 through V_7

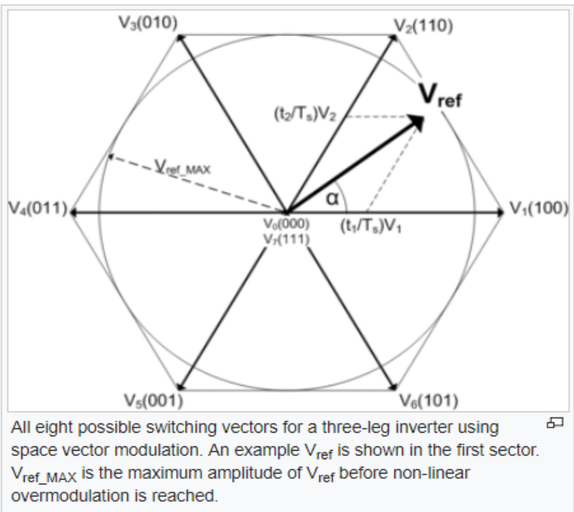

Fig 5: All eight possible switching vectors for a three leg inverter using space vector modulation

V. TABLE OF COMPARISON OF SPWM & SVPWM TECHNIQUE

SPWM		SVPWM
Sinusoidal PWM is a type of "carrier-based" pulse width modulation.	(1)	Space Vector Modulation (SVM) was originally developed as vector approach to Pulse Width Modulation (PWM)
Sinusoidal PWM is based on sine wave.	(2)	Space vector PWM is based on mathematical derivation
SPWM uses pre-defined modulation signals to determine output voltages. In sinusoidal PWM, the modulation signal is sinusoidal, with the peak of the modulating signal always less than the peak of the carrier signal.	(3)	It is a more sophisticated technique for generating sine wave that provides a higher voltage with lower total harmonic distortion. Space Vector PWM (SVPWM) method is an advanced; computation intensive PWM method and possibly the best techniques for variable frequency drive application.
Three phase reference modulating signal is compared against a common triangular carrier to generate the PWM signals for the three phases.	(4)	A revolving reference voltage vector is provided as voltage reference instead of three phase modulating waves.
The highest possible peak phase fundamental is very less in SPWM when compared with SVPWM.	(5)	The highest possible peak phase fundamental is more than SPWM
SPWM technique generates more harmonic distortion if compared with SVPWM	(6)	The study of space vector modulation technique reveals that space vector modulation technique utilizes DC bus voltage more efficiently and generates less harmonic distortion when compared with SPWM technique.
Sinusoidal PWM drive cannot produce a line-line output voltage as high as the line supply. One option to mitigate this discrepancy is to use higher supply voltages.	(7)	SVPWM drive can produce a line-line output voltage as high as the line supply.
Compared to SVPWM, harmonic spectrum of SPWM is not that much accurate.	(8)	SVPWM offers better harmonic spectrum.

Table 1: Comparison of SPWM & SVPWM techniques

Switching losses in SPWM and SVPWM:

For low power applications, switching losses are acceptable for specific range but for high power applications, switching losses become more significant. Because of switching losses, high frequencies (greater than 20 kHz) are less efficient than lower frequencies (as low as 100 Hz) due to efficiency of system reduces as switching losses increased, since for reducing filtering requirements we have to increase switching frequency which results in greater switching losses. Although switching losses can be reduced by modifying carrier signal in SPWM or using zero switching technique or shifting to multilevel inverters but on the other

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hand it results in greater harmonic distortion or poor power factor. SVPMW has greater flexibility to reduce switching losses. In SVPWM reduced switching losses are because of the changing of any one switching state which results in one single phase voltage change every time. If system needs further reduction in switching losses than another technique could be used for switching loss reduction based on stopping the control pulses of SVPWM for some duration and this duration depends upon angle of the load power factor. For different modulation indexes, extra switching can be eliminated in SVPWM.

Block diagram of proposed system

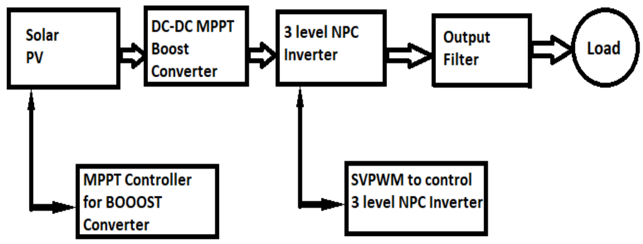


Fig 6: Block diagram of proposed system

First the dc output voltage from the PV array is given to the boost dc-dc converter which boosts the output voltage of the PV array as well as it regulates its output voltage irrespective of the variation in solar radiation and temperature. This dc-dc converter is controlled with MPPT control technique. Capacitor can further smoothen the PV current and voltage for the selection of the IGBTs.In the boost converter topology, the freewheel diode serves as the blocking diode to avoid the reverse current. Irrespective of variation in solar radiation and temperature, the system should always track maximum power to make the system more efficient.

VI. Simulation and Validation of the Proposed Topology and Control System

Simulations have been carried out using MATLAB/Simulink to verify the effectiveness of the proposed topology and control system.

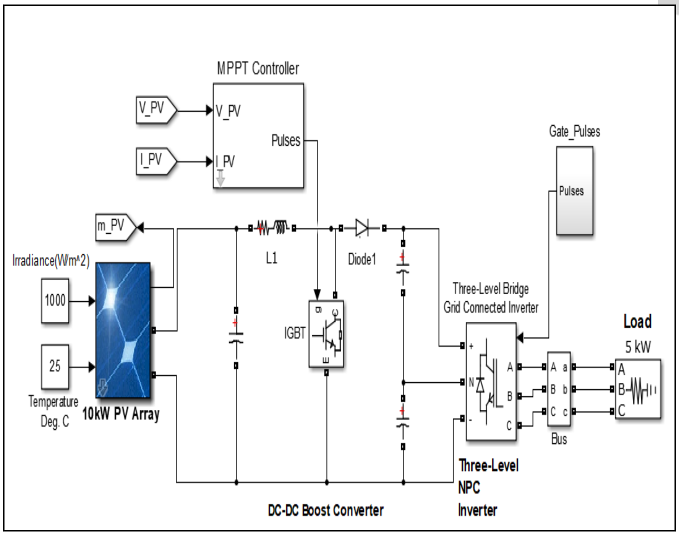
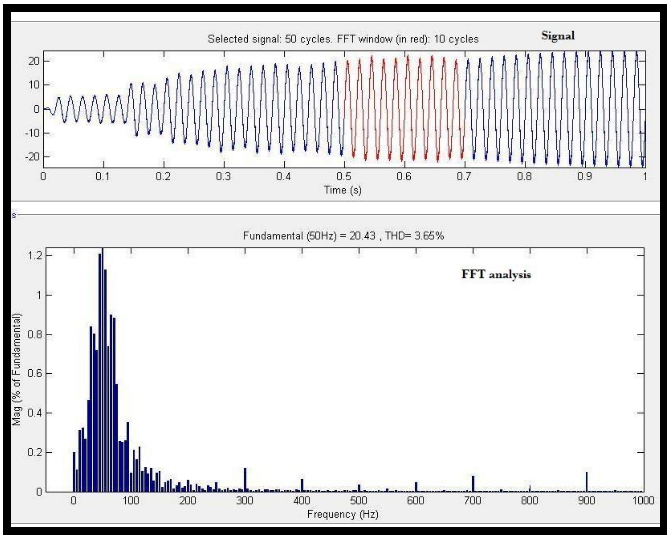


Fig 7: Block diagram of simulated system

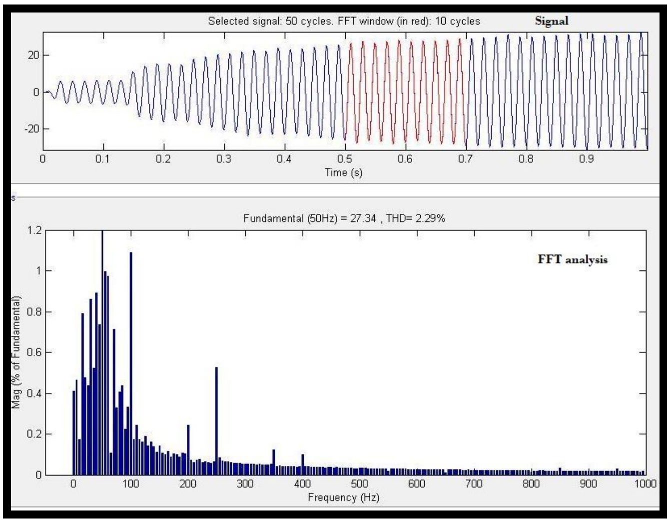
Two simulations are carried out using MATLAB/SIMULINK model. One is using SPWM technique and another is using SVPWM technique.FFT analysis is carried out to compare both the results.FFT analysis is carried out to get Total harmonic distortion values:

Simulation results of SPWM technique are as follows:



FFF analysis setting as follows :
Start time(s): 0.5
Number of cycles: 10
Fundamental frequency (Hz): 50
Maximum frequency (Hz): 1000
Maximum frequency for THD computation:Nyquist frequency
Total Harmonic Distortion(THD) by using technique SPWM: 3.65 %

Simulation results of SVPWM technique are as follows:



FFF analysis setting (SVPWM) as follows :
Start time(s): 0.5
Number of cycles: 10
Fundamental frequency (Hz): 50
Maximum frequency(Hz): 1000

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Maximum frequency for THD computation: Nyquist frequency

Total Harmonic Distortion (THD) by using technique SVPWM: 2.29 %

Comparison of THD values of SPWM and SVPWM techniques:

Modulation Technique	THD (%)
SPWM	3.65 %
SVPWM	2.29 %

Table 2: THD (%) values of SPWM and SVPWM techniques after performing simulation.

As shown in table 2, it is seen that Total Harmonic Distortion (THD) in case of Sinusoidal Pulse Width Modulation is more as compared to Space Vector Pulse Width Modulation. Hence, SVPWM technique is more advantageous than SPWM. Compared to conventional PWM and sinusoidal PWM, SVPWM generates the precise pulses which are required for the three phase inverters. SVPWM generates the pulses based on the sector formation. Moreover output voltage of this inverter is formed with the reduced value total harmonic distortion using SVPWM technique.

VII. CONCLUSION

In this paper, SPWM and SVPWM techniques have been investigated and compared. For this purpose, we also performed extensive simulations of these techniques using MATLAB tools. It has been observed that SVPWM has showed superior performances due to less THD, greater PF and less switching losses because SVPWM utilizes advance computational switching technique to reduce THD. It also reduces switching losses because of the changing of any one switching state which results in one single phase voltage change every time. Furthermore, at high switching frequencies SVPWM gives better results as compared to SPWM. Thus, based on all obtained results, we concluded that SVPWM technique provides greater overall performance and efficiency as compared to SPWM technique.

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