http://www.jctjournals.com ISSN(ONLINE):2278 – 3814

Volume-8, Issue-01, January, 2019
JOURNAL OF COMPUTING TECHNOLOGIES (JCT)
International Journal
Impact Factor– 3.017

Performance Analysis of SVPWM based Single Phase Voltage Source Inverter

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***Abstract*— The inverter topology which produce single phase AC with conversion of DC is known as single phase inverter. The inverters sometimes operate in a very pulse width modulated (PWM) method and switch between different circuit topologies, which implies that the power converter may be a nonlinear, specifically piecewise smooth system additionally to the present, the control methods utilized in the inverters are just like those in DC-DC converters. This paper discusses the review of the multilevel inverter topology developed by the different researchers.**

***Keywords*— DC/AC, PWM, UPS, MLI, SHEPWM, OHSW etc.**

I. INTRODUCTION

The DC-AC converter, also known as the inverter, converts dc power to ac power at desired output voltage and frequency. The dc power input to the inverter is obtained from an existing power supply network or from a rotating alternator through a rectifier or a battery, fuel cell, photovoltaic array or magneto hydrodynamic generator. The filter capacitor across the input terminals of the inverter provides a constant dc link voltage. The inverter therefore is an adjustable-frequency voltage source. The configuration of ac to dc converter and dc to ac inverter is called a dc-link converter.

Inverters can be broadly classified into two types, voltage source and current source inverters. A voltage–fed inverter (VFI) or more generally a voltage–source inverter (VSI) is one in which the dc source has small or negligible impedance. The voltage at the input terminals is constant. A current–source inverter (CSI) is fed with adjustable current from the dc source of high impedance that is from a constant dc source.

A voltage source inverter employing thyristors as switches, some type of forced commutation is required, while the VSIs made up of using GTOs, power transistors, power MOSFETs or IGBTs, self-commutation with base or gate drive signals for their controlled turn-on and turn-off A standard single-phase voltage or current source inverter can be in the half-bridge or full-bridge configuration. The single-phase units can be joined to have three-phase or multiphase topologies. Some industrial applications of Inverters are for adjustable-speed ac drives, induction heating, standby aircraft power supplies, UPS (uninterruptible power supplies) for computers, HVDC transmission lines, etc.

In this paper discuss the performance of single phase inverter based on space vector PWM method. In the next section firstly discuss the literature based on multilevel inverter and further discuss the basic problem associated with them. A SVPWM based single phase inverter is developed and checked in MATLAB platform.

II. BACKGROUND OF MULTI-LEVEL INVERTER

Multilevel inverters are now well known to power industries and have tremendous capabilities at medium and high voltage applications. Various aspects of multilevel inverters are researched and reported in the literature. Some of these aspects are Multilevel Inverter Topologies/Design of Modular Structure, and Modulation Techniques. The modulation techniques employed for 2-level inverters can be applied for MLI such as SPWM, OHSW and SHEPWM etc. with appropriate modifications. There are so many reports and research paper available in the field of MLI. For this research work, some of research papers are reviewed.

Author [1] reviewed and analysed the reduction in power switch count through the proposed multilevel inverter topologies. The objective of reduction in overall part count in the newer topology as compared to the conventional ones have been incorporated. The proposed topology exhibit the up gradation of newly developed topologies in terms of qualitative and quantitative parameters. In [2] a new structure of symmetrical multilevel inverter is presented with less number of controlled switches, power diodes and DC sources as compared to the classical approach available in the literature. The past few years have witnessed the growing interest in the development of newer topologies of multilevel inverter. The topologies which have been emerged recently possess increased number of output voltage steps with reduced number of switches, DC voltage sources, voltage stress across switches and losses as compared with the conventional topologies. The multilevel inverter topology has been designed with a view to decrease the component count especially for large out levels [3]. It employs floating input dc sources connected in alternate manner with opposite polarities among one another by power switches. Each individual input dc level appear as the additive sum of the other input levels resulting into decreased number of power switches as compared to the conventional ones.

A comprehensive analysis of a new single-phase cascaded multilevel inverter is presented and discussed in [4]. The proposed inverter topology consists of series connected basic unit and is capable of generating only positive levels at the output. To achieve this, the combination of H bridge with proposed topology is made to develop cascaded multilevel inverter. Four different algorithms have been introduced to synthesize all voltage levels at the output terminals. The approach presented in [5] is based on fault-tolerant single-phase five-level inverter designed for PV applications. The simulation and result analysis has been carried out on a laboratory prototype. The five-level output voltage is obtained through one leg of a three-level neutral point inverter and a two-level half-bridge inverter. In paper [6] reported a fault-tolerant control strategy for a T-type three-level inverter when under open-circuit fault condition. The method presented in the paper has been described by analyzing fault into two cases: the faulty occurrence in half-bridge switches and neutral point switches. During the open-circuit faults occurred in a neutral-point switch, two methods have been presented and compared based on thermal analysis and neutral-point voltage oscillation. The devised algorithm during switch failure has been proved to be capable of improving the reliability of the T-type inverter without any additional requirement of component.

A four-pole induction-motor drive based multilevel inverter topology has been outlined in [7]. A single dc source with a magnitude when compared with conventional five-level inverter topologies is used in this topology which reduce the power balancing issues up to great extent. Due to single DC source being used in this configuration, path for zero-sequence current is provided due to the presence of zero-sequence voltage in the output which is intended to flow through the phase winding of motor and switches. Sine–triangle pulse width modulation (SPWM) is used to reduce the zero-sequence currents which manage to shift the lower order harmonics near to switching frequency in the linear modulation region. In paper [8] implemented a single-phase high step-up converter is presented, developed not only to increase the relatively low photovoltaic (PV) voltage to a high bus voltage with increased efficiency, but also to offer a neutral point terminal for the half-bridge-based inverters. In this configuration, two symmetrical high step-up converters are merged and implemented to obtain an improved converter with neutral point terminal, which is greatly desired for the half bridge-based inverters. In [9] presented and analyzed in this study demonstrates a coupled-inductor single-stage boost inverter for grid-connected photovoltaic (PV) system which requires boosting operation in the case of PV array voltage being lower than the grid voltage for transforming the dc voltage into ac voltage supplying to the grid together with higher power factor and equipped maximum power point tracking (MPPT) mechanism. In [10] outlined the framework of a single-phase transformer less grid-connected photovoltaic converter dependent on two cascaded full bridges with different dc-link voltages. The converter can develop up to nine voltage levels with a single dc bus, since one of the full bridges is fed by a flying capacitor. The multilevel output lowers down the harmonic distortion and electromagnetic interference.

A recent review of literature has been carried out in [11] on fault-tolerance techniques devised for two-level and multilevel inverters. This review includes the facts and inferences drawn out through journal publications, revealing that the remedial actions are composed of both hardware and software reconfigurations. While the conventional two-level inverters depend mostly on hardware reconfiguration, multilevel inverters exhibit more capabilities to withstand internal faults with a balanced combination of hardware and software reconfigurations. In [12] describe a multilevel inverter topology with new approach using a level doubling network (LDN). The LDN is equivalent to a half-bridge inverter obtaining twice the number of output voltage levels. The LDN concept employ the ability of self-balancing in the course of positive and negative cycles without any closed-loop control/algorithm, and it does not consume or supply any power. The topology utilizes the concept of symmetric cascaded H-bridge MLI but exhibit a similar characteristic of an asymmetric topology with regard to the number of levels.

Modular multilevel inverter topology of a three-level inverter has been proposed in [13]. The THD of the output voltage waveform was observed to be very less and the simulation results reveal that rise in the levels causes reduction in voltage harmonics whereas, the current harmonics goes high. The modular MLI is greatly desired in HVDC, especially without passive filters at the AC side and DC side. In [14] discussed a multilevel inverter topology with boost converter with a purpose to reduce the power demand and supply the required peak voltage. The desired ac output waveform obtained from dc sources is synthesized with the proposed configuration of multilevel inverters. The study carried out in the paper has mainly focused on reduction of device count in multilevel inverter thereby improving the quality of output voltage waveform. In [15] presents a Z Source -T shape - Neurtal point Diode Clamped (NPC) - Multi Level Inverter (MLI) power conversion system (Z-T-NPC-MLI) by employing New Space Vector PWM (SVPWM) scheme. The developed impedance source inverter merges the merits of boosting and conversion of DC to AC power. A model-based on open semiconductor switch fault and closed semiconductor switch fault designation methodology is developed for a voltage-source electrical inverter (VSI) supply for a Squirrel Induction motor drive [16]. Fuel economy and less emission of pollutants have attracted the realization of electric vehicles in the industrial market. To cater to the high demand and higher dependability on power electronic converters, fault detection and mitigation is challenging. In this regard, the model is developed to analyse open and short faults.

III.PROBLEM STATEMENT

Inverter is one of power conversion device that widely used in the world to convert DC input voltage to AC output voltage. The output voltage waveforms of ideal inverters should be sinusoidal. However, the waveform of practical inverter is non-sinusoidal and contains harmonics. Then, for this project, it should get closer sinusoidal waveform within +- 5% harmonics contains. Harmonic contents in inverter output depends more to number of pulses per cycle. As an example, square wave switching method will produce more harmonic contents in inverter output compared to pulse width modulation switching technique. This is due to number of pulses per cycle of pulse width modulation can be modified on the frequency of triangular carrier waveform. The frequency of triangular waveform can be modified from lower frequency to higher frequency. If higher frequency is used, the number of pulses per cycle also increased and at the same time it will reduce the harmonic contents of the inverter.

In switching losses problem, the number of pulses per cycle also affected. The use of high switching technique will contribute to the high power losses and it also needs to take care on the inverter switching design. The following factors are to be considered in order to meet the requirement.

1. Cost of equipment
2. Size of filter
3. Total harmonic distortion
4. Power loss in switching elements.

IV. SPACE VECTOR PWM FOR SINGLE PHASE SYSTEM

The circuit of single-phase inverter power is a full bridge inverter circuit ordinarily, as shown in Figure 1. The switch elements of the up and down bridge arms cannot be conducted simultaneously at any moment when the inverter power working, the switch states of the up and down bridge arms are complementary without considering the stagnant wake. Because of this, we can describe the working state of the inverter by using the switch state of the power devices on the two up bridge arms. The ideal two position switch Ka and Kb represents the switch state of the power devices in order to study on calculation easily. The circuit model is shown in Figure 1.

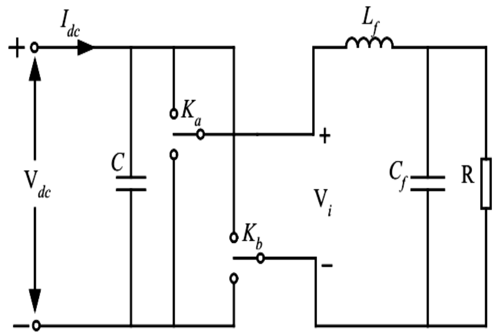

Fig. 1: Circuit of Single Phase Full Bridge Inverter

The each switch has two states of ‘1’ and ‘0’ in Figure 1, ‘1’ shows the switch contact the upper contactor, that is, the upper bridge arm MOSFET conduction. On the other hand, ‘0’ shows the switch contact the lower contactor, that is, the lower bridge arm MOSFET conduction. Thus, it has four states by the combination of Ka and Kb. The output voltage under the four switch states can be marked as v0, v1, v2 and v3 by the method of natural binary code. The table 1 describes the corresponding relationship of the power device switching state and output voltage vector.

Table 1: Switching State and Output Voltage Vector of Power Device

K_a	K_b	V_i	V_k ($k=0\sim3$)
0	0	0	v_0
0	1	$-V_{dc}$	v_1
1	0	V_{dc}	v_2
1	1	0	v_3

The voltage vector V=[Vab] forms 4 discrete voltage space vectors in one-dimensional space, as shown in Figure 2, we can see the vector v_1 and v_2 on the x axis, the vector v_0 and v_3 on the original point.

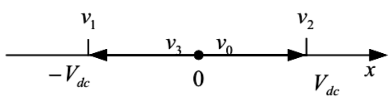

Fig. 2: Space Vector output Voltage for Single Phase Inverter

We can analyse the single-phase sinusoidal power supply by the same method, supposing

$$u = U_m \sin \omega t \qquad [1]$$

Thus, Figure 3 describes the single-phase power supply vector u=[u] in one-dimensional space, the modulus of u changes by the sine law follow the time t .

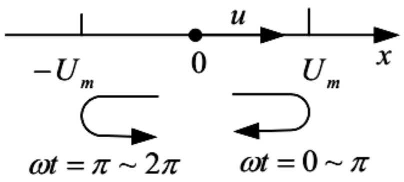

Fig.3: Space Vector of Sinusoidal Voltage

Obviously, the inverter output state transforms from v_0, v_1, v_2 and v_3. If the modulus of u over V_{dc}; then can't synthesize the equivalent vector of sinusoidal power supply. Because of this, we can define modulation ratio M, as:

$$M = \frac{U_m}{V_{dc}} \leq 1 \qquad [2]$$

A. **simulation & result**

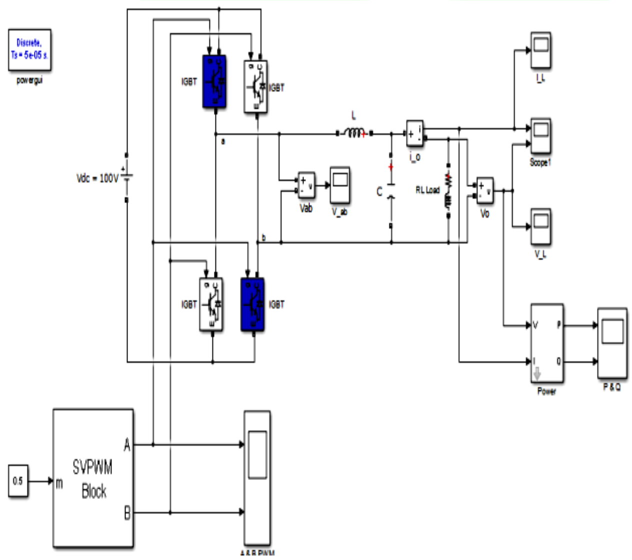

Fig. 4: SIMULINK Model of Proposed SVPWM based single Phase Inverter

The main aim of the proposed SVPWM based Bipolar Single Phase Inverter is designing and implementation for domestic loads. For so the new type of modulation is used which is more advance and high efficient rather than the available PWM scheme. In this section the result is discussed of the proposed work SVPWM based Bipolar Single Phase Inverter for medium voltage application. The whole work is simulated in MATLAB 8.3 version. The performance of the proposed system is defined for the domestic load condition. Table 2 show the parameter used in the proposed work.

Table II: Parameter Used in the Proposed System

Parameter	Value
DC Link Voltage	100 V
Switch used for inverter	4 IGBT Switch(A Bipolar Device)
Modulation Index	M_a= 0.5
Switching Frequency	5kHz
Sampling Time	50µS
Filter Inductance	L= 10mH
Filter Capacitance	C= 470µF
Load (Domestic)	230 V, 50Hz, 5kW, 0.1kVAr

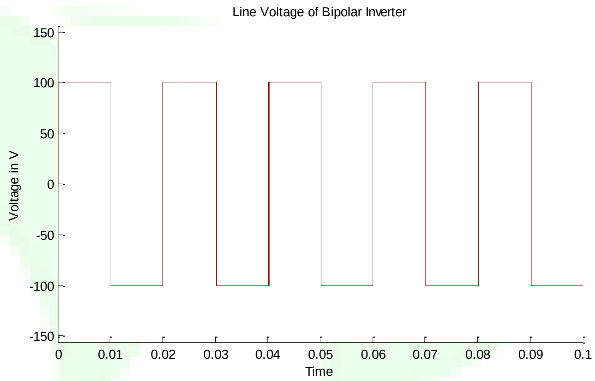

Fig.5: Line Voltage of Proposed SVPWM based System

Figure 5 shows the output voltage of the proposed single phase inverter. Here the output is purely square wave in nature. The maximum amplitude is found 100V.

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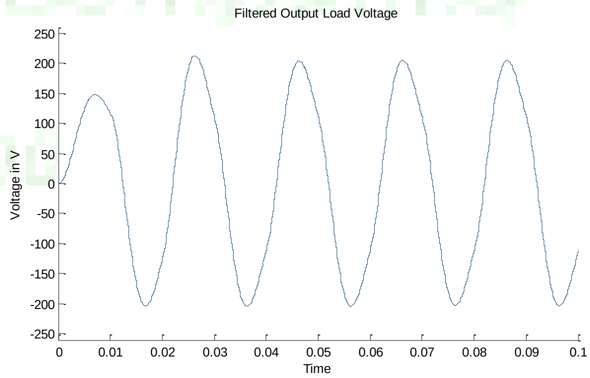

Fig 6: Load Current of Proposed SVPWM based System

Figure 6 shows the load voltage after application of LC filter. Here it is clearly shown that the output of the proposed inverter produce sinusoidal in nature. The peak value of the voltage is found here 200V. Figure 7 and 8 shows the FFT analysis of the proposed system before and after filter action.

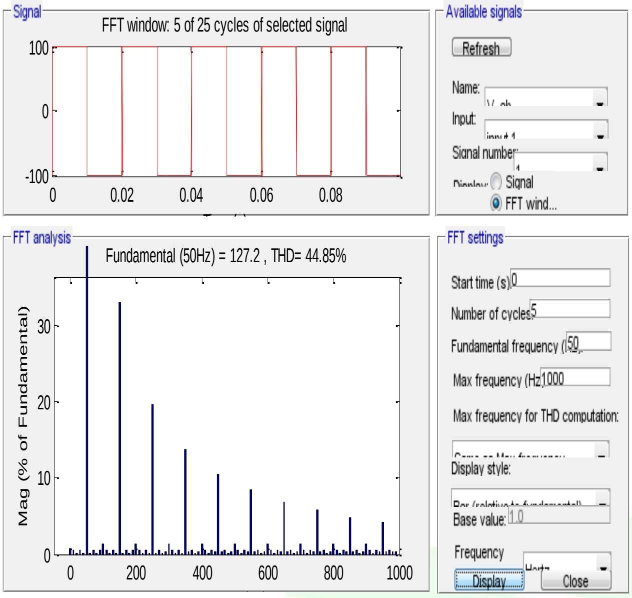

Fig. 7: FFT Analysis of Line Voltage without Passive Filter

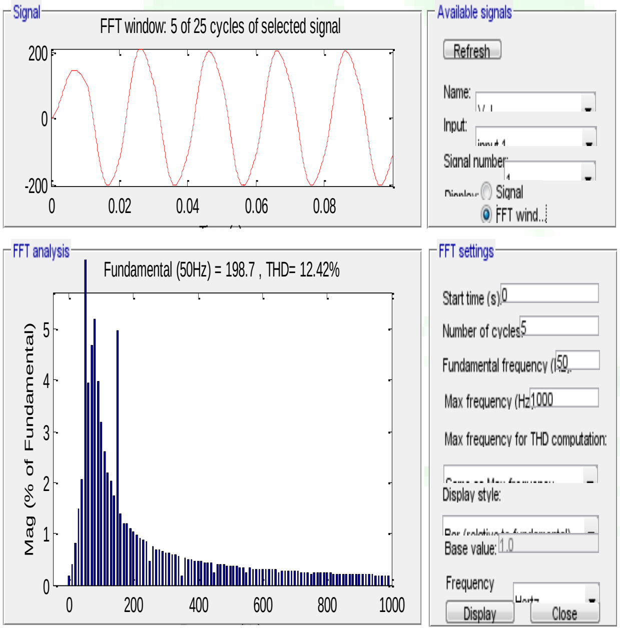

Fig. 8: FFT Analysis of Line voltage with Passive Filter

From the figure 7 it is clearly seen that the THD of the system is 44.85% at the fundamental frequency 50Hz. From figure 8 with the application of the Filter the THD level get decrease to 12.42% at the same fundamental frequency 50Hz. So it is clearly shown that the harmonic contents get reduce in the proposed work

Figure 9 shows the active power consumption of the load in the proposed system. Initially it is shown that the power is zero it is due to initialization of the system after that it increases to 2.2kW and at 0.05 sec it is stable to 2kW.

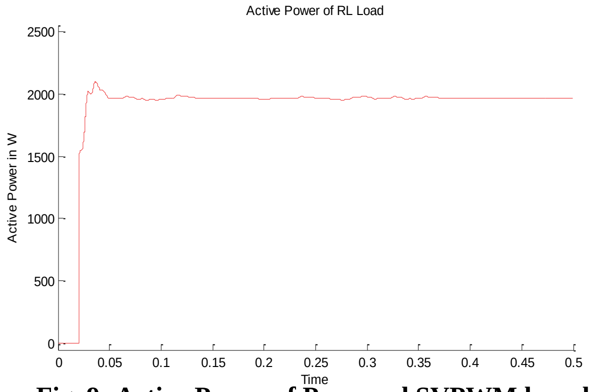

Fig. 9: Active Power of Proposed SVPWM based System

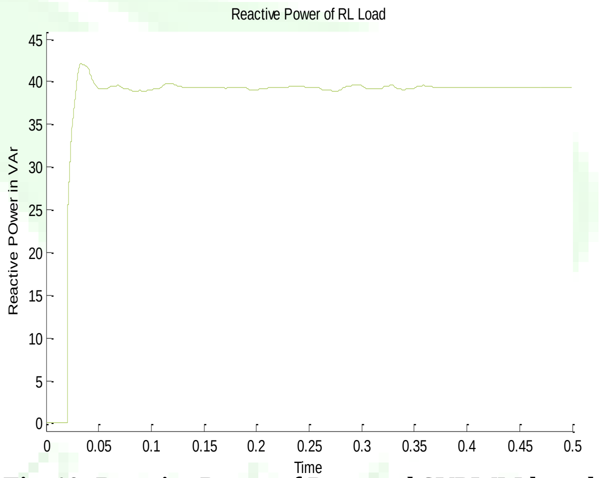

Fig. 10: Reactive Power of Proposed SVPWM based System

Figure 10 shows the reactive power consumption of the load in the proposed system. Similarly as active power consumption the reactive power is also initiated from zero to the 45 VAr and after 0.05 sec gets stabilized by 40 VAr.

IV. CONCLUSION

Analysis Power inverters generate sinusoidal voltages from discrete voltage levels, and pulse width modulation (PWM) strategies accomplish this task of generating sinusoids of variable voltage and frequency. Modulation methods for Power Converter can be classified according to the switching frequency methods. Many different PWM methods have been developed to achieve the following: Wide linear modulation range, less switching loss, reduced Total Harmonic Distortion (THD) in the spectrum of switching waveform: and easy implementation and less computation time. In this paper discuss the various work in related to the multilevel inverter based on single phase supply system. In this paper discusses the development of SVPWM technique for single phase inverter topology. The proposed technique is applied on the domestic load of 2kW. The performance of the proposed system is verified in the MATLAB simulation. The THD of the system is found 12.42%.

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