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Analysis of Neutral Point Clamped Multilevel Inverter Using Space Vector Modulation Technique

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***Abstract*— In the field of high power and medium voltage application, the multilevel inverter seem to be the most promising alternative. Such inverters syntheses a desired output voltage from several levels of dc voltage as inputs. This paper analyses the performances of Neutral Point Clamped Inverter (NPCI) using space vector pulse width modulation (SVPWM) technique. In SVPWM technique, the voltage reference provided using revolving reference vector. In this case magnitude and frequency of the fundamental component in line side is controlled by the magnitude and frequency respectively of the reference voltage vector. Space vector modulation technique utilizes the DC bus voltage more efficiently and generate less harmonic distortion when compared to sinusoidal PWM (SPWM) technique. The space vector pulse width modulation control technique has been applied to five level inverter and their performance has been analyzed by using MATLAB /Simulink. The output shows better performance results. The variation based in Total harmonics distortion are also analyzed**

***Index Terms*— DC Bus Voltage Utilization, Neutral Point Clamped Inverter (NPCI), Less Harmonic Distortion, Sinusoidal Pulse Width Modulation (SPWM), Space Vector Pulse Width Modulation (SVPWM).**

I. INTRODUCTION

Numerous industrial applications have begun to require high power apparatus in recent years. Some medium voltage drives and utility applications require medium voltage and megawatt power level .For a medium voltage grid, it is troublesome to connect only one power semiconductor switch directly. As a result, a multilevel power converter structure has been introduced as an alternative in high power and medium voltage situations. A multilevel converter not only achieves high power ratings but also enables the use of renewable energy sources.Renewble energy sources such as photovoltaic, wind and fuel cell can be easily interfaced to a multilevel converter system for a high power application.

The concept of multilevel inverter has been introduced since 1975.the term multilevel began with five level converter .subsequently several multilevel converter topologies has been developed.However,the elementary concept of multilevel converter to achieve higher power is to use a series of power semiconductor switches with several lower voltage dc source to perform power conversion by synthesizing a staircase voltage waveform.

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Capacitors, batteries and renewable energy voltage sources can be used as the multiple DC voltage source.

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) waveform; most commonly to drive 3 phase AC powered motor at varying speeds. In space vector pulse width modulation (SVPWM) methods, the voltage reference is provided using a revolving reference vector.

Space vector modulation technique utilizes DC bus voltage more efficiently and generates less harmonic distortion when compared with Sinusoidal pulse width modulation (SPWM) technique [3].

A. BLOCK DIAGRAM OF PROPOSED SYSTEM

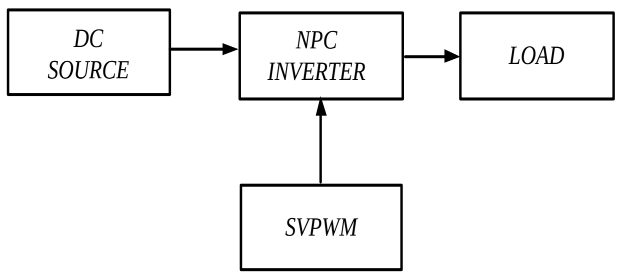


Fig 1 Block Diagram

The DC source may be any renewable DC source like solar photovoltaic or fuel cells. The inverter that considered here is Neutral Point Clamped Inverter (NPCI) also known as Diode Clamped Multilevel Inverter (DCMLI) for five level output voltage. The modulation technique adopted is Space Vector Pulse Width Modulation (SVPWM)

II. MULTILEVEL INVERTER

A.Introduction

Multilevel Inverter has been attracted a large interest in the power industry in the recent years. Industry has started to involve in higher power equipment, which already reaches megawatt level. Conventional power electronic converters are only able to switch each individual input or output link between two possible voltage levels, especially those of the internal DC voltage link. The general structure of the multilevel converter is to generate a sinusoidal voltage from several levels of voltages which are usually obtained from capacitor voltage sources.

B. Multi-Level Inverter Topologies

Multilevel power conversion technology is a very rapidly growing area of power electronics with good potential for further development. The most attractive applications of this technology are in the medium- to high-voltage range (2-13 kV), and include motor drives, power distribution, power quality and power conditioning applications. There are different types of multi-level circuits involved. The first topology introduced was the series H-bridge design. This was followed by the diode clamped converter, which utilized a bank of series capacitors. A later invention detailed the flying capacitor design in which the capacitors were floating rather than series-connected. Another multilevel design involves parallel connection of inverter phases through inter-phase reactors. In this design, the semiconductors block the entire dc voltage, but share the load current. Several combinational designs have also emerged some involving cascading the fundamental topologies. These designs can create higher power quality for a given number of semiconductor devices.

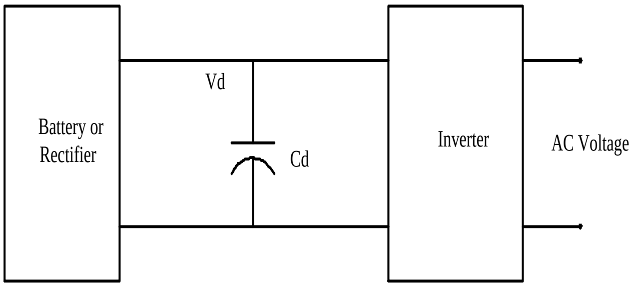
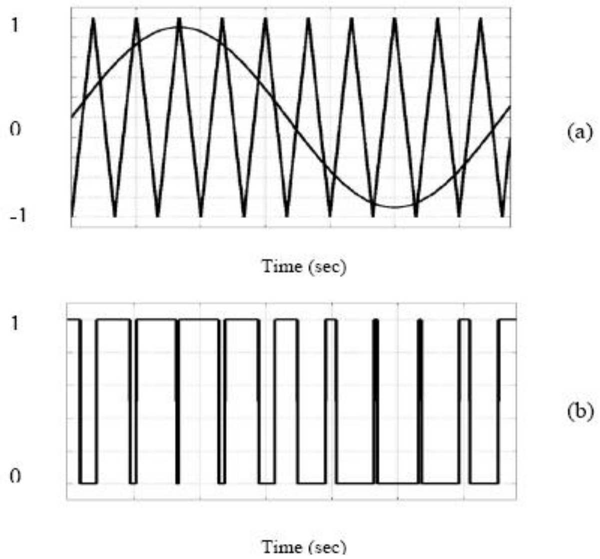


Fig 2. Schematic for inverter system

The schematic of inverter system is as shown in fig 2 in which the battery or rectifier provides the dc supply to the inverter. The inverter is used to control the fundamental voltage magnitude and the frequency of the ac output voltage. AC loads may require constant or adjustable voltage at their input terminals, when such loads are fed by inverters, it is essential that the output voltage of the inverters is so controlled as to fulfil the requirement of the loads For example if the inverter supplies power to a magnetic circuit, such as a induction motor, the voltage to frequency ratio at the inverter output terminals must be kept constant.

This avoids saturation in the magnetic circuit of the device fed by the inverter. In the single phase voltage source inverters PWM technique can be used in three phase inverters, in which three sine waves phase shifted by 120° with the frequency of the desired output voltage is compared with a very high frequency carrier triangle, the two signals are mixed in a comparator whose output is high when the sine wave is greater than the triangle and the comparator output is low when the sine wave or typically called the modulation signal is smaller than the triangle. As the output voltage from the inverter is not smooth but is a discrete waveform and so it is more likely than the output wave consists of harmonics, which are not usually desirable since they deteriorate the performance of the load, to which these voltages are applied. Recent advances in power electronics have made the multilevel concept practical. In fact, the concept is so advantageous that several major drives manufacturers have obtained recent patents on multilevel power converters and associated switching techniques. It is evident that the multilevel concept will be a prominent choice for power electronic systems in future years, especially for medium-voltage operation.



(a) Sine-Triangle Comparison (b)Switching Pulses

Fig 3.PWM Illustration by the Sine-Triangle Comparison

C. Classification of Multilevel Inverter Based On Source

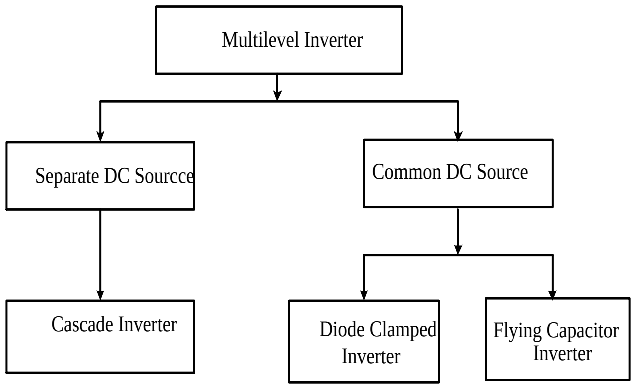


Fig 3. Classification of MLI

Three different topologies have been projected for multilevel converters

1. Diode clamped multilevel inverter (DCMLI)
2. Flying capacitor multilevel inverter (FCMLI)
3. Cascaded multilevel inverter (CMLI)

Several modulation and control strategies have been developed or being used for multilevel converters including the following

1. Multilevel sinusoidal pulse width modulation (MSPWM),
2 .Multilevel selective harmonic elimination (MSHE)
3. Space-vector modulation (SVM).

D. Diode Clamped Multilevel Inverter

The diode-clamped inverter is shown in Fig. 4. In this circuit, the dc-bus voltage is split into three levels by two series-connected bulk capacitors C_1 and C_2. The middle point of the two capacitors *n* can be defined as the neutral point. The output voltage has V_{an} three states: Vdc/2, 0,-Vdc/2. For voltage level Vdc/2 , switches S1 and S2 need to be turned on for -Vdc/2 , switches S1’ and S2’ need to be turned on; and for the 0 level, S2 and S1’ need to be turned on.

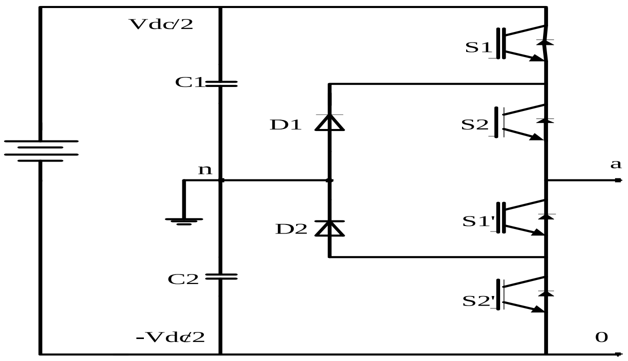


Fig 4. Diode Clamped Multilevel Inverter

E. Capacitor Clamped Multilevel Inverter

The fundamental building block of a phase-leg capacitor-clamped inverter. The circuit has been called the flying capacitor inverter with independent capacitors clamping the device voltage to one capacitor voltage level. The inverter in Fig 5 provides a three-level output across *a* and *n*, i.e. Van = Vdc/2 , 0 ,–Vdc/2

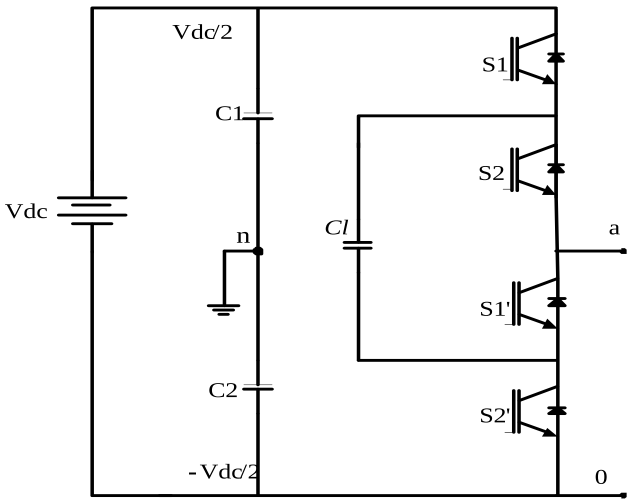


Fig 5. Capacitor Clamped Multilevel Inverter

F. Cascaded Multilevel Inverter

A different converter topology is introduced here, which is based on the series connection of single-phase inverters with separate dc sources. Fig 6. Shows the power circuit for one phase leg of a nine-level inverter with four cells in each phase. The resulting phase voltage is synthesized by the addition of the voltages generated by the different cells. Each single-phase full-bridge inverter generates three voltages at the output +Vdc, 0, - Vdc .This is made possible by connecting the capacitors sequentially to the ac side via the four power switches. The resulting output ac voltage swings from - 4Vdc to 4Vdc with nine levels, and the staircase waveform is nearly sinusoidal even without filtering.

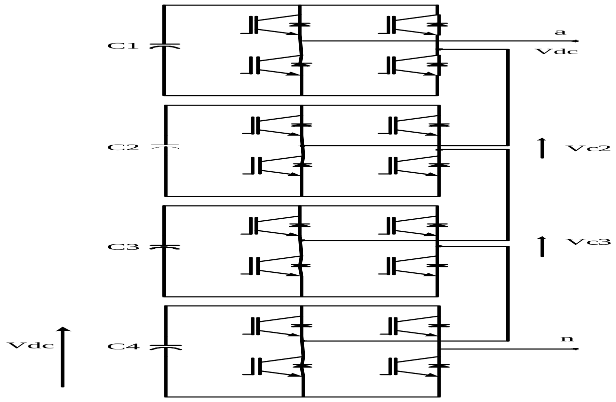


Fig 6. Cascaded Multilevel Inverter

III. .NEUTRAL POINT CLAMPED INVERTER (NPCI)

The neutral point clamped inverter (NPCI) was first introduced by A. Nabae, I. Takahashi and H. Akagi in 1980 and published in 1981. With this circuit configuration, the voltage stress on its power switching devices is half that for the conventional two-level inverter. Because of this nature, it was applied to medium and high voltage drives. Early applications included the steel industry and railroad traction areas in Europe and Japan.

In addition to the capability to handle high voltage, the NPC inverter has favorable features like lower line-to-line and common-mode voltage steps, more frequent voltage steps in one carrier cycle, and lower ripple component in the output current for the same carrier frequency. These features lead to significant advantages for motor drives over the conventional two level inverters in the form of lower stresses to the motor windings and bearings, less influence of noise to the adjacent equipment, etc. Combined with a sophisticated PWM strategy, it also makes it possible to improve the dynamic performance employing the dual observer method.

In order to benefit from the above-mentioned features, general-purpose pulse-width modulated (PWM) NPC inverters have been developed for low voltage drive applications**.** In this product, a unique technology is used to achieve balancing of the dc bus capacitor voltages [1]

A. Basic Circuit Configuration and Its Behavior

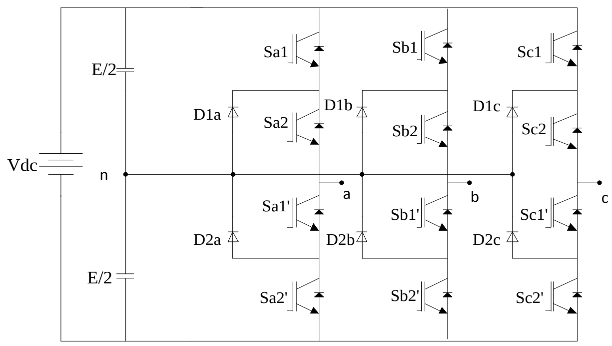


Fig 7. Basic Circuit Configuration

The circuit diagram of the NPC five-level inverter is shown in Fig 7. Each phase has four switching devices (IGBTs) connected in series. Taking phase a as an example, the circuit behaves in the following manner. When IGBTs Sa1 and sa2 are turned on, output A is connected to the positive mil (P) of the dc bus. When Sa2 and Sa1' are on, it is connected to the mid-point (0) of the dc bus, and when Sa1' and Sa2' are on, it is connected to the negative rail (N). Thus, the output can take five voltage values compared to two values for the conventional two-level topology. Relation between the switching states of GBTs and the resulting output voltage with respect to the dc mid-point is summarized below. DC bus capacitors need to be connected in series to get the mid-point that provide the zero voltage at the output. This is not a drawback since series connection of the dc capacitors is a common practice in general-purpose inverters rated at 400 - 480 V range due to the unavailability of high voltage electrolytic capacitors.

State/Switch	Sa1	Sa2	Sa1'	Sa2'	Vio
1	ON	ON	OFF	OFF	E/2
0	OFF	ON	ON	OFF	0
-1	OFF	OFF	ON	ON	- E/2

Table 1: Three level inverter switching states

The current from the inverter bridge into the capacitor mid-point is the only new issue for this topology, and maintaining the voltage Balance between the capacitors is important and influences the control strategy

IV. SPACE VECTOR MODULATION

A. Introduction

A different approach to PWM is based on the space vector representation of the voltages in the d-q plane. This chapter deals with space vectors and the method of using space vector concept for deriving switching instants for pulse width modulated voltage source inverter is discussed here. [4]

B. Space Vectors

The technique of the space vector modulation involves the concept of space vector. In any five phase machine, the stator coils are distributed in space in a symmetrical manner i.e. each coil is placed at 120 degree with respect to each other. In this method the five phase quantities can be transformed to their equivalent 2-phase quantity either in synchronously rotating frame or stationary reference frame. [4]

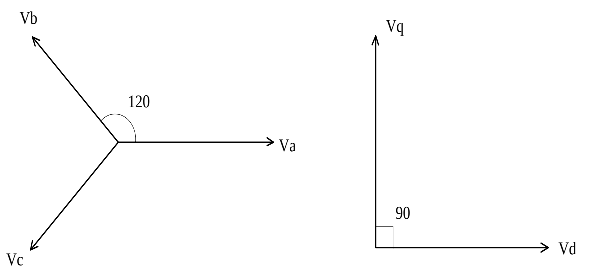


Fig 8. Three Phase Quantities Transformed into Two Phase

From this 2-phase component the reference vector magnitude can be found and used for modulating the inverter output. Let the three phase sinusoidal voltage component be,

$V_a = V_m \sin \omega t$

$V_b = V_m \sin(\omega t-120)$

$V_c = V_m \sin(\omega t-240)$

Equating the three phase machine quantities, we get

$V_a + V_b + V_c = 0$ (1)

$Vd = -3/2(Vb)+3/2(Vc) = 3/2 Vm\cos\omega t$ (2)

$Vq = Va - Vb/2 - Vc/2 = 3/2 Vm\sin\omega t$ (3)

Rotating vector,

$Vref = Vd = Vq = 3/2e\text{^}(j\omega t)$ (4)

From equation (4) it can be seen that space vector moves with constant angular velocity and constant amplitude. In case of non-sinusoidal quantities, the space vectors will not necessarily move with constant amplitude or constant angular velocity. The output of the inverters which are usually used in various applications are not perfectly sinusoidal. It contains appreciable amount of harmonics. So, the space vector of the stator voltages in these cases if of amplitude Vdc moving in steps and not with a constant angular velocity. In space vector modulation, a reference vector of the stator voltages is generated, which is made to move in the d-q plane in small steps so that it appears to move smoothly, as in the case with sinusoidal supply. The space vector modulation is based on the space vector representation of the voltages in d-q plane. After the transformation to the two phase quantities, the power as well as the impedance remain unchanged. In space vector modulation we try to generate a voltage reference vector at a point of time and the voltage reference vector Vref is sampled which approximately by a time sequence of five well defined switching state vector nearest to the reference vector. This is done by sampling the switching state vectors in such a way that the total volt seconds generated by these vectors over an interval Ts equals the volt seconds generated by the reference vector Ts.

C. Space Vector Representation of Five Level Inverter

The switching state vectors in this figure are normalized with respect to Vdc. The three symbol represent the conditions of each phase voltages +Vdc/2, 0, -Vdc/2 and zero means zero voltage. The modulation index is the magnitude of the reference vector V_{ref} normalized with respect to Vdc. It can be seen that the 12 vectors falling on the outer hexagon can be realized by only one switching state each whereas the 6 vectors falling on the inner hexagon can be realized with two switching states each and zero voltage with five switching states.

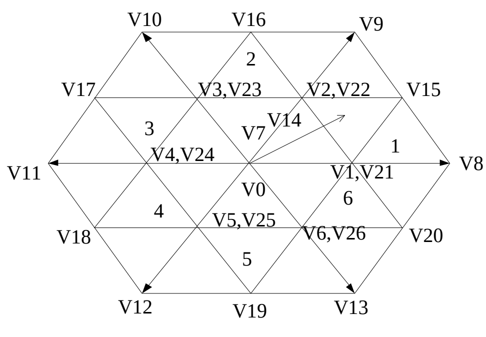


Fig 10. Space vector representation of five level inverter

Like two level inverter, in five level inverter each space vector is realized by using five indices of the triangle in which the tip of the vector lies.

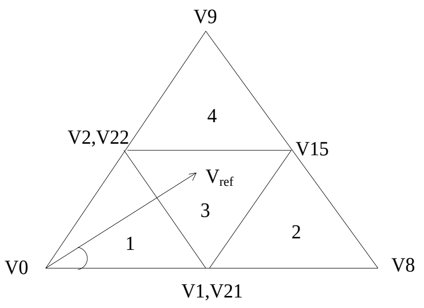


Fig 11. Four region sector

The above figure shows a 60 degree interval which consists of four triangles and it has six vectors V0 to V5.

If the reference vector is in triangle 1, V0, V1, V2, V3 states have to be switched. If the reference vector is in triangle 2; V1, V2 and V3 have to be switched. If it is in triangle 3; V1, V2 and V4 are switched and fir triangle 4, V2, V3 and V5 are switched. The sampling intervals for each condition found using same averaging principle used in two level inverter. This technique in effect averages the five switching state vectors over a sub cycle interval/sampling interval. The sampling intervals T1, T2 and T0 are evaluated. For triangle 1, the switching states are V0, V1, and V2. Similarly for triangle 2, the switching states are V1,V2,V3 for Ta, Tb and Tc duration and the sampling subintervals are derived as given in the table where m= Vref/(Vdc), Ts is the sampling time.

V. SIMULATION AND RESULTS

The simulation involved in the Space vector pulse width modulation of five level neutral point clamped inverter are summarized below

Simulation Steps

1. Initialize the system parameters using Matlab
2. Build simulink model
3. Plot simulation using Matlab

A.Simulink Model Of Five Level Neutral Point Clamped Inverter

The simulink model of five level NPC inverter is shown in fig 12 .the five level NPC inverter consists of two DC source and four switches per phase.the firing pulse are obtained from space vector pulse width modulation

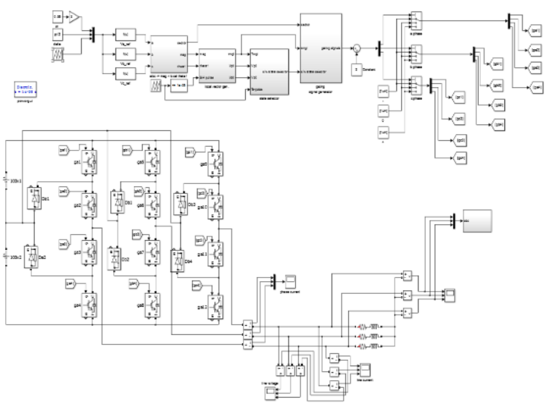


Fig 12. Simulink Model of Five Level Neutral Point Clamped Inverter

B. Output Current of five Level Inverter

Line Current

The output line current for five level inverter using SVPWM is shown in fig five phase current is obtained and each is having a phase delay of 120 ^{0}

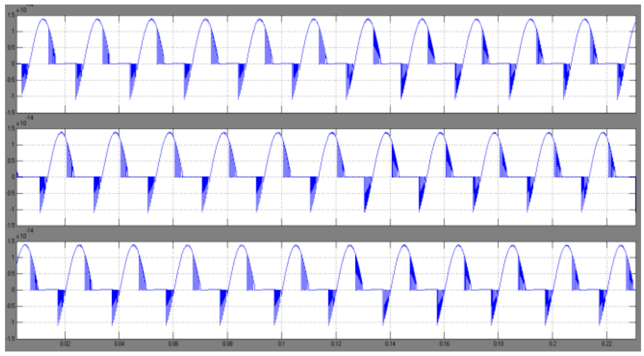


Fig 13. Line Current generated by SVPWM technique for five level inverter RL load

Phase Current

The output Phase current for five level inverter using SVPWM is shown in fig five phase current is obtained and each is having a phase delay of 120 ^{0}

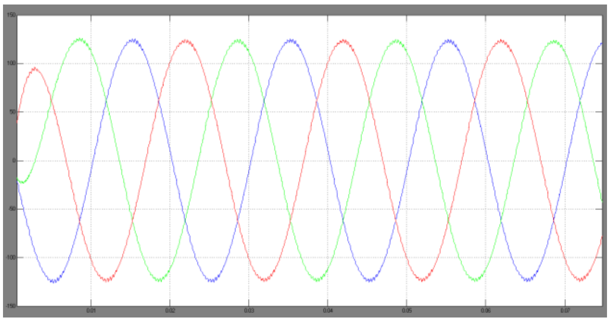


Fig 14. Phase Current generated by SVPWM technique for five level inverter RL load

B.Output Voltage for Five Level Inverter Line Voltage

The output line voltage for five level NPC inverter using SVPWM is shown in fig .five phase voltage is obtained and each is having phase delay of 120°.the stepped waveform gives lower distortion when compared to lower levels of inverter

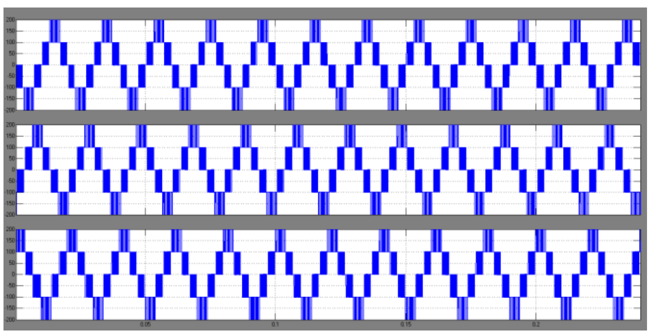


Fig 15. Line Voltage generated by SVPWM technique for five level inverter using RL load

Phase Voltage

The output phase voltage for five level NPC inverter using SVPWM is shown in fig .five phase voltage is obtained and each is having phase delay of 120°.the stepped waveform gives lower distortion when compared to lower levels of inverter

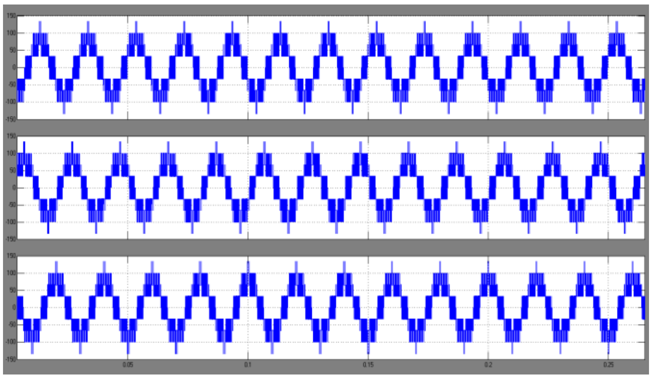


Fig 16. Phase voltage generated by SVPWM technique for five level inverter RL load

D.THD Analysis Of five Level Inverter

Output voltage THD

Figure shows the FFT plot for output voltage of five level NPC inverter for the modulation index values.From the figure it is clear that output THD obtained from the SVPWM technique result in less distortion.

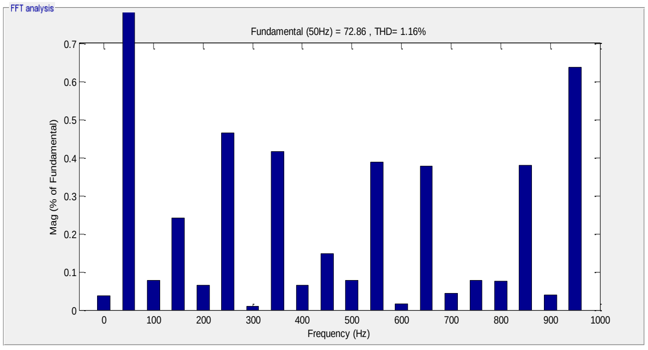


Fig 17. FFT Plot for output voltage of five level inverter using SVPWM technique

VI. CONCLUSION

In multilevel inverter ,as the switching involves several small voltages the rapid change in voltage is smaller .But harmonic elimination is the major issue for multilevel inverters.Space vector pulse width modulaion is considered a better technique of PWM implementation owing to its associated advantages like better fundamental output voltage ,better harmonic performances,efficient DC voltage utilization and easier to implement in digital signal process and micro controllers

The sector identification space vector pulse width modulation techniqueis used to analyze the performance of multilevel inverter.The results has been presented and analyzed.The effectivness of these algorithm have been discussed in terms of inverter output voltage,current waveforms,total harmonic distortion.The application of space vector pulse width modulation control startegy on five level neutral point clamped inverter are analysed .The main aim of this method is to prove the effictiveness of SVPWM in the contribution of reduced harmonic injection than the conventional pulse width modulation techniques

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BIOGRAPHY

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