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Design and Implementation of Seventeen Level T type inverter with Minimal components

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Abstract : The multilevel inverters are resourceful in producing a voltage waveform with superior-quality staircase counterfeit sinusoidal and depressed harmonic distortion. Several conventional topologies are proposed to realize the MLI however, the limitations of these topologies may involve more DC sources, Complex control circuit and power-switching devices, which in turn, increases the cost and size of the inverter. These drawbacks can be eliminated with the combined topology by cascaded H-Bridge and T-Type inverter. As compared with the established multilevel topologies the recommended topology having a reduced number of DC sources, power-switching devices, more efficient, and cost-effective. The proposed MLI is a blend of a single-phase T-Type inverter and an H-Bridge module made of sub switches. This article incorporates the design and simulation of the multilevel inverter with Half height control technique. Further, the 17-level is examined with different combinational loads. The proposed inverter is stable during nonlinear loads, and it is well suited for FACTS and renewable energy grid-connected applications. An operational guideline has been explained with correct Figures and tables.

***IndexTerms* - Multi-Level Inverter (MLI), Half height method, Equal phase method, Total Harmonic Distortion (THD), T-Type Inverter**

I. INTRODUCTION

Multilevel inverters are the inverters in which the output of the inverter will have more than one level and as number of levels increase the output voltage is closer to sinusoid and gradually the THD decreases. As a result, a multilevel power inverter structure has been introduced as an alternative in high power and medium voltage situations. A multilevel inverter not only achieves high power ratings but also enables the use of renewable energy sources. Renewable energy sources such as photovoltaic, wind, and fuel cells can be easily interfaced to a multilevel inverter system for a high-power application. The concept of multilevel inverters has been introduced since 1975. The term multilevel began with the three-level inverter. Subsequently, several multilevel inverter topologies have been developed. However, the elementary concept of a multilevel inverter to achieve higher power is to use a series of power semiconductor switches with several lower voltage dc sources to perform the power conversion by synthesizing a staircase voltage waveform. Capacitors, batteries, and renewable energy voltage sources can be used as the multiple dc voltage sources. The commutation of the power switches aggregates these multiple dc sources to achieve high voltage at the output.
MLI's incorporate with power semiconductor components and various DC Sources to build up staircase waveform tends towards sinusoidal. Mainly three traditional multilevel inverter topologies have existed: they are neutral point clamped (NPC), cascaded H-bridge (CHB), and flying capacitors (FCs). CHB-MLI having high voltage and power levels also more reliable, T-Type inverter topology without H-Bridge was proposed in [2] to achieve higher levels at various load conditions with fourteen power switches, including three bidirectional switches, [3] produces higher level and high-power quality with the help of eight Switches, four diodes and four DC sources. it requires more power semiconductor switches [7], The topology in [8] suggested a basic structure with eight unidirectional and one bidirectional switch to produce 15 levels, A Square T-Type topology was proposed in [9] to produce seventeen levels with four DC power sources. In [10] modular multilevel converter by using many modules can be connected in series parallel combination to produce higher number of levels, but number of capacitors required is more, the circuit in [12] is a nine-level inverter with twelve switches; three different frames are cascaded in [13] to get the desired nine-level output with ten switches. A Square T-Type topology was proposed in [14] to produce seventeen levels with four DC sources. K-type structure in [15] uses two additional switches to deliver thirteen levels and reduces the DC sources to two.

At Present in many industrial applications have bit higher power appliances in the last couple of years. A couple of medium voltage service appliance requires high-power and medium voltage level. It is challenging directly to connect only one power electronic switch to the medium power grid. MLIs are turning into a well-known option to two-level inverters in the view of their several advantages, such as lesser harmonic distortion, simplified filters and better wave capability taking after a sinusoidal output because of excellent power quality, MLIs are broadly used in all disciplines of electrical engineering, for example, renewable energy conversion, high voltage DC transmission.

II. Circuit Diagram

The circuit diagram of proposed T-type Multi-Level inverter cascaded with hybrid H-bridge inverter.

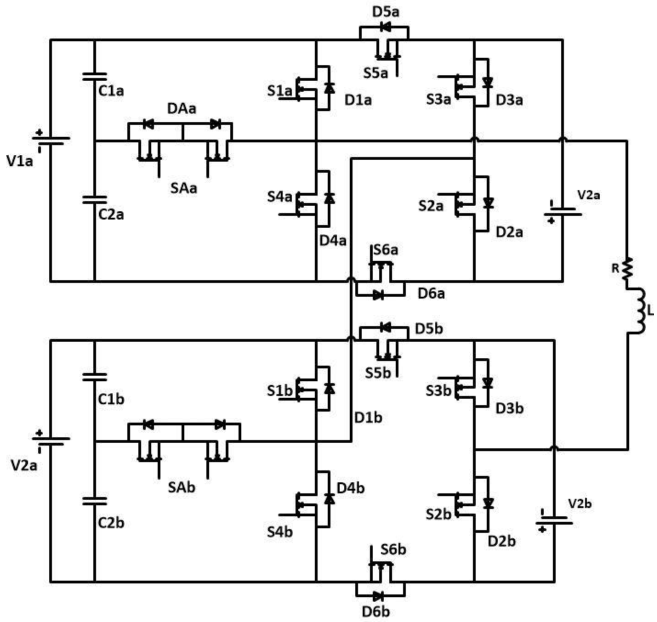

Fig. 1 Circuit diagram of 17-level inverter

The structure of the proposed 17 level inverters is incorporated with four DC sources V1a, V1b, V2a and V2b along with twelve unidirectional switches from S1a to S6b and two bidirectional switches SAa and SAb and it has four Capacitors C1a, C1b, C2a and C2b. Which are connected to design a seventeen level T-type inverter. The specific arrangement reduces the additional DC source requirement also simplifies the number of switches needed. For working and the functioning of the introduced topology, various working modes have been represented along with conducting power electronic devices and path of load current Io as depicted.

III. Load Design

Kirloskar 1HP Medium height water pump

Specifications:

RMS Input voltage = 230 V

Peak Input voltage = 325.2 V

Speed = 1440 RPM

Frequency = 50 Hz

Power factor = 0.75

Power Output of motor = 1 Hp = 746 W

RMS output current = $\frac{Po}{Vrms} = \frac{746\ W}{230\ V}$ = 3.24 A

Peak output current = I rms * $\sqrt{2}$ = 4.58 A

Peak output voltage = V rms * $\sqrt{2}$ = 325.2 V

Impedance = $\frac{Vm}{Im}$ = 71 Ohm

Power factor = $\frac{Active\ power}{Apparent\ power} = \frac{I^2R}{I^2Z} = \frac{R}{Z}$

Cos (Ø) = $\frac{R}{Z}$

0.75 = $\frac{R}{71}$

R = 53.25 Ohm

$Z^2 = R^2 + Xl^2$

$Xl^2 = Z^2 - R^2$

$Xl = \sqrt{(Z^2 - R^2)}$

XL = 46.96 Ohm

2*pi*f*L = 46.96

L = $\frac{46.96}{2*3.14*50}$

L = 0.14 H

IV. Modes Of Operation

In this portion, the proposed inverter operation is explained through the various modes of output voltage levels produced in a steady state. The DC source voltage is equally shared by the DC link capacitors C1a, C1b, C2a and C2b with equal magnitudes.

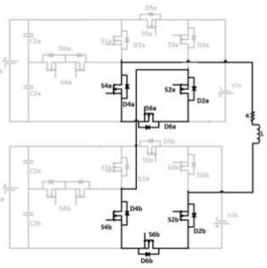

Fig:2(a)Mode 0 operation

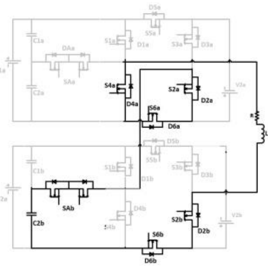

Fig:2(b)Mode 1 operation

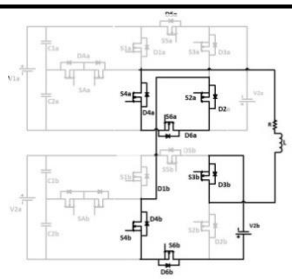

Fig:2(c)Mode 2 operation

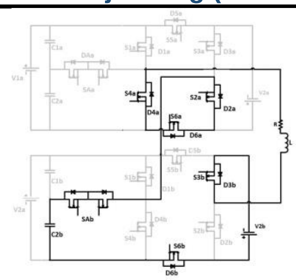

Fig:2(d)Mode 3 operation

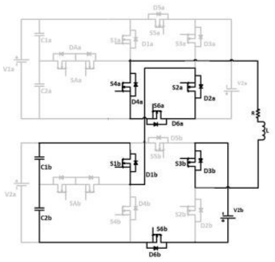

Fig:2(e) Mode 4 operation

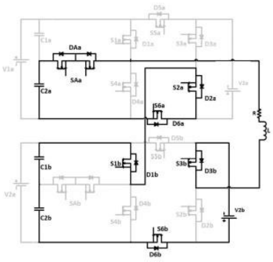

Fig:2(f)Mode 5 operation

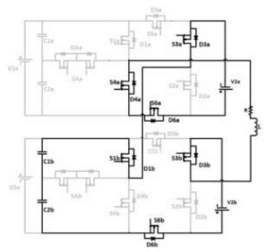

Fig:2(g)Mode 6 operation

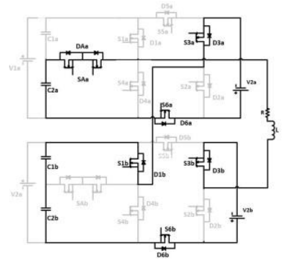

Fig:2(h)Mode 7 operation

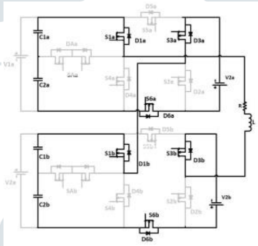

Fig:2(i)Mode 8 operation

V. SWITCHING STATES OF SEVENTEEN LEVEL T-TYPE INVERTER

Table 1 Switching States of Seventeen level T-Type Inverter

Level	SAa	S1a	S2a	S3a	S4a	S5a	S6a	Sab	S1b	S2b	S3b	S4b	S5b	S6b	Output Voltage(V)
L1	0	1	0	1	0	0	1	0	1	0	1	0	0	1	325
L2	1	0	0	1	0	0	1	0	1	0	1	0	0	1	284.38
L3	0	0	0	1	1	0	1	0	1	0	1	1	0	1	243.76
L4	1	0	1	0	0	0	1	0	1	0	1	0	0	1	203.14
L5	0	0	1	0	1	0	1	0	1	0	1	0	0	1	162.52
L6	0	0	1	1	1	0	1	1	0	0	1	0	0	1	121.9
L7	0	0	1	0	1	0	1	0	0	0	1	1	0	1	81.28
L8	0	0	1	0	1	0	1	1	0	1	0	0	0	1	40.66
L9	0	0	1	0	1	0	1	0	0	1	0	1	0	1	0
L10	0	1	0	1	0	1	0	0	0	1	0	1	0	1	-40.62
L11	0	0	0	1	1	1	0	0	0	1	0	1	0	1	-81.24
L12	1	0	1	0	0	1	0	0	0	1	0	1	0	1	-121.86
L13	0	0	1	0	1	1	0	0	0	1	0	1	0	1	-162.48
L14	0	0	1	0	1	1	0	1	0	1	0	0	0	1	-203.1
L15	0	0	1	0	1	1	0	0	1	1	0	0	0	1	-243.72
L16	0	0	1	0	1	1	0	1	0	1	0	0	1	0	-284.34
L17	0	0	1	0	1	1	0	0	0	1	0	1	1	0	-325

VI. CONTROL STRATEGIES

In this chapter, a brief explanation about different control techniques for calculating switching angles is presented. The switching angles, phase delays and duty cycles are tabulated for Equal phase angle and half height method to know the difference between them. Among these two techniques half height method performs better than the other one. Hence this technique is selected to propose inverter. Mainly the control technique will depend on the total harmonic distortion (THD). For all the levels, the switching angles should be calculated in such a way that it should minimize the THD because it will directly impact on the THD calculations.

A. Equal Phase Angle Modulation Technique

The equal phase (EP) angle criteria are derived from the simplest idea, to averagely distribute the switching angles in the range 0–π. Here the thickness of every step in the output voltage waveform is considered equal and the corresponding switching angles are obtained.

In this method, for the quarter wave symmetry, the calculation of main switching angles is
Determined by the equation 1, as follows,

θj = j ∗ (180 /N) ………………………………… (1) Where, j = 1,2,3, 4…. (N-1)/2,
and N= number of output level.

The switching angles are distributed over the time period of 0.02.

Let θ1, θ2…. be the switching angles calculated by the equation (1),
t1, t2, t3… be the phase delay in seconds given by (2)
d1, d2, d3….be the duty cycles of the switches as per the equation (3).

The frequency is fixed as 50Hz, therefore the time period, T=20 milliseconds. The phase delays for all the switches can be calculated by the equation,

tj = (θj / 360) * T …………………………………. (2)

The pulse width (duty cycle) for each output level can be calculated by,

d = j+1 – j (or (θj+1 – θj)/ 360) …………………… (3)

B. Half Height Modulation Technique

The half-height (HH) method is explained as, when the fundamental value increases to the half-height of the level

In the Ha1f Height switching modu1ation technique the tota1 period (0 – 360 degrees) of the output waveform are divided into four quadrants i.e.

The period from 0 to 90 degree is referred as the main switching ang1e which is ca1cu1ated as

$$a_k = \sin^{-1}\frac{(2k-1)}{(N-1)}$$

Where k = 1, 2, 3, 4…………$\frac{(N-1)}{2}$

N = Number of output vo1tage 1eve1s

The period from 90 to 180 degree is referred as the second quadrant switching ang1e which is ca1cu1ated as

$$a_{\frac{N+1}{2}} = \pi - a_{\frac{N-1}{2}}, \pi - a_{\frac{N-2}{2}}, \ldots\ldots\ldots, \pi - a_1$$

The period from 180 to 270 degree is referred as the third quadrant switching ang1e which is ca1cu1ated

$$a_N = \pi + a_1, \pi + a_2, \ldots\ldots\ldots, \pi + a_{\frac{N-1}{2}}$$

The period from 270 to 360 degree is referred as the fina1 quadrant switching ang1e which is ca1cu1ated

$$a_{\frac{3N-1}{2}} = 2\pi - a_{\frac{N-1}{2}}, 2\pi - a_{\frac{N-2}{2}}, \ldots\ldots, 2\pi - a_1$$

VII. SIMULATION MODEL

Seventeen level t-type inverter circuit is simulated in computer using MATLAB software and the circuit is analyzed for resistive-inductive load with the help of fundamental switching techniques to compare the results. The THD obtained in this simulation is within the IEEE519 standards limit without using any filter circuits. The circuit is also simulated with equal phase angle and half height method techniques and the THD obtained is compared. Through the half height method, we obtained the lowest THD. The Simulink circuit model of the symmetrical inverter and its gate pulse simulation circuits are shown.

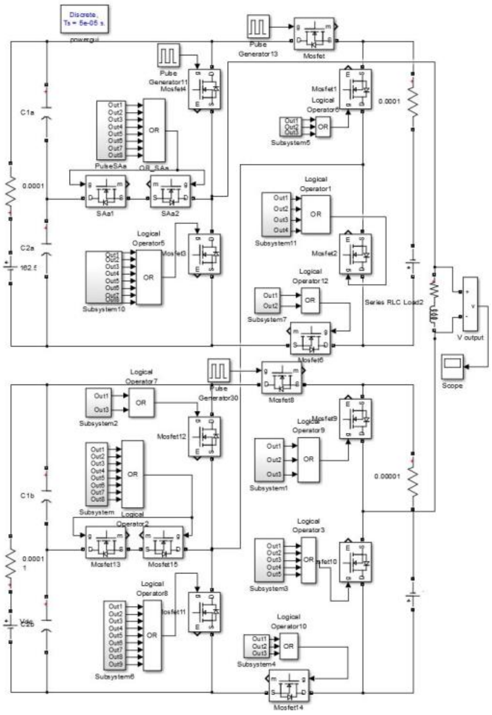

Fig. 3. MATLAB Simulink Model of 9-level T type inverter

VIII. Results And Discussion

A. Output Voltage

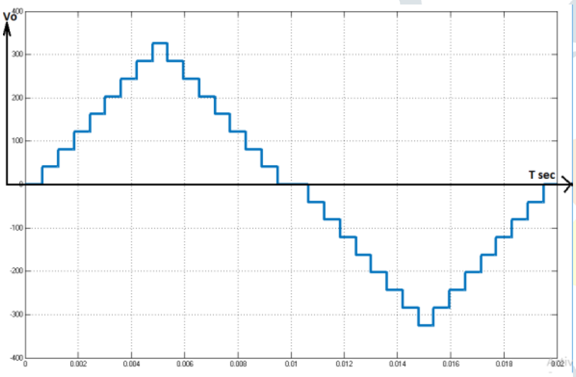

Fig. 4 Output voltage for 9-level inverter using equal phase angle method

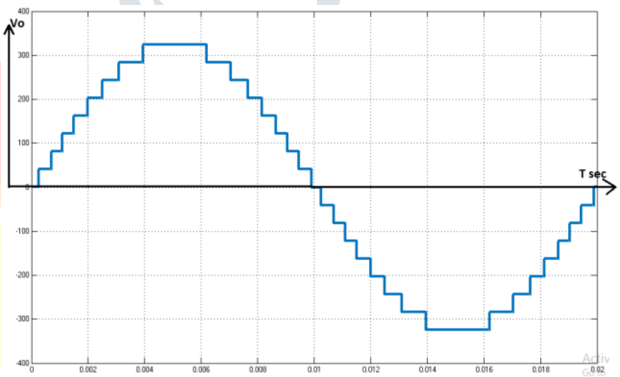

Fig. 5 Output voltage for 9-level inverter using half height method

B. THD Analysis

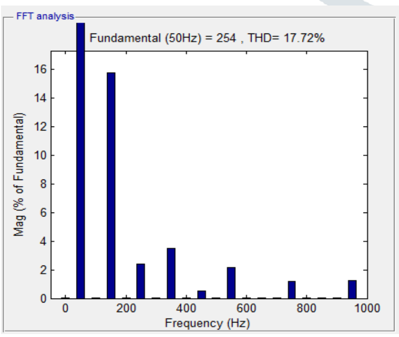

Fig. 7 FFT analysis for equal phase angle method

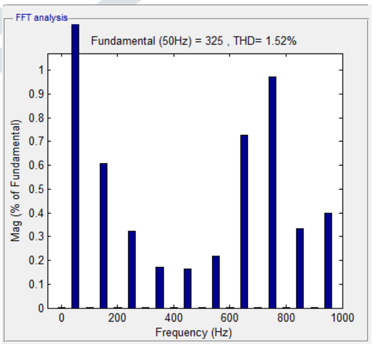

Fig. 8 FFT analysis for half height method

TABLE II
SWITCHING STATES OF SEVENTEEN LEVEL INVERTER

Modulation technique	Type of load	THD % Voltage
Equal phase angle modulation technique	R-L Load	17.72%
Half height modulation technique	R-L Load	1.52%

IX. Conclusion

This work mainly concentrates on reducing number of switches and reducing total harmonic distortion. This 17-level T type inverter generates 17 (8 positive, 8 negative and one zero level) levels output waveform. Due to the use of fewer number of components, the circuit complexity, cost, voltage stresses on switches are reduced. The MATLAB simulation is done for equal phase angle method and half height modulation technique. The comparison is done between equal phase method and Half Height modulation technique in terms of simulation results with RL loads considering the THD parameter to highlight the best performance of the 17-level T type inverter circuit with Half Height modulation technique. Thus, simulation results show the better performance and superiority of the 17-level T type inverter circuit over the conventional multilevel inverter topologies. The THD value obtained for voltage is about 17.72% for RL load using Equal Step method and THD with same RL load using Half Height modulation technique about 1.52%. So, there by concluding that THD using Half Height PWM technique is better. The presented MLI is accomplished with reduced THD and reduces number of switches. This MLI is well suited for renewable energy applications.

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