

Selective Harmonic Elimination of Multilevel Inverter Using SHEPWM Technique

B. Ashok, A.Rajendran

Abstract—The emergence of multilevel inverters has been in increase since the last decade. These new types of converters are suitable for high voltage and high power application due to their ability to synthesize waveforms with better harmonic spectrum. Numerous topologies have been introduced and widely studied for utility and drive applications. Amongst these topologies, the multilevel cascaded inverter was introduced in Static VAR compensation and drive systems. This project presents a new technique for getting an effective multilevel SHEPWM control techniques is used to reduce odd harmonics. Selective harmonic elimination Technique in Seven Level Multilevel inverter with SRM is used in MATLAB Simulink environment is used to simulate the results.

Keywords— MATLAB Simulink, PWM control techniques, Multilevel Inverter.

I. INTRODUCTION TO MULTILEVEL INVERTER

Multilevel inverters are significantly different from the ordinary inverter where only two levels are generated. The semiconductor devices are not connected in series to for one single high-voltage switch. In which each group of devices contribute to a step in the output voltage waveform. The steps are increased to obtain an almost sinusoidal waveform. The number of switches involved is increased for every level increment. Figure 1 shows the block diagram of the general multilevel inverter.

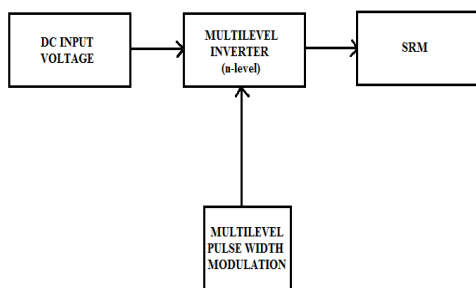


Fig.1 Block Diagram of Multilevel Inverter with SRM

Generally, the output waveform of the multilevel inverter is generated from different voltage sources obtained from the capacitor voltage sources. In the past two decades, several multilevel voltage source converters have been introduced. In that some of the topologies are popular and some are not popular.

II. PROPOSED MULTILEVEL INVERTER

Here the proposed multilevel inverter is Seven Level. This proposed converter consists of less number of switches when compared to the other familiar topologies. The initial cost reduces because of the switch reduction.

Manuscript received on May, 2013.

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For the proposed topology, we just need to add only one switch for every increase in levels. So initial cost get reduced. The proposed multilevel inverter consists of seven MOSFET switches and three separate DC sources with a load. By switching the MOSFETS at the appropriate firing angles, we can obtain the seven level output voltage. MOSFET is preferred because of its fast switching nature. Because of the reduction in the number of switches the initial cost reduces, controlling becomes easier, losses becomes less due to the elimination of the harmonics, overall weight reduces because of the usage of less number of components.

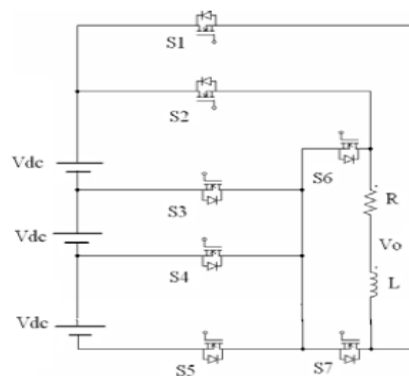


Fig.2 Circuit Diagram of the Seven Level Proposed Multilevel Inverter

Three various supplies are given individually. By switching the MOSFETS, according the table 1 given above, the various levels of output is obtained.

TABLE 1 SWITCHING CONDITIONS

SL.NO.	CONDUCTING SWITCHES	AMPLITUDE OF THE OUTPUT VOLTAGE
1	S2,S7,S3	+Vdc
2	S2,S7,S4	+2Vdc
3	S2,S7,S5	+3Vdc
4	-	0
5	S1,S6,S3	-Vdc
6	S1,S6,S4	-2Vdc
7	S1,S6,S5	-3Vdc

III. SHE PWM (SELECTIVE HARMONIC ELIMINATION)

There are many popular methods are used to reduce the harmonics in order to get an effective results. The popular methods for high switching frequency are Sinusoidal PWM and Space Vector PWM. For low switching frequency methods are space vector modulation and selective harmonic elimination. The SPWM technique has disadvantage that it cannot completely eliminate the low order harmonics. Due to this it cause loss and high filter requirement is needed. In Space Vector Modulation technique cannot be applied for unbalanced DC voltages. SHE PWM technique uses many

mathematical methods to eliminate specific harmonics such as 5th, 7th, 11th, and 13th harmonics. The popular Selective Harmonic Elimination method is also called fundamental switching frequency based on harmonic elimination Theory.

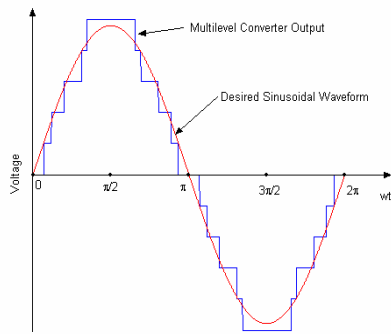


Fig.3 Staircase Sinusoidal Waveform Generated By H-Bridge Cascaded Multilevel Voltages

As shown in Fig.3, a multilevel converter can produce a quarter-wave symmetric stepped voltage waveform synthesized by several DC voltages.

IV HARMONIC ELIMINATION THEORY

By applying Fourier series analysis, the output voltage can be obtained. Fourier Series is an infinite sum of trigonometric functions that are economically related.

$$f(t) = a_0 + \sum_{n=1}^{\infty} c_n \cos(2\pi n f_0 t + \varphi_n) \quad (1)$$

Where

n= integer multiple,

φ_n = initial phase for nth harmonic

a_0 and c_n = Fourier co-efficients

The output voltage equation derived for different voltage sources is given below.

$$v(t) = \sum_{n=1,3,5}^{\infty} \frac{4V_{dc}}{n\pi} ((v_1 \cos(n\varphi_1) + v_2 \cos(n\varphi_2) \dots v_s \cos(n\varphi_s)) \sin(n\omega t) \quad (2)$$

Where

S = No. of dc sources connected per phase

V_1, V_2, V_3 = level of Dc voltage $0 < \theta_1 < \theta_2 < \theta_3 \dots < \theta_s < \frac{\pi}{2}$ = Switching angles

For the above Fundamental peak voltage v(t), it is required to determine the switching angles $0 < \theta_1 < \theta_2 < \theta_3 \dots < \theta_s < \frac{\pi}{2}$ and some lower order harmonics of phase voltage are zero. Among no of switching angles one is used for fundamental voltage selection and remaining (s-1) switching angles are needed to eliminate lower order harmonics. For a balanced three phase system, triplen harmonics are eliminated automatically by using line-line voltages so only non-triplen odd harmonics are present. To

minimize harmonic distortion and to achieve adjustable amplitude of the fundamental component, up to s-1 harmonic contents can be removed from the voltage waveform. To keep the number of eliminated harmonics at a constant level, all switching angles must satisfy the condition $0 < \theta_1 < \theta_2 < \theta_3 \dots < \theta_s < \frac{\pi}{2}$ otherwise the total harmonic distortion (THD) increases dramatically.

In order to achieve a wide range of modulation indexes with minimized THD for the synthesized waveforms, a generalized selective harmonic modulation method is proposed, which is called virtual stage PWM. An output waveform is shown in Figure 4.

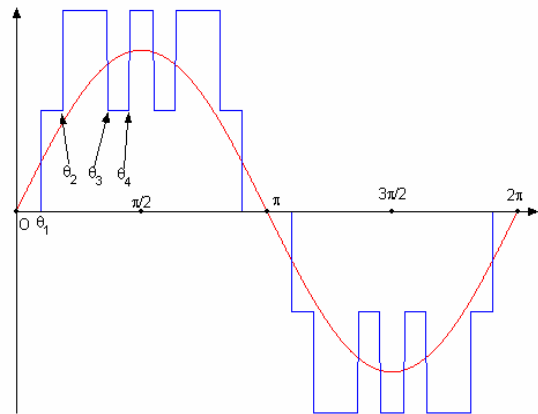


Fig.4 Output waveform of virtual stage PWM control

Hence the relation between the fundamental voltage and maximum voltage is given by modulation Index. It is given by m_1 , is the ratio of fundamental voltage v_1 to the maximum voltage.

The maximum voltage is given by

$$V_{1max} = \frac{4}{\pi} sV_{dc}$$

$$m = \frac{\pi v_1}{4sV_{dc}} \quad (3)$$

For an 7- level inverter, there are 4 H-bridges per phase, s=4 i.e., five degrees are available; one degree is used to control the magnitude of fundamental voltage and remaining degrees are used to eliminate 5th, 7th, 11th, and 13th order harmonic components. The above statements are given by

$$\begin{aligned} \cos(\theta_1) + \cos(\theta_2) + \dots + \cos(\theta_s) &= 4m_1 \\ \cos(5\theta_1) + \cos(5\theta_2) + \dots + \cos(5\theta_s) &= 0 \\ \cos(7\theta_1) + \cos(7\theta_2) + \dots + \cos(7\theta_s) &= 0 \\ \cos(11\theta_1) + \cos(11\theta_2) + \dots + \cos(11\theta_s) &= 0 \quad (4) \end{aligned}$$

The above equation is a 4 transcendental equations known as Selective Harmonic Elimination. Here, $\theta_1, \theta_2, \theta_3, \theta_4$ and θ_s are the unknown values.

V RESULTANT METHOD FOR TRANSCENDENTAL EQUATIONS SOLVING USING RESULTANT THEORY

$$a(x_1, x_2) = a_3(x_1)x_2^3 + a_2(x_1)x_2^2 + a_1(x_1)x_2 + a_0(x_1) = 0 \quad (5)$$

$$b(x_1, x_2) = b_3(x_1)x_2^3 + b_2(x_1)x_2^2 + b_1(x_1)x_2 + b_0(x_1) = 0 \quad (6)$$

Where

$$a_3(x_1), a_2(x_1), a_1(x_1), a_0(x_1),$$

$b_3(x_1), b_2(x_1), b_1(x_1), b_0(x_1)$ are

the polynomials in x_1 . The polynomials of x_1 and x_2 .

$$\alpha(x_1, x_2) = \alpha_2(x_1)x_2^2 + \alpha_1(x_1)x_2 + \alpha_0(x_1) \quad (7)$$

$$(x_1)x_2^2 + \beta_1(x_1)x_2 + \beta_0(x_1) \quad (8)$$

$$\frac{a(x_1, x_2)}{b(x_1, x_2)} = \frac{\alpha(x_1, x_2)}{\beta(x_1, x_2)}$$

The resulting matrix is given by

$$\begin{bmatrix} b_0 x_1 & a_0 x_1 & 0 & 0 & 0 & 0 \\ b_1 x_1 & a_1 x_1 & b_0 x_1 & a_0 x_1 & 0 & 0 \\ b_2 x_1 & a_2 x_1 & b_1 x_1 & a_1 x_1 & b_0 x_1 & a_0 x_1 \\ b_3 x_1 & a_3 x_1 & b_2 x_1 & a_2 x_1 & b_1 x_1 & a_1 x_1 \\ 0 & 0 & b_3 x_1 & a_3 x_1 & b_2 x_1 & a_2 x_1 \\ 0 & 0 & 0 & 0 & b_3 x_1 & a_3 x_1 \end{bmatrix} \begin{bmatrix} -\alpha_0 x_1 \\ \beta_0 x_1 \\ -\alpha_1 x_1 \\ \beta_1 x_1 \\ -\alpha_2 x_1 \\ \beta_2 x_1 \end{bmatrix} = \begin{bmatrix} 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \end{bmatrix}$$

$a(x_1, x_2)$ and $b(x_1, x_2)$ are co prime. For a particular value for x_1 results in a singular $S(x_1)$, then there are non-zero solutions to above equations.

VI. SIMULATION RESULTS

Simulation results of the proposed converter for seven levels using MATLAB/Simulink. The PWM technique is used for pulse generation. The output waveform is phase voltage and it comprises seven levels. The SHE PWM technique is used to reduce the odd harmonics. The seven level output is shown below.

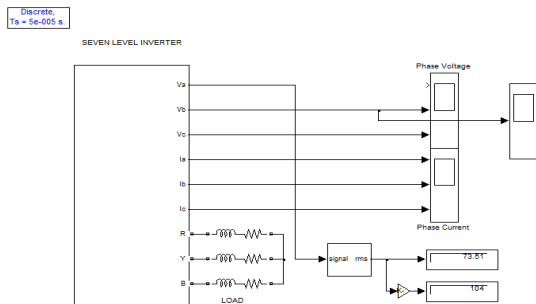


Fig.5 Seven Level Inverter SIMULINK Model

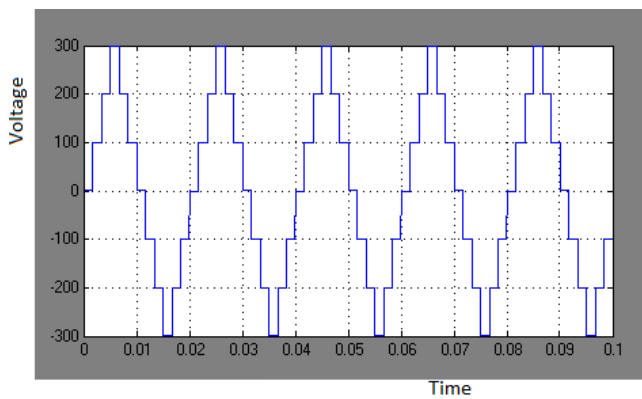


Fig.6 Output of seven level inverter

We get 7 levels of output for the simulated Seven Level Multilevel Inverter without any connection of any load. Let we see the MATLAB model of Seven Level Multilevel

Inverter with Switched Reluctance Motor and its output is shown below.

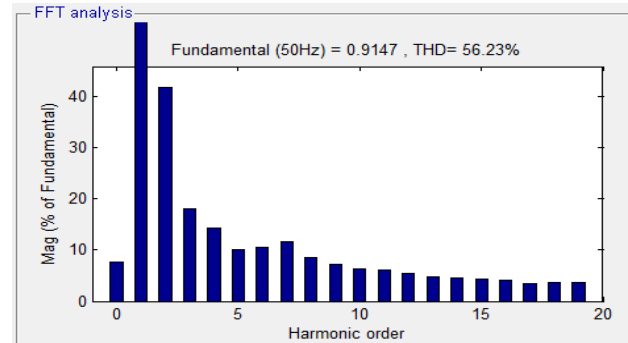


Fig.7 THD values in Seven Level Inverter In order to reduce odd harmonics like 3rd, 5th, 7th, and 11th the MATLAB model is designed.

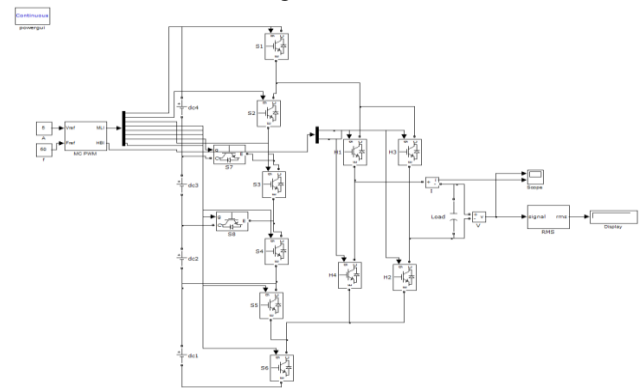


Fig.8 SHE PWM SIMULINK Model

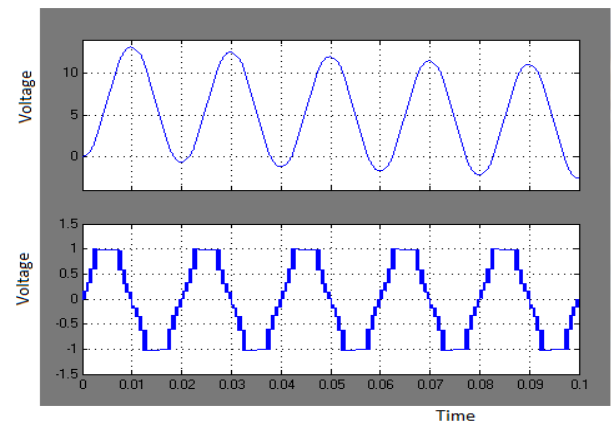


Fig.9 Comparison of Seven Level output with Sine wave

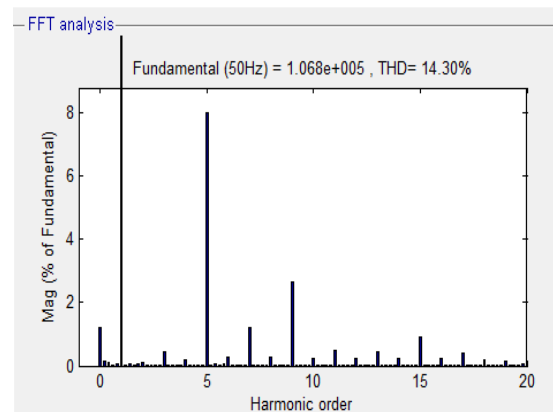


Fig.9, 5th Harmonic Reduction

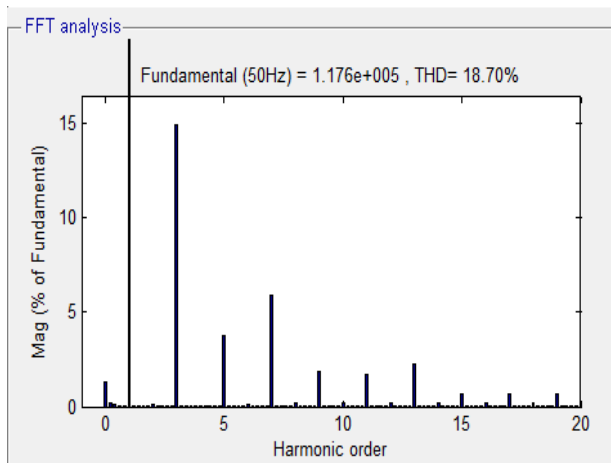


Fig.107th Harmonic reduction

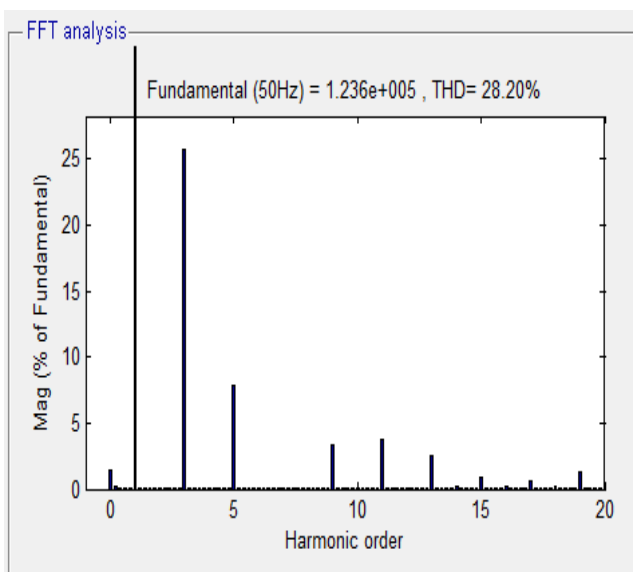


Fig.11th Harmonic reduction

TABLE 2 COMPARISON OF THD VALUES IN MULTILEVEL INVERTER VS. SHE PWM TECHNIQUE

HARMONIC ORDER	THD VALUE (%) USING MULTILEVEL INVERTER	THD VALUE (%) USING SHE PWM TECHNIQUE
3	40	0
5	10	7
7	11	6
11	7	4

VII. CONCLUSION

The simulation of the seven-level multilevel inverter is successfully done using Selective Harmonic Elimination pulse width modulation technique. The reduction of THD values are compared in Table 2. From the simulation results we calculated THD value and compared the THD value of multilevel inverter with ordinary PWM technique and SHE PWM technique. Thus THD value is reduced using SHEPWM Technique.

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