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Low Harmonics Single Phase Multilevel Power Inverter

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Abstract: This study deals with the simulation and development of a single phase multilevel inverter. The aim of the study is to investigate the performance and features of transformer and transformer-less multilevel inverters. In order to generate sinusoidal wave with minimum THD, harmonic elimination method has been used to calculate conducting angle of each H-bridge. This generates the output waveform with certain voltage and low THD. PIC microcontroller has been used to generate the signals required to operate the system. The proposed circuit was simulated using Pspice/Orcad and the results were compared with the hardware experimental results and a good agreement has been found between simulation and laboratory results.

Key words: Multilevel inverter, harmonic elimination, cascaded inverter

INTRODUCTION

Recently, many reports were talking about the disadvantages of the normal single inverters or two level inverters especially due to high voltage change rates dv/dt, which produced a common-mode voltage across the motor winding and power electronics switches. Multilevel converters were introduced to overcome this problem. A multilevel inverter converts the electric power from dc to ac form by synthesizing desired sinusoidal voltage from a series of single-phase, full bridge (H-bridge) inverter units. Separate dc sources are required to supply such inverter, which may be obtained from batteries, fuel cells, or solar cells or from one dc source synthesizing a combination state of diodes or capacitors, for high power application (Tolbert *et al*., 2002). Multilevel converter can be operated without using a high frequency technique of Pulse Width Modulation (PWM), which has the disadvantage of electromagnetic interference with communication signals and produces high stress on the switches at the high voltage application (Rashid, 2004). Unlike diode clamed and flying-capacitor inverters, cascade multilevel inverter needs the least number of components to achieve the same number of voltage level. Cascade multilevel converters have wide applications especially for High-power Electrical Vehicle (HEV) motor drives because it can be used to convert small dc voltage to high ac voltage.

High frequency switching can exacerbate the problem because of the numerous times that common-mode voltages should impress upon the motor each cycle. The main problems reported were motor bearing failure and motor winding insulation breakdown because of circulating current, dielectric stresses, voltage surge and corona discharge (Corzine and Familiant, 2002). Multilevel inverters overcome these problems since individnal switching devices have much lower dv/dt per switching and they operate at high efficiencies since these devices switch on and off at a much lower frequency than PWM - controlled inverter system (Tolbert *et al*., 1999). The multilevel voltage source inverter is a unique structure that allows them to reach high voltages with low harmonics. For this reason, multilevel inverters can easily provide the high power required for a large electric drives.

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Cascade Multilevel Inverter

The cascade H-bridge inverter consists of a number of single phase H-bridge units with or without PWM techniques. Figure 1 shows H-bridge unit and its voltage waveforms, while Fig. 2 shows the construction of a single phase cascaded inverter. The main function for each H-bridge is increase the voltage level and to control the width of its output as shown in Fig. 3. Each H-bridge has its conducting angle (α), which means that each H-bridge can produce output waveform with different width. The summation of output voltages of all H- bridges produces the final out voltage of the system with low harmonics.

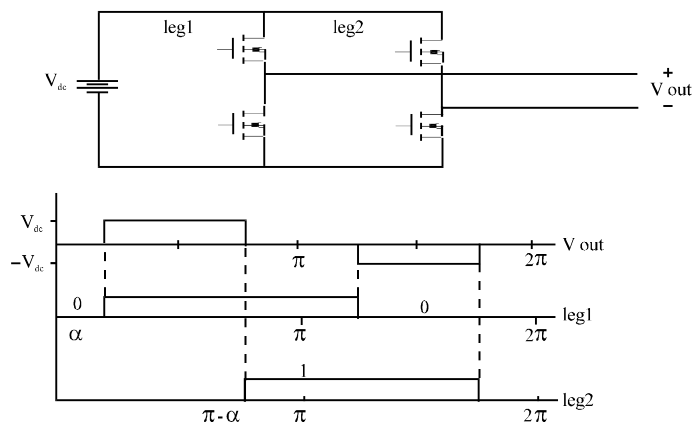

Fig. 1: H-bridge unit

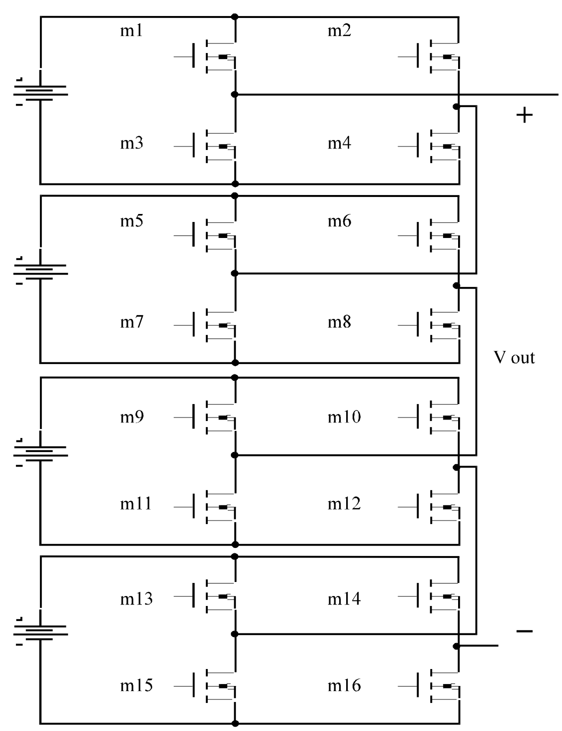

Fig. 2: Cascade multilevel circuit

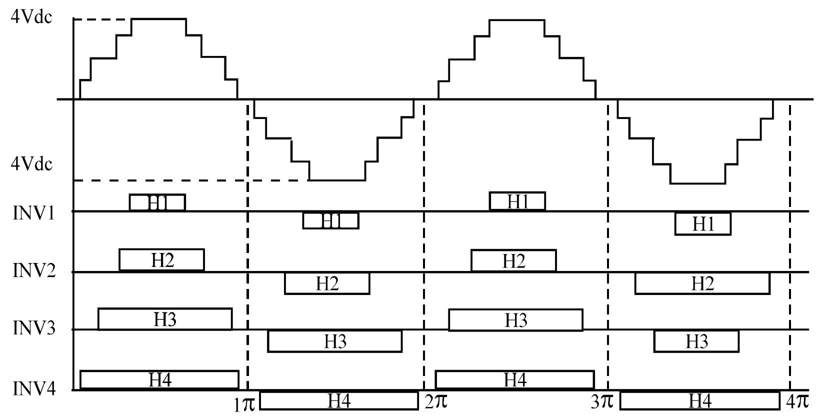

Fig. 3: Synthesis of the output voltage

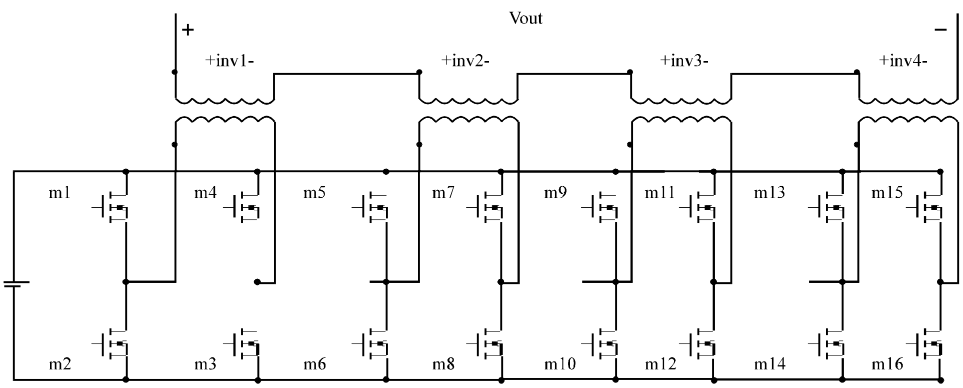

Fig. 4: Schematic diagram of transformer multilevel cascaded inverter

The cascade H-bridge multilevel inverter uses a separate dc source for each H-bridge; at any time, the output of each H-bridge has one of three discrete levels; positive, negative or zero, adding them together results in a staircase waveform, V_{an} as shown in Fig. 3. The schematic diagram of transformer type multilevel cascaded inverter is shown in Fig. 4. This type usually used in practice to eliminate the high number of dc supplies required to supply each H- Bridge separately and for this reason this type has been chosen in this study.

Harmonics Eliminations Method

Choosing appropriate conducting angles for the H-bridges can eliminate a specific harmonic in the output waveform (Rashid, 2004). The required conduction angles can be calculated by analyzing the output phase voltage of cascade inverter assuming that four H-bridges have been used, the output voltage V_{a0} can be given as:

$$V_{a0} = V_{a1}+V_{a2}+V_{a3}+V_{a4}+V_{a5} \,.. \quad (1)$$

Since the wave is in symmetry along the x-axis, both Fourier coefficient A_0 and A_n are zero. Just the analysis of B_n is required.

$$B_n = \frac{4V_{dc}}{n\pi}\left[\sum_{j=1}^{4}\cos(n\alpha_j)\right].... \quad (2)$$

j = Number of dc sources
n = Odd harmonic order

Therefore, to choose the conducting angle of each H-bridge precisely, it is necessary to select the harmonics with a certain amplitude and order, which needs to be eliminated. To eliminate 5th, 7th and 11th, harmonics and to provide the peak fundamental of the phase voltage equal to 80% of its maximum value, it needs to solve Eq. 3, with modulation index M = 0.8.

$$\begin{aligned}&\cos(5\alpha_1) + \cos(5\alpha_2) + \cos(5\alpha_3) + \cos(5\alpha_4) = 0\\&\cos(7\alpha_1) + \cos(7\alpha_2) + \cos(7\alpha_3) + \cos(7\alpha_4) = 0\\&\cos(11\alpha_1) + \cos(11\alpha_2) + \cos(11\alpha_3) + \cos(11\alpha_4) = 0\\&\cos(\alpha_1) + \cos(\alpha_2) + \cos(\alpha_3) + \cos(\alpha_4) = 0.8*4 \ \ldots\ldots\ldots\ldots\ldots.. \quad (3)\end{aligned}$$

Solution of this set of nonlinear transcendental equations can be achieved by using numerical methods such as Newton-Raphson method. Table 1 shows a set of conduction angles which produce a minimum harmonics contents, with different modulation indices.

Minimizing Total Harmonic Distortion

To minimize the THD the following procedure can be followed. The conducting angle to give a certain value of the THD can be determined as follows (Feng *et al*., 1998):

$$THD\% = 100.\sqrt{\left(\frac{V(t)_{rms}}{V_f(t)_{rms}}\right)^2 - 1} \quad (4)$$

Taking the partial derivative of the THD,

$$\frac{\partial THD^2}{\partial \alpha_j} = 0 \quad (5)$$

The conducting angle for minimum value of THD can be obtained.

Simulation of the System

Pspice/orcade software has been used as a tool to simulate the circuit which consists of single phase rectifier and the inverter circuit with and without transformer. Figure 5 shows the simulation result of output voltage for the diode clamped transformer cascade inverter.

Table 1: Sets of the conducting angles with different modulation indices

m_a	α_1	α_2	α_3	α_4
0.1	6.103	4.156	2.672	0.58
0.2	14.99	1.907	6.148	0.467
0.3	45.097	12.235	39.217	17.037
0.4	0.667	10.98	7.245	4.973
0.5	7.389	6.892	4.82	0.894
0.6	10.988	7.28	195.26	194.574
0.7	5.024	15.05	57.35	64.52
0.8	18.494	24.078	0.67	0.171
0.85	11.615	87.606	56.628	74.916

Figure 6 shows the analysis of frequency spectrum of the output voltage waveform and it is clear from the figure that the harmonics with order 5th, 7th and 11th have been eliminated and this gives advantage of the multilevel to reduce the total harmonic distortion more with out implementing PWM technique. Reduction of harmonics content means that the THD has lower value. This feature of multilevel inverter meets the requirement of the high power applications which can be provided with high voltage output and low THD and this can be achieved by adjusting the H-bridge conduction angle to eliminate the high amplitude harmonics.

Experimental Result

To verify the validity and superiority of the multilevel inverter, a hardware laboratory prototype model has been constructed which consists of four full-single phase bridge inverter units, four cascaded transformers with the same size. Low cost microprocessor PIC16F877A has been used to generate required signal to control the entire system. Figure 7 shows block diagram of the hardware system.

Figure 8 demonstrates the experimental output voltage of the inverter, with 50 Hz and modulation index of 0.8.

Using the method minimizing harmonic with iterative process can provide faster solution to calculate the THD for large number of steps. It has been found in the simulation that the THD is eqnal to 7.51% and in experiment is 8.39% for the same output voltage. And these values can be reduced further if the number of H- bridges increases. This result confirms the superiority for the multilevel inverter with the best result recorded for the PWM inverter topology as 19.7% (Tolbert *et al*., 2002; Lai and Feng, 1996).

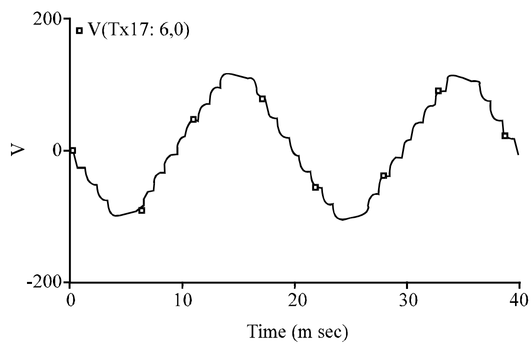

Fig. 5: Output voltage of transformer cascade multilevel inverter

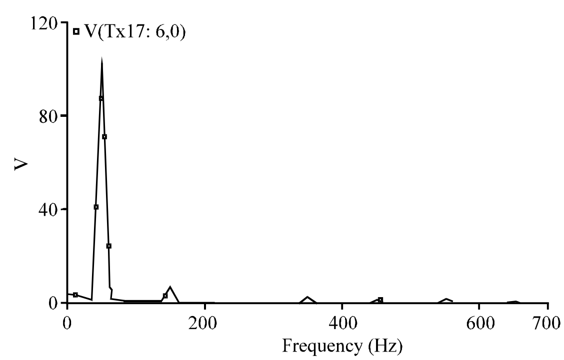

Fig. 6: Frequency spectrum analysis of multilevel wave form

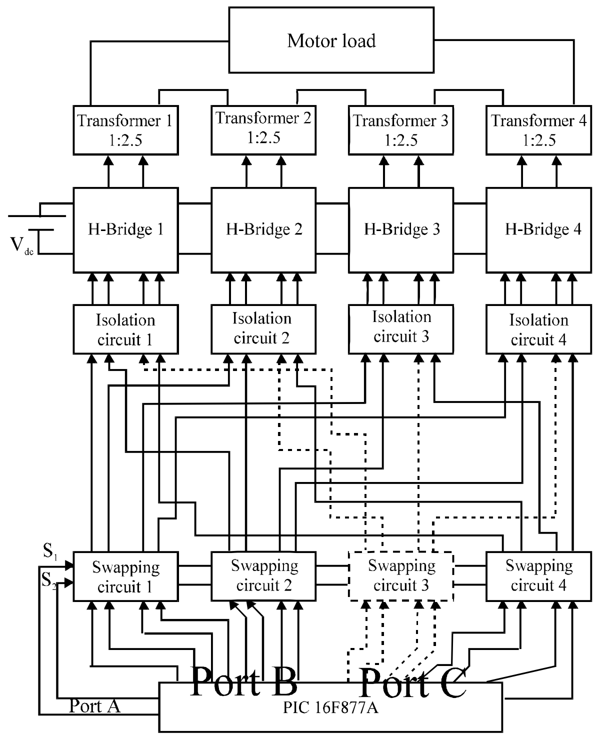

Fig. 7: Block diagram of system hardware

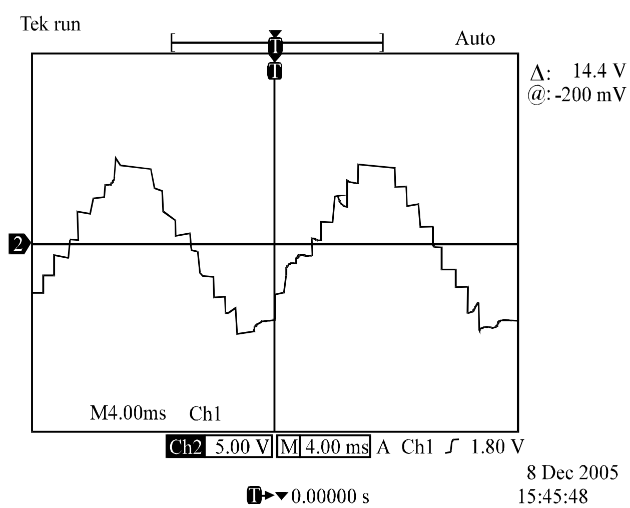

Fig. 8: Cascade multilevel inverter output at M = 0.8 and f = 50 Hz

Although the transformer is considered as bulky and loose component but utilization of its leakage inductance gives us higher order of harmonic elimination, also the isolation between each bridge is guaranteed.

CONCLUSION

In this study the cascaded multilevel inverters have been investigated. Multilevel transformer type with ouly one dc supply has been chosen. Software model has been developed using Pspice soft ware. Simulation and experimental voltage waveforms have been obtained and compared which showed a close agreement between them.

Reduction of harmonics and THD value has been achieved easily with out using PWM technique. This can be obtained if the conduction angles of single phase H-bridges are properly chosen. It has been found in the simulation that THD is equal to 7.51% and in experiment is 8.39% for the same output voltage; these values are much lower than PWM inverter. With this control strategy of multilevel cascaded switches, it is possible to construct high power drives with high output voltage and low harmonics or THD.

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