Design of 7-Level Hybrid Inverter Control Circuit

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Abstract

Use of multilevel inverters is becoming popular in the recent years for high power applications. The important feature of these inverters is of having low harmonics content in the output voltage. The switching angles in a multilevel inverter are computed so as to produce an ac output voltage with minimum harmonics. A new control circuit is designed to achieve these angles. This control circuit has the ability to control the RMS output voltage using sinusoidal pulse width modulation (SPWM). The results presented in this work prove the ability of the designed control circuit to gain the required ac output voltage with minimum distortion.

تصميم دائرة سيطرة لمبدل هجين ذو سبعة مستويات

ربيع هاشم ثجيل / قسم الهندسة الكهربائية – كلية الهندسة – جامعة البصرة

الخلاصة

أصبحت المغيرات المتعددة المستوى في السنوات الأخيرة شائعة الاستعمال في تطبيقات القدرة العالية، السمة المهمة لهذه المغيرات هي باحتواء الفولتية الخارجة على توافقيات ذات قيم قليلة، يتم حساب زوايا القدح للمغيرات المتعددة المستوى بحيث تعطي فولتية اخراج متناوبة تحتوي على اقل قيمة للتوافقيات، تم تصميم دائرة سيطرة جديدة لكي يمكن الحصول على هذه الزوايا، دائرة السيطرة هذه لها المقدرة على التحكم بالفولتية الخارجة باستعمال طريقة تضمين عرض الموجة الجيبي (SPWM)، النتائج المقدمة في هذا البحث تبرهن على قابلية دائرة السيطرة في الحصول على الفولتية المتناوبة المطلوبة بحيث تحتوي على اقل تشويه.

1.Introduction

Multilevel power conversion has been received increasing attention in the past few years for high power applications. These converters are suitable in high voltage high power applications due to their ability to synthesize waveforms with better harmonic spectrum and attain higher voltages with a limited maximum device rating [1,2,3,4,5]. Also these inverters are suitable for uses as medium voltage adjustable speed motor drives, static Var compensation, dynamic voltage restoration, harmonic filtering, or for a high voltage dc back-to-back inversion [6].

Multilevel inverters can be classified into:

1. The diode clamped multilevel inverters.
2. The flying capacitor multilevel inverters.
3. The conventional hybrid multilevel inverters.
4. The modified hybrid multilevel inverters.

The last two types are the most important since they use no capacitors in their constructions. The modified hybrid bridge topology offers a distinctive advantage in the number of levels it can generate with the same number of dc sources and switching power devices when compared to the conventional configuration [1,2].

The switching angles in multilevel inverters are computed using staircase modulation methods to ensure minimum harmonics content. The basic advantages of this strategy are its simplicity for hardware realization and minimization of switching frequency [3,4,5,6].

Sinusoidal pulse width modulation (SPWM) techniques are one of the most popular modulation methods in industrial applications and had been reviewed extensively[3]. These techniques can be used to control the output voltage of multilevel inverters.

In the present work, 7-level hybrid multilevel inverter is used to generate the required ac output voltage. A complete new control circuit is proposed to achieve these levels with minimum harmonics in the output voltage.

2.Hybrid Modulation Technique

The present hybrid 7-level inverter (Fig.1) composed of two inverters (units): A square wave inverter with XV dc source and a sinusoidal pulse width modulation inverter with V dc voltage. The first unit is constructed using Integrated Gate Commutated Thyristors (IGCTs) while the second unit using Insulated Gate Bipolar Transistors (IGBTs).

The output voltage of the used hybrid inverter V_o is :

$$V_o = V_1 + V_2 \quad \ldots(1)$$

Where: V_1 = Unit one output voltage.
V_2 = Unit two output voltage.

The switching angles of these two units are computed using the periodic staircase voltage shown in Fig.2 so as to ensure minimum output voltage distortion. This staircase voltage can be analyzed using Fourier series as:

$$b_n = \frac{4}{\pi}\int_0^{\pi/2} V_t \mathrm{Sin}(n\omega t)\, d\omega t \quad \text{for odd n} \quad \ldots(2)$$

$$b_n = 0 \quad \text{for even n} \quad \ldots(3)$$

$$a_n = \frac{4}{\pi}\int_0^{\pi/2} V_t \mathrm{Cos}(n\omega t)\, d\omega t$$
$$= 0 \quad \text{for all n} \quad \ldots(4)$$

Using equation(2) and Fig.2, the following can be deduced:

$$b_n = \frac{4\ V}{n\ \pi}\,[\mathrm{Cos}n\alpha_1 + (X-1)\mathrm{Cos}n\alpha_2 + \mathrm{Cos}n\alpha_3\,] \quad \ldots(5)$$

Where:
V = Amplitude of the dc source of the first inverter of the 7-level hybrid inverter.
n = Degree of harmonic.
α_1, α_2, and α_3=Angles of the switching boundaries.
X = Constant of the dc source of the second inverter of the 7-level hybrid inverter.

The total harmonic distortion (THD) can be calculated using the following formula [7]:

$$\mathrm{THD} = \frac{\sqrt{\sum_{n=2}^{\infty} (b_n)^2}}{b_1} \quad \ldots(6)$$

Where: b_1 = The amplitude of the fundamental component of the output Voltage.

Equations (5) and (6) are solved to get α_1, α_2, α_3, and X which ensure minimum THD. Newton Raphson method is used to solve these nonlinear equations. The results are:

$\alpha_1 = 8.479°$
$\alpha_2 = 27.761°$
$\alpha_3 = 51.48°$
$X = 2.0715$

The dc supply of the first unit is selected to be V = 100 volts, therefore, XV = 207.15 volts will be the dc supply of the second unit.

The output voltage of each unit and the total inverter output voltage are shown in Fig.3.

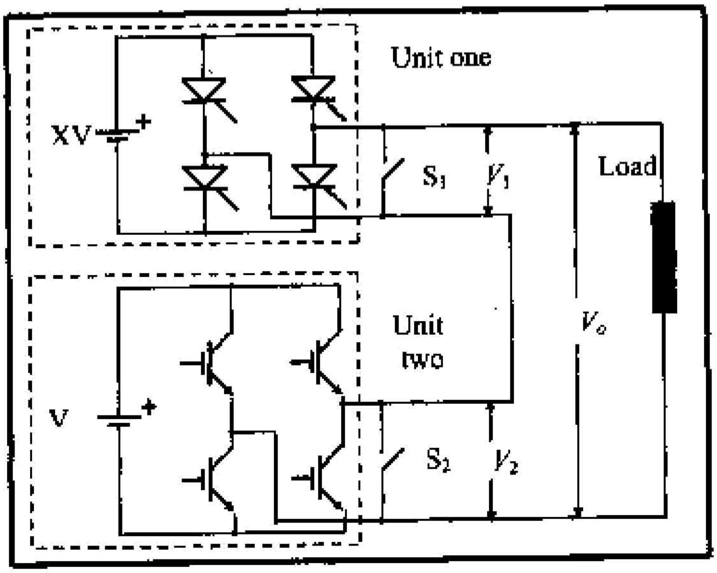

Fig.1 Hybrid 7-level inverter.

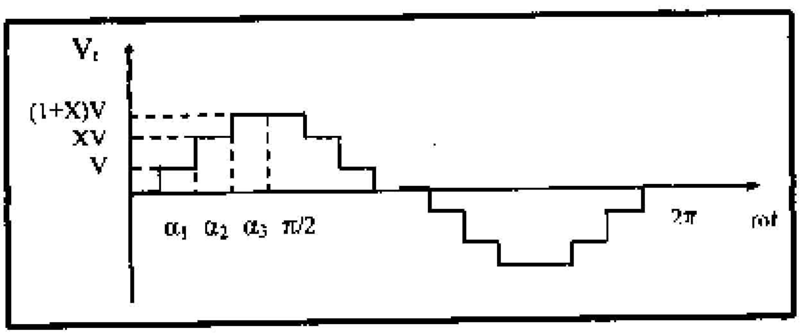

Fig.2 Staircase voltage.

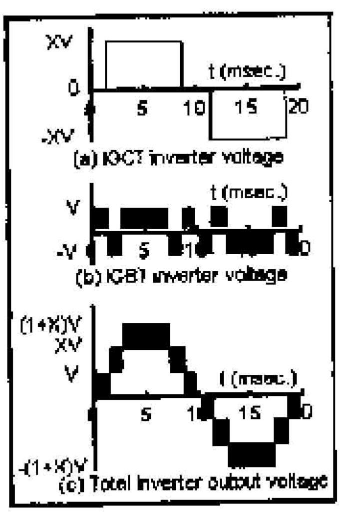

Fig.3 Voltages of the two units and total output voltage.

3. The Firing Circuit

The firing circuit is illustrated in Fig.4 as a block diagram.

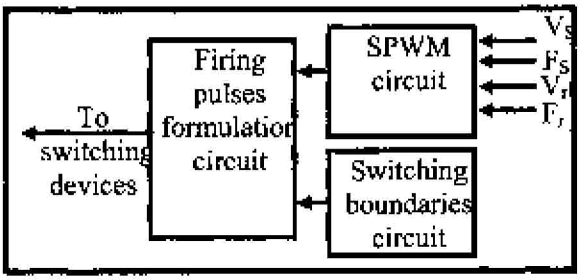

Fig.4 Firing circuit's block diagram.

It is clear that the circuit is composed of the following items:

1. Sinusoidal pulse width modulation circuit.
2. Switching boundaries circuit.
3. Firing pulses formulation circuit.

All these parts are simulated using MATLAB computer program.

3.1 Sinusoidal Pulse Width Modulation Circuit (SPWM)

Sinusoidal PWM techniques are one of the most popular modulation methods in industrial applications[3]. This method involves a comparison of the reference input, which basically is a sinusoidal waveform with Vs amplitude, against a triangular carrier waveform and detection of cross-over instances determines switching events. Fig.5 shows the parts of this circuit.

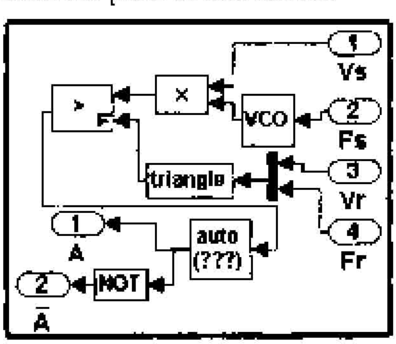

Fig.5 Sinusoidal pulse width modulation circuit.

The voltage -controlled oscillator (VCO) generates sinusoidal voltage with Fs frequency and unity voltage amplitude. The triangular generator generates triangular voltage with Fr frequency and Vr voltage amplitude. Fig.6 shows the generation of the SPWM pulses.

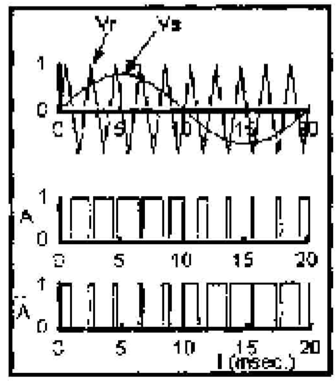

Fig.6 Generation of SPWM pulses.

3.2 Switching Boundaries Circuit

This circuit, shown in Fig.7, gives the boundaries of the sets of pulses shown in Fig.3.

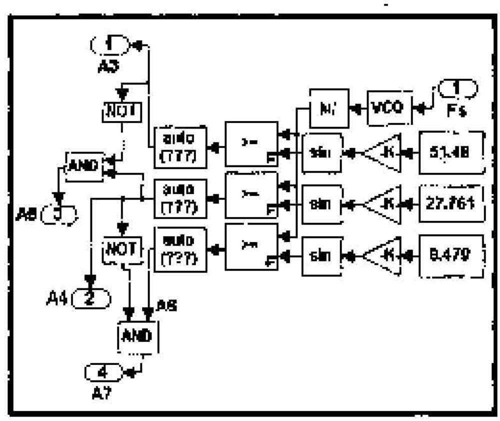

Fig.7 Switching boundaries circuit.

The operation of this circuit can be summarized, with the aid of Figs.7 and 8 as follows : The angles α_1, α_2, and α_3 , which are calculated previously, are converted to the dc voltages $V_{\alpha1}$, $V_{\alpha2}$, and $V_{\alpha3}$ respectively by taking the sinusoidal magnitudes at these angles. These dc voltages are compared with the absolute value of the sinusoidal signal generated by the used VCO. The outputs of these comparisons are treated logically to produce the required switching boundary pulses.

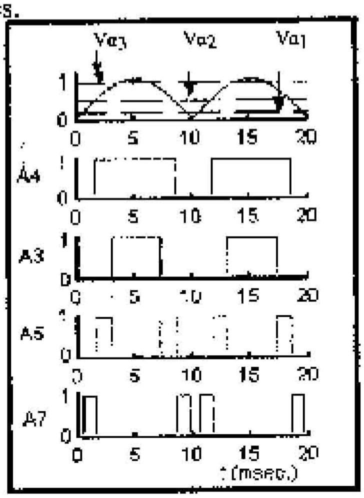

Fig.8 Switching boundary pulses.

3.3 Firing Pulses Formulation Circuit

This circuit will formulate and generate the switching devices firing pulses, (see Fig.9).

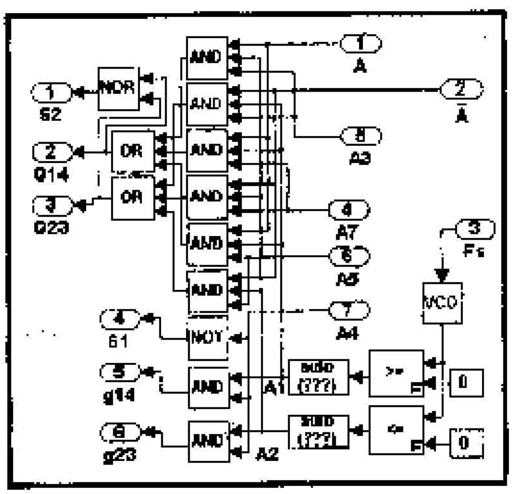

Fig.9 Firing pulses formulation circuit.

In this circuit, A, $\overline{A}$, A_3, A_4, A_5, and A_7 are the outputs of the previous two circuits. A_1 and A_2 pulses represent the positive and negative half cycles of the used VCO respectively. All these signals are logically treated to generate the switching devices firing pulses. These logical operations are given by :

$$g_{14}=A_4 \cdot A_1 \qquad ...(7)$$

$$g_{23}=A_4 \cdot A_2 \qquad ...(8)$$

$$S_1=\overline{A_4} \qquad ...(9)$$

$$G_{14}=A \cdot A_2 \cdot A_3+A \cdot A_1 \cdot A_7+A \cdot A_1 \cdot A_5 \qquad ...(10)$$

$$G_{23}=\overline{A} \cdot A_1 \cdot A_3+\overline{A} \cdot A_2 \cdot A_7+\overline{A} \cdot A_2 \cdot A_5 \qquad ...(11)$$

$$S_2=\overline{G_{14}+G_{23}} \qquad ...(12)$$

The pulses g_{14}, g_{23}, and S_1 control the IGCT unit of the hybrid inverter. Pulses G_{14}, G_{23}, and S_2 control the IGBT unit. These pulses are shown in Fig.10.

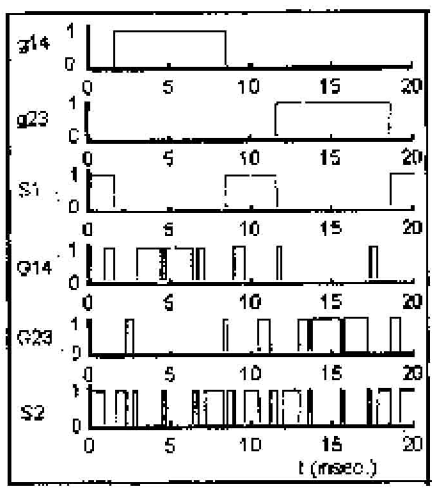

Fig.10 Firing pulses of the two units.

The overall firing circuit is shown in Fig.11. This circuit is simulated using MATLAB-simulink software.

4. Simulation Results

The feasibility of the proposed approach is verified using computer simulation. A model of the 7-level hybrid inverter is constructed in MATLAB software. A hybrid modulation strategy which combine fundamental frequency switching for the Integrated Gate Commutated Thyristors (IGCT) and open loop SPWM control for the Insulated Gate Bipolar Transistors (IGBT) is employed. The overall inverter circuit is illustrated in Fig.12. The switches S_1 and S_2 are used to ensure circuit continuity.

The resultant output voltage obtained from command signals with V_s=0.8 volts and the switching patterns for the IGCT thyristors and IGBTs are illustrated in Fig.3. It may be seen that although the IGCT inverter switching is stepped (Fig.3a), the overall waveform is mainly decided by the

5. Conclusions

A hybrid approach for multilevel power conversion has been presented. It is shown that by employing non-identical dc sources one can obtain significant increase in the number of output voltage levels. This approach enables one to obtain a 7-level conversion with only two dc bus levels. This reduces the cost of the inverter.

This paper has proposed a new control circuit to control the firing of the inverter units with the ability of output voltage control and THD reduction. Computer simulation results are presented in this paper to support these goals. These results prove the aim of designing this new control circuit, the aim of having an ac output voltage with minimim distotion.

To conclude, in comparison with all the rest of control strategies, the used controller with SPWM technique offers excellent THD figures. The concept described in this paper can be extended for uses in closed loop output voltage control IGBT inverter's switching (Fig.3b). The IGBT inverter acts as a voltage controller without largely sacrificing the THD. This is completely verified in Figs.13 & 14. These figures prove that the triangular generator frequency (F_r) has almost no effects on the THD in the output voltage , while the sinusoidal amplitude (V_s) can control the output voltage in acceptable manner.

A low pass filter (15 mH & 100 μF) is used to minimize the unwanted distortion. Fig.15 Shows the hybrid inverter voltage before and after this filter. This figure proves that this small filter is quite sufficient to improve the output voltage quality. This is due to fact that a well designed hybrid inverter produces only a small distortion in the output voltage.

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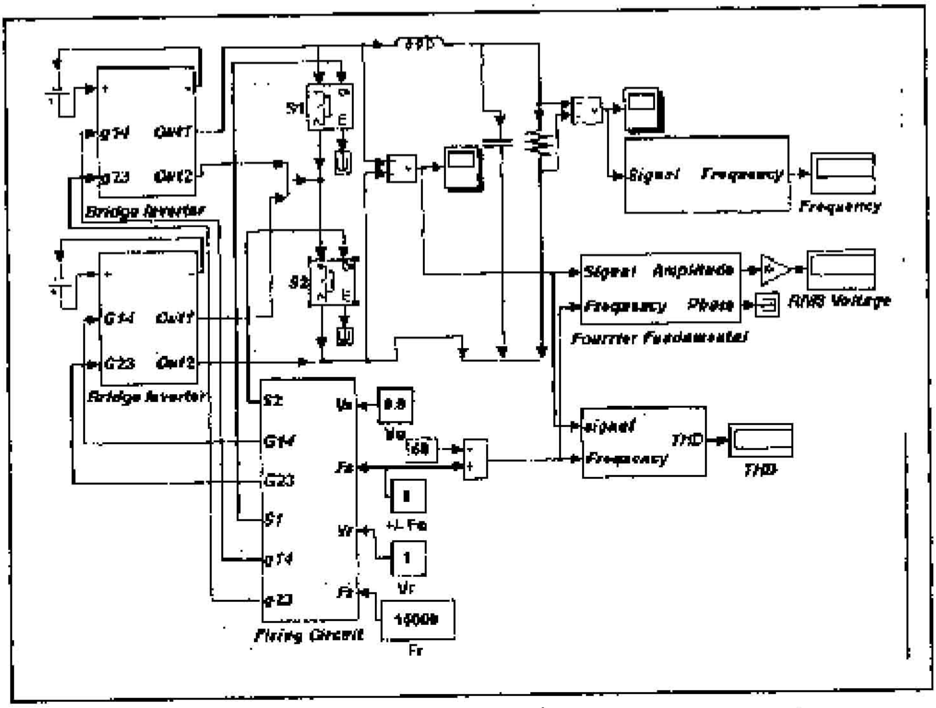

Fig.11 The overall firing circuit.

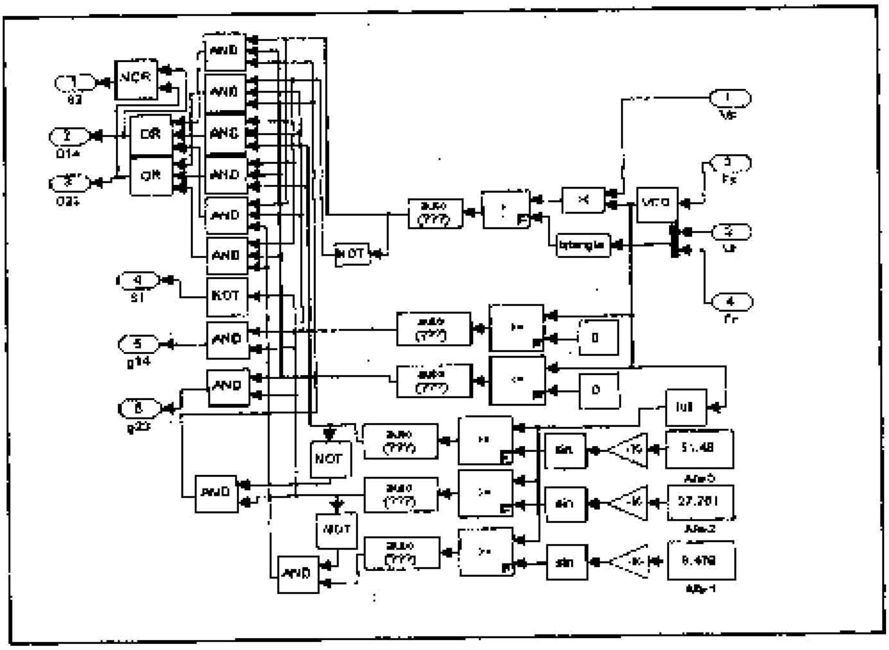

Fig.12 The hybrid 7-level inverter overall circuit

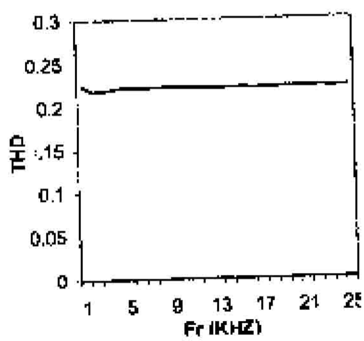

Fig.13 THD against Fr at Vs=0.8 volt.

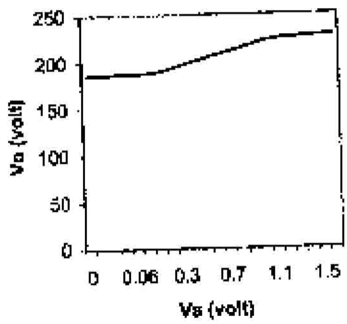

Fig.14 Inverter output voltage against Vs.

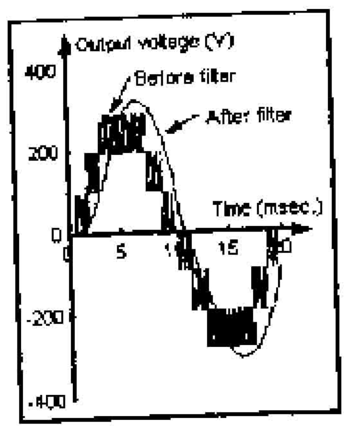

Fig.15 Hybrid inverter output voltage.