CARRIER PWM WITH MULTI-CONTROL-VOLTAGES FOR FIVE LEVEL HYBRID INVERTER

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ABSTRACT

This paper proposes Carrier Modulation Techniques with using multi-control-voltages for Hybrid inverter that joined 3rd level cascade and 2nd level inverter. This technique is based on the analysis of the hybrid inverter by separating it into basic inverters in order to decide how to control. Every analyzed basic inverter will have a separate control voltage. These control voltages uses the maximum threshold ***1*** *or minimum threshold* ***0*** *of amplitude carriers that based on D-PWM to reduce many of switching on a phase. The using hybrid inverter is able to reduce number of switches to the standard configuration with the same level, so it makes reducing the cost of production. Simulation results are provided in order to validate the proposed method.*

Keywords: *carrier modulation; hybrid inverter; reduce switching; multi control-voltages; 5-level inverter.*

TÓM TẮT

Bài báo này đề xuất kỹ thuật điều chế sóng mang với việc sử dụng đa sóng điều khiển cho cấu hình nghịch lưu ghép giữa cascade 3 bậc và nghịch lưu 2 bậc căn bản. Kỹ thuật này dựa trên nguyên tắc phân tích cấu hình nghịch lưu ghép thành các nghịch lưu căn bản để thực hiện điều khiển. Mỗi cấu hình nghịch lưu căn bản đã phân tích sẽ có một sóng điều khiển riêng. Các sóng điều khiển này sử dụng các ngưỡng cực đại 1 hoặc cực tiểu 0 của biên độ các sóng mang trên cơ sở điều chế gián đoạn để giảm số khóa phải chuyển mạch trên một pha. Việc sử dụng cấu hình ghép sẽ giúp giảm số linh kiện so với cấu hình nghịch lưu chuẩn có cùng số bậc do đó giúp giảm giá thành khi tiến hành sản xuất. Kết quả của giải thuật được kiểm chứng qua mô phỏng.

Keywords: *điều chế sóng mang; nghịch lưu ghép; giảm số lần chuyển mạch; đa sóng điều khiển; nghịch lưu 5 bậc.*

1. INTRODUCTION

Multi-level inverter is the power converter device which has an important role in the various applications such as electric motor control, transportation, quality control of electrical system, converted forms of renewable energy as solar power, wind power on grid. If we use standard configurations for multi-level inverters, it makes the number of power switches and capacitors increase. Therefore, many research works have been done to find better solutions to connect the basic inverter to reduce the number of components till now [1,2]. Then, the proposed algorithms matching the hybrid configuration also need to be studied. Basically, there are two PWM techniques to controlling multi-level inverters are space vector PWM and carrier modulation techniques which are based on functions of control voltage. The carrier based PWM methods can be advantageously utilized in: controlling common mode voltage, controlling of complicated inverter topologies as 4-leg, 5-leg multi-level inverters and compensation of unbalanced DC sources [3]. When joining two or more inverters, each one will need more control voltages. What are those control voltage functions? How to analyze and determine values of these functions and all of those made in the recent studies.

In the research report [4], the hybrid configuration has been proposed, in which NPC inverter connected with Cascade inverter. In this configuration, NPC inverter generates a DC voltage threshold and cascade configuration creates positive and negative voltages. Compared to the standard configuration, this configuration allows reduction of the power switches. However, the applied controlling method is rather complex so there has not proposed algorithm that it is really suitable for configuration yet. Approaching with hybrid inverter through modulation algorithm [4] has also suggested the coordination between the Space Vector algorithm and multi-carrier modulation algorithm. The authors have combined spectrum of voltage control carrier algorithm and components to components and the switches in the space vector technique (SV), to provide suitable distribution pulses for switches. This algorithm is based on the SV technique, thus the calculation is complex and not optimal. When number of level [5] (by insert many modules) is increased by combined to more inverters, a modification for the technique of K. Baskaran and C. Govindaraju [6] into multi-carrier modulation algorithm has been tried. Nevertheless, this algorithm is based on the principle of SV, so the authors have not yet optimized the offset function in the carrier modulation techniques. New algorithms in this research will fully resolve that problems and have been experimented on hybrid 5-level inverters.

2. 5-LEVEL HYBRID INVERTERS

5-level inverter can use the standard configurations as NPC, flying capacitor, cascade or H-NPC [7, 8, 9, 10] (Fig.1 a, b, c, d) or hybrid configuration (proposed) (Fig.1 e). Table 1 shows the minimum number of switches (IGBT, diode) and DC capacitors necessary for the hybrid configuration.

In Fig.1, each phase of the 5-level hybrid inverter is the combination of a circuit inverter 3-level cascade and a basic inverter. If considering that a 3-level cascade inverter is the basic inverter, the 5-level hybrid inverter will consist of three of basic inverters (Fig.2).

Table 1. *Structure components of different configurations*

Configuration	IGBT	Diode	Capacitor
NPC	8	6	4
Flying C	8	0	6
Cascade	8	0	0
H- NPC	8	4	2
Proposed	6	0	0

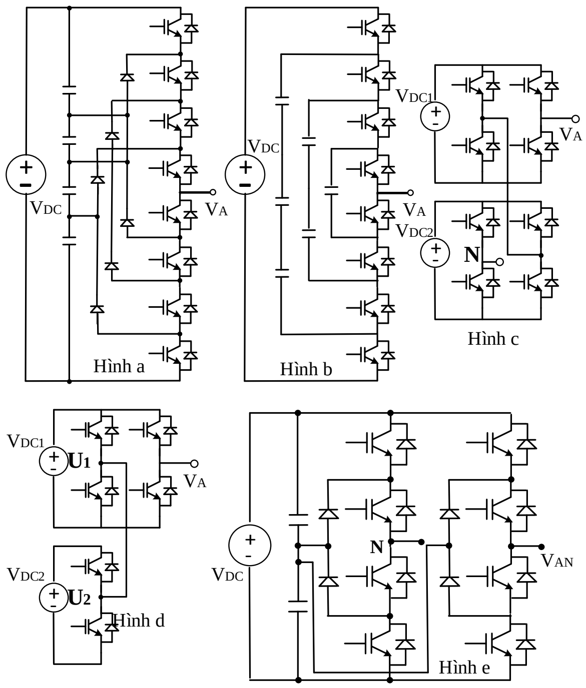


Figure 1. *The structure of the phase A, 5-level invertera) NPC, b) Flying capacitor, c) cascade, d) H Bridge-NPCe) Proposed*

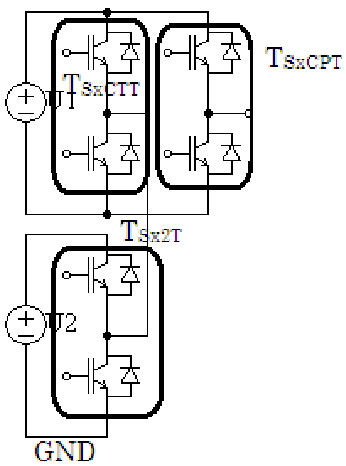


Figure 2. *Phase structure of proposed inverter.*

Let U_{xg} is voltage form output basic inverter to ground of source. U_{xg} can be calculated as in Eq. (1)

$$U_{xg} = u_2.T_{Sx2T}+u_1.T_{SxCTT} - u_1.T_{SxCPT} \quad (1)$$

Wherein, T_{Sx2T} is status of upper switch in the basic inverter; T_{SxCTT} and T_{SxCTP} are statuses of left and right upper switch of cascade inverter. Then U_{xg} is determined according to statuses of switches in Table 2.

Table 2. *Determination of* U_{xg}

U_{xg}	T_{Sx2T}	T_{SxCTT}	T_{SxCPT}	U_{xg} ($u_2 = 2.u_1$)
$-u_1$	0	0	1	$-u_1$
0	0	0	0	0
$+u_1$	0	1	0	$+ u_1$
u_2-u_1	1	0	1	$+ u_1$
$+u_2$	1	0	0	$+2u_1$
u_2+u_1	1	1	0	$+3 u_1$

If $u_1 = 2.u_1 = 2u$, then U_{xg} has five levels which are –u, 0, u, 2u and 3u (5-level). Therefore, U_{ag}, U_{bg}, and U_{cg} are decided as in Eq. (2)

$$\begin{bmatrix} U_{ag} \\ U_{bg} \\ U_{cg} \end{bmatrix} = u.\begin{bmatrix} 2.T_{Sa2T} + T_{SaCTT} - T_{SaCTP} \\ 2.T_{Sb2T} + T_{SbCTT} - T_{SbCTP} \\ 2.T_{Sc2T} + T_{ScCTT} - T_{ScCTP} \end{bmatrix} \quad (2)$$

As a result, we can calculate phase voltages of proposed inverter by Eqs. (3) and (4).

$$\begin{bmatrix} U_{an} \\ U_{bn} \\ U_{cn} \end{bmatrix} = \tfrac{1}{3}\begin{bmatrix} 2 & -1 & -1 \\ -1 & 2 & -1 \\ -1 & -1 & 2 \end{bmatrix}\begin{bmatrix} U_{ag} \\ U_{bg} \\ U_{cg} \end{bmatrix} \quad (3)$$

$$\begin{bmatrix} U_{an} \\ U_{bn} \\ U_{cn} \end{bmatrix} = \frac{u}{3}\begin{bmatrix} 2 & -1 & -1 \\ -1 & 2 & -1 \\ -1 & -1 & 2 \end{bmatrix}\begin{bmatrix} Ta \\ Tb \\ Tc \end{bmatrix} \quad (4)$$

Wherein, $T_x = 2.T_{Sa2T} + T_{SaCTT} - T_{SaCTP}$

It could be seen that U_{xg} contains the 3^{rd} harmonic, phase to pole voltages (U_{xn}) and line to line voltages (U_{xy}) [11]. Proposing that the 5-level hybrid inverter is formed from combination of three of basic inverters, there are three control voltages for them. They are v_{a1t}, v_{a1p} and v_{a2} corresponding to left leg, right leg of cascade inverter and basic inverter. Then, the pulse model is in Fig 3.

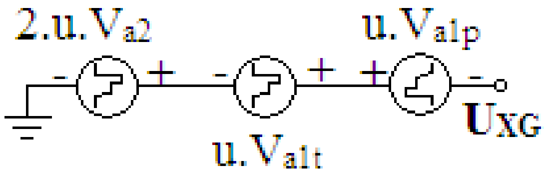


Figure 3. *Pulse model A phase proposed inverter.*

Fig.3 and Table 2 show that in order to get $-u \le U_{ag} < 0$), one must control the right leg cascade inverter (phase to pole is $u.V_{x1p}$). Generally speaking, it should be controlled if U_{ag} varies within (u_1, $2.u_1$).

The output voltage of basic inverter only belongs to values from 2.u to 0 depending on its control voltage being positive or negative. This ensures that switching frequency of the switches in the basic inverter which has the highest voltage supply is at least.

3. CARRIER PWM WITH MULTI CONTROL-VOLTAGES

According to the above analysis, the algorithm PWM with multi control voltage for proposed inverter is determined values according to v_{x1t}, v_{x1p} and v_{x2} functions. Values of v_{x1t}, v_{x1p} and v_{x2} will be calculated to reduce switching frequency. Beside, switching losses is proportional to the voltage in switches [3, 11, 12] so that v_{x2} must be determined to reduce the number of switching (of IGBTs) on two level inverters.

Control voltages of X phase (v_x) are calculated by Eq. (5).

$$v_x = v_{1,x}\cos(\omega t + j_x) + 2 + v_{offset} \quad (5)$$

According to Table 2, value of v_{x2} is equal to 0 or 1 and decided as (6)

$$v_{x2} = \begin{cases} 1 \ if \ v_x \ge 2 \\ 0 \ if \ v_x < 2 \end{cases} \quad (6)$$

Define L_x, H_x and ε_x in (7), (8) and (9)

$$L_x = \begin{cases} int(v_x) & if \ int(v_x) < 4 \\ int(v_x) - 1 & else \end{cases} \quad (7)$$

$$H_x = L_x + 1 \quad (8)$$

$$\varepsilon_x = \begin{cases} H_x - v_x \ if \ L_x mod\ 2 = 0 \\ v_x - L_x if \ L_x mod\ 2 \ne 0 \end{cases} \quad (9)$$

If L_x is even, there is only control voltage for the right leg cascade and that for the left branch cascade is always zero. Whilst, when L_x is odd, control voltage for the left leg cascade is zero and that for the right is e_x.

Therefore, v_{x1t}, v_{x1p} can be calculated by Eqs. (10) and (11)

$$v_{x1t} = \begin{cases} 0 \ \ if \ L_x mod\ 2 = 0 \\ \varepsilon_x if \ L_x mod\ 2 \ne 0 \end{cases} \quad (10)$$

$$v_{x1p} = \begin{cases} \varepsilon_x \ \ if \ L_x mod\ 2 = 0 \\ 0 \ \ if \ L_x mod\ 2 \ne 0 \end{cases} \quad (11)$$

The offset functions in Eq. (5) can be used for optimal reduction of switching losses, and common mode voltage reduction…

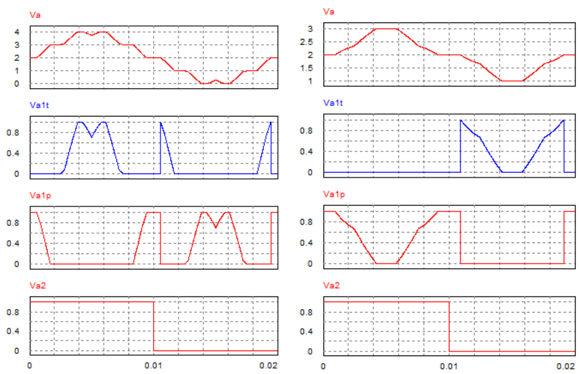


Figure 4. *Control voltages at a)m=0.9, b)m=0.4*

Fig.4 shows control voltages for 5-level hybrid inverter at m=0.9 and m=0.4. At the same time, there is only one of the control voltages (v_{x1t}, v_{x1p}) not equal to the top or bottom of carrier voltages, and the control voltage for basic inverter (with higher voltage) is either **1** or **0**. So the number of switching is minimum. Flow chart for the algorithm PWM with multi control voltage is showed in Fig.5.

Because only simple commands such as add, subtract, compare are used in the control program, the required time to calculate values of control voltages are very small. Therefore, this algorithm is appropriate to apply for controlling in closed loop control, or in different orientation control techniques.

4. SIMULATION RESULTS

To validate the theoretical analysis, simulation tries have been implemented for the 5-level hybrid inverter, each phase consists of one H-bridge inverter and one basic inverter in series. The H-bridge is supplied by the DC low voltage of 100VDC and the basic is supplied by higher one of 200VDC. A three-phase RL load is set as R=256Ω, L=125mH, frequency of carrier control is f_C=5100Hz. Offset function is decided to reduce numbers of switching.

Simulation results have indicated that when control voltage is equal to the top or bottom of carrier voltages, there is no switching, then there is no change of voltage phase to pole. Thus, the number of switching is reduced. Fig.7 describes the comparison of THD of phase load voltage between the proposed algorithms (5-level hybrid inverter) versus the switching algorithm (in 5-level cascade inverter). It has been found that when the modulation index is less than 0.36, THD of phase voltage on cascade inverter is smaller than that on the hybrid system. But, with m>0.36, they are the same. Both the algorithms (and then configurations) are going to meet the standards of Viet Nam (TCVN-7909 2.2-2008) and the international standards EN61000-2-2.

Fig.8a shows bare FFT of phase voltages in hybrid inverters at modulation index m=0.4 and m=0.9. FFT results indicated that the low harmonics (5^{th} and 7^{th}) are small, so they should be destroy by the inductance of the grid.

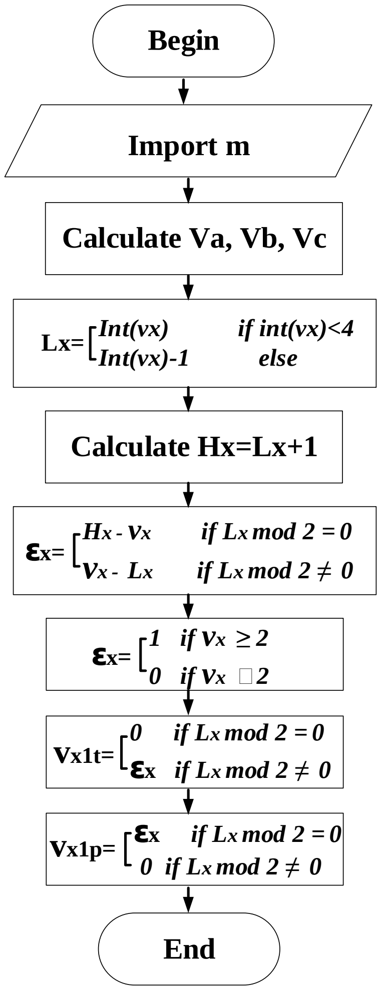
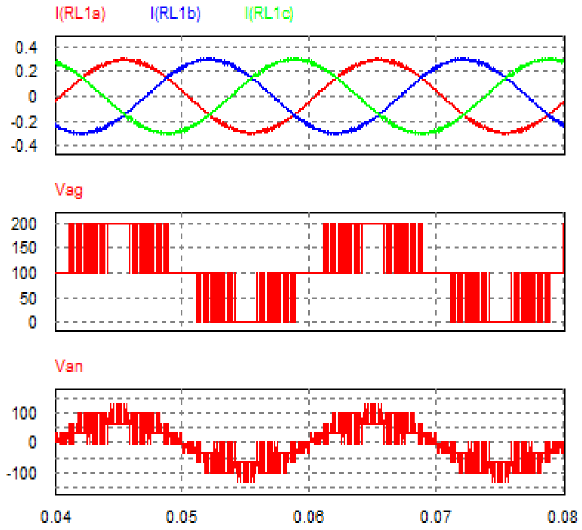


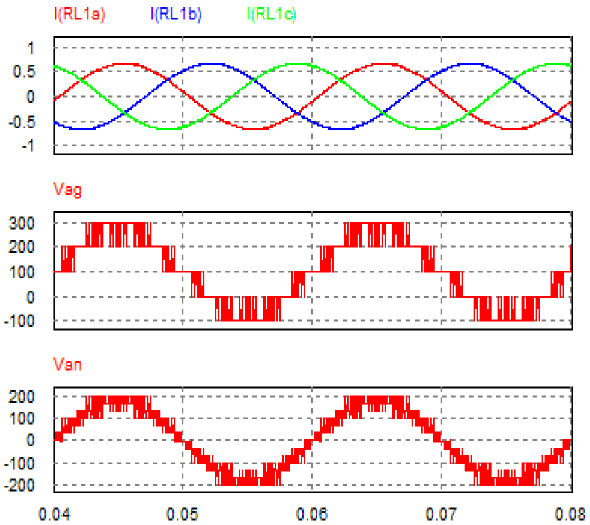
Figure 5. *Flow chart of proposed algorithm*

The survey result rates (%) between the amplitudes of the harmonics and fundamental component show that the even harmonic does not appear, the third and multiples of third harmonics are destroyed as presented in the Eqs. (3), (4) and (5). The harmonics with largest amplitude are 5^{th}, 7^{th}, and 11^{th}. The rates of them to the fundamental wave are also smaller than the values in TCVN-7909 2.2-2008 and EN6100-2-2 standard. Fig.9 includes the control characteristic of the proposed algorithm, carrier PWM with multi-control voltages, applied in 5-level hybrid inverter.

The control characteristic is the trend that the controlling of hybrid inverter with the proposed algorithm can be combined of the common control functions.



a) m=0.4



b) m=0.9

Figure 6. *Simulation results of proposed modulation index m=0.4 and m=0.9.*

5. CONCLUSION

This paper shows the possibility of using the hybrid structure to reduce the number of switches and thus to reduce the cost of inverters. Based on mathematical analysis 5-level hybrid inverter, the carrier PWM with multi-control voltages is proposed. The offset functions can be applied in PWM technique with multi control voltages on hybrid inverter. The algorithm can be applied to more complex configuration and combined for optimization objective functions.

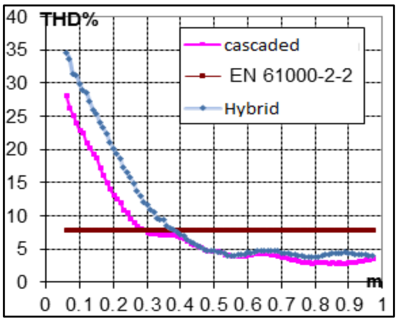
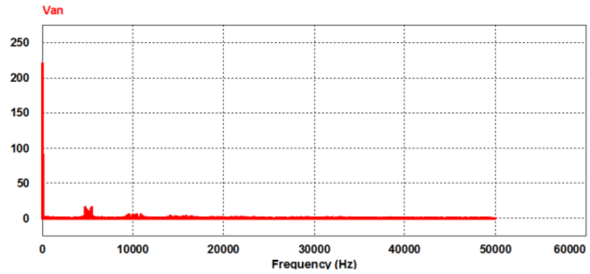
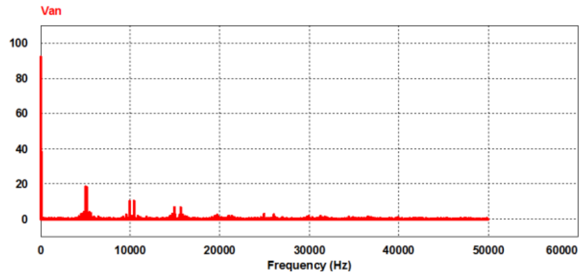


Figure 7. *THD of phase voltage cascade and hybrid inverter.*



a)



b)

Figure 8. *FFT of phase voltages in hybrid inverter with proposed algorithn at*

a) m=0.9, b) m=0.4.

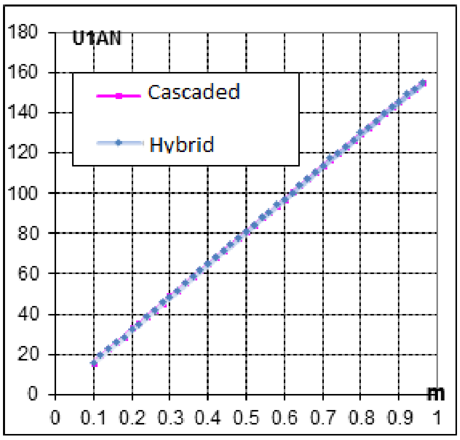


Figure 9. *The cotrol characteristic of the proposed algorithm.*

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