

CARRIER BASED PWM OF HYBRID 5-LEVEL INVERTER WITH OPEN-END WINDING THREE- PHASE LOAD

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ABSTRACT

This paper presents a simple carrier based PWM technique to control a hybrid multilevel inverter. A conventional 3-level NPC inverter and 2-level inverter are connected in series to supply an open-end winding three phase load. Proposed PWM method is then verified in steady state and dynamic transient phenomena using MATLAB simulation program.

I. INTRODUCTION

Multilevel inverters are becoming important for many application areas for their advantages in high power rating, better waveform of voltage and currents, reduction of voltage stress on power semiconductor devices and less electromagnetic interference

Recently different types of hybrid multilevel inverters have been introduced. They prove to be a perspective solution for hardware implementation of multilevel inverter. Hybrid inverters can get a simpler structure comparing to conventional NPC and cascaded multilevel inverters. They may require less number of DC power sources or switching devices. Besides that, it can be advantageous to use ready-on market power converter modules for setting various hybrid inverter topologies. Therefore,

cost can be reduced and system may become less bulky.

One problem in hybrid inverter solution is to propose PWM technique. Until now, there have been proposed different PWM methods, which are deduced mainly from conventional PWM methods and valid for concrete hybrid inverter structures. Therefore, it is needed to find a new PWM solution, which can be generally valid to different types of hybrid inverters. The aim of the paper is to propose a possible carrier PWM solution.

II. ANALYSIS OF HYBRID INVERTER

Let consider three-phase hybrid multilevel inverter consisting of three level NPC inverter and two level inverter as shown in Fig.1.

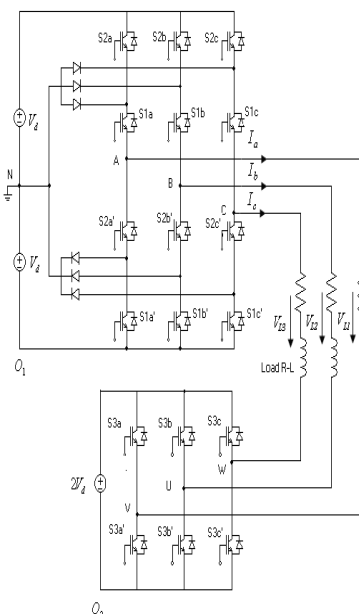


Figure 1: Model of hybrid 5-level inverter.

The three DC sources are set as follows: two dc cells in 3 level NPC inverter are equal V_d and the dc source of two-level is $2V_d$.

From Fig.1, an equivalent model can be deduced as shown in Fig 2a and 2b. In these equivalent circuits, for any phase x , $x=a,b,c$, parameters V_{1x0}, V_{2x0} and V_{3x0} present corresponding two leg voltage components of 3-level NPC inverter and leg voltage of 2-level inverter. The resulting voltage V_{10}, V_{20} and V_{30} express virtual total leg voltages of three phase inverter.

For proposed carrier based PWM, each

switching pair is controlled by a modulating signal, hence it is needed nine modulating signals for instance, in order to produce trigger pulses to A-phase devices, there are deduced ξ_{1a}, ξ_{2a} for 3-level NPC inverter and ξ_{3a} for 2-level inverter. Similarly, the signals $\xi_{1b}, \xi_{2b}, \xi_{1c}, \xi_{2c}, \xi_{3b}, \xi_{3c}$ are deduced for two remaining phases.

$$\text{Where } 0 \leq \xi_{jx} \leq 1 \quad (\text{with } j=1,2,3).$$

The leg voltage components and total virtual leg voltages can be deduced as follows:

$$\begin{aligned} V_{1a0} &= \xi_{1a} \cdot V_d; \quad V_{1b0} = \xi_{1b} \cdot V_d; \quad V_{1c0} = \xi_{1c} \cdot V_d \\ V_{2a0} &= \xi_{2a} \cdot V_d; \quad V_{2b0} = \xi_{2b} \cdot V_d; \quad V_{2c0} = \xi_{2c} \cdot V_d \\ V_{3a0} &= \xi_{3a} \cdot 2V_d; \quad V_{3b0} = \xi_{3b} \cdot 2V_d; \quad V_{3c0} = \xi_{3c} \cdot 2V_d \\ V_{10} &= (V_{1a0} + V_{2a0} - V_{3a0}) = (\xi_{1a} + \xi_{2a} - 2\xi_{3a})V_d \\ V_{20} &= (V_{1b0} + V_{2b0} - V_{3b0}) = (\xi_{1b} + \xi_{2b} - 2\xi_{3b})V_d \\ V_{30} &= (V_{1c0} + V_{2c0} - V_{3c0}) = (\xi_{1c} + \xi_{2c} - 2\xi_{3c})V_d \end{aligned} \quad (1)$$

Notice that: $0 \leq \xi_{2x} \leq \xi_{1x} \leq 1$

and $0 \leq \xi_{3x} \leq 1, x=a,b,c$.

Five levels of total virtual leg voltages - As a results, the hybrid inverter is of 5 levels, and

corresponding leg voltage components can be deduced and filled in Table 1. To produce a phase voltage value between two following levels, it is needed to determine three modulating signals $\xi_{1x}; \xi_{2x}$ and ξ_{3x} , which will be deduced in the next section.

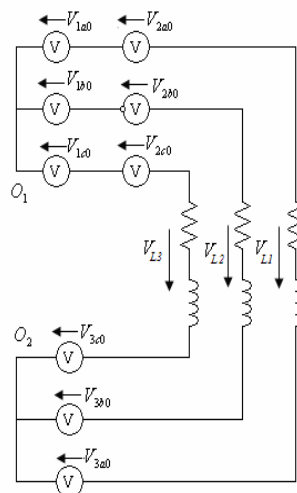


Fig 2a: Equivalent model

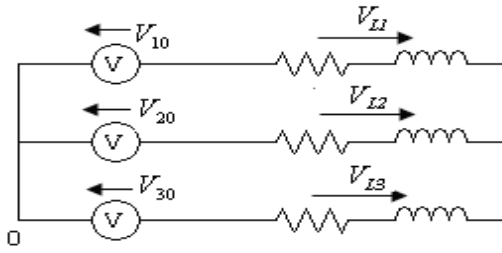


Fig 2b: Final equivalent model

V_{j0}	$[V_{1x0}, V_{2x0}, V_{3x0}]$	ξ_{1x}	ξ_{2x}	ξ_{3x}
$-2V_d$	$[0, 0, 2V_d]$	0	0	1
$-2V_d < V_{j0} < -V_d$	$[X, 0, 2V_d]$	ξ	0	1
$-V_d$	$[V, 0, 2V_d]$	1	0	1
$-V_d < V_{j0} < 0$	$[V_d, X, 2V_d]$	1	ξ	1
0	$[V_d, V_d, 2V_d]$ (1) $[0, 0, 0]$ (2)	1	1	1
$0 < V_{j0} < V_d$	$[X, 0, 0]$	ξ	0	0
V_d	$[V_d, 0, 0]$	1	0	0
$V_d < V_{j0} < 2V_d$	$[V_d, X, 0]$	1	ξ	0
$2V_d$	$[V_d, V_d, 0]$	1	1	0

Table 1: Virtual total leg voltage and corresponding leg voltage components

where ξ : variable ($0 \leq \xi \leq 1$)

$$V_{j0} = V_{Lj} + V_0 \quad (2)$$

$(V_{0 \min} \leq V_0 \leq V_{0 \max})$

V_{Lj} : Load voltage, ($j=1,2,3$).

$$\begin{cases} V_{0 \max} = 2 \cdot V_d - Max \\ V_{0 \min} = -2V_d - Min \end{cases} \quad (3)$$

$$\begin{cases} Max = Max(V_{L1}, V_{L2}, V_{L3}) \\ Min = Min(V_{L1}, V_{L2}, V_{L3}) \end{cases}$$

Offset voltage for minimum common mode:

$$V_0 = \begin{cases} V_{0 \max} & \text{if } V_{0 \max} < 0 \\ 0 & \text{if } V_{0 \max} \geq 0 \geq V_{0 \min} \\ V_{0 \min} & \text{if } V_{0 \min} > 0 \end{cases} \quad (4)$$

Limit of the fundamental voltage in the linear range is:

$$V_{L \max} = \frac{(n-1) \cdot V_d}{\sqrt{3}} \quad (n: \text{level}) \quad (5)$$

For example, for a virtual voltage $-2V_d < V_{j0} < -V_d$, modulating signals of three switching pairs are defined as:

$$\xi_{2x} = 0; \xi_{3x} = 1 \text{ and } \xi_{1x} = (V_{j0} + 2V_d) / V_d.$$

(Because of $V_{j0} = (\xi_{1x} + 0 \cdot 2) V_d$).

III. PROPOSED PWM ALGORITHM

Algorithm for producing three phase modulating signals $\xi_{1x}; \xi_{2x}$ and ξ_{3x} can be deduced and explained using Fig.3. The three phase load voltages are used to limit offset voltage, which is selected for minimum common mode voltage criterium. The virtual total voltage is obtained as a sum of load voltage and selected offset. Using deduced Table 1, the modulating signals will then compare with carrier waves for generating trigger pulses.

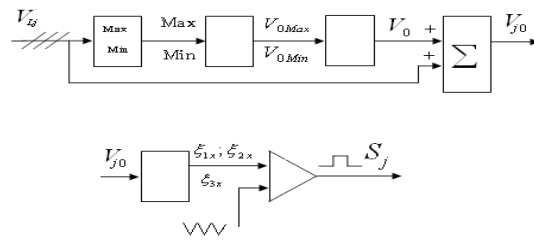


Figure 3- Algorithm for generating modulating signals

The previously described algorithm can be expressed as follows:

VI. SIMULATION RESULTS

1) Three phase hybrid 5-level inverter with RL load

— Simulation of the system described in Fig.1 is realized with MATLAB /SIMULINK, version R2008b.

— Input data: DC sources: $V_d=100V$, three phase balanced RL load as $R=10\Omega$, $L=100mH$; output voltage: $m=0.9$, $f=50Hz$; Control: $f_{carr}=1500Hz$, $T_s=5.e^{-6}(s)$

Diagrams of load voltage, currents, total leg voltage and common mode voltage are shown in Fig.4-5-6-7.

2) Field Oriented Control of Open-End-Winding Induction motor fed hybrid 5-level inverter.

The proposed PWM method is also applied in an electric drive of Open-End-Winding Induction motor fed hybrid inverter- Fig.8. A closed speed control of induction motor drive is implemented using Indirect Field oriented control method –Fig.9, which is commonly known from many literatures.

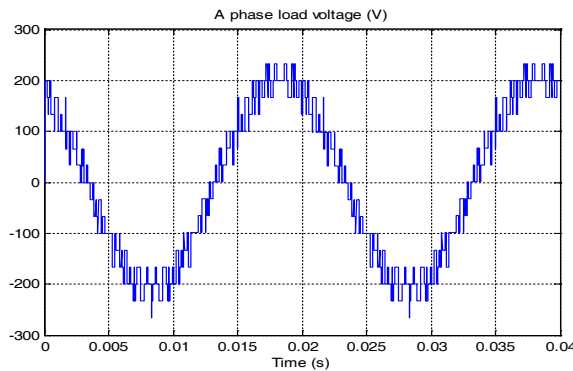


Figure 4: A phase load voltage

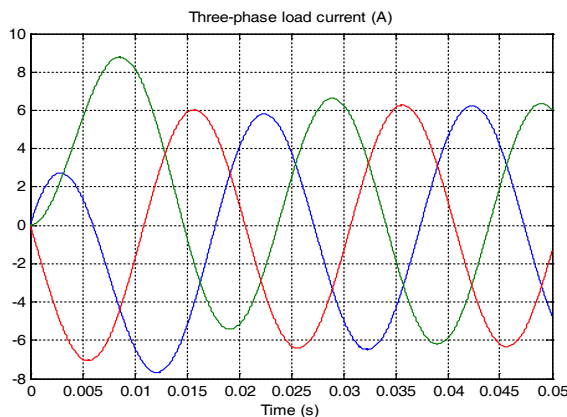


Figure 5: Three-phase load current.

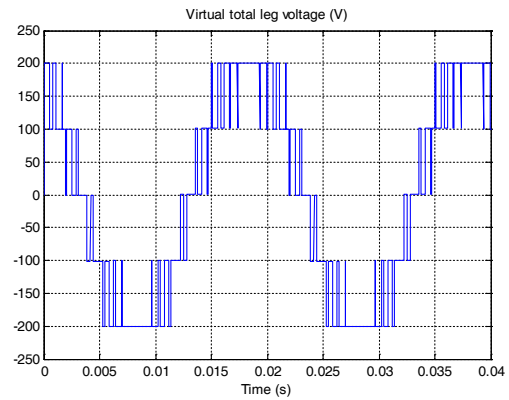


Figure 6: Virtual total leg voltage

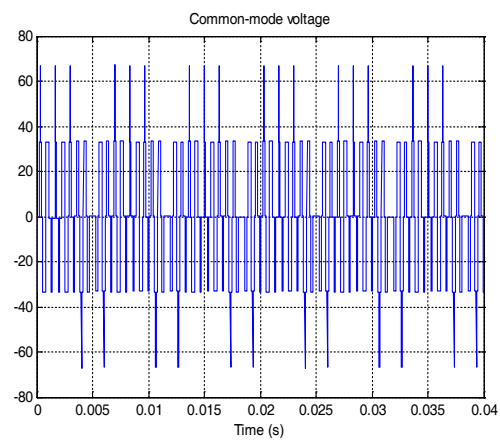


Figure 7: Common-mode voltage (V)

Simulation parameters: $U_d=200V$, switching frequency $f_c=6kHz$. Motor parameters are; $P_n=4kW$; $U_n=400V$; $f=50Hz$; $n=1400r/m$; $p=2$; $R_s=1.405\Omega$; $R_r=1.395\Omega$; $L_m=0.1722mH$; $L_s=0.178mH$; $L_r=0.178mH$; $J=0.0131KgN.m$;

a) Motor runs in no-load regime:

Motor starts at no load to the speed of 1400 r/m within 0.35s, then speed decreases to zero until 0.7 s, in the next starting the speed increases to value of 1000 r/m-Fig.10-11-12.

b) Motor runs in load regime:

Motor speeds up to 1400 r/m at no load . Load torque of 15Nm is applied after starting 0.3s then and abruptly decreased to zero at the instance 0.7s. Diagrams of speed and electromagnetic torque, stator currents and voltage are shown in Fig.13-14-15.

In the simulation results, operation of the motor drive system fed by hybrid inverter under different conditions and proposed PWM algorithm has shown be stable and good performance.

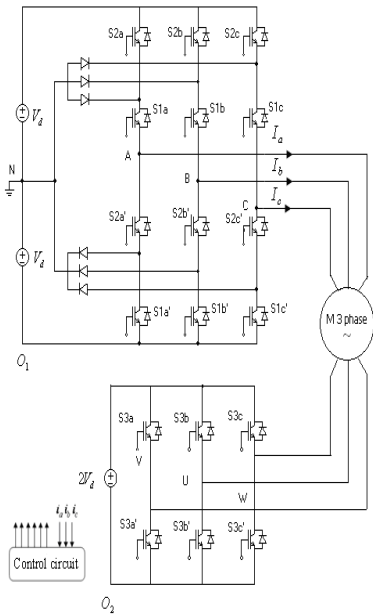


Figure 8: Model proposed of motor - hybrid multilevel inverter .

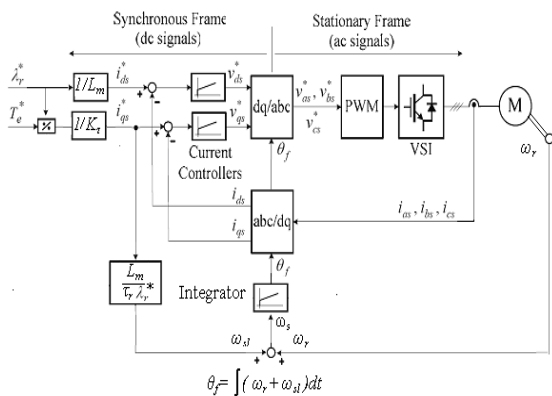


Fig. 9: Diagram of method indirect control FOC.

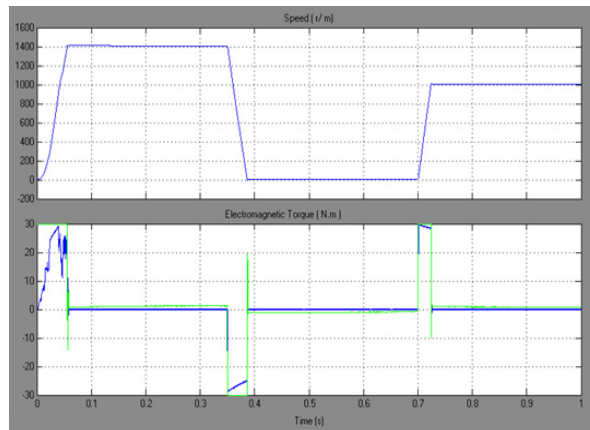


Figure10: Diagrams of speed and electromagnetic torque.

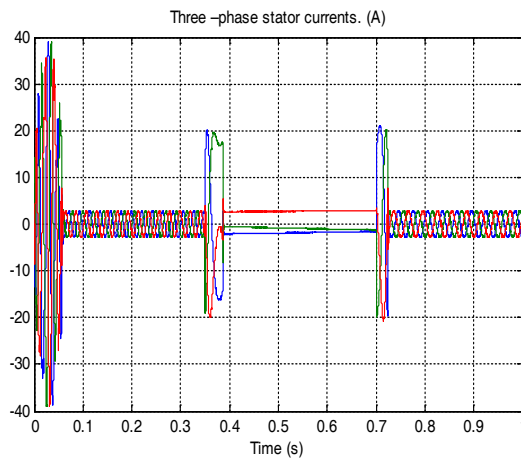


Figure 11: Three –phase stator currents.

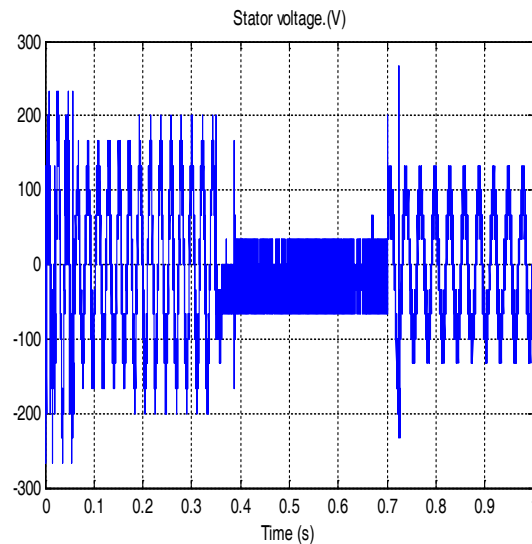


Figure 12: Stator voltage.

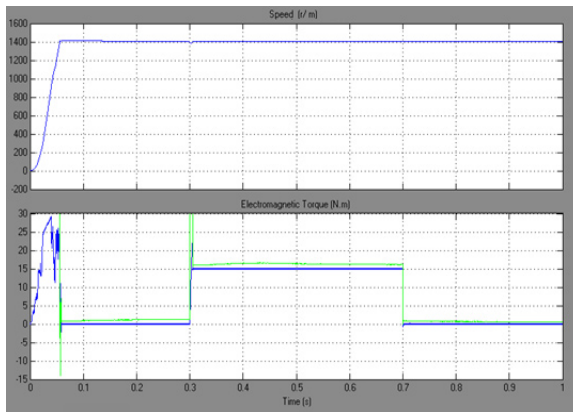


Figure 13: Diagrams of speed and electromagnetic torque.

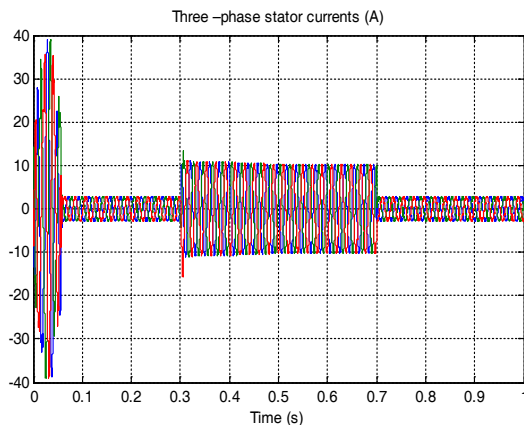


Figure 14 Three-phase stator currents

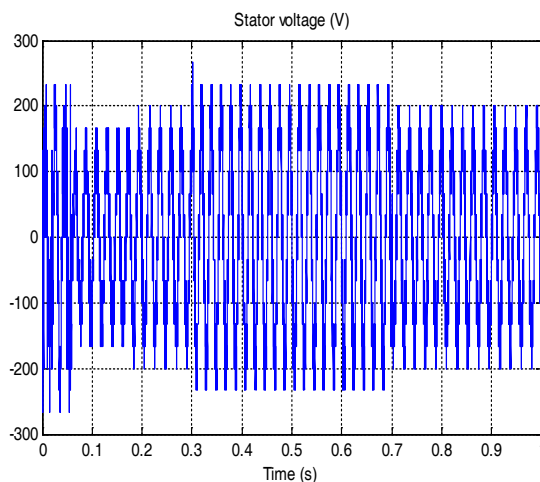


Figure 15: Stator voltage

V. CONCLUSION

In the paper, a new approach to analysis of carrier based PWM for hybrid multilevel inverter consisting of 3-level NPC inverter and 2-level inverter to supply an open-end winding three-phase load has been presented. The method, which is described

for linear modulating range can be extended to overmodulation, too. For demonstration, simulations were implemented for balanced RL load and induction motor drive, whose speed is controlled by indirect field oriented control method. A good response from simulations has confirmed the validity of the proposed PWM algorithm.

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