Improvement of Asymmetric 180-Degree Switching Algorithm Controlling Three-Phase Asynchronous Motor

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Abstract

The paper presents the method of synthesizing the algorithm for controlling semiconductor locks of three-phase inverter circuits according to the asymmetric 180-degree switching law to control three-phase asynchronous motors, and simultaneously evaluating, comparing oscillation speed and motor torque of motor when increasing pulse width modulation frequency. The results are surveyed and evaluated by simulation models on Matlab-Simulink software. The model allows us to evaluate the quality of speed and torque control of three-phase asynchronous motors when using the asymmetric 180-degree switching algorithm. At the same time, this switching algorithm also eliminates co-conductive current in the columns of the inverter circuits thanks to using the brake mode by closing the semiconductor locks simultaneously.

Keywords — *Inverter, Switching algorithm, 180-degree rule, asynchronous motor.*

I. INTRODUCTION

Currently, achievements in the fields of electronics and semiconductor engineering have allowed the integration of motors, pulse power amplifiers, and control units into one, on the basis of an actuator. When studying the control and calculation of the digital drive system with reciprocating converters using bipolar transistors such as BJT, IGBT, or MOSFET, the synthesis of the control algorithms of "pulse power amplifier – actuator" is extremely important. The paper researches the synthesis method and investigates the control algorithm of the 3-phase inverter circuit using the braking mode by simultaneously interrupting the semiconductor locks that control 3-phase asynchronous motors. The advantage of this method ensures that conduction currents do not occur on the columns of the three-phase inverter circuit, simplifying the microcontroller structure with conventional switching rules when using "dead time" [1], [3], [5].

II. THE SYNTHESIS OF ASYMMETRIC 180^0 SWITCHING ALGORITHM

There are many methods of using different inverters to control 3-phase asynchronous motors according to the frequency-voltage control method. However, the 3-phase inverter circuit has many advantages compared to others, such as the number of semiconductor locks, the secondary source as well as the output of the motor is small that easily eliminate the high order harmonics of the output voltage. The method synthesizing the control algorithm with a 3-phase inverter circuit to control three-phase asynchronous motor is shown in Figure 1 [2], [4].

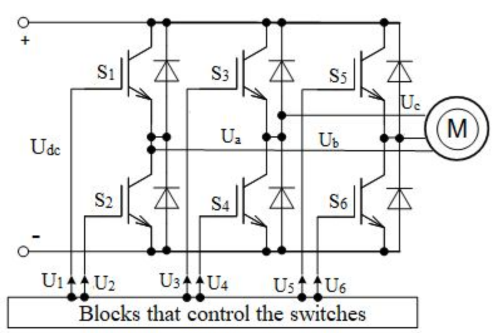


Figure 1: Three-phase inverter circuit diagram

The values U_1, U_2, U_3, U_4, U_5, U_6 in Fig 1 are logic functions that control the switches of a 3-phase inverter. The symbol U_n is the absolute voltage value applied to the windings of a 3-phase asynchronous motor. As is known, the 3-phase inverter circuit exists 2^6 = 64 trạng thái khác nhau, different modes; however, the number of working modes is smaller [4]. The symbols for these modes are V_x and V_{xy}. In which: V_x (x = 0, 1, ..., 7) – is the modes that the binary code of the semiconductor locks S_1 S_3 S_5 reverses with the one of S_2 S_4 S_6, x is the price decimal value of the binary code of S_1 S_3 S_5; V_{xy} – the remaining working modes of the three-phase inverters; x - is the decimal value of the binary code for S_1 S_3 S_5, y - is the decimal value of the binary code for S_2 S_4 S_6 [4].

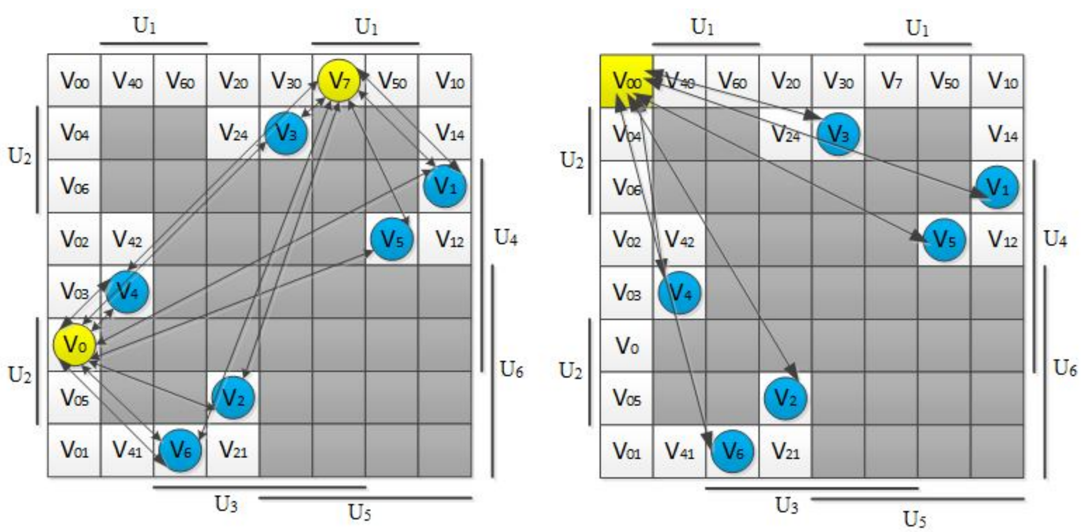
There are many types of switching rules 180^0 such as symmetric, asymmetric upper branch-brake V_0, lower branch-brake V_7, with these rules, in 3-phase inverter circuits, there will always exist a time period where two semiconductor locks on the same column, switch with reversed values, which causes the co-conduction current in the inverter circuit, leading to the risk of damage, loss of safety for the system, Figure 2a. Therefore, the paper proposes an asymmetric switching algorithm, using six motor modes V_x (x = 1, 2, ..., 6) and braking mode V_{00} differs from the two normal types of upper and lower branch braking. Representations of these switches are shown on the Karnaugh Maps in Figure 2b.

The use of this brake mode will eliminate the currents that are co-conducting in the columns of the inverter circuit when switching [5] occurs. Then, the voltage applied to the motor winding is determined by equation (1), (2), (3) [5].

$$U_{ab} = \begin{cases} +U_n \, khi\left(U_6 \cdot \overline{U_5} \cdot U_4 \cdot \overline{U_3} \vee \overline{U_6} \cdot U_5 \cdot U_4 \cdot \overline{U_3} \vee U_6 \cdot \overline{U_5} \cdot \overline{U_4} \cdot U_3\right) \cdot \overline{U_2} \cdot U_1 = 1 \\ 0 \, khi \overline{U_6} \cdot \overline{U_5} \cdot \overline{U_4} \cdot \overline{U_3} \cdot \overline{U_2} \cdot \overline{U_1} = 1 \\ -U_n \, khi\left(\overline{U_6} \cdot U_5 \cdot \overline{U_4} \cdot U_3 \vee U_6 \cdot \overline{U_5} \cdot \overline{U_4} \cdot U_3 \vee \overline{U_6} \cdot U_5 \cdot U_4 \cdot \overline{U_3}\right) \cdot U_2 \cdot \overline{U_1} = 1 \end{cases} \quad (1)$$

$$U_{bc} = \begin{cases} +U_n \, khi\left(U_6 \cdot \overline{U_5} \cdot U_2 \cdot \overline{U_1} \vee \overline{U_6} \cdot U_5 \cdot U_2 \cdot \overline{U_1} \vee U_6 \cdot \overline{U_5} \cdot \overline{U_2} \cdot U_1\right) \cdot \overline{U_4} \cdot U_3 = 1 \\ 0 \, khi \overline{U_6} \cdot \overline{U_5} \cdot \overline{U_4} \cdot \overline{U_3} \cdot \overline{U_2} \cdot \overline{U_1} = 1 \\ -U_n \, khi\left(\overline{U_6} \cdot U_5 \cdot \overline{U_2} \cdot U_1 \vee U_6 \cdot \overline{U_5} \cdot \overline{U_2} \cdot U_1 \vee \overline{U_6} \cdot U_5 \cdot U_2 \cdot \overline{U_1}\right) \cdot U_4 \cdot \overline{U_3} = 1 \end{cases} \quad (2)$$

$$U_{ca} = \begin{cases} +U_n \, khi\left(U_4 \cdot \overline{U_3} \cdot U_2 \cdot \overline{U_1} \vee \overline{U_4} \cdot U_3 \cdot U_2 \cdot \overline{U_1} \vee U_4 \cdot \overline{U_3} \cdot \overline{U_2} \cdot U_1\right) \cdot \overline{U_6} \cdot U_5 = 1 \\ 0 \, khi \overline{U_6} \cdot \overline{U_5} \cdot \overline{U_4} \cdot \overline{U_3} \cdot \overline{U_2} \cdot \overline{U_1} = 1 \\ -U_n \, khi\left(\overline{U_4} \cdot U_3 \cdot \overline{U_2} \cdot U_1 \vee U_4 \cdot \overline{U_3} \cdot \overline{U_2} \cdot U_1 \vee \overline{U_4} \cdot U_3 \cdot U_2 \cdot \overline{U_1}\right) \cdot \overline{U_6} \cdot U_5 = 1 \end{cases} \quad (3)$$



a) b)

Figure 2: Karnaugh Maps asymmetric 180^0 switching a) with braking modes V_0, V_7; b) with braking mode V_{00}

Applying Karnaugh Maps, analyzing Fig. 2a shows that these switches are dangerous switches, which will cause co-conduction currents in one of the branches of a 3-phase inverter. The switches in Fig. 2b are non-dangerous, two-way converters that do not cause overlapping currents in the inverter circuits [5]. To synthesize the 3-phase inverter circuits control algorithm, we will use the following binary logic variables: S_G - determines the direction of rotation of the motor, with S_G = 0, the motor rotates forward. With S_G = 1, the motor is reversed; Q - to adjust the average value of the voltage applied to the motor's stator windings. The mean, in this case, is determined by the time periods during which the engine is either in engine mode or in braking mode. The pulse hash frequency of Q will be a multiple of 6 times the frequency of the generated voltage impulse. Variables are creating rotating magnetic fields Y_A, Y_B, Y_C. These are responsible for creating a phase displacement angle of 120^0 between the voltages U_{ab}, U_{bc}, U_{ca} with a rotating magnetic field jump of 60^0 [2]. The above logical variables have the time chart described in Figure 3 below.

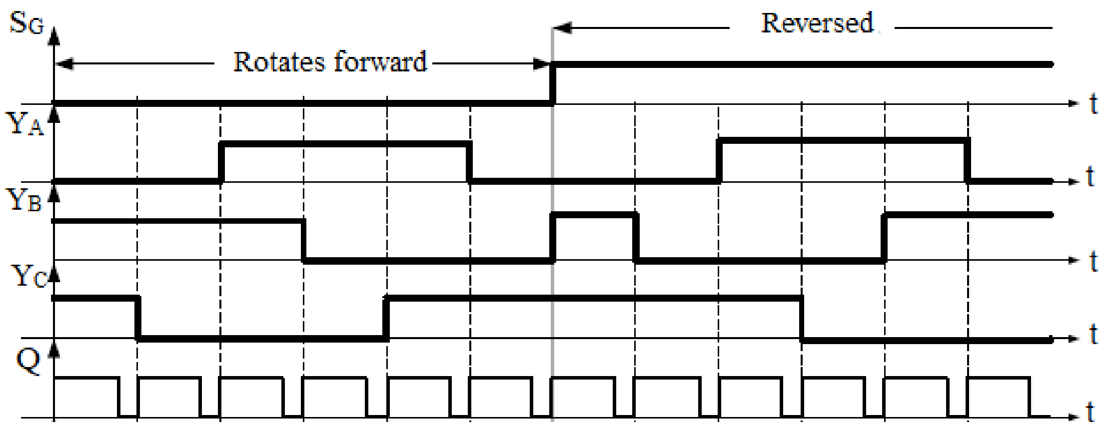


Figure 3: Logical variables time chart

To define the logical expressions for the control logic functions U_6, U_5, U_4, U_3, U_2, U_1, according to the above logic variables, we construct the truth table of the dependencies of the functions on the obtained logic variables above, as shown in table 1.

Table 1. The truth table of the dependencies of the functions on the logical variables

i	S_G	Y_A	Y_B	Y_C	**Q**	U_6	U_5	U_4	U_3	U_2	U_1	V_i
0	0	0	0	0	0	~	~	~	~	~	~	~
1	0	0	0	0	1	~	~	~	~	~	~	~
2	0	0	0	1	0	0	0	0	0	0	0	V_{00}
3	0	0	0	1	1	0	1	1	0	1	0	V_1
4	0	0	1	0	0	0	0	0	0	0	0	V_{00}
5	0	0	1	0	1	1	0	0	1	1	0	V_2
6	0	0	1	1	0	0	0	0	0	0	0	V_{00}
7	0	0	1	1	1	0	1	0	1	1	0	V_3
8	0	1	0	0	0	0	0	0	0	0	0	V_{00}
9	0	1	0	0	1	1	0	1	0	0	1	V_4
10	0	1	0	1	0	0	0	0	0	0	0	V_{00}
11	0	1	0	1	1	0	1	1	0	0	1	V_5
12	0	1	1	0	0	0	0	0	0	0	0	V_{00}
13	0	1	1	0	1	1	0	0	1	0	1	V_6
14	0	1	1	1	0	~	~	~	~	~	~	~
15	0	1	1	1	1	~	~	~	~	~	~	~
16	1	0	0	0	0	~	~	~	~	~	~	~

i	S_G	$\mathbf{Y_A}$	$\mathbf{Y_B}$	$\mathbf{Y_C}$	**Q**	$\mathbf{U_6}$	$\mathbf{U_5}$	$\mathbf{U_4}$	$\mathbf{U_3}$	$\mathbf{U_2}$	$\mathbf{U_1}$	V_i
17	1	0	0	0	1	~	~	~	~	~	~	~
18	1	0	0	1	0	0	0	0	0	0	0	V_{00}
19	1	0	0	1	1	1	0	0	1	0	1	V_6
20	1	0	1	0	0	0	0	0	0	0	0	V_{00}
21	1	0	1	0	1	0	1	1	0	0	1	V_5
22	1	0	1	1	0	0	0	0	0	0	0	V_{00}
23	1	0	1	1	1	1	0	1	0	0	1	V_4
24	1	1	0	0	0	0	0	0	0	0	0	V_{00}
25	1	1	0	0	1	0	1	0	1	1	0	V_3
26	1	1	0	1	0	0	0	0	0	0	0	V_{00}
27	1	1	0	1	1	1	0	0	1	1	0	V_2
28	1	1	1	0	0	0	0	0	0	0	0	V_{00}
29	1	1	1	0	1	0	1	1	0	1	0	V_1
30	1	1	1	1	0	~	~	~	~	~	~	~
31	1	1	1	1	1	~	~	~	~	~	~	~

From truth table 1, to get the simplified equations of logic functions U_6, U_5, U_4, U_3, U_2, U_1, we use the Karnough Maps with the functions U_5, U_3, U_1 as shown in Figure 4.

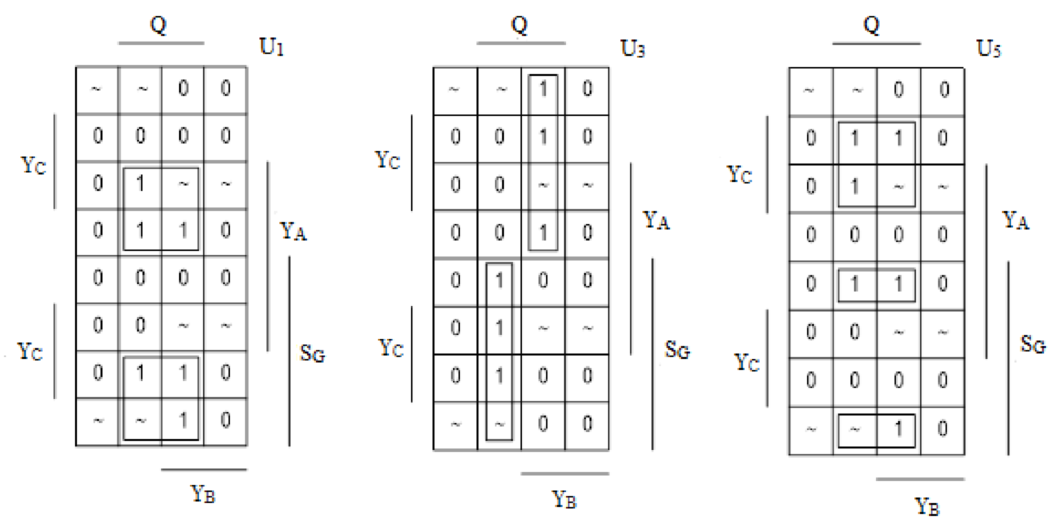


Figure 4: Karnaugh maps for logic functions U_5, U_3, U_1

From the Karnaugh Maps in Fig. 4, after some transforms, the control logic functions U_1, U_3, U_5 will be obtained when using pulse width modulation as follows:

$$U_1 = (S_G \oplus Y_A) \cdot Q, U_3 = (S_G \oplus Y_B) \cdot Q, U_5 = (S_G \oplus Y_C) \cdot Q \tag{4}$$

In this switching algorithm, all of the motor modes of the transistors in the same column of the inverter circuit is opposite; only in the braking mode, these locks are closed, preventing current from passing. This is the reason why the logic functions controlling locks will have a value of 0. Therefore, we can easily identify the functions U_2, U_4, U_6 with expressions:

$$U_2 = \overline{(S_G \oplus Y_A)} \cdot Q, U_4 = \overline{(S_G \oplus Y_B)} \cdot Q, U_6 = \overline{(S_G \oplus Y_C)} \cdot Q \tag{5}$$

III. SIMULATION AND RESULTS EVALUATION

To check and evaluate the quality of controlling 3-phase asynchronous motor speed with the asymmetric 180^0 switching law as summarized above, we use the Matlab simulation model, as shown in Figure 5 below.

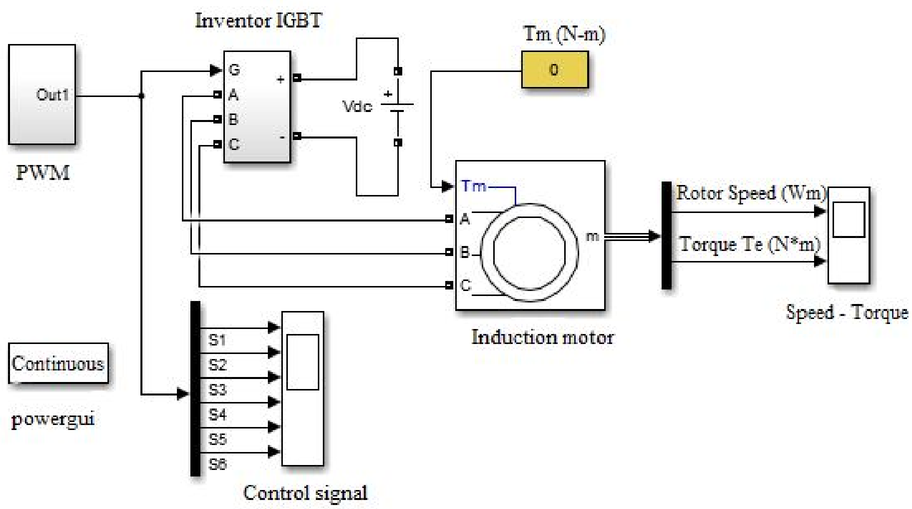


Figure 5: A simulation model of 3-phase asynchronous motor control on Matlab Simulink

The simulation model consists of the following blocks:

Invector IGBT - is a 3-phase inverter circuit simulation block with IGBT switches; PWM - is a simulation block that synthesizes the asymmetric 180^0 switching algorithm pulse width modulation; Induction motor - is a simulation block of a 3-phase asynchronous motor with parameters of 5HP, 460V, 60Hz, 1750 RPM; Vdc - is the DC power supply to the inverter circuits with value 759V; Control signal, Speed - Torque - are the units that display the results of measuring the signals controlling the switches of the inverter circuit, the speed, and torque of 3-phase asynchronous motors. To control 3-phase asynchronous motors, we use the frequency-voltage adjustment method with the rule of U / f = const in the asymmetric 180^0 switching mode. The simulation results with the specific case when the working frequency is 48Hz are shown below. To observe the form of the control signals of the semiconductor switches and the form of the phase voltage before feeding the motor windings, we consider the case where the frequency of Q is 12 times the frequency of the voltage pulse. Then, the pulse drives the semiconductor switches of the inverter circuits, and the phase voltage form is shaped like Figure 6, 7.

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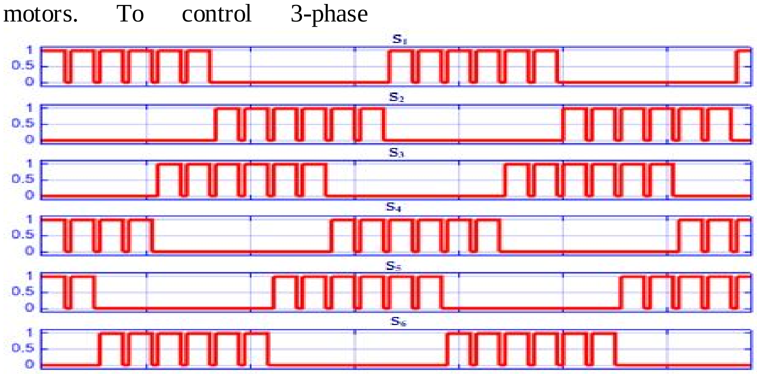

Figure 6: Pulse form controlling inverters

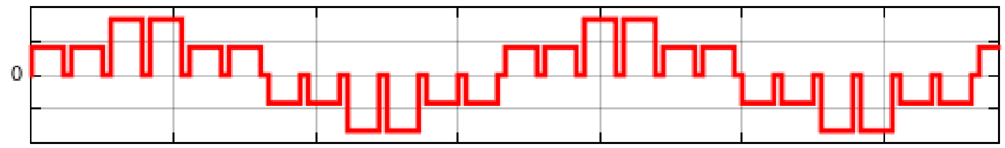

Figure 7: Voltage form before feeding for phases motor

Observe the pulse signal pattern that controls the switches of the 3-phase inverter in Figure 6. See that there was no moment, on the same column of the inverter circuits, there are two simultaneous switches that have reverse logic values. Therefore, there will be no currents co-conducting on the columns of the inverters. This improves the reliability and safety of the 3-phase inverters' working process. To improve the quality of motor speed control, you can change the PWD frequency by changing the Q signal pulse modulation frequency. To evaluate the quality of motor control, we simulate with two cases when Q is taken at a frequency of 6 and 12 times the frequency of voltage impulse regulation, respectively. The result of the excess of speed and torque is shown in Figure 8 below.

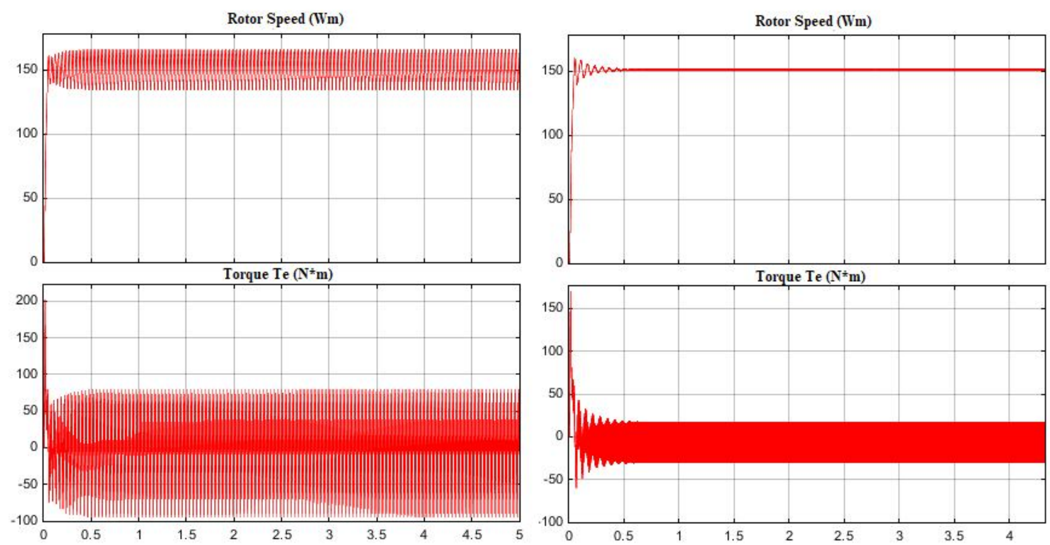

Figure 8: Speed and Torque Motor form when changing pulse-modulation frequency Q alternatively 6 and 12 times voltage pulse frequency corresponding to figures a and b

Simulation results in Figures 8a and b show that the speed oscillation decreases by approximately 10 times, and the motor torque decreases drastically by nearly 3 times when we increase the pulse-modulation frequency Q by 2 times.

IV. CONCLUSIONS

The paper proposes logic variables and synthesis of the asymmetric 180-degree switching law algorithm that controls the speed of 3-phase asynchronous motors. Constructing and determining the values of variables, truth table values , and logic functions, then building logic function expressions that control the switches of the three-phase inverter bridge. Using the Karnaugh Maps allows you to reduce the expression of the control logic function. The simulation results have demonstrated that it is possible to enhance the quality of speed and torque control of a triple asynchronous motor by varying the frequency of the Q signal modulation, or the voltage pulse hashing frequency. The innovative switching algorithm help eliminate currents that are co-conducting on 3-phase inverter circuit branches. This contributes to improving reliability, safety, and longevity for power pulse amplifiers in 3-phase asynchronous motor control systems.

ACKNOWLEDGMENT

This study was supported by Thai Nguyen University of Technology; http://www.tnut.edu.vn/.

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