

DEVELOPING AN IMPROVED SWITCHING ALGORITHM FOR FOUR-PHASE BRIDGE INVERTER WITH PHASE VOLTAGE STATE DISTRIBUTION VARYING STRATEGY FOR TWO-PHASE ASYNCHRONOUS MOTOR LOAD APPLICATION

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ARTICLE INFO	ABSTRACT
Received: 16/10/2024 Revised: 26/11/2024 Published: 27/11/2024	The paper proposes a method for developing an asymmetric switching algorithm to control a four-phase bridge inverter with a two-phase asynchronous motor load, which improves the voltage state distribution rule for each phase. This method is based on changing the voltage state distribution rules according to the sine and cosine functions to control the speed of the two-phase asynchronous motor using the voltage-frequency adjustment law. The performance of the proposed method is evaluated through criteria including the mechanical stiffness characteristic, the error steady-state speed, the transient time, and the stator current characteristics of the two-phase asynchronous motor. The advantages of the proposed method are verified through the simulation process, in which the performance of the proposed method is compared to the conventional asymmetric switching methods, and other pulse width modulation method such as pulse width modulation, and sine pulse width modulation.
KEYWORDS	
Sequential switching law	
Pulse width modulation	
Sine pulse width modulation	
Four-phase bridge inverter	
Four-phase bridge inverter states	

XÂY DỰNG THUẬT TOÁN CHUYỂN MẠCH CẢI TIẾN ĐIỀU KHIỂN NGHỊCH LƯU CẦU BỐN PHA VỚI TẢI ĐỘNG CƠ KHÔNG ĐỒNG BỘ HAI PHA CÓ THAY ĐỔI QUY LUẬT PHÂN BỐ TRẠNG THÁI ĐIỆN ÁP TRÊN TỪNG PHA

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THÔNG TIN BÀI BÁO	TÓM TẮT
Ngày nhận bài: 16/10/2024 Ngày hoàn thiện: 26/11/2024 Ngày đăng: 27/11/2024	Bài báo đề xuất phương án xây dựng thuật toán chuyển mạch không đối xứng điều khiển nghịch lưu cầu 4 pha với tải động cơ không đồng bộ hai pha có cải tiến quy luật phân bố trạng thái điện áp trên từng pha, trên cơ sở thay đổi quy luật phân bố trạng thái điện áp khác 0 và điện áp 0 theo tỷ lệ quy luật hàm sin và cosin để điều khiển tốc độ động cơ không đồng bộ hai pha theo các luật điều chỉnh tần số - điện áp. Kết quả phân tích, đánh giá hiệu năng làm việc của động cơ không đồng bộ hai pha dựa trên các tiêu chí như độ cứng đặc tính cơ, dao động tốc độ xác lập của động cơ, thời gian quá độ, đặc tính dòng điện mạch stato... Ưu điểm của phương pháp đề xuất cải tiến được khẳng định thông qua việc so sánh đánh giá hiệu năng làm việc của động cơ với nghịch lưu cầu 4 pha ở chế độ chuyển mạch không đối xứng cải tiến với chế độ chuyển mạch không đối xứng thông thường, ngoài ra còn đánh giá so sánh với các phương pháp điều chế độ rộng xung, điều chế độ rộng xung sin.
TỪ KHÓA	
Luật chuyển mạch tuần tự	
Điều chế độ rộng xung	
Điều chế độ rộng xung sin	
Nghịch lưu cầu bốn pha	
Các trạng thái cầu nghịch lưu 4 pha	

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1. Introduction

Nowadays, electric drive systems are widely used in many fields such as automated production conveyor systems, electric drive systems for electric vehicles, airplanes, elevators, and other applications. Specifically, the alternating current (AC) drive systems with synchronous motors, and asynchronous motors, two-phase and three-phase asynchronous motors, and servo motors are gradually replacing electric drive systems with direct current (DC) motors. The asynchronous motor with low cost and long lifespan, is one of the most popular motors in industrial electric drive systems. All of the above characteristics are associated with the development of semiconductor technology with high switching frequency power electronics devices along with industrial inverters [1] - [3]. These industrial inverters have many outstanding advantages in terms of size, cost, ease of replacement, production, and increasingly improved stability. With the stable work quality and the increasing switching frequency of semiconductor devices, the demand to improve the switching techniques of single-phase, two-phase, and three-phase bridge inverters for AC motors has become increasingly urgent [4]-[6]. The switching techniques focus on improving stability against disturbances, increasing power rating, and reducing the transient time of the system.

Currently, there are various pulse width modulation techniques such as pulse width modulation (PWM), sine pulse width modulation (SPWM), and space vector modulation (SVPWM) [7]-[11]. Besides, digital switching laws such as symmetric switching law (SSL), sequential switching law (SSL), energy-saving sequential switching law (ESSL), and asymmetric switching law (ASL) are also effective solutions for modern electric drive systems. These digital switching techniques are becoming more popular and widely used [12]-[14]. The common characteristic of digital switching laws is that the output voltage is formed by square pulses with equal pulse width, where the zero voltage states and non-zero voltage states are distributed according to certain rules. With these voltage forms, the total harmonic distortion (THD) has a significant impact on the performance of the system, root mean square (RMS) value, the peak value of current and voltage waveforms [3]-[5], [15]-[17]. That means the distribution of the voltage states of zero and non-zero in the voltage pulses of the inverter has a significant impact on the quality of the voltage pulses [15]-[20]. These influences lead to issues such as a significant heat generation in conductors of motors, affecting the durability of insulation materials, impacting the operation of protective devices like fuses, or circuit breakers. They cause measuring devices to potentially misread data, affecting telecommunications equipment, power loss along transmission lines, fluctuations in speed or system stability, and the performance of system. Therefore, researching improvements to the asymmetric switching law to enhance the performance of two-phase asynchronous motors when implementing motor control with frequency-voltage variation laws using a four-phase inverter plays an important role [21], [22].

2. Materials and Methods

The diagram for a four-phase inverter with a two-phase asynchronous motor load is shown in Figures 1, [5], [8], in which U_i , with $i = 1:8$, are the control signals for turning on and off the corresponding semiconductor switches S_i of the four-phase bridge inverter. The signals $U_1, U_2, U_3, U_4, U_5, U_6, U_7, U_8$ in Figure 1 are logic functions with corresponding values of 0 and 1. These functions determine the control states of the switches $S_1, S_2, S_3, S_4, S_5, S_6$ in the four-phase inverter. $U_i = 1$ corresponds to the state where the S_i is conducted, while $U_i = 0$ corresponds to the state where the S_i is non-conducted (i is an integer number from 1 to 8). With the four-phase inverter, there are $2^8 = 256$ different states, however, the number of operational states is 81, and the number of forbidden states is 175, [5]-[8]. The symbol for these states is t_x . In which: x ($x = 0, 1...255$) is the decimal value of the binary code $U_8 U_7 U_6 U_5 U_4 U_3 U_2 U_1$ that determines the control state of the corresponding semiconductor switches $S_8 S_7 S_6 S_5 S_4 S_3 S_2 S_1$. The idea of the asymmetric switching law for the four-phase bridge inverter will use 5 states, including one braking state t_{170} , and four power states for the motor, which are $t_{102}, t_{105}, t_{150}$, and t_{153} . The direction of the current flowing through phases A and B and the vector form of the total magnetic

field in the stator circuit of the two-phase asynchronous motor corresponding to the states t_{153} , t_{105} , t_{102} , and t_{150} is illustrated in Figure 2.

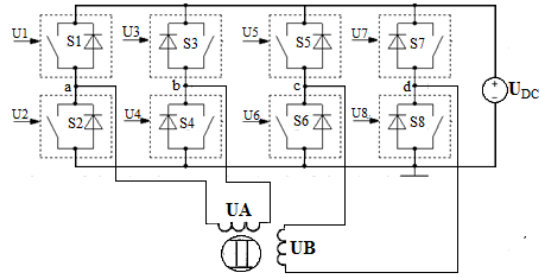


Figure 1. The diagram for a four-phase inverter with a two-phase asynchronous motor load

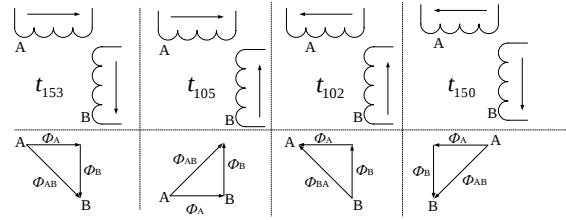


Figure 2. The direction of the current flowing through phases A, B, and the total magnetic field vector on the stator windings of a two-phase asynchronous motor corresponds to the states of a four-phase bridge inverter

From Figure 2, it can be observed that for one of the four states of the inverter bridge, namely t_{153} , t_{105} , t_{102} , and t_{150} , both stator windings of the motor will be powered at the same time but with different current directions. The motor will rotate clockwise if powered according to the order of states t_{153} , t_{105} , t_{102} , t_{150} , and it will rotate counterclockwise if powered in the reverse order.

To summarize the control algorithm for the four-phase bridge inverter using the asymmetric switching law, the following binary logic variables will be used:

- The SG is a pulse with values of 0 and 1 corresponding to the motor rotating clockwise or counterclockwise. Thus, when the motor rotates clockwise, the value of $SG = 0$, and counterclockwise corresponds to $SG = 1$.
- The YA is a voltage pulse with values of 0 and 1 corresponding to the negative half-cycle and positive half-cycle of the alternating voltage pulse applied to phase A of the stator.
- The YB is a voltage pulse with values 0 and 1 corresponding to the negative half-cycle and positive half-cycle of the alternating voltage pulse applied to phase B of the stator. Thus, the pulses YA and YB are always out of phase by an angle of 90 degrees.
- The Q is a pulse with values of 0 and 1 used to adjust the average value of the alternating voltage pulse applied to the stator windings of the motor. In practice, the Q is often used in two forms: symmetrical or asymmetrical, with equal switching periods. The asymmetrical form has a time diagram as shown in Figure 3. The average voltage applied to the stator windings of the motor is adjusted by changing the voltage pulses width carrying the value $Q = 1$ compared to when $Q = 0$, at which point the motor is either in motor mode or braking mode, respectively.

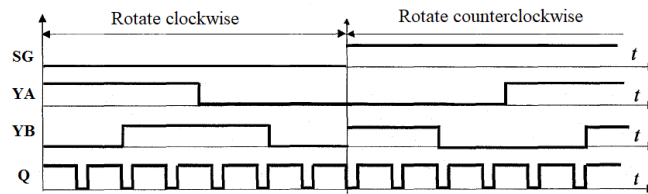


Figure 3. The time diagram of the SG, YA, YB, and Q

To determine the controlling logic functions U_8 , U_7 , U_6 , U_5 , U_4 , U_3 , U_2 , and U_1 according to the logic variables SG, YA, YB, and Q, a truth table is synthesized the dependency of the functions on the logic variables as shown in Table 1.

From Table 1, after some algorithmic transformations, the logic control functions U_8 , U_7 , U_6 , U_5 , U_4 , U_3 , U_2 , and U_1 dependent on the variables SG, YA, YB, and Q will be obtained as follows [8]:

$$\begin{aligned}
 U_1 &= (SG \oplus YA) \cdot Q; U_2 = \overline{U_1}; \\
 U_3 &= (\overline{SG \oplus YA}) \cdot Q; U_4 = \overline{U_3}; \\
 U_5 &= (SG \oplus YB) \cdot Q; U_6 = \overline{U_5}; \\
 U_7 &= (\overline{SG \oplus YB}) \cdot Q; U_8 = \overline{U_7};
 \end{aligned} \tag{1}$$

Table 1. Truth table of the dependence of functions on logical variables

i	SG	YA	YB	Q	U8	U7	U6	U5	U4	U3	U2	U1	t _i
0	0	0	0	0	1	0	1	0	1	0	1	0	t ₁₇₀
1	0	0	0	1	0	1	1	0	0	1	1	0	t ₁₀₂
2	0	0	1	0	1	0	1	0	1	0	1	0	t ₁₇₀
3	0	0	1	1	1	0	0	1	0	1	1	0	t ₁₅₀
4	0	1	0	0	1	0	1	0	1	0	1	0	t ₁₇₀
5	0	1	0	1	0	1	1	0	1	0	0	1	t ₁₀₅
6	0	1	1	0	1	0	1	0	1	0	1	0	t ₁₇₀
7	0	1	1	1	1	0	0	1	1	0	0	1	t ₁₅₃
8	1	0	0	0	1	0	1	0	1	0	1	0	t ₁₇₀
9	1	0	0	1	1	0	0	1	1	0	0	1	t ₁₅₃
10	1	0	1	0	1	0	1	0	1	0	1	0	t ₁₇₀
11	1	0	1	1	0	1	1	0	1	0	0	1	t ₁₀₅
12	1	1	0	0	1	0	1	0	1	0	1	0	t ₁₇₀
13	1	1	0	1	1	0	0	1	0	1	1	0	t ₁₅₀
14	1	1	1	0	1	0	1	0	1	0	1	0	t ₁₇₀
15	1	1	1	1	0	1	1	0	0	1	1	0	t ₁₀₂

The output voltage waveform of the four-phase inverter on each phase will have a shape like Figure 4 but out of phase by an angle of 90 degrees.

It is observed that, with the asymmetric switching law being implemented as above, the distribution rule of voltage pulses that are non-zero and zero on each phase is always evenly distributed and has the same pulse period. This type of voltage pulse has the advantage of being easy to implement; however, the THD value is large, and the fundamental harmonic has a smaller index compared to some other pulse width modulation techniques. This leads to an increase in temperature and a decrease in the lifespan of the motor, as well as affecting the performance indicators of the motor such as characteristic stiffness, transient time, etc. Therefore, in the case of a two-phase asynchronous motor load, when implementing the asymmetric switching law to control the two-phase bridge inverter, the authors propose a method to allow the voltage form on each phase to vary with different pulse widths, for example, in the positive half-cycle with 5 pulses as shown in Figure 5, similarly for the negative half-cycle. To achieve this, the authors propose using two variables Q_1 and Q_2 , and eliminating variable Q . Variables Q_1 and Q_2 have meanings similar to variable Q , used to change the average output voltage of the four-phase bridge inverter placed on each phase of the two-phase asynchronous motor; however, the pulse widths of variables Q_1 and Q_2 are not equal and can vary according to any rules. The change in the pulse forms of Q_1 and Q_2 will have a period equal to half the cycle and be in phase with each half-cycle corresponding to the YA and YB variables. Thus, to achieve the voltage pulse shape on each phase of the stator circuit of the two-phase asynchronous motor as shown in Figure 5, it is necessary to create logic 0 and 1 pulses of the variables Q_1 and Q_2 with pulse widths changing according to the shape shown in Figure 5 in each cycle resembling the positive half-cycle of the desired voltage.

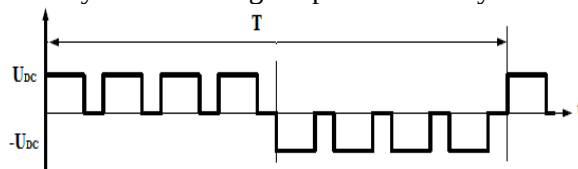


Figure 4. The output voltage waveform of the four-phase bridge inverter applied to each phase of the two-phase asynchronous motor

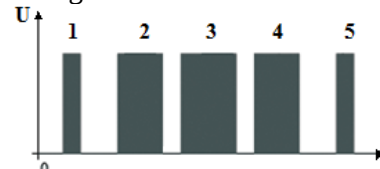


Figure 5. The output voltage waveform of the H bridge inverter in the positive half-cycle under SPWM mode

To find the control functions $U_8, U_7, U_6, U_5, U_4, U_3, U_2, U_1$ based on the variables SG, YA, Q_1, YB, Q_2 , one can perform similarly to the conventional asymmetric switching laws by constructing a truth table of the values $U_8, U_7, U_6, U_5, U_4, U_3, U_2, U_1$ according to the variables $SG, YA, Q_1,$

YB , Q_2 similar to truth table 1. However, since YA , YB , Q_1 , and Q_2 are distinct for each phase A and phase B voltage pulse, the forms of the control functions U_8 , U_7 , U_6 , U_5 , U_4 , U_3 , U_2 , U_1 can be obtained from the equation (1) by substituting Q_1 and Q_2 with each phase as follows:

$$\begin{aligned} U_1 &= (SG \oplus YA).Q_1; & U_2 &= \bar{U}_1 \\ U_3 &= (SG \oplus YA).Q_1; & U_4 &= \bar{U}_3 \\ U_5 &= (SG \oplus YB).Q_2; & U_6 &= \bar{U}_5 \\ U_7 &= (SG \oplus YB).Q_1; & U_8 &= \bar{U}_7 \end{aligned} \quad (2)$$

With the proposed improved switching scheme, it is possible to implement other pulse width modulation techniques such as SPWM and PWM by creating variables Q_1 and Q_2 with rules for varying the pulse widths of zero and non-zero respectively. When adding the variables Q_1 and Q_2 , there are four cases for the values of Q_1 and Q_2 . In the case where Q_1 and Q_2 are both equal to 1, meaning both phases of the motor are powered, this case will correspond to 4 states: t_{153} , t_{105} , t_{102} , t_{150} ; in the case where Q_1 and Q_2 are both equal to 0, neither phase of the motor is powered, corresponding to state t_{170} as shown in Table 1. In the two cases where Q_1 and Q_2 are different, one of the two phases of the motor will be powered while the other will not, thus using two variables Q_1 and Q_2 will add four states of the four-phase bridge inverter. When powering each phase, there are four possibilities: powering with a positive voltage or with a negative voltage, corresponding to the phase that is not powered, with the logic functions U_4 , U_3 , U_2 , U_1 having values of 1, 0, 1, 0 for phase A , or U_8 , U_7 , U_6 , U_5 having values of 1, 0, 1, 0 for phase B . The four switching states of the four-phase bridge inverter when powering each phase of the two-phase asynchronous motor, by adding the two variables Q_1 and Q_2 , will be t_{166} , t_{169} powering phase A , phase B with a voltage of 0; t_{106} , t_{154} powering phase B , phase A with a voltage of 0.

To improve the performance of a two-phase asynchronous motor, the authors propose a method for distributing the pulse states non-zero and 0 pulses of the variables Q_1 and Q_2 as follows: Supposed that we need to modulate the pulsed alternating voltage on the phases of a two-phase asynchronous motor with a period of T (seconds) and a voltage adjustment factor k_p . The total time for holding the voltage states is non-zero will be $T - k_p.T = (1 - k_p)T$ seconds. Therefore, with p being the number of non-zero voltage pulses that need to be modulated in a half-cycle of the stator phase voltage, the i th pulse width of Q_1 and Q_2 , starting from the beginning of each cycle, will be calculated according to the formula (3) [15], [16]:

$$\delta_{Pi} = \frac{k_p T \sin(i\pi / (p+1))}{2 \sum_{i=1}^p \sin(i\pi / (p+1))} \quad (3)$$

To ensure symmetry in the distribution of the zero and non-zero voltage states, we modulate the number of zero voltage pulses to $p+1$ when the average voltage is less than the rated voltage, that is, $k_p > 0$. The modulation order is such that in one-half of the AC voltage cycle, it always starts and ends with a zero voltage value. At that point, the pulse width of the zero pulse i th of Q_1 and Q_2 , measured from the beginning of each cycle, will be determined according to formula (4) [15], [16]:

$$\delta_{0i} = \frac{(1 - k_p) T |\cos(i\pi / (p+2))|}{2 \sum_{i=1}^{p+1} |\cos(i\pi / (p+2))|} \quad (4)$$

With the calculation method for the width of the pulses of Q_1 and Q_2 as mentioned above, within the scope of this article, the proposed algorithm will be referred to as the improved switching law (CM_CT).

3. Results and Discussion

In this study, the authors will explain, analyze, and compare the performance of a four-phase asynchronous motor operating in a four-phase bridge inverter when operating with the proposed method, and different pulse-width modulation methods such as the asymmetric switching law,

SPWM, and PWM, in which, PWM differs from SPWM only in that the control signal is constant, with the voltage form consisting of equal pulses [5], [8], [15].

To simulate and evaluate the performance of a two-phase asynchronous motor and its speed control, a simulation model was completed in Matlab Simulink as shown in Figure 6. In this model, the two-phase asynchronous motor operates with a frequency of 50 Hz and a rated voltage of 110 V. The comparison and analysis of the performance of the single-phase asynchronous motor were conducted using various pulse width modulation modes (PWM). The survey options were carried out under conditions where the frequency-voltage was regulated with a constant load according to the U/f law as constant, with other U/f controls being implemented similarly. The Q_i blocks correspond to different cases of pulse width modulation such as CMC_CT, PWM, and SPWM.

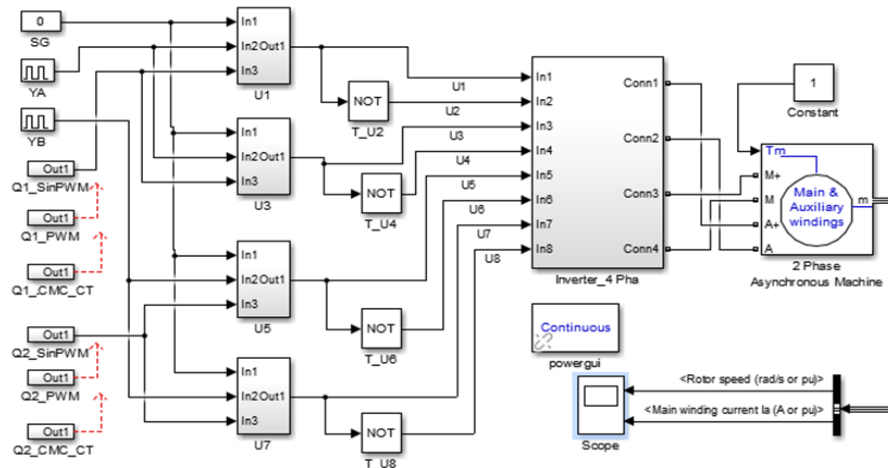


Figure 6. Four-phase bridge inverter switching control model with a two-phase asynchronous motor load

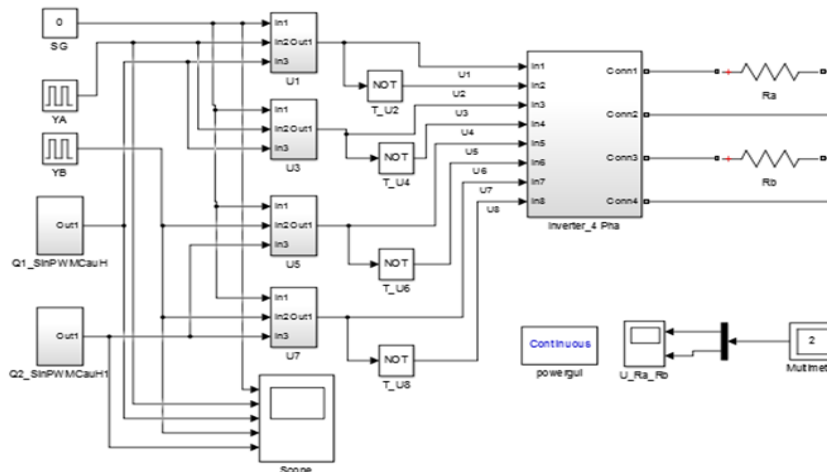


Figure 7. Four-phase bridge inverter switching control model with resistive load

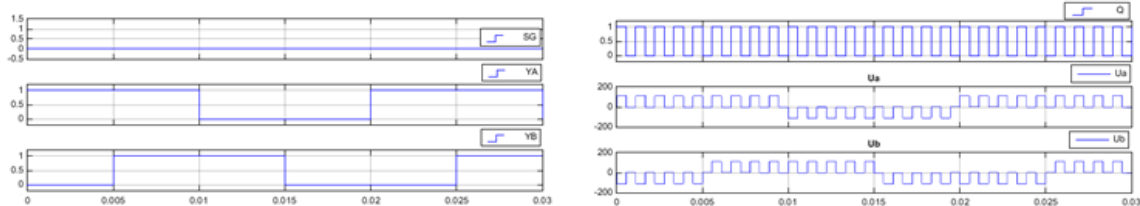


Figure 8. The SG, YA, YB, Q variables, and the phase output voltages of a four-phase bridge inverter with an resistance load in the case of the asymmetric switching law

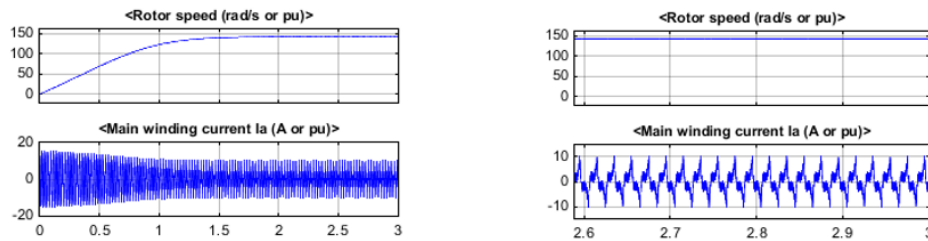


Figure 9. The speed characteristics and stator current phase A of the motor in asymmetric switching mode at a frequency of 50 Hz, $T_m = 1$ N.m

To investigate the output voltage of a four-phase bridge inverter before supplying it to the stator of a two-phase asynchronous motor, a simulation model is used with a resistive load R as shown in Figure 7. In this, the R_a and R_b correspond to the resistors placed at the output of phase A and phase B of the four-phase bridge inverter.

The signal forms of the SG , YA , YB , Q_1 , and Q_2 variables, and the output voltage across the phases of the four-phase bridge inverter with $p = 9$, under resistive load conditions in the case of the asymmetric and proposed switching laws when the motor rotates clockwise are shown in Figure 8 and Figure 10.

The simulation results of speed for a specific case where the desired voltage frequency is 50 Hz, the number of modulation pulses per half-cycle is 9, and the load has a torque of 1 N.m are illustrated in Figure 7 and Figure 8. The remaining cases are described in the form of result parameter Tables 1, 2, 3, and 4.

Figure 8 and Figure 10 show that the output AC pulse voltage waveform of the four-phase bridge inverter with the CMC_CT method has a distribution pattern of voltage states that are non-zero and zero, as implemented according to formulas (3) and (4), is differs from the AC pulse voltage waveform in the case of asymmetric switching where the AC pulse voltage waveform is evenly chopped.

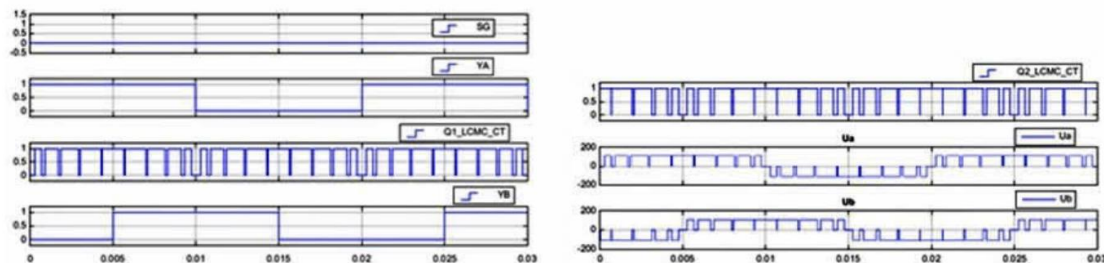


Figure 10. The SG , YA , YB , Q variables, and the phase output voltages of a four-phase bridge inverter with an resistance load in case of the proposed switching method

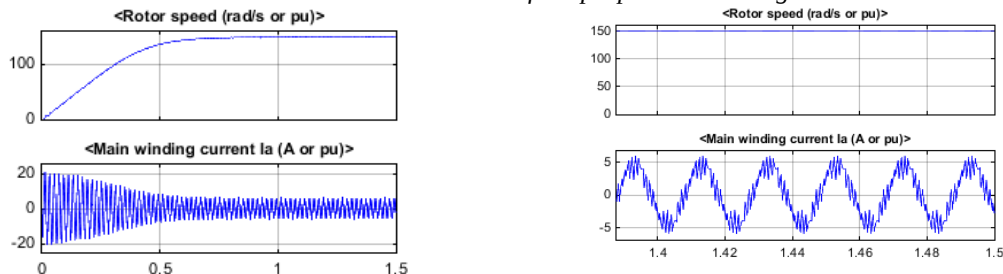


Figure 11. The speed characteristics and stator current phase A of the motor in the proposed switching mode at a frequency of 50 Hz, $T_m = 1$ N.m

Figures 9 and 11 show the speed and current characteristics of phase A of the two-phase asynchronous motor in both asymmetric and the proposed switching modes. As can be seen, with

the CMC_CT method, the steady-state speed response is greater than the asymmetric switching mode, the transient time in the CMC_CT method is less than half that of the asymmetric switching method. The stator current form of the motor in the CMC_CT method has a peak amplitude significantly lower than that in the asymmetric switching method and has a shape closer to a sine wave when operating at the same frequency of 60 Hz and with the same number of pulses per half cycle, which is 9. However, in the case of asymmetric switching method, the peak amplitude of the starting current on the stator circuit is lower compared to the CMC_CT case.

To compare the working performance of a two-phase asynchronous motor with a four-phase bridge inverter under SPWM and PWM modes, the speed characteristic will also be investigated similarly. Table 2, Table 3, and Table 4 summarize the simulation results of the motor's working parameters under different pulse width modulation schemes as the load gradually increases from zero to the maximum load torque that the motor can work. In the tables, the symbol T_m represents the load torque applied to the motor and $T_{m, max}$ is the maximum load torque at which the motor can start accelerating to reach a steady state. When the load torque applied to the motor exceeds $T_{m, max}$, the motor will not be able to start accelerating and will rotate in reverse if the load has potential energy. In the table, the marked cells indicate cases where the motor cannot operate due to exceeding the maximum load threshold under the corresponding pulse width modulation mode.

Table 2. Motor speed when the load changes from zero with the load torque increased by 1 in pulse width modulation modes with a modulation voltage frequency of 50 Hz

Load torque T_m (N.m)	The established rotational speed of the motor ω (rad/s)			
	CM_CT	ASL	PWM	SPWM
0.0	156.85	156.25	156.55	156.9
1.0	150.1	142.25	146	138.3
2.0	142.2	121.7	132.25	102.8
3.0	132.7	-	111.4	-
4.0	120.25	-	-	-
5.0	101.55	-	-	-
$T_{m, max}$	5.7	2.9	3.8	2.3

Table 3. The transient time of the motor when changing the load torque from 0.0 to 5.0 in pulse width modulation modes

Load torque T_m (N.m)	Transient time (s)			
	CM_CT	ASL	PWM	SPWM
0.0	0.55	1.1	0.8	1.3
1.0	0.6	1.5	1.1	2.1
2.0	0.75	2.2	1.5	4.2
3.0	0.85	-	2.3	-
4.0	1.1	-	-	-
5.0	2	-	-	-

Table 4. The change in the speed of the motor when the load torque varies in pulse width modulation modes with each torque increment of 1 N.m

Load torque T_m (N.m)	$\Delta\omega$ (rad/s)			
	CM_CT ($\Delta\omega_4$)	ASL ($\Delta\omega_3$)	PWM ($\Delta\omega_2$)	SPWM ($\Delta\omega_1$)
0 : 1	6.75	14	10.55	18.6
1 : 2	7.9	20.55	13.75	35.5
2 : 3	9.5	-	20.85	-
3 : 4	12.45	-	-	-
4 : 5	18.7	-	-	-

Table 2 describes the established speed of the motor when the load changes from 0 to 5 in different pulse width modulation modes with a modulation frequency of 50 Hz. The bottom row

indicates the maximum torque ($T_{m, max}$) that the motor can achieve in each pulse width modulation mode corresponding to the columns.

Table 2 also shows that the maximum torque that the motor can achieve in the CMC_CT mode is significantly higher than in the asymmetric method, PWM, and SPWM modulation modes. Specifically, in the CMC_CT mode, the maximum torque reached by the motor is 5.7 N.m, which is much greater than the 2.3 N.m in the SPWM mode, and 2.9 N.m and 3.8 N.m in the corresponding asymmetric switching and PWM wide modulation modes.

Table 3 shows that the transient time of the motor in the improved switching mode is the fastest and significantly shorter than in the other pulse width modulation modes.

Table 4 describes the established speed error when varying the load torque of the motor from no load with an incremental increase of 1 N.m to the maximum torque that the motor can operate at each mode of the inverter switching. From Table 4, it can be seen that the average characteristic stiffness across each torque range of the motor in the improved switching mode is the highest, which enhances the stability of speed in response to changes in load.

4. Conclusion

The article proposes a solution to improve the switching control algorithm for the four-phase bridge inverter switching by changing the distribution rules for the holding time of the motor states and braking states, or the holding time of non-zero voltage pulses and zero voltage on each half-cycle of the alternating voltage for each phase of the two-phase asynchronous motor. The analysis results indicate that the established speed parameters, the stiffness of the mechanical characteristics in the stable operating region, the speed transient time of the motor, and the maximum load torque that the motor can operate under the proposed switching mode are significantly better compared to when the motor operates with a four-phase bridge inverter switching in SPWM, PWM, and asymmetric switching modes. The characteristics of the stator current in improved switching mode, when the motor operates at a frequency of 50 Hz, are closer to a sine wave compared to when the motor operates in conventional asymmetric switching mode. Its peak amplitude is also significantly smaller, helping to reduce energy losses in the form of heat in the motor. The proposed method has created a pulse source voltage from a four-phase bridge inverter supplying a two-phase asynchronous motor, which enhances the mechanical power of the motor, improves its load capacity and stability under the influence of load disturbances, and reduces transient time. This is significant in applying a two-phase asynchronous motor in electric drive systems, making motor control simpler and increasing the load capacity and mechanical power of the motor.

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