HARDWARE IMPLEMENTATION OF DIGITAL SIGNAL CONTROLLER FOR THREE PHASE VECTOR CONTROLLED INDUCTION MOTOR

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ABSTRACT

The primary objective of this paper is to design, develop, implement and test a simplified switching inverter topology suitable for three phase induction motor drives. The simplified topology is presented and the principle of operation is described in detail. A modified time switching is used instead of the standard pulse width modulation techniques.

The proposed controller increases the power delivered to the motor from a given dc voltage supply, reduces the losses due to high frequency switching and increases the efficiency of the motor by decreasing the distortions of voltages and currents at high powers. The results of the described approach indicate the efficiency and reliability in driving power switches.

Keywords*: Inverter, Time Switching, Three Phase Induction Motor*

1. INTRODUCTION

Variable speed induction motor drives are widely spread in electromechanical systems for a large spectrum of industrial applications. When high dynamic performance and high precision control in a wide speed range are required, vector control based induction motor drive can be used with speed sensor [1]or without it.

The variable frequency converter can be implemented by using several techniques such as pulse width modulated sinusoidal voltage source inverter,square wave voltage source inverter (six step modulation) and space vector modulation [2-3].

In this paper, a compact and low-cost motor driving device capable of converting dc power into ac phase power is designed.

The main object of this driving device is to propose controller that, will increase the delivered power to the motor from dc voltage supply. Another objective is an inverter method which reduces the motor losses due to high frequency switching. These objectives are accomplished by using the modified time-switching scheme (six step modulation), where the switches of the inverter are "on" for electrical-phase-and-rotation intervals of 180° as opposed to the conventional 120°.

Inversion is accomplished through a phase shift of the transistors to produce phase and line voltages displaced by 120°. This three-phase output voltage is applied to the stator windings of the motor. Various AC motor controllers have been designed to eliminate the disadvantages inherent in the conventional systems of this kind such as dead time effects, [4], [5], but such methods could not reduce the possibility of arm short in alternative switching. In [6], the dead time effect could fundamentally avoid by minimization of dead time but dead time compensation is needed. In [7], the dead time is not needed except instant of current polarity change. Another disadvantage is the electro-magnetic noise during forward rotation for forward and reverse system.

The paper is organized as follows. Section 2 presents the suggested controller topology. In this section the system schematic block diagram of induction motor control circuit and the power circuit of a three-phase bridge inverter are presented. Section 3 presents the design of base drive circuit. Section 4 gives description of the controller and results The conclusions are given in Section 5, and the references are given in Section 6.

2. SUGGESTED CONTROLLER TOPOLOGY

Figure 1 shows the construction of the motor controller.The figure shows a three phase induction motor,three phase voltage source inverter with suggested controller and the position sensor(PS).

The controller has two mode of operation; it can work as open loop controller or closed loop. In the case of open loop, the frequency of the square wave generator can be adjusted by variable resistance in square wave generator

In closed loop, encoder is used as a sensor.

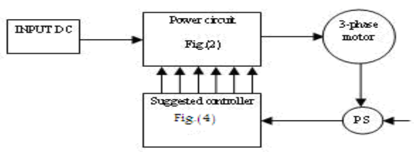


Fig. 1 System schematic block diagram.

Figure 2 shows the power circuit (three-phase voltage source inverter) with terminals A, B and C respectively. V_a, V_b and V_c are the output voltages of the inverter. The inverter consists of six switches with two switches for each phase, the collector of the high side switch is connected to the dc link high, the emitter of the low side switch is connected to the dc link return and the junction is connected to the phase windings. The high speed transistor switches are alternately turned on and off based on a predetermined switching pattern.The transistor switches operate from signals sent by the motor controller.

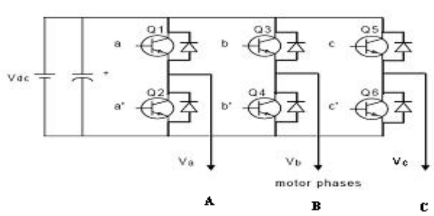


Fig. 2 Power circuit of the Three-phase bridge inverter.

There are two possible patterns of basing signals, these are, [8]:In the first pattern three transistors turned on at any instant; this results in output voltage waves that are defined under all conditions of load(six step modulation).In the second pattern two transistors turned on at any instant, this results in undefined output voltage waves under some load conditions.

In order to implement the six step modulation, the inverter must be driven by using the following signals shown in Fig. 3.

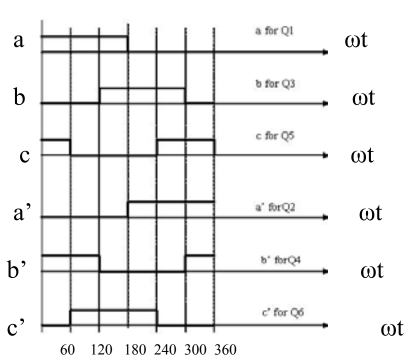


Fig3. The control signals

3. IMPLEMENTATION OF THE CONTROLLER CIRCUIT

In the paper, It is designed the pattern of base signals a, b, c, a', b' and c' these signals are applied and removed at 60° intervals of the output voltage waveforms according to Table 1.

Table1.Sequence for the transistors switching and the rotor position signals

Intervals ωt (°)	Transistors ON	recycle
0 TO 60	Q1,Q4,Q5	
60 TO 120	Q1,Q4,Q6	
120 TO 180	Q1,Q3,Q6	
180 TO 240	Q2,Q3,Q6	
240 TO 300	Q2,Q3,Q5	
300 TO 360	Q2,Q4,Q5	

The inverter is operating in a square wave mode; the magnitude of the motor voltage is DC bridge supply voltage. By controlled by b changing the frequency of the three signals a, change the frequency of and c, it is possible to the stator voltage. The controller includes two square-wave generators. One of these generators operates with frequency of 100 HZ, as shown in Fig. 6(the top signal of the figure). The frequency can be adjusted by the variable resistance in this generator. In this way the frequency of the three square waves is modified [9], [10].

Using Table 1, the truth table of logical operations is shown in Table 2. The input of this logic circuit is the output of the counter from zero to five (X, Y and Z) and the output of the circuit are Y_1, Y_2, Y_3, Y_4, Y_5 and Y_6.

Table2. Truth table of the logical operations in Table 1.

Z	Y	X	Y 1	Y 3	Y 5	Y 2	Y 4	Y 6
0	0	0	1	0	1	0	1	0
0	0	1	1	0	0	0	1	1
0	1	0	1	1	0	0	0	1
0	1	1	0	1	0	1	0	1
1	0	0	0	1	1	1	0	0
1	0	1	0	0	1	1	1	0

After simplification, the Boolean functions Y_1, Y_3 and Y_5 are:

$$Y_1 = \overline{X}\ \overline{Z} + X\ \overline{Y}\ \overline{Z} \quad (1)$$

$$Y_3 = Y\,\overline{Z} + \overline{X}\,\overline{Y}\,Z \qquad (2)$$

$$Y_5 = \overline{X}\,\overline{Y} + X\,\overline{Y}\,Z \qquad (3)$$

By using inverter we obtain Y_2, Y_4 and Y_6. The Boolean functions (1), (2) and (3) may be transformed from an algebraic expression into a logic diagram composed of AND, OR, and NOT gates. The circuit consists of square wave generator with frequency from 100 to 300 Hz. The output of this circuit acts as the input to divide by 2 counter circuit, we use master slave JK flip flop to represent it. The outputs of the counter act as the input to the logic circuit.

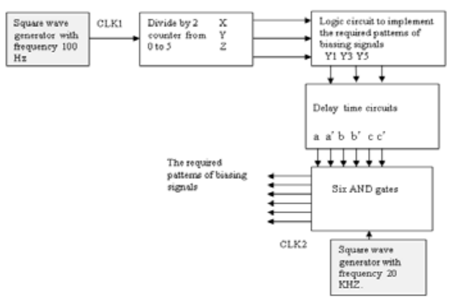
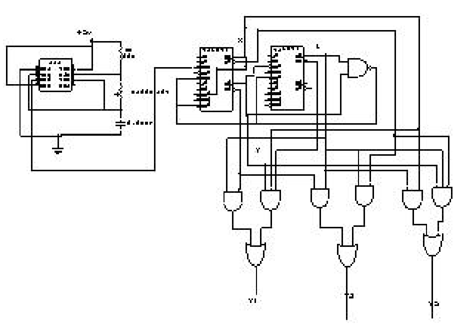


Fig. 4. Block diagram of the controller board.

Figure 4 shows the block diagram of the control board. There are two input signals to the control board. The first one is the low frequency signal, which determines the speed of the motor. The second input is the high frequency signal, which determines the switching frequency of the inverter.Figure 5 shows the circuit diagram of the controller.



5: Circuit diagram of the controller.

4. EXPERIMENTAL RESULTS OF THE CONTROLLER CIRCUIT

The controller generates motor control signals a, b, c, a', b' and c' to the base drive circuits and which control the base current of the transistors. The controller provides commutation commands a, b, c, a', b' and c' which turn "ON" and "OFF" transistors Q_1-Q_6, according to rotor position as seen in the truth Table1. This allows that, the power applies to the selected phase windings A, B and C of motor as shown in Fig. 2. The commutation commands a, b and c are supplied to the respective gates of the three upper transistors Q_1, Q_3, and Q_5. The commutation commands

a', b' and c' are supplied to the respective gates of the three lower transistors Q_2, Q_4 and Q_6. The circuit diagram of proposed controller is shown in Fig. 5. Table 1 shows that each of the transistors, during full power, is "on" for three consecutive 60° intervals for a total of 180°. Thus, during each 60° interval, three transistors are "on", rather than turning two transistors "on" as in the conventional 120° control circuits. During the interval where the rotor position is between 0° and 60° commutation commands a, b and c are supplied to the transistors Q_1, Q_4, and Q_5. When the rotor is between 60° and 120°, the transistors Q_1, Q_4, and Q_6 are turned "on". When rotor is between 120° and 180°, the transistors Q_1, Q_3 and Q_6 are turned "on".

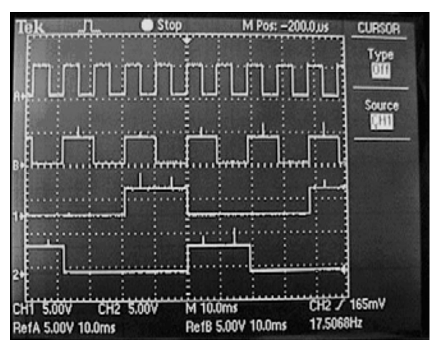


Fig. 6: Signal patterns of the counter.

Fig. 6 illustrates four signals, the first signal is the output of the square wave generator with frequency 100 Hz (CLK1), the second signal is X, the third is Y signal and the fourth is Z signal.

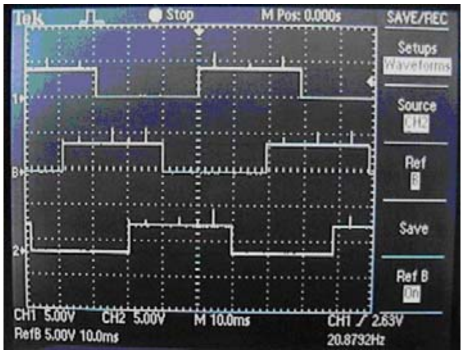


Fig. 7: Phases sequences with frequency of 100 Hz.

Figure 7 illustrates the pluses required for Q_1 (Y_1), Q_3 (Y_3) and Q_5 (Y_5). It has a frequency of 100 HZ and a duty cycle of 50 %.

In order to avoid cross conduction problems, a delay ”dead time”, must be added between a, b ,c and a’, b’, c’. Fig. 10 shows the circuit used to create the “dead time”.

The RC value and the negative Schmitt trigger threshold voltage, V_N, determine the delay t_{dt} as follows:

$$t_{dt} = -RC\ln\left(V_N \big/ 5 \right) \qquad (4)$$

Fig. 9 represents the input and output of the dead time circuit in Fig. 8 .The first signal is the input signal to the dead time circuit, Y_1 or Y_3 or Y_5, the second signal is the output signal for upper switch and the third is the output signal for lower switch. This figure shows the experimental waveforms showing the time delay between the pulses for the upper switch and the lower switch.

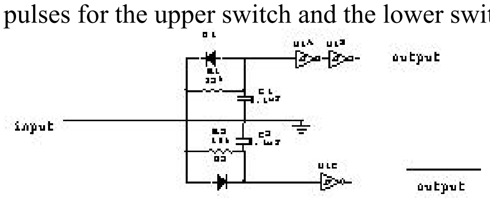


Fig. 8: Dead Time Circuit.

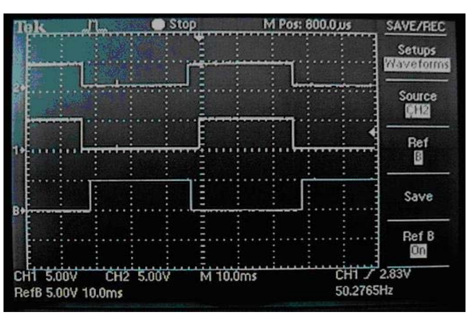


Fig. 9: Input and output of dead time circuit.

If this signal were applied to the inverter, it would make the inverter switch at a very low frequency (100 Hz).This would result in bulky magnetic components, higher harmonics, higher torque ripple and other effects, which are not preferable. Thus the switching frequency should be increased, while keeping the motor speed at the same value and we get an efficient power stage. This is achieved by combining the above pulses with a high frequency waveform, by means of an AND gate [11].

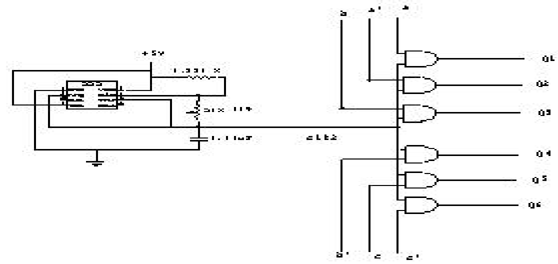


Fig. 10: circuit diagram of high frequency switching.

The switching frequency for this system was decided to be 20 KHz but, the applied frequency to phases is still 100 Hz. The switching frequency circuit diagram is shown in Fig. 10.

Fig. 11 shows the transistor gate patterns for upper and lower switch for one phase. The figure clearly indicates that each transistor is gated for 180°. This switching pattern ensures minimum inverter switching losses and prevents short circuiting of the system.

Fig.12 illustrates the transistor gate patterns for two phases in order to ensure that no overlap in any arm.

Fig. 13 shows the transistor gate patterns for Q_1, Q_3 and Q_5 and Fig. 14 shows the transistor gate patterns for Q_2, Q_4 and Q_6. Fig.15 and Fig.16 indicates that each transistor is gated for 180°.

This switching pattern ensures minimum inverter switching losses and short circuiting of the system.

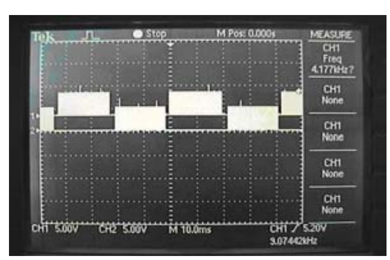


Fig. 11: Transistor gate patterns for upper and lower switches after delay and chopping.

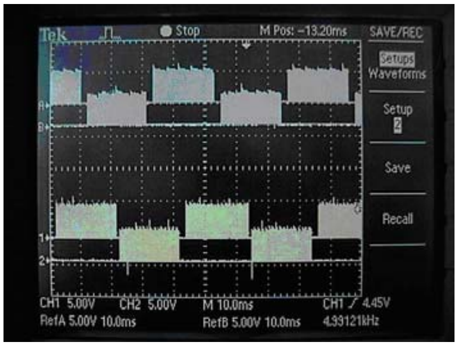


Fig. 12: Transistor gate patterns for two phases.

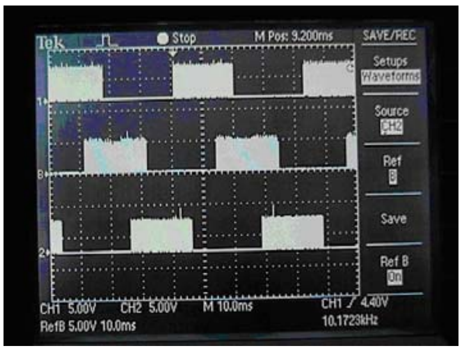


Fig. 13: Transistor gate patterns for Q_1, Q_3 and Q_5

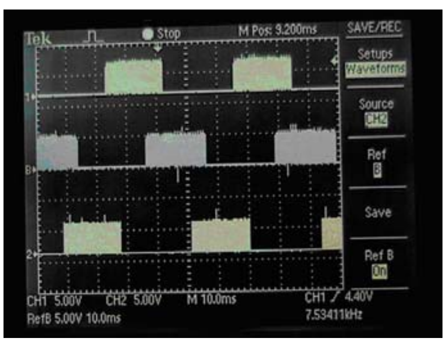


Fig. 14: Transistor gate patterns for Q_2, Q_4 and Q_6

After obtaining the signals a, b, c, a', b' and c', each signal are connected with small isolation transformer or opto-coupler in order to isolate the power circuit from logic gate circuit.

5. Conclusion

A simplified controller has been suggested, designed, implemented, and tested. Some interesting waveforms have recorded and found much closer to satisfy the controller action of the motor under consideration.

The circuits and methods of this paper produce six signals to drive the inverter which can be easily implemented in a digital gate array.

Experimental results show that the proposed controller realizes good switching characteristics.

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