Design and Experimental Analysis of a High Speed Two-Phase Induction Motor Drive for Weaver Machines Applications

Ghazanfar Shahgholian¹, Jawad Faiz², Navid Sedri¹, Pegah Shafaghí¹, Mehdi Mahdavian³

Abstract — In this paper the design and manufacture of a drive for Two-phase induction motor is represented by digital programming techniques for achieving the desired motivating switching pulses. The motor considered motor for practical experiments is a special motor that is named accumulator. This motor has a low power and controllable speed. The main application of this motor is in the production of textiles and it is designed for working in hot, humid and dusty environments and also its drive should be capable for continuous work in such environment. So effort has been done that the components in the actual and simulated models be exactly the same. In this way the obtained outputs will be compared and the better results will be achieved. Copyright © 2010 Praise Worthy Prize Sr.l. - All rights reserved.

Keywords: Two-Phase Induction Motor, Design, High Speed

Nomenclature

- u_q, u_d: q- and d-phase stator voltages
- i_q, i_d: q- and d-phase stator currents
- u_r, u_r: q- and d-phase rotor voltages
- i_r, i_r: q- and d-phase rotor currents
- \( \lambda_q, \lambda_d \): q- and d-axis stator flux
- \( \lambda_q, \lambda_d \): q- and d-axis rotor flux
- \( \omega_r \): mechanical speed
- \( J \): polar moment of inertia of rotor
- \( T_L \): load torque
- \( T_e \): electromagnetic torque
- \( R_s \): stator resistance
- \( R_R \): rotor resistance
- \( L_S \): stator inductance
- \( L_R \): rotor inductance
- \( L_MS \): magnetizing inductance
- \( s \): slip

I. Introduction

Induction motors drive systems with fast response of speed and torque have been used more in the industrial variable speed drive systems and an important role in many other applications. It is mechanically robust and can be used at speed higher than DC motors available for industrial applications. IM drives have been and are the workhorses in the industry for variable speed applications in wide power range that covers fractional horsepower to multi megawatts [1]-[3].

For the fractional horsepower application the single-phase and two-phase induction motors are the most popular. The two-phase induction motor (TPIM) is one of the most widely used types of ac machines. The main disadvantage of a TPIM is its inability to produce a smoothly rotating internal flux as is typical of three phase induction machines [4]. The first induction motors are appeared when the weaving industries are made and weaver machines are invented. The continuous and steady operation of a weaver machine requires it to have a high efficiency. Its peripherals should also have a high efficiency. Before the creation of induction motors, dc motors were inefficient to work in hot, humid and dusty environment, dc motors have commutator and the friction due to the commutation components in a contaminated environment fairly high temperature causes it to worn out. When induction motors are appeared the quality of production raised to that nowadays various type of them are used in different parts of industry. One of the main parts of a weaver machine is to supply the wefts. For this purpose, a two-phase induction motor in company with a speed control drive is used. The reason of using this type of induction motor respect to other types is its higher efficiency and less service requirements for work in such environments. Thus their control drive is also essential. This combination continuously is sending the weft to the weaver machine so that by motor operation and pulling the thread the provided spindles are gently opened and stored in the storage section (in front of the machine). In this way the machine can open the stored thread and pull it inside. The accurate operation of supplying the wefts requires a 24 hours work of the machine and any flaws in this part causes the machine to stop or meters of materials to be destroyed.

The motor should have a fast reaction against the reduction in stored threads. It should operate to reach the desired speed and after supplying the weft should immediately stop working. This process may repeat many times in a minute. For increasing of efficiency, the control system should work in a way that the motor has
the minimum number of steps. For this purpose, in the design of this system a software and intelligent method is used which is able to regulate the motor operation to reach to minimum step. Many papers have been published in the field of control, modeling and simulation [5]-[9]. A two-phase drive can be obtained by using different configurations of inverters and windings. A space vector pulse width modulation for constant power operation of a TPIM is proposed in [10]. In [11], square voltage waveforms with quadrature phase shift are supplied to the two-phase winding of a high speed ac drive by an inverter. In [12] an inverter circuit composed of eight power transistors and in [13] a conventional three-phase inverter are proposed for driving two-phase induction motors. Comparative performance evaluation of three different control techniques with the same fundamental voltage for two-phase winding capacitor induction motor drives are proposed in [14]. A double two-phase induction motor system by connecting the neutral lines of a pair of two-phase machines, only four switches need be used for each machine and the two machines share one set capacitors is proposed in [15].

In this paper the design and manufacture of a drive is represented for TPIM with digital programming technique for winding machines is represented. The new drive system has lower heat dissipation and less energy losses compared with the similar cases. For the designed system a low power motor with controllable speed turned accumulators is used. The simulation results are determined by Matlab software and they are compared with the motor made in the laboratory.

II. Mathematical Model

Mathematical model is important for the controller design in non linear system. State equations are commonly used in the simulation procedure. The two-phase induction motor is composed of two symmetrical windings. That is, the number of windings of phase A is the same as that of the windings of phase B [16]. Considering that in a symmetrical TPIM, the angle difference between the two phase windings is 90°, the maximum rotational torque will be obtained when the phase difference between input voltages also is 90° out of phase. Two phase equivalent model of an asymmetrical two phase induction motor in the stationary reference frame and with rotor quantities referred to the stator is given by [17]:

\[
\frac{d}{dt} \lambda_{sp} = -R_s i_{sp} + u_{sp} 
\]

\[
\frac{d}{dt} \lambda_{sb} = -R_s i_{sb} + u_{sb} 
\]

\[
\frac{d}{dt} \lambda_{sr} = -R_p i_{sr} - \sigma_s \lambda_{sb} + u_{sp} 
\]

\[
\frac{d}{dt} \lambda_{lr} = -R_p i_{lr} + \sigma_r \lambda_{sp} + u_{sr} 
\]

To design, simulate and make a drive for a particular motor, the first step is to determine the circuit parameters and characteristics of the motor. Using the dc experiments with a voltage of 12V for determining the stator resistance and the number of poles, locked rotor experiment and unload experiment, the motor parameters as in Fig. 1 is shown in Table 1.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
<th>Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>L_{st}</td>
<td>35</td>
<td>mH</td>
</tr>
<tr>
<td>R_s</td>
<td>0.33</td>
<td>Q</td>
</tr>
<tr>
<td>L_{st}</td>
<td>1.5</td>
<td>mH</td>
</tr>
<tr>
<td>R_p</td>
<td>0.12</td>
<td>Q</td>
</tr>
<tr>
<td>L_{sp}</td>
<td>0.07</td>
<td>mH</td>
</tr>
</tbody>
</table>

Fig. 1. Equivalent circuit

The rotor is a squirrel cage type in class B, the operating voltage of the circuit is 50V dc which is obtained from a three-phase power supply and a diode bridge. There are four poles which are normally determined by examining, the stator windings and the number of its turns. Because the termination and windings of the poles are indistinct, therefore the number of poles in the examined motor is determined by a new method. At first a dc current is supplied to one phase of motor and then by rotating a permanent magnet inside the stator and counting the number of attraction and repels, the number of stator poles is obtained.

Figures 2, 3 and 4 are show the simulation results of the speed and torque variations, and phase’s current in terms of time for designed parameters.

Figure 5 represents the speed variations in terms of time for braking state by lowering the frequency. As it is seen the braking is performed in 2.5 seconds and after about 3.3 seconds is quickly returned to its normal state.
III. Intermediate and Command Circuits

The intermediate circuit consists of a CMOS to TTL converter to adjust the microcontroller commands to the switches. For this purpose a MC40109, IC which is a CMOS family is used. This IC contains four AND gates with a CMOS input and a TTL output. Likewise two MC4049 IC are used as inverter (NOT) to command to switches of one arm. It is noted with inversions of the command by the hardware, if there is any error in microprocessor the switches are not damaged.

The main part of the command is made up of the microcontroller family ATMEG-AVR named ATMETGA8L shown in Figure 7. The advantages of this microcontroller are:

a) Its operation with no error in frequencies above 16 MHz.
b) Using the OIPCC technology (one instruction per cycle).
c) Capability of activating an anti noise operation system.
d) Having 6 internal A/D with 10 bit distinct power and a 250 KHz sampling frequency.
e) Having three internal timers (16 bit and 8 bit).
f) Ability to communicate with measuring equipments by means of a serial port.
g) Having an internal EEPROM 512 byte and an FLASH 8 kbyte.

Figure 6 shows the circuit diagram and the opto designed component.

The opto operation is in a way that the light emitter (LED) sends the infrared light towards the mirror (reflector) installed at the storage section and the optical collector receives the reflected light at the same time. As long as the light is emitted from the mirror (reflector), the motor keeps running. However when the received light is less than the adjustable range, it means that the storage volume is filled by strings and prevents the mirror to reflect light and the motor should be stopped.
One of the processor tasks is to make a PWM wave and establish a 90° phase difference between the two phases and eventually control the motor speed. A 16 bit timer makes the PWM wave in the processor. That is, the timer in PWM mode compares the triangular wave with a 15 KHz frequency with a square wave obtained in control feedback and makes the one phase PWM pulses. This wave is shifted 90° by another timer and other phase pulses are made in the same way. The above microcontroller has 6 internal A/D which four of them have the following direct applications:

a) Determine the starting torque value for operation by means of regulating a potentiometer.

b) Determine the braking reaction time by means of adjusting a potentiometer.

c) Determine the maximum motor speed by means of a 10 turn's volume mounted on the front frame.

d) Determine the eye sensitivity through a multy turn mounted on the front frame.

In actual design, the BJT transistors Mj1105 and Mj1106 are used as PNP and NPN ones which their internal shape are shown in Figure 8. A couple of them mounted on one arm and each phase is driven by two arms.

These transistors are designed for switching circuits and are Darlington type with 200 watt power output and can withstand a current up to 30 amperes. They also contain an internal commutating diode. For long term applications only the high quality transistors with a valid commercial mark are usable and similar transistors are destroyed in unsuitable environmental conditions. To get best possible biasing and less off time of the switches, a resistor with a lowest possible value should be considered on the base emitter junction. This interchanges the electrons and holes in minimum time in the junction and transistor turns off.

On the other hand reducing the value of the resistor causes the motivating voltage to decrease and for an appropriate bias, with lowering the resistance the intermediate circuit voltage must get higher.

The intermediate circuit components are formed by TTL complex circuits, so the maximum value of this voltage is 18 volts.

Finally with examination of drive output and consideration of working desired conditions of parts, the motivate voltage and resistance of junctions evacuation are selected 16.2 volts and 3.30 ohms respectively. To get 16.2 volts for voltage from main voltage (50 volts) one IC voltage regulator LM317 is used with on 40 mm² radiator mounted on it (according to Figure 9).

This regulator can be present 0-36 volts voltages in output by selection of regulator resistors. In this way it provides 1 amp current for load (intermediate current).

### IV. Power Circuit

Among the different switching algorithms and methods presented for a two phase drive, the eight switch method is used in this paper as in Figure 10. This method has a higher starting torque and fewer harmonic than other methods and has a higher efficiency. In addition in this method there is a balance in the heat losses and the flow of currents between the switching and all the switches and all the switches are under the same pressure against the shock due to the start and stop of the motor [1]. The main stage of design is the power transistor biasing. A wrong biasing may cause transistors to go to the saturation state and be off for longer time.
The switch time of one transistor may coincide with another transistor off time on the same arm. In fact at this time both switches are on and a large amount of current flows through them. This causes transistors to be overheated and breakdown. Likewise, due to the low motivated current in transistors, switching is not completely performed which reduces the drive efficiency and increases the losses. As a result transistors are gradually gets hot and destroyed by heat. Since the transistor biasing, in the quiescent point is considered with a constant voltage, it is essential to provide a regulated voltage for appropriate operation of the power switches. Fluctuation in voltage may cause them to operate differently and results in their destruction. Therefore to prevent such a problem a voltage regulator circuit for the input supply is also designed (Figure 11).

When motor speed is very high, if it is stopped, the energy that is obtained from motor movement inertia injected to input supply through commutating diodes. This causes increasing of voltage until twice as much. If there isn’t any voltage stabilizer circuit then the switches will be destroyed. Figure 13 shows the effect of regulator on voltage stabilizer.

V. Speed Control

The speed control for two phase induction motors is carried out by adjusting the control winding voltage by the quadrature control signal of an ac amplifier while exciting the reference winding voltage with constant frequency and amplitude [18]. The speed control is done directly by the square wave frequency control. In the programming the speed control is dependent to two control parameters (M) that are obtained from volume of speed control and stop bit is resulted from opto sensor.

In attention to the flowchart in Figure 14 the value of motor speed (V) is calculated corresponding to number of motor stops in specified time (timer). According to the flowchart receiving of reference speed will be determined with minimum motor stop (one stop in on time unit).
VI. Braking

Figure 15 show the designed motor and drive and introduce of different parts. From among the different presented methods of braking presented, in this paper a new method which is a combination of the frequency lowering and DC voltage injection methods is used for an induction motor. The best results will be obtained. If the braking command is stopped it will be used frequency reduction method and if the braking command is continues the DC voltage will be injected into the stator. This process is in a way that while the braking is continuous, inverter is converted into a full bridge chopper and the modulation factor reduces to 0.1%. At this time the flow current in motor is equal to 0.65A and no damages occurs in windings and motor is immediately stopped. Figures 16 and 17 shows the simulation and practical results in both cases of braking and normal operation.
VII. Conclusion

The presented drive in this paper is completely digital type and even its inputs will be eventually considered and examined as digital. The internal contents of the system are not generally comparable with earlier analog drives installed on these motors. The simulation and practical results show that the TPIM drive used in weaver machines have the following advantages:

a) The digital drive has a speed control feedback and as a result by obtaining the ideal speed, the motor efficiency and therefore its life time is increased.

b) The Electromagnetic torque and current outputs that are presented show a decrease in the signal to noise ratio and unwanted harmonics. This causes the motor to operate softer with less noise due to the decrease of switching frequency.

c) The components that are used in the design of the new control system require an extremely low supply (in mA) which increases the efficiency at the drive consumption energy of drive and its life time. These components are also inexpensive and can be provided easily.

d) Since in this new design most of the work is done and regulated intelligently by the microprocessor (which are previously done by the user), with this system is considerably easier than the analog drives. User can use the drive having the least information about the system operation such as: speed regulation by means of the presented flowchart, V/f ratio by means of the stored table in ROM and eye sensitivity by means of the string type phase control.

e) In the designed sensor for eye an infrared light (invisible light) is used which prevents the effect of visible lights on the eyes.

References


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