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THEORY & MANAGE OF DESIGNED DEVELOPED PROTOTYPE SIX PHASE INDUCTION MOTOR

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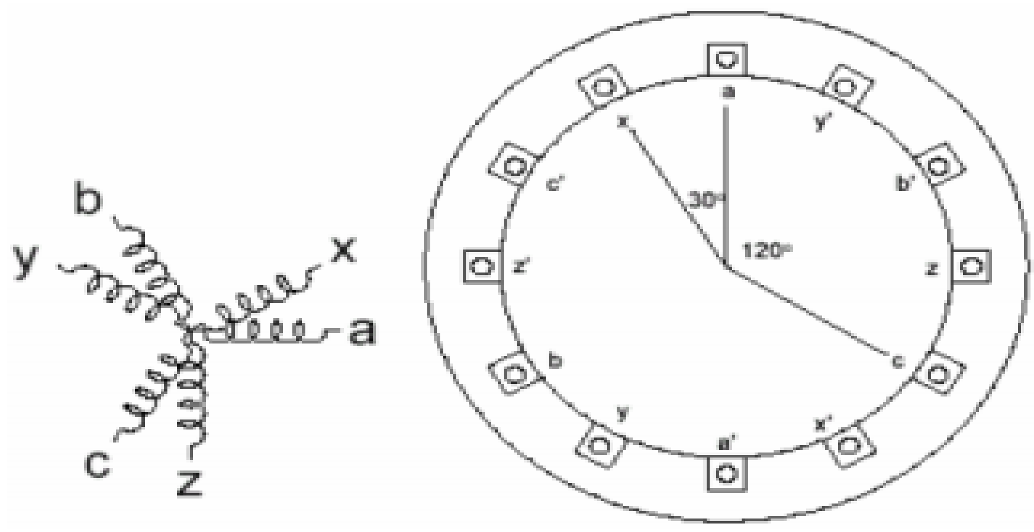
ABSTRACT: *Electric propulsion for ships emerged during the early 7th century. However, propulsion systems driven by diesel engines and gas turbines have been the most widely used. Electric ship propulsion has gained a renewed interest during recent decades because it provides several advantages. Some of these benefits include reduced fuel consumption and maintenance, improved maneuverability, less propulsion noise and vibration, reduced vulnerability to a single system failure and flexibility in location of thruster devices. The increased interest in electric ship propulsion can be mainly attributed to advances in power electronics, digital control systems and electric machine design. These advances have enabled the recently increasing applications of electric motor drives in the marine industry.*

KEYWORDS: *Digital control systems and electric machine design*

INTRODUCTION

Three-phase induction machines are today a standard for industrial electrical drives. Cost, reliability, robustness and maintenance free operation are among the reasons these machines are replacing dc drive systems. The development of power electronics and signal processing systems has eliminated one of the greatest disadvantages of such ac systems, which is the issue of control. With modern techniques of field oriented vector control, the task of variable speed control of induction machines is no longer a disadvantage, the need to increase system performance, particularly when facing limits on the power ratings of power supplies and semiconductors, motivates the use of increased phase number, and encourages new PWM techniques, new machine design criteria and the use of harmonic current and flux components. In a multiphase induction motor, more than three phase windings are housed in same stator and the current per phase in the motor is thereby reduced. In the most common of such structures two sets of three phase windings are spatially phase shifted by 300 electrical (Fig 1). In such motors each set of three phase stator winding is excited by a three Phase inverter, therefore total power rating of the system is theoretically doubled. It is also believed that drive system with multiphase induction motors will improve the system reliability. Ward and Harner for the first time in 1969 have presented the preliminary investigation of an inverter fed five phase induction motor and suggested that the amplitude of torque pulsation can be reduced by increasing the number of stator phases. Very few examples of design of multiphase induction motors can be found in the literature.



(a) Electric diagram. (b) Basic construction.

Fig. 1: Basics of Six Phase Induction Motor

The reason given for using five phases was to reduce the current such that it would match the ratings of available thrusters, for inverter source. However, the third harmonic current was found to be excessive when it was supplied by inverter. Motors with many phases have been proposed for high degree of reliability. These few attempts to develop multiphase induction motors show that they have some advantages over conventional three phase induction motors. Recent surveys of the state-of-the art in this area indicate an ever increasing interest in multiphase machines within the scientific community world-wide. After extensive literature surveys it is observed that very little research efforts are applied in the direction of practical design, development and control of multiphase induction motors. So the goal of this research is to design and develop a six phase prototype induction motor, this novel design should be free from third harmonic current injection for torque improvement. Aim of this research is also to control the speed of developed prototype six phase induction motor with arbitrary phase displacement using vector control technique.

REVIEW OF LITERATURE

The study of electrical machines with more than three phases dates back to the 610s. The theory for three, four and six – phase armature windings for a symmetrical poly-phase system was presented in [1]. Double winding generators were proposed later in order to reduce the fault current stress on circuit breakers [2]. The extension of Park's 2-reaction theory to multiphase synchronous machines was discussed in [3]. However, there was limited opportunity for application of multiphase machines. One of the reasons for this is the machines had to be supplied from three phase sources as power processing units were yet to come.

Research on multiphase machines started to get more attention in early 670s with the advent of power diodes and thyristors. Nelson and Krause [4] presented analysis of multiphase induction machines with arbitrary displacements between winding sets. They also indicated that, in a machine with two three phase groups, an arrangement with 17 electrical degree displacements between the two phase groups gives significantly improved torque characteristic. Lipo [5] presented a d-q model for a six-phase machine supplied from a current source inverter (CSI). A comprehensive work including space harmonics, time harmonics and symmetrical component analysis of multiphase induction motors was done by Klingshirn [4]. Experimental work on six- and nine-phase machines was also presented by the same author [6]. A six-phase induction motor voltage driven by a voltage source inverter (VSI) was presented in [7].

J.M.Kwon et al. [12], work on Three-phase photovoltaic system with three-level boosting MPPT control. This method proposes a three-phase photovoltaic (PV) system with three-level boosting maximum power point tracking (MPPT) control. A simple MPPT control using a power hysteresis tracks the maximum power point (MPP), giving direct duty control for the three-level boost converter. The three-level boost converter reduces the reverse recovery losses of the diodes. Also, a weighted-error proportional and integral (PI) controller is suggested to control the DC link voltage faster. All algorithms and controllers were implemented on a single-chip microprocessor. Experimental results obtained on a 10- kW prototype show high performance, such as MPPT efficiency (MPPT effectiveness) of 99.6%, a near-unity power factor, and a power conversion efficiency of 96.2%

Lipo and Zhao [8] introduced the modeling of six-phase induction machine using vector space decomposition. This was an important work that simplified the modeling and control of six-phase machines. It simplified the vector control of these machines using space vector and other PWM techniques. Research on multiphase machines has proliferated over the last decade. In many of the publications, the most widely discussed multiphase machine is a six phase induction machine with 17 electrical degree separation between phase groups and with isolated neutral points [5], [6], [7]-[13].

The six-phase induction machine can be modelled using the technique of vector space decomposition as demonstrated in [8], [11]-[13]. This method results in a model of the machine in single six-phase reference frame with three pairs of axes decoupled from one another. A less common modeling technique is the dual stator approach mentioned in [10], [11] and [13]. It considers the six-phase machine as two coupled three-phase machines, and uses three phase transformations.

Vector control is the commonly used control technique for multiphase induction machines although direct torque control can also be used [9]-[11]. Two different current control techniques can be used in vector (field oriented) control: double synchronous frame control (DSFC) and single synchronous frame control (SSFC) [11]. Current control in stationary reference frame is also mentioned in [12]. There are various pulse width modulation (PWM) techniques for VSI driven multiphase induction machine. Sinusoidal PWM, sinusoidal PWM with third harmonic injection, and different variations of space vector PWM are the most common as discussed in [6], [9] and [14].

In many of the publications referred, only normal operation of six-phase induction machine is considered [5][8] [11][12]. The two stator phase groups of the machine share the power equally. Moreover, the machine is supplied using a six-phase VSI. The analysis in [13] considered unbalanced current sharing between the two phase groups. Fault tolerance operation of multiphase drives to open circuit in one or some of the phases is discussed in [15] and [16]. The work in [17] analyzed the fault tolerant operation to one or more failed inverters in a six-phase induction machine supplied by four 2-level three-phase inverters.

MULTIPHASE INDUCTION MOTORS

In traditional electric machine applications a three-phase stator winding is selected, since the three-phase supply is readily available. However, when an AC machine is supplied from an inverter, the need for a predefined number of phases on stator, such as three, disappears and other phase numbers can be chosen. The early interest in multiphase machines was caused by the possibility of reducing the torque ripple in inverter fed drives, when compared to the three-phase case. Another advantage of a multiphase motor drive over a three-phase motor drive is an improved reliability due to fault tolerance features, this being one of the main reasons behind the application of six-phase (double-star) and nine-phase (triple-star) induction motor drives in locomotives.

SPEED CONTROL

The motor is also tested with single three phase Voltage source inverter. This is done to check the suitability of the developed six phase motor for variable frequency operation. The three phase and six phase current waveforms are obtained and compared. The six phase current is double than that of three phase current. (Figure 2 and 3)

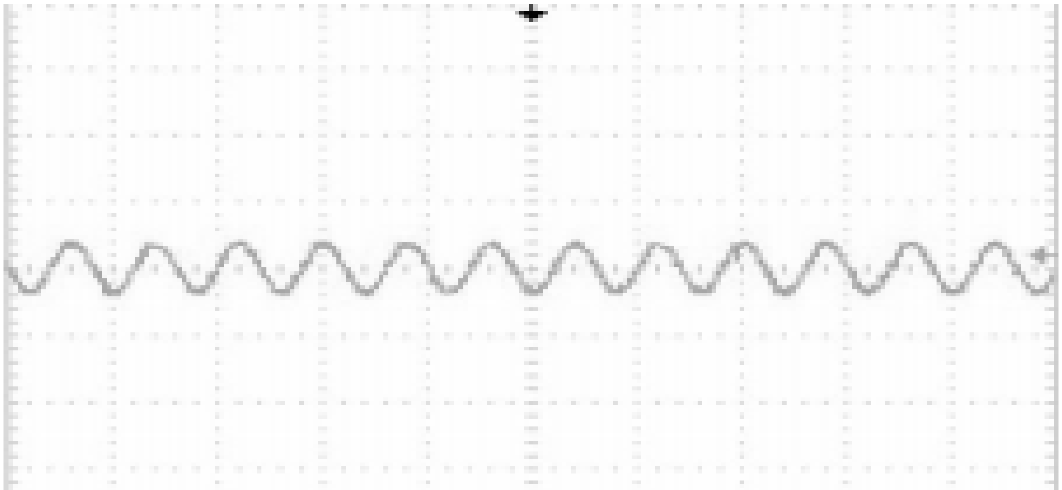


Fig. 2: Three phase current when only one three phase set energized through inverter

The three phase drive consists of three-phase AC-choke at the mains end together with the DC-link capacitor form an LC-filter, which, again, together with the diode bridge produce the DC-voltage supply to the IGBT Inverter Bridge block. The AC-choke also functions as a filter against High Frequency disturbances from the mains as well as against those caused by the frequency converter to the mains. It, in addition, enhances the waveform of the input current to the frequency converter. The entire power drawn by the frequency converter from the mains is active power. The IGBT Inverter Bridge produces a symmetrical, 3-phase PWM-modulated AC-voltage to the motor. The Motor and Application Control Block is based on microprocessor software. The microprocessor controls the motor on the basis of information it receives through measurements, parameter settings, control I/O and control keypad. The motor and application control block controls the motor control ASIC which, in turn, calculates the IGBT positions. Gate drivers amplify these signals for driving the IGBT inverter bridge. The control keypad constitutes a link between the user and the frequency converter. The control keypad is used for parameter setting, reading status data and giving control commands. It is detachable and can be operated externally and connected via a cable to the frequency converter. Instead of the control keypad, also a PC can be used to control the frequency converter if connected through a similar cable. Frequency converter can be equipped with a control I/O board which is either isolated (OPT-A8) or not isolated (OPT-A1) from the ground. Since Encoder and related circuitry required for high Power applications sensor control is costlier, sensor-less control is developed and implemented for controlling prototype induction motor.

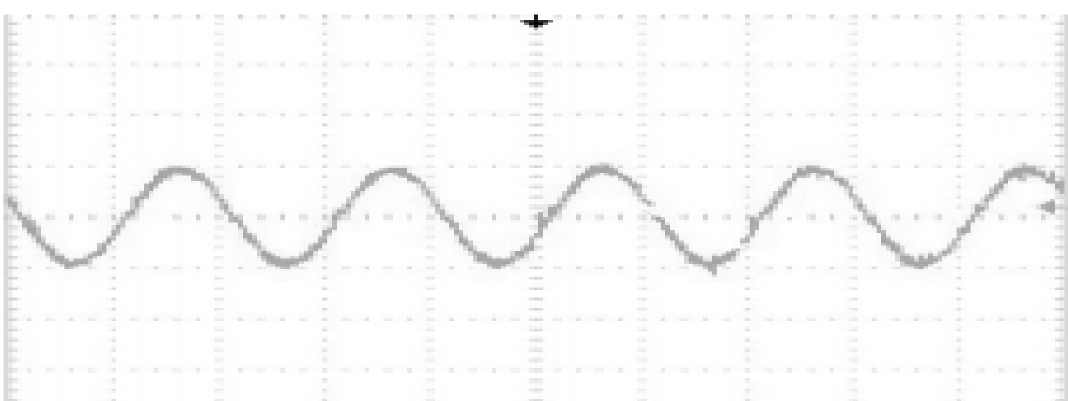


Fig. 3: Six phase current when six phases energized through inverter

For sensor-less control, the motor control algorithm and Space vector Pulse width Modulation (SVPWM) for inverter are implemented. The mathematical model of the motor and control algorithm is fed into the Field Programmable Gate an rray (FPGA), through Software. Matlab program is also loaded into FPGA.

STATUS OF VARIABLE SPEED DRIVE

The electrical machine that converts electrical energy into mechanical energy and vice versa, is the workhorse in a drive system the basic function of a variable speed drive is to control the flow of energy from the mains supply to the mechanical system process. Energy is supplied to the mechanical system through the motor shaft. Two physical quantities are associated with the shaft namely torque and speed, in practice either one of them is controlled and referred to as torque control or speed control.

Apart from flexibility of operation at various frequencies, variable frequency drives have an added advantage of energy conservation. Fig. 4 show how the power consumption reduces in variable frequency drives as compared to constant speed drives.

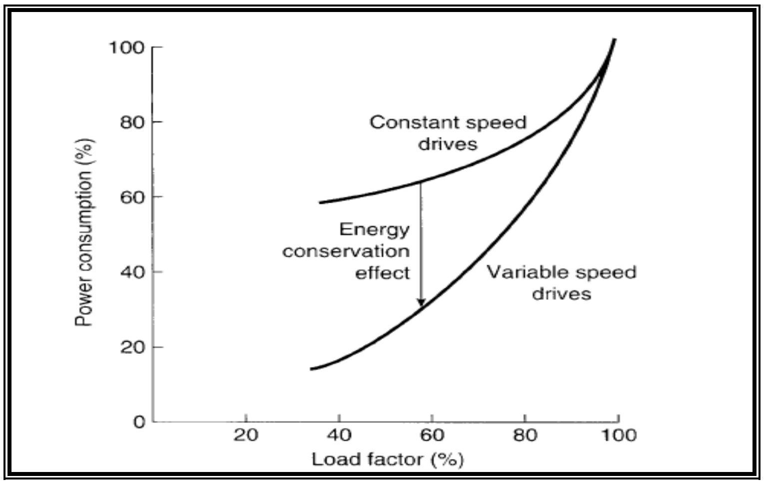


Fig.4: Energy Saving Characteristics of Variable Frequency Drives

In the past ac motor drives were mainly used in fixed speed applications. Variable speed applications were dominated by dc drives. Direct current (dc) motor drives were used for speed control because the flux and torque of dc motors can be controlled independently and the electromagnetic torque is linearly proportional to the armature current. Thus desirable speed and position control can be achieved.

But dc motors have disadvantages due to existence of commutator and brushes. Firstly Brushes require periodical maintenance secondly owing to the sparks created by the commentators; dc motors cannot be used in potentially explosive environment. Finally mechanical contacts of commutator and brushes limit high speed operation.

These problems can be overcome by ac motors which have simple and rugged structures. Their small dimensions as compared to dc motors allow ac motors to be designed with substantially higher output rating, low weight and low rotating mass.

Although squirrel cage induction motor was cheaper than dc motor, the converter and control circuit of an induction motor drive was very expensive compared to those for a dc drive Therefore the total cost of an induction motor drive was significantly higher than that of a dc drive.

The fast progress in the development of ac motor drives in the past two decades was mainly due to development of power electronic devices, powerful and inexpensive microprocessors and modern ac motor control technologies. This resulted in reduction in cost of ac drive.

The ac variable speed drive has experienced two major control strategies namely scalar control and vector control.

Scalar control is used in low cost, low performance variable speed drives. This method does not guarantee good dynamic performance because transient states of motor are not considered in the control algorithm. Though some efforts were made to improve the scalar-control performance, the result is still unsatisfactory. So the vector control was introduced by Hasse and Blashke in order to achieve performance comparable to dc drives. Main advantage of vector control is that good dynamic performance of the drive is obtained.

CONCLUSION

An attempt has been made in this paper to review state-of-the-art and highlight recent developments in the area of multiphase induction motor drives. As with any other rapidly moving area, no survey can ever be complete and the authors apologise to all the researchers whose important work may have been overlooked. The authors believe that the paper will be useful for all those already engaged in the research on multiphase motor drives in general and multiphase induction motor drives in particular, as well as for complete novices in this field who are currently embarking on research in this exciting sub-area of variable-speed electric motor drive control.

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