

## MODELING AND SIMULATION OF TORQUE CONTROL OF SIX PHASE INDUCTION MOTOR WITH MULTI LEVEL CONVERTER

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**Abstract**— *This paper presents a configuration with multilevel inverter with six-phase induction motor, this configuration proposes torque control of two pole induction motor in rotating reference frame. The model is simulated in Simulink environment to evaluate its performance under load and no-load conditions. The results show reliable and good performance of the motor. Total circuit is simulated in MATLAB simulink.*

**Keywords**— *Torque controlled configuration, multi level inverter, D-q model, six-phase induction motor.*

### INTRODUCTION

Amongst many types of electrical motors, induction motors still enjoy the same popularity as they did a century ago. Several factors which include robustness, low cost and low maintenance have made them popular for industrial applications when compared to dc and other ac motors. Another aspect in induction motor drives which has been researched recently is the use of multiphase induction motors where the number of stator phases is more than three. Here, a multi-phase system is a system with more than three stator phases. Among the different multi-phase induction motor drives being researched, following important advantage for the dual-3-phase induction motor having two stator winding sets spatially shifted by 30 electrical degrees with separated neutral is: The dual-3- phase solution can generate higher torque as compared to conventional three phase motor. This characteristic makes

them convenient in high power and/or high current applications, such as ship propulsion, aerospace applications, and electric / hybrid vehicles (EV). [5] Output Torque of multiphase induction motors is much higher than that of conventional three phase Induction Motor. Emil Levi [1] provides a review of the recent developments in the area of multiphase induction motor control. In this paper Vector control and direct torque control (DTC) are addressed and utilization of the additional degrees of freedom that exist in multiphase machines for differing purposes is described (higher stator current harmonic injection for torque enhancement and control of a group of series-connected multiphase motors supplied from a single multiphase VSI).

Asynchronous, induction motor is one of the very important and widely used ac motors. Single phase and three phase both induction motors are popular and widely used because of its simplicity, robustness, good performance. But multiphase (more than three) induction motors are becoming popular and have been being studied from many years because of its several advantages over conventional three-phase induction motors or induction motors having lesser phases. The advantages are better fault tolerance[1][2][3][4], higher efficiency, lower current ripple, less torque pulsation, reliability[5] and facility to split

certain amount of power in to multiple phases to reduce the power per-phase. This power splitting enables to use devices of less rating in case of high power applications[6]. Multi-phase motors are used in case of ship propulsion, traction, electric vehicles etc. where high power and reliability is required. Simulation of symmetrical induction machinery was done in [7]. Multiphase machines' use in electric vehicles was studied in [8]. R. Gregor, F. Barrero, S. Toral and M.J. Durán studied induction motor drive test-rig to obtain superior performance [9]. Anushree Kadaba, Shaohua Suo, Gennadiy. Sizov, Chia-Chou Yeh, Ahmed Sayed-Ahmed, Nabeel A.O.

Demerdash designed reversible three-phase to six-phase induction motor[10]. A spectral method of speed ripple analysis for a fault-tolerant six-phase squirrel-cage induction machine was presented in [11]. Matrix converter has been used to drive six-phase induction motor in [12]. Transient analysis of three-phase induction machine using different reference frames has been done in [13]. Rangarajan M. Tallam, Thomas G. Habetler and Ronald G. Harley studied transient model of induction motor with winding faults[14]. [15] presents experimental investigation of a naval propulsion drive model with the PWM-based attenuation of the acoustic and electromagnetic noise. G.Renukadevi, K.Rajambal developed a generalized model of multiphase induction motor with symmetrical winding displacement[16]. Use of multiphase machines is proposed in [17]. Control of five phase induction motor using space vector modulation, is discussed in [18]. [19] This paper deals with the high performance Backstepping control strategy which is based on laws

allowing an explicit control of system stability in closedloop operation of five-phase induction motor drives. Using flux-linkage model, stability analysis of five phase induction motor has been done in [20]. Y. Maouche, A. Boussaid, M. Boucherma, A. Khezzar studied pulsating torque and harmonic components in rotor current of six-phase induction motor under healthy and faulty conditions. In this paper a dynamic model of asymmetrical six-phase, cage type induction motor is developed to study the performance of the motor in detail. The model is simulated in MATLAB/Simulink environment. The study gives a detailed idea about the motor and indicates towards the smooth and promising performance of the motor.

## **BRIEF CONSTRUCTIONAL DETAILS OF INDUCTION MOTOR**

A poly phase induction motor consists essentially of two major parts, the stator and the rotor. The construction of each one is basically a laminated core provided with slots which house windings. When one of the windings is excited with AC voltage, a rotating field is set up. This field produces an emf (Electromotive Force) in the other winding by transformer action which in turn circulates current in the later if it is short circuited. The currents flowing in the second winding interact with the field produced by the first winding thereby producing a torque which is responsible for the rotation of the rotor. Basically a three phase Induction motor consists of stator and rotor. The Induction motor is invented by Great scientist Nikol Tesla. A set of insulated electrical windings are placed inside the slots of the laminated magnetic path in stator. The cross-

sectional area of these windings must be large enough for the power rating of the motor. For a 3-phase motor, 3 sets of windings are required, one for each phase. As with the stator, the rotor consists of a set of slotted steel laminations pressed together in the form of a cylindrical magnetic path and the electrical circuit. There are two types of motor rotors: The wound rotor and Squirrel cage rotor. Because of the ease of winding, Squirrel cage induction motor is designed.

### ACTUAL DESIGN OF PROTOTYPE SIX PHASE INDUCTION MOTOR

To begin with, an m-phase symmetrical induction machine, such that the spatial displacement between any two consecutive stator phases equals  $\alpha = 2\pi/m$ , is considered. Stator winding is treated as m-phase and it is assumed that the windings are sinusoidally distributed, so that all higher spatial harmonics of the magnetomotive force can be neglected. The phase number m can be either odd or even. When the number of phases is six, i.e.  $m = 6$ , there are two, three phase windings. The two, three phase windings are displaced by 60° in symmetrical design but there is a problem of magnetic circulating currents. So asymmetrical design is implemented in which two, three phase windings are displaced by 30°, which eliminates  $(6n + 1)$  order harmonics, where  $n = 1, 3, 5, \dots$  [1]. A six phase machine can be easily constructed by splitting the 600 phase belt into two portions each spanning 300°. The winding distribution factor increases from 0.965 for three phase to 1.0 for six phase for split phase belt connection.[8] A true six phase that retains the same winding pitch and distribution factor is shown in the table 1 below. Table 1

**Multiphase Winding configuration** The six-phase machine uses the same magnetic frame with the baseline machine. So initially the stator dimensions, stator size, rotor size etc. were kept same as 3 phase, 3 HP induction motor. And the same stator is rewound for making six phase it is clear that the torque of six phase induction motor is more and found to be approximately 1.6 times more than equivalent three phase motor. Also Efficiency of six phase induction motor is 1.4 times more than that of equivalent three phase induction motor. The torque of six phase induction motor is much higher than equivalent three phase induction motor. Prototype six phase induction motor torque is 1.6 times that of equivalent three phase motor. In [1]-[6] torque improvement is obtained by third harmonic current injection. Third harmonic current injection needs large inductors. The application of multiphase induction motor is mainly in high power-high current applications so the use of inductor for current injection is uneconomical. Though the initial cost of six phase induction motor is increased as compared to three phase induction motor but at the same time efficiency and torque are significantly improved. Also torque improvement with third harmonic current injection is 1.4 times that of equivalent three phase induction motor [1]-[6] while the developed prototype six phase induction motor torque is 1.6 times that of equivalent three phase induction motor. As the motor rating increases it is tedious to arrange third harmonic current. 1. Same design can be extended in multiples of three, e.g. for 9 phase there will be three sets of three phase windings with 200 phase shift. 2. The design is applicable for

even phase number only. 3. Looking to the area of application i.e. high power high current application though the initial cost is higher than that of equivalent three phase but efficiency and torque are much higher. 4. From the no load and load tests conducted separately on ABC and XYZ, it is obvious that the prototype motor is highly reliable: If one of the three phase sets is not supplied the motor will continue to run as three phase and continuity of operation is maintained as the neutrals are separate. 5. Instead of copper conductors, aluminum conductors may be used to reduce the cost, thus making it more economical.

## MULTILEVEL INVERTER

Multilevel power conversion was first introduced 20 years ago [1]. The general concept involves utilizing a higher number of active semiconductor switches to perform the power conversion in small voltage steps. There are several advantages to this approach when compared with traditional (two-level) power conversion. The smaller voltage steps lead to the production of higher power quality waveforms and also reduce the  $dv/dt$  stresses on the load and reduce the electromagnetic compatibility (EMC) concerns. Another important feature of multilevel converters is that the semiconductors are wired in a series-type connection, which allows operation at higher voltages. However, the series connection is typically made with clamping diodes, which eliminates overvoltage concerns. Furthermore, since the switches are not truly series connected, their switching can be staggered, which reduces the switching frequency and thus the switching losses. One clear

disadvantage of multilevel power conversion is the larger number of semiconductor switches required. It should be pointed out that lower voltage rated switches can be used in the multilevel converter and therefore the active semiconductor cost is not appreciably increased when compared with the two level case. However, each active semiconductor added requires associated gate drive circuitry and adds further complexity to the converter mechanical layout. Another disadvantage of multilevel power converters is that the small voltage steps are typically produced by isolated voltage sources or a bank of series capacitors. Isolated voltage sources may not always be readily available and series capacitors require voltage balance. To some extent, the voltage balancing can be addressed by using redundant switching states, which exist due to the high number of semiconductor devices. However, for a complete solution to the voltage-balancing problem, another multilevel converter may be required [2–4] Before proceeding with the discussion of multilevel modulation, a general multilevel power converter structure will be introduced and notation will be defined for later use. Although the primary focus of this chapter is on power conversion from DC to an AC voltages (inverter operation), the material presented herein is also applicable to rectifier operation. The term *multilevel converter* is used to refer to a power electronic converter that may operate in an inverter or rectifier mode. shows the general structure of the multilevel converter system. In this case, a three-phase motor load is shown on the AC side of the converter. However, the converter may interface to an electric utility or drive

another type of load. The goal of the multilevel pulse-width modulation (PWM) block is to switch the converter transistors in such a way that the phase voltages  $v_{as}$ ,  $v_{bs}$ , and  $v_{cs}$  are equal to commanded voltages  $v_{as}^*$ ,  $v_{bs}^*$ , and  $v_{cs}^*$ . The commanded voltages are generated from an overall supervisory  $v_{as}^* * v_{bs}^* * v_{cs}^* * v_{cs}$ .

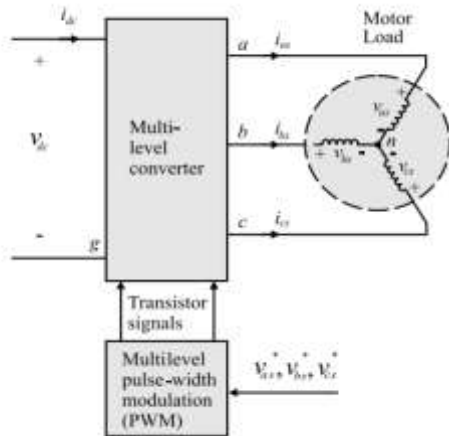


Fig 1 proposed configuration

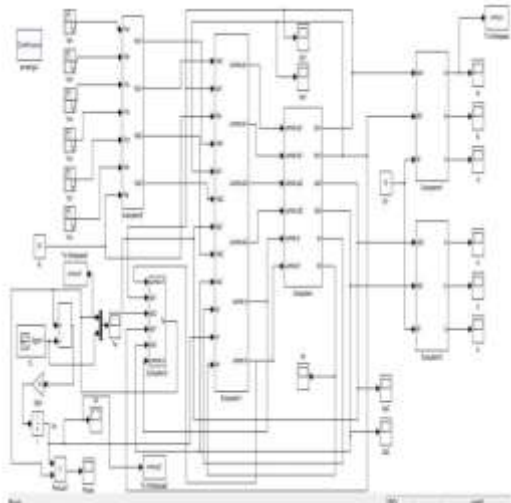


Fig 2 simulink model for proposed circuit

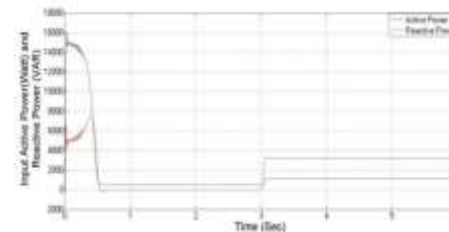
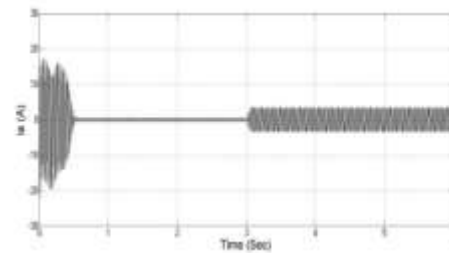
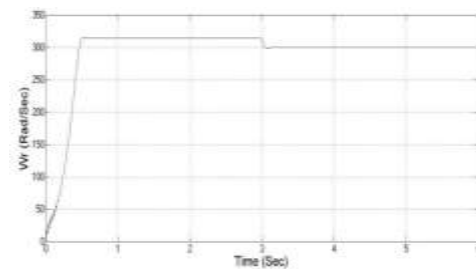
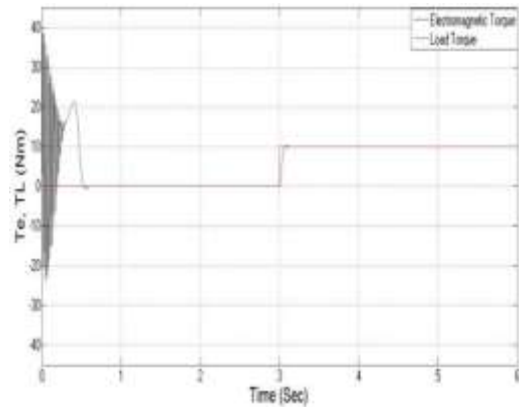


Fig 3 simulation results

### CONCLUSION

The result indicates towards high performance, good efficiency, less current per phase. Torque generation is smooth. Torque and speed ripples are negligible at steady state. As phase currents are not high and efficiency is good, it is suitable for high power applications. With respect to three phase motor devices of less rating can be used per phase for certain amount

of power The result indicates towards high performance, good efficiency, less current per phase. Torque generation is smooth. Torque and speed ripples are negligible at steady state. As phase currents are not high and efficiency is good, it is suitable for high power applications. With respect to three phase motor devices of less rating can be used per phase for certain amount of power.

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