A Literature Review on Speed Controlled Techniques of Induction Motor Drive

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Abstract—This paper propose a comparative study of different controlled techniques of induction motor drive, gives an overview of the induction motor (IM) drives. It also examines various controlmethodologies, using voltage and current control. Induction motors are extensively used in industrial and household appliances and consume more than 50% of the total generated electrical energy.In this paper presents exhaustive literature review of various techniques of a 3-phase Induction Motors such as pwm, phase controlled, and vector controlled methods. Authors strongly believe that this survey article will be very much useful to the researchers for finding out the relevant references in the field of speed of control an 3-phase Induction motors by vector control methods with the help of Simulation results of the proposed system are obtained using MATLAB/Simulink software and how it helps in various applications such as electric Traction, automotive industries and more other places.

***Index Terms—**Induction motor drive, Power electronics, Multi converterspulse width modulation (PWM), shoot-through state, Z-source inverter.*

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I. INTRODUCTION

In modern industrialized countries, more than half the total electricalEnergy used is converted to mechanical energy through AC induction motors. Induction motors are extensively used in industrial and household appliances and consume more than 50% of the total generated electrical energy. Single-phase induction motors are widely used in home appliances and industrial control. During the last few years, the concept of speed and torque control of asynchronous motor drives has gained significant popularity. This way, it has been possible to combine the induction-motor structural robustness with the control simplicity and efficiency of a direct current motor. This evolution resulted to the replacement of the dc machines by induction motors in many applications in the last few years.Earlier only dc motors were employed for drives requiring variable speedsdue to facilitate of their speed control methods [1]. The conventional methods of speed control of aninduction motor were either too extravagant or too inefficient thus limiting their application to only constantspeed drives. They are used to drive pumps, fans, compressors, mixers, agitators, mills, conveyors, crushers, machine tools, cranes, etc. This type of electric motor is so popular due to its simplicity, reliability, less maintenance and low cost. Today, with advancements in power electronics, microcontrollers, and digital signal processors(DSPs), electric drive systems have improved drastically. Initially the principle of speed control was based on steady state consideration of the induction motor. *V/f* control was the commonly used one for the open-loop speed control of drives with low dynamic requirements.

In this paper, literature review on speed controlled techniques of induction machine drive and the strategies for pulse width modulation technique are narrated. Approaches for sensorless operation of induction motor and field weakening control are reviewed. Analysis of research contributions in propulsion applications are also carried out. Finally, the research gap in propulsion application with induction motor require an intensive and time-consuming effort for the tuning of their electrical parameters in order to achieve satisfactory performance is presented in open literatures. Various technique methods are now available for the control of induction motor drives;a briefclassification of the available drive types is given in *figure (1)*,

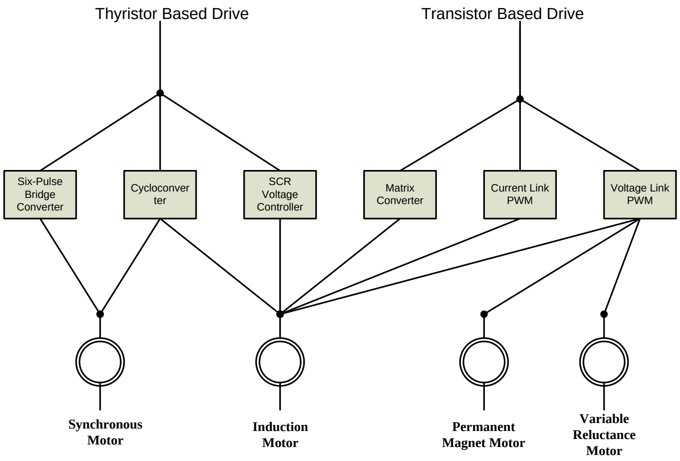


Fig.1 a brief classification of the available drive types

Such as the popular constant Volts per Hertz control [1] or the ever more popular field-oriented, or vector, control method [2]-[4]. Recently, ABB has introduced direct torque control (DTC), a speed-sensorless control approach [5]. There has also been some investigation into the application of neural networks to various aspects of induction motor control such as adaptive control [6], sensorless speed control [7]–[10], inverter current regulation [11]–[13], as well as for motor parameter identification purposes [14], [15] and flux estimation purposes [16], [17]. There has been less attention devoted to the implementation of neural-network-based field-oriented control in induction motor drives [18], [19].

This paper is organized as follows: Section II discusses the concept and definitions regarding with induction motor drives. Section III-IV-V presents the review of phase controlled, frequency controlled, and vector controlled techniques of 3-phase IM drive. Section VI presents the summary of the paper. Section VII presents the conclusions of the paper.

II. INDUCTION MOTER DRIVE

When a three phase supply is given to the three phase stator winding, a magnetic field of constant magnitude and rotating at synchronous speed Ns is produce [20]-[21]. This rotating Magnetic field sweeps across the rotor conductors and hence an electromagnetic force (EMF) Is induced in rotor conductors.as the rotor conductors are short circuited on themselves the Induced EMF sets up a current in the rotor conductors in such a direction as to produce a torque. Which rotates the rotor in same direction as magnetic field so that relative speed decreases? The speed of rotor gradually increases and tries to catch up with the speed of rotating magnetic Field, relative speed becomes zero and hence no EMF will be induced in the rotor conductor, the torque becomes zero. Hence, rotor will not be able to catch up with the speed of magnetic field but rotates at a speed Nr which is slightly less than the synchronous speed.

Equivalent circuit

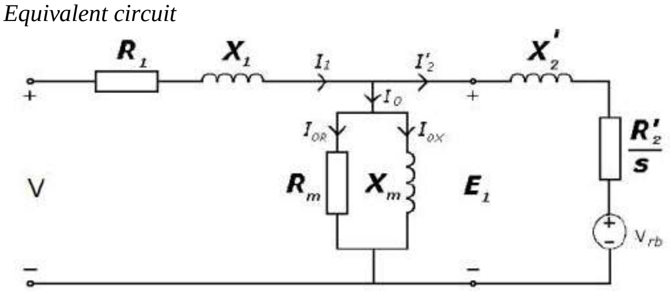


Fig. 2per phase equivalent circuit of induction motor

The equivalent circuit [23] is as shown in figure (2), from the equivalent circuit diagram the various powers can be written as follows:

Input power $=3V_sI_s cos\Phi$ (1)

Stator copper loss, $P_{s=3I_s^2R_s}$ (2)

Core loss=3 V_m^2/R_m (3)

Power across air gap=P_g=3$R_s/s.I_r^2$ (4)

Rotor copper loss Pr=3$I_r^2R_r$ (5)

Output power =Po-Pg=3 $I_r^2R_r$(1-S/s) (6)

Since the output power is the product of developed torque Te and speed ωm, Te can be expressed as
Te=Po/ω_m

Te=(3/ω_m)$I_r^2R_r$(1-S/S)=3(P/2)I_r^2($R_r/R_{\omega e}$) (7)

From the equivalent circuit, the approximate equivalent circuit can be obtained as Shown in fig 3.5, where the core loss resistor Rm has been dropped and the magnetizing inductance Lm has been shifted to the input. This approximation is easily justified for an integral hourspower machine, where (R_s+$j_{\omega e}L_{is}$) <<$\omega_e L_m$. The performance prediction by the simplified circuit typically varies within 5 percent from that of the actual machine

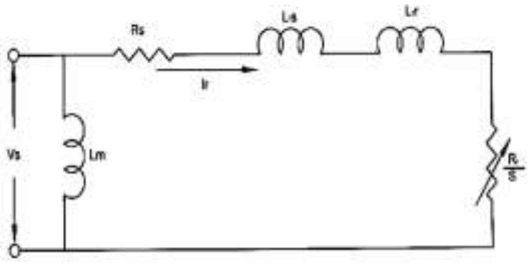


Fig 2 Approximate per phase equivalent circuit of IM

In figure 2, the current Ir is figured out by:

I_r=V_s/$\sqrt{(R_s+R_r/S)^2}+\omega^2(L_{is}+L_{ir})$^2 (8)

Substuting equation (3.9)in (3.8) yields

Te=3($\frac{P}{2}$)$Rr/S\omega e.\frac{V_s^2}{\left(R_s+\frac{R_r}{S}\right)^2}$+$\omega_e^2(Lis+Lir)^2$ (9)

A further simplification of the equivalent circuit of fig 3.4 can be made by the neglecting stator parameters Rs and L_{is} . this assumption is not unreasonable for an integral horsepower machine, particularly if the speed is typically above 10 percent. Then the equation (3.10) can be simplified as

$$T_e = 3\left(\frac{P}{Z}\right)\left(\frac{v_s}{\omega_e}\right)^2 \left(\frac{\omega_{si}R_r}{R_r^2+\omega_{si}^2L_{ir}^2}\right) \quad (10)$$

Where ,ω_{si}=Sω_e
The air gap flux can be given by,

Ψm=$\frac{V_s}{\omega_e}$ (11)

In a low-slip flux region,eqution(3.11) can be approximated as

$T_e = 3\left(\frac{P}{2}\right)\frac{1}{R_r}\varphi_m^2\omega_{si}$ (12)

Where, R_r^2>>$\omega_{si}^2L_{ir}$ equation (3.11) is important because it indicated that at constant flux ψmType equation here., the torque Te is proportional to slip frequency ωsi, or at constant slip frequency ω_{si}, torque T_e is proportional toφ_m^2.

Slip: the slip can be defined as the difference between the synchronous speed and actual speed of the machine. It can be expressed in the percentage. Based on this slip sped, the voltage induced in the rotor winding changes, which in turn changes the rotor current and also the torque. As slip increases, the rotor current and the torque also increases. The rotor moves in the same direction as that rotating magnetic field to reduce the induced current (Lenz's law). The slip can be expressed as given below [24]-[26]:

slip S=N_s- $\frac{\text{Nr}}{\text{Ns}}$ (13)

or slip S=$\frac{\omega_e-\omega_r}{\omega_e}$=$\frac{\omega_{si}}{\omega_e}$ (14)

or rotor speed N_r=N_s(1-S) (15)

Synchronous speed is given by N_s=$\frac{120\text{f}}{P}$ (16)

where p represents the number of poles and f is stator frequency in Hz, therefore equation 3.16 becomes,

Rotor speed N_r=$\frac{120\text{f}}{P}$ (1-S) (17)

Thus, the speed of an induction motor depends on slip 'S', stator frequency number of poles 'P' for which the windings are wound.

However, with the help of power electronicconverter it is possible to vary the speed of an induction motor. The fundamental elements needed in an Electric motor drive systeminclude:

- Power electronic Converter
- Electric Motor

- Controller(Analog/Digital)

A flow control of the dye in the paper mill with the Quasi-Z-Source Indirect Matrix Converter (QZSIMC) fed induction motor drive. More than a decade Voltage Source Inverter (VSI) and Current Source Inverter (CSI) have been used to control the speed of the induction motor which in turns controls the flow of dye. Recently Matrix Converter (MC) has been an excellent competitor for the VSI or CSI for its compactness [20], [21], has presented a new topology of load commutated SCR based current source inverter fed induction motor drive with open-end stator winding[22], has suggested a novel fault-tolerant control (FTC) scheme for direct torque control (DTC) of induction motor (IM) drives against the line current sensor failures. Said A. Deraz1, *et al.*[23],has been presenteda new current-limiting soft-starter for a three-phase induction motor drive system using pulse width modulation (PWM) AC chopper. A novel configuration of three-phase PWM AC chopper using only four insulated gate bipolar transistors (IGBTs) is also proposed. It requires only one current sensor. The duty ratio of the chopper IGBTs is obtained from the closed-loop current control in order to limit the motor starting current at a preset value. Only two complementary gate pulses are obtained from the control circuit to control the four IGBT switches. PratibhaNaganathanl, *et al.* [24],has discussedTwo cascaded two-level inverters can synthesise three-level voltage space vector Forthe cascaded three-level inverter controlled induction motor, this study proposes a five-level torque controller (FLTC)-based direct torque control (DTC) method especially for improving steady-state motor torque performance and retaining the high dynamic performance.

III. PHASE CONTROLLED INDUCTION MOTOR DRIVES

The most important method of power electronics ac power controlled is phase called phase control. Three-phase fully controlled bridge rectifier circuit shown in figure (3) is the, most widely used rectifier circuit, which consists of rectifier transformer, six Thyristor Bridge connected, load, trigger and synchronization aspects of the composition.

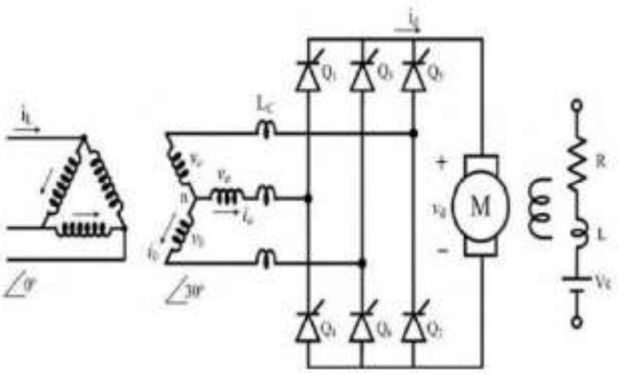


Fig. 3 Function diagram.

Review on phase controlled induction motor using different techniques. B. Prathap Reddy, *et al.* [25], has suggestedtwo cascaded two level inverters can synthesize three-level voltage space vector for. the cascaded three-level inverter controlled induction motor, this study proposes a five-level torque controller(FLTC)-based direct torque control (DTC) method especially for improve steady-state motor torque performance and retaining the high dynamic performance. I. Gonzalez-Prieto, *et al.* [26], has been presented the most serious and recent competitor to the standard field oriented control (FOC) for inductionmotors (IM) is the finite control set model predictivecontrol (FCS-MPC) [27], has discussed Direct torque control (DTC) has been widely used as an alternative to traditional field-oriented control (FOC) methods for three-phase drives[28],has been suggestedDirect torque control (DTC) has been recently used for the development of high performance five-phase induction motor (IM) drives, This work analyzes the fault-tolerant capability of six-phase drives with parallel converter supply. Different scenarios considering up to three faults for single and two neutral configurations are examined, optimizing off-line the post-fault currents and modifying accordingly the control strategies [30],[29].Has discussedA model predictive control scheme for multiphase induction machines, configured as multi three-phase. Complete details about the predictive control scheme and adopted flux observer are included[31],has been suggestedDirect torque control (DTC) has been recently used for the development of high performance five-phase induction motor (IM) drives, where normal operation of the system has been usually considered and the ability of DTC to manage the situation has been analyzed in comparison with different rotor field-oriented control (RFOC) strategies. Mario Bermudez, *et al.* [32], has discussed Three-phase machines are the industry standard for electrical drives, but the inherent fault tolerance of multiphase machines makes them an attractive alternative in applications requiring high reliability. This novel strategy is then combined with minimum losses and maximum torque criteria to obtain a variable current injection method that minimizes the drive derating, reduces the copper losses and improves the braking transients. Experimental results confirm the successful performance in the different zones for the case of a six-phase induction motor drive.Ignacio González-Prieto1, *et al.* [33], has suggested, a direct torque and flux control is described for a six-phase asymmetrical speed and voltage sensor less induction machine (IM) drive, based on non-linear back stepping control approach. First, the decoupled torque and flux controllers are developed based on Lyapunov theory, using the machine two axis equations in the stationary reference frame.

IV. FREQUENCY CONTROLLED INDUCTION MOTOR DRIVES

Variable-frequency AC drives (VFD) are now available from fractional kilowatts to very large sizes for use inelectric generating stations. In immensely colossal sizes, naturally commutated converters are more mundane, usually driving synchronous motors. However, in low to medium sizes (up to 750kW) transistor based PWM voltage source converters driving induction motors are almost exclusively utilized. Today's modernstrategy for controlling the AC output of such a modern power electronic converters using PWM technique. PWM varies the duty cycle of the converter at a high switching frequency (HSF) to achieve a target average low frequency (LSF) output voltage or current. PWM technique based drives are used to control both the frequency and the magnitude of the voltages applied to motors.Frequency controlled induction motor drives perform speed control on the basis of change in frequency and are classified as

4.1 Voltage source drive

Various control techniques are used to control speed of induction motor drive are as follows:

- Constant air gap flux control
- Constant slip speed control
- Pulse width modulation
- Constant volt/Hz control

4.1.1 Constant air gap flux control

SeyedMohd. J. R. Fatemi, *et al.* [34], has been presented distributed generation (DG) into low voltage (LV) systems demands that the generation system remain grid connected during voltage sags to ensure the operational stability. has been proposedA variable-frequency drive (VFD) having a 440-V front-end current source rectifier (CSR) interface to a voltage source inverter (VSI) feeding a

Permanent-Magnet Axial-flux Air Core motor combination is a solution for low-horsepower pump and fan control that is both power dense and compatible with a shipboard environment. Power density and efficiency comparisons are made between equivalent CSR/VSI- and voltagesource- conversion-based VFDs to demonstrate that the CSR/VSI-based VFD is more power dense, has presented the implementation of the controller is based on the machine air gap flux which is measured by detecting the third harmonic component of the stator phase voltages. This new controller does not require any sensors in the air gap of the machine nor does it require complex computations. Only access to the stator neutral connection is necessary to measure the air gap flux hasbeen suggested Comprehensive analysis of the starting period of inverter-fed large induction motors reveals that these motors are subjected to additional components of pulsating torsional torque. These torque pulsations may coincide with the natural torsional frequency of the large motor system and produce hazardous shaft torque oscillations. To alleviate the torsional toque problem and limit the motor starting current, a constant air-gap flux using slip frequency control scheme is proposed to operate the motor inverter[35],[36], [37]. Has proposed control strategy employs constant air-gap flux control technique to independently control the stator currents of both the main and auxiliary windings of the two-phase unsymmetrical motor [38], [39].Winding function method is adopted in this paper basing on air-gap magnetic flux density equations, and a new equivalent circuit is presented so as to analyze single linear induction motor (SLIM) applied in linear metro. Haspresented evaluates the consequences of iron loss representation omission in control systems of indirect vector controlled induction machines. Operation in the constant flux region is discussed and all the four machines are encompassed by the analysis. It is shown that errors in the orientation angle and discrepancies between actual and commanded flux and torque values are relatively significant for the 1.1 kW and 4 kW machines[40].

4.1.2 Constant slip speed control:

Yifan Tang,*et al.* [41], has discussedVariable-speed constant-frequency generating systems are used in wind power, hydro power, aerospace, and naval power generations to enhance efficiency and reduce friction. In these applications, an attractive candidate is the slip power recovery system comprising of doubly excited induction machine or doubly excited brushless reluctance machine and PWM converters with a dc link. S. Rahman, *et al.*[42], has discussed steady state and transient operation of thyristor and diode controllers for variable voltage control of three-wire 3-phase induction motors is considered. Takayoshi Matsuo, *et al.* [43], has been presented the usual method of induction motor torque control uses the indirect field orientation principle in which the rotor speed is sensed and slip frequency is added to form the stator impressed frequency. In this paper two new field oriented control schemes are presented which employ rotor end ring current detection and thereby remove the dependence of the controller accuracy on temperature so that the controller is entirely independent of rotor time constant variations. The field orientation schemes do not require an incremental encoder for rotor position sensing. The motor torque can be accurately controlled even down to zero speed operation. has been suggested Adjustable-speed operations of induction motors are required to maintain their maximum efficiency levels. This can be achieved by constant slip operation of induction motors. In applications like submersible motor pumps, variable-speed operation is also needed to obtain maximum efficiency at all loads. To maintain a constant slip operation of induction motors, it is necessary to monitor the motor’s speed from its shaft. Conventional methods use speed sensors attached to the shaft. Speed monitored by these sensors is fed back to maintain constant slip operation in scalar control schemes. Has been proposed a definite relation exists between the flux level, torque and slip speed of a vector controlled induction motor. An untuned vector controller generates an inappropriate slip frequency that changes the operating flux of the machine. The torque characteristic is analysed with three aspects of magnetic state: true saturation curve, hard-limit saturation curve, and constant inductance model [44], [45], and [46].Has been suggestedadjustable-speed drive is attractive for pump, compressor, and other centrifugal load applications due to its flexibility and high operating efficiency, compared with the conventional constant-speed drive system. The drive system can successfully run in the full speed range with the proposed control method and control sequences.

4.1.3 Constant Volt/Hz control:

An induction motor drive with constant voltage and frequency, three-phase source is the input. With the AC to DC rectifier, DC to AC inverter, and controller, the voltage and frequency can be varied as [47], has proposed Constant volts-per-hertz induction motor drives and vector-controlled induction motor drives utilize pulse width modulation (PWM) to control the voltage applied on the motor. The method of PWM influences the pulsations in the torque developed by the motor. Space-vector-based approach to PWM facilitates special switching sequences involving division of active state time, proposed a space-vector-based hybrid PWM technique which is a combination of the conventional and special switching sequences. has been introduced*q*-axis rotor flux can be chosen to form a model reference adaptive system (MRAS) updating rotor time constant online in induction motor drives [48],[49].Has been suggested implementation of a positive sequence model for a squirrel cage induction motor speed control drive for use in time-domain simulations of power systems is addressed. The drive model modulates the motor stator voltage magnitude and frequency to maintain constant rotor speed [50].The adjustable-speed drive is attractive for pump, compressor, and other centrifugal load applications due to its flexibility and high operating efficiency, compared with the conventional constant-speed drive system. Since the centrifugal load torque reduces quickly with speed (square relationship), the partially rated converter may provide enough torque at low speeds. The closed loop voltage control technique and a multi-winding transformer-rectifier based AC link system are used to obtain the multiple variable voltage DC sources for the cascaded multilevel inverter. A nearest level modulation based control technique has been implemented for the multilevel inverter to obtain the fixed level voltage waveforms with constant total harmonic distortion and reduce switching losses[51].

4.1.4 Pulse Width Modulation (PWM):

Jose Titus, *et al.* [52],has studied ability of an electrical drive to continue operation without tripping in spite of short duration voltage sags or power supply interruptions is known as Power Failure Ride through capability. Critical production processes in industries require the drives to smoothly ride-through during momentary power interruptions. The reliability of the drive is dependent on the maximum duration for which a total power supply failure can be tolerated without process interruption[53],has suggestedproposes a simple method for single switchand double switches open-circuit fault diagnosis in pulse width modulatedvoltage-source inverters (PWM VSIs) for vector controlledinduction motor drives, which also applies to secondaryopen-circuit fault diagnosis. According to the phase angle of onephase current, the repetitive operation process of VSI is evenly dividedinto six operating stages by certain rules. At each stage, onlythree of the six power switches exert a vital influence on this operationand the others make a negligible influence[54],uses a disturbance observer for varioustypes of induction motor control was evaluated. The disturbance observer is designed to have fast response that isten times faster than the current controller for vector control. The voltage error is efficiently corrected using the proposed method, and the current distortion can be reduced by approximately 1/3[55].Has discussed dc link filter elements in a three-phase voltage source inverter-fed induction motor system can affect the performance of the drive system if not properly chosen. The inverter is transistorized six-step voltage source inverter,while the motor is a modified standard three-phase squirrel-cage motor. The field-oriented control method is appropriately applied both for control of voltage build-up as well as dynamic transients [56], [57].

4.2 Current source drive:

Presentedin order to precisely define the harmonic content of the main flux and stator voltage of an induction motor that is fed by a high-frequency carrier in addition to the normal set of stator voltage; this paper performs the analytical calculation of the zero-sequence components of the air-gap flux and stator voltage has suggested harmonic current injection method to optimize air-gap and yoke flux density distribution for multiphase motor simultaneously. The proposed method fully makes use of multiple control freedoms, and the optimal coefficients for corresponding harmonic current are derived. A three-phase induction motor is designed to verify the effectiveness of multiphase motor with concentrated full-pitched winding. Furthermore, the torque density and efficiency for two motors are compared under various load condition [58], [59], [60],has discussed high-order harmonics of the magnetic field can be used in some typologies of multiphase machine to improve the torque density. However, maximizing the torque capability depends on the thermal, voltage, and current constraints of the machine and the inverter. Below the base speed, the torque improvement is obtained by adding a third harmonic component to the fundamental component of the air-gap magnetic field [61],has been proposed dual-current-loop control algorithm, the torque and air-gap flux of a doubly fed induction motor are controlled directly [62],has discussed **c**omprehensive analysis of the starting period of inverter-fed large induction motors reveals these motors are subjected to additional components of pulsating torsional torque has been suggesteda sensor less V/f control system of induction motor drive. Active current is calculated via the measured alpha-beta components of the generalized current vector as a sum of their projections on the vector of basic harmonic voltage, the position of which is predetermined by the generalized vector of PWM modulating signals [63], [64],has presented most speed control algorithms for induction motors (IM) require at least two current sensors. The currentstress of the semiconductor devices decreases proportionally with the phase number, torque ripple is reduced, rotor harmonic currents are smaller, and power per rms ampere ratio is higher forthe same machine volume[66].

V. VECTOR CONTROLLED INDUCTION MOTOR DRIVES

A. Direct vector control:

A model predictive control scheme for multiphase induction machines, configured as multit three-phase structures, is proposed in this paper. The predictive algorithm uses a direct flux vector control scheme based on a multi three- phase approach, where each three-phase winding set is independently controlled [67], [68]. Direct torque control (DTC) has been recently used for the development of high performance five-phase induction motor (IM) drives, where normal operation of the system has been usually considered and the ability of DTC to manage the situation has beenanalyzed in comparison with different rotor field-oriented control (RFOC) strategies[69]. The control strategy, whichis based on the indirect field oriented control (IFOC) algorithm, is able to control themotor speed from zero to the rated value under full load condition during motoring and regenerating operation modes [70]. The study presents the direct flux and current vector control of an induction motor (IM) drive, which is a relatively newer and promising control strategy, through the use of model predictive control (MPC) techniques [71]. Direct torque control (DTC) scheme is quite popular in a voltage. However, in a current sourceinverter (CSI) fed IM drive, there is no direct relation between the stator fluxamplitude and the applied current vector. Further, filter capacitor in between the inverter and motor terminals decouples the motor from the CSI [72].A loss-minimizing strategy is proposed for induction motordrives to ensure maximum efficiency operation for a given torque demand. Theproposed strategy directly regulates the machine stator flux according to the desiredtorque, using an optimal stator flux reference [73]. Medium-voltage (MV) drives are generally based on either voltage-source inverters or current-source inverters (CSIs). CSIs feature simple topology, motor-friendly waveforms, power reversal capability, and short-circuit-proof protection; hence, they are widely used as high-power MV drives. Direct vector control (DVC)CSI drives ensure improved performance by decoupled control of the machine flux and torque using two independent control loops.

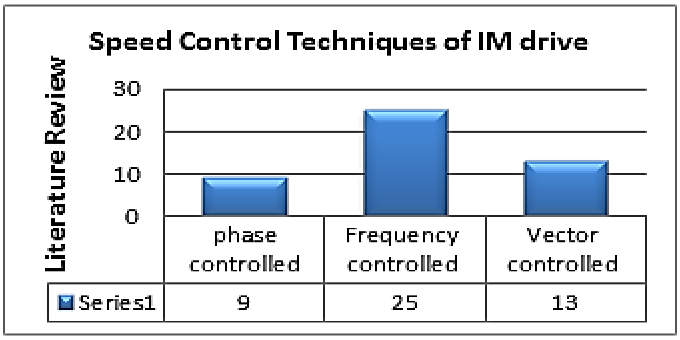
B. Indirect vector control

The fuzzy-logic controller (FLC) is based on the indirect vector control. The fuzzy-logic speed controller is employed in the outer loop. Indirect vector-controlled induction motor (IVCIM) dynamics,a numerical analysis of these bifurcations for proportional–integral-controlled IVCIM is made in this brief using full-order IM model [74], [75] [76] in recent years, vector control schemes for IM drive systems have gained wide acceptance in high performance applications. Crucial to the success of the vector control scheme is the knowledge of the instantaneous position of the rotor flux. The position of the rotor flux is measured in the direct vector control scheme and estimated in the indirect vector control scheme[77], [78]. Medium-voltage (MV) drives are generally based either voltage-source inverters or current-source inverters (CSIs). CSIs feature simple topology, motor- friendly waveforms, power reversal capability, and short-circuit-proof protection; hence, they are widely used as high-power MV drives. Direct vector control (DVC) CSI drives ensure improved performance by decoupled control of the machine flux and torque using two independent control loops [79].

VI. Literature Review Summary

The following figures give summary of the papers as:

Table 1. Speed Control Tech. and number of literatures survey



Pi-Chart 1.VSI, CSI and number of literatures survey

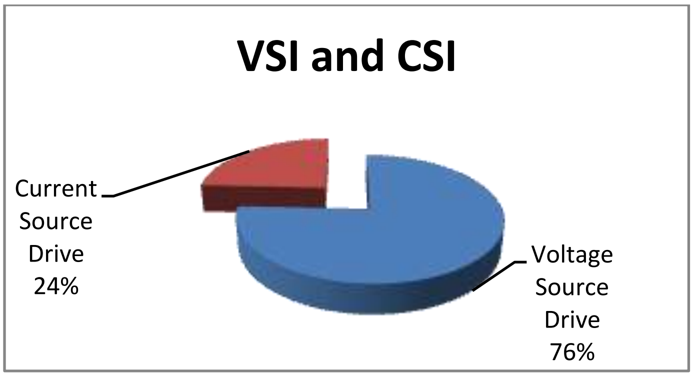
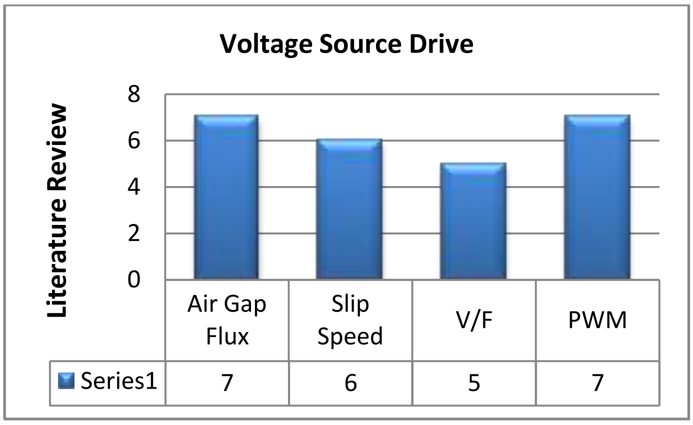
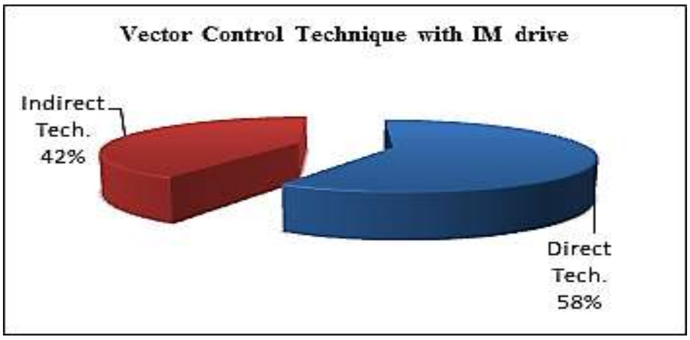


Table 2. Voltage and number of literatures survey



Pi-Chart 2.VCT and number of literatures survey



VII. CONCLUSION

This paper has been addressed a survey of several technical literature concerned with on speed control of induction motors drive. In this literature review paper all types of control induction drive methodssuch as phase controlled, frequency controlled, vector controlled. This critical review also shows that speed controlled of three phase induction motor by different methods. Authors strongly believe that this survey article will be very much useful to the researchers for finding out the relevant references as well as the previous work done in the field of enhancement of performance parameters of three phase induction motor by phase controlled, frequency controlled, vector controlled methods etc. So that further research work can be carried out. In which normal induction drive, phase induction motor drive, frequency controlled and vector controlled technique in details. In which frequency controlled explain in details with its types (voltage and current source drive).

REFERENCES

[1] J. Zubek, A. Abbondanti, and C. J. Norby, "Pulsewidth modulated inverter motor drives with improved modulation," *IEEE Trans. Ind. Applicat.*, vol. 11, pp. 695–703, Nov./Dec. 1975.

[2] K. Hasse, "Zur Dynamic DrehzahlgeregelterAntrieebeMitStromrichterGespeistenAsyn-chronKuzschlublaufermaschinen," Ph.D. dissertation, TechnischeHochschule Darmstadt, Darmstadt, Germany, 1969.

[3] F. Blaschke, "Das Verfahren der FeldorientierungzurRegelung der Drehfeldmaschine," Ph.D. dissertation, Univ. Braunschweig, Braunschweig, Germany, 1973.

[4] F. Blaschke, "The principle of field orientation as applied to the newtransvector closed-loop control system for rotating-field machines," *Siemens Rev.*, vol. 34, pp. 217–220, May 1972.

[5] P. Vas, A. F. Stronach, and M. Neuroth, "DSP-controlled intelligent high-performance ac drives present and future," in *IEE Colloq. VectorControl and Direct Torque Control of Induction Motors*, Oct. 1995, pp. 7/1–7/8.

[6] Y. S. Kung, C. M. Liaw, and M. S. Ouyang, "Adaptive speed control for induction motor drives using neural networks," *IEEE Trans. Ind. Electron.*, vol. 42, pp. 25–32, Feb. 1995.

[7] D. L. Sobczuk and P. Z. Grabowski, "DSP implmentation of neural network speed estimator for inverter fed induction motor," in *Conf. Rec.IEEE IECON'98*, 1998, pp. 981–985.

[8] P. Vas, A. F. Stronach, and M. Neuroth, "DSP-based speed-sensorless vector controlled induction motor drives using AI-based speed estimator and two current sensors," in *Proc. IEE 7th Int. Conf. Power Electronicsand Variable Speed Drives*, 1998, pp. 442–446.

[9] H.-C. Lu, T.-H. Hung, and C.-H. Tsai, "Sensorless vector control of induction motor using artificial neural network," in *Proc. IEEE Int. Symp.Circuits and Systems*, vol. II, 2000, pp. 489–492.

[10] Q. Xie, S. Wan, Y. Yi, J. Zhao, and Y. Shen, "Speed-sensorless control using Elman neural network," *J. Syst. Eng. Electron.*, vol. 12, no. 4, pp. 53–58, 2001.

[11] M. R. Buhl and R. D. Lorenz, "Design and implementation of neural networks for digital current regulation of inverter drives," in *Conf. Rec.IEEE-IAS Annu. Meeting*, 1991, pp. 415–423.

[12] D. R. Seidl, D. A. Kaiser, and R. D. Lorenz, "One-step optimal space vector pwm current regulation using a neural network," in *Conf. Rec.IEEE-IAS Annu. Meeting*, 1994, pp. 867–874.

[13] B. Burton, F. Kamran, R. G. Harley, T. G. Habetler, M. A. Brooke, and R. Poddar, "Identifcation and control of induction motor stator currents using fast on-line random training of a neural network," *IEEE Trans.Ind. Applicat.*, vol. 33, pp. 697–704, May/June 1997.

[14] K. Madani, G. Mercier, M. Dinarvand, and J.-C. Dpecker, "A neurovector based electrical machines driver combining a neural plant identifier and a conventional vector controller," in *Proc. SPIE 2nd Conf.Applications and Science of Computational Intelligence II*, 1999, pp. 476–485.

[15] L. R. Valdenebro, J. R. Hernandez, and E. Bim, "A neuro-fuzzy based parameter identification of an indirect vector-controlled induction motor drive," in *Proc. IEEE/ASME Int. Conf. Advanced Intelligent Mechatronics*, 1999, pp. 347–352.

[16] A. K. P. Toh, E. P. Nowicki, and F. Ashrafzadeh, "A flux estimator for field oriented control of an induction motor drive," in *Conf. Rec.IEEE-IAS Annu. Meeting*, 1994, pp. 585–592.

[17] M. G. Simoes and B. K. Bose, "Neural network based estimation of feedback signals for a vector controlled induction motor drive," in *Conf.Rec. IEEE-IAS Annu. Meeting*, 1994, pp. 471–479.

[18] A. Barazzouk, A. Cheriti, and G. Olivier, "A neural networks based field oriented control scheme for induction motors," in *Conf. Rec IEEE-IASAnnu. Meeting*, 1997, pp. 804–811.

[19] T. Sun and B. Sun, "Research on the application of FNN controller to vector-controlled induction motor drives," in *Proc. Fifth Int. Conf. ElectricMachines and Systems*, vol. 2, 2001, pp. 1293–1295.

[20] D.SriVidhyaand Dr.T.Venkatesan, "Quasi-Z-Source Indirect Matrix Converter Fed Induction Motor Drive for Flow Control of Dye in Paper Mill", *IEEE Transactions on Power Electronics*.

[21] Richu Sebastian C and P.P.Rajeevan, "Load Commutated SCR based Current Source Inverter fed Induction Motor Drive with Open-end Stator Windings", *IEEE Transactions On Industrial Electronics, 0278-0046 (c)* 2017.

[22] MurliManohar and SukantaDas,"Current Sensor Fault-Tolerant Control for Direct Torque Control of Induction Motor Drive Using Flux Linkage Observer",IEEE *Transactions on Industrial Informatics*

[23] *Said A. Deraz andHaitham Z. Azazi1,*"Current limiting soft starter for three phaseinduction motor drive system using PWM AC chopper", IET *Power Electronics.*

[24] *PratibhaNaganathan1,Srirama Srinivas and HridyaIttamveettil,* "Five-level torque controller-based DTC method for a cascaded three-level inverter fed induction motor drive", *IET Power Electron.,© The Institution of Engineering and Technology* 2017 *Vol. 10 Isspp. 1223-1230.*

[25] B. Prathap Reddy, MadhukarRao, AManoranjanSahoo and SivakumarKeerthipati,*"*A Fault Tolerant Multilevel Inverter for Improving the Performance of Pole-Phase Modulated Nine-Phase Induction Motor Drive," IEEE *Transactions On Industrial Electronics*

[26] I. Gonzalez-Prieto, M.J. Duran, J.J. Aciego, C. Martin, and F. Barrero,*"*Model Predictive Control of Six-phase Induction Motor Drives Using Virtual Voltage Vectors", IEEE *Transactions On Industrial Electronics*.

[27] Mario Bermudez, Ignacio Gonzalez-Prieto, and Federico Barrero, *IEEE,*

[28] Hugo Guzman,Mario J. Duran, and Xavier Kestelyn,*"*Open-Phase Fault-Tolerant Direct Torque Control Technique for Five-Phase Induction Motor Drives", IEEE *Transactions On Industrial Electronics*

[29] Mario Bermudez,Ignacio Gonzalez-Prieto,FedericoBarrero Hugo Guzman4, Xavier Kestelyn1, *Member*, *IEEE*, Mario J. Duran3, "An Experimental Assessment of Open-Phase Fault-Tolerant Virtual Vector Based Direct Torque, Control in Five-Phase Induction MotorDrives", IEEE *Transactions On Power Electronics.*

[30] M.J. Duran, I. Gonzalez, M. Bermudez, F. Barrero,H. Guzman, and M.R. Arahal*, "*Optimal Fault-Tolerant Control of Six-Phase Induction Motor Drives with Parallel Converter", IEEE *Transactions On Industrial Electronics.*

[31] S. Rubino, R.bojoi, S.A. Odhano,P. Zancheta, "Model Protective Direct Flux Vector Control Of Multi Three Phase Induction Motors Drives", 978-1-5090-2998-3/17/$31.00, IEEE, 2017.

[32] Mario Bermudez, Ignacio Gonzalez-Prieto, Federico Barrero, Hugo Guzman, Xavier Kestelynl and Mario J. Duran, "AnExperimental Assessment of Open-Phase Fault-Tolerant Virtual Vector Based Direct Torque Control in Five-Phase Induction Motor Drives", IEEE *Transactions On Power Electronics.*

[33] Ignacio González-Prieto1, Mario. J. Duran1 and Federico J. Barrero, "Fault-tolerant Control of Six-phase Induction Motor Drives with Variable Current Injection", IEEE *Transactions OnPower Electronics.*

[34] Seyed Mohammad Jalal Rastegar Fatemi1, Navid Reza Abjadi, JafarSoltani,andSaeedAbazari," Speed sensorless control of a six-phase induction motor drive using backstepping control", IET *Power Electron.*,2014,

[35] NadeemJelani, and Marta Molinas,*"*Asymmetrical Fault Ride Through as Ancillary Service by Constant Power Loads in Grid-Connected Wind Farm", IEEE *Transactions On Power Electronics*.

[36] Robert Cuzner, *Senior Member,* Daniel Drews, William Kranz, AshishBendre,and GiriVenkataramanan,*"* Power-Dense Shipboard-Compatible,Low-Horsepower Variable-Frequency Drives, IEEE, *Transactions On Industry Applications, Vol. 48, No. 6, November/December 2012*.

[37] Julio C. Moreira and Thomas A. Lip, "A New Method for Rotor Time Constant Tuning in Indirect Field Oriented Control", IEEE *Transactions On Power Electronics, Vol. 8, No. 4, October 1993.*

[38] N.M.B. Abdel-Rahim and A. Shaltout, " Torsional vibration controlof large induction motors using constant air gapflux scheme", IET *Electric Power Applications Received On 6th May 2011 Revised On 26th January 2012.*

[39] N.M.B. Abdel-Rahim,"Fuzzy-Logic Control of Unsymmetrical Two Phase Induction Motor", 978-1-4673-2421-2/12/$31.00 IEEE©2012.

[40] Wei Xu, JianguoZhu,andYouguangGuo Faculty of Engineering and Information Technology University of Technology, Sydney, Longcheng Tan1 Shuhong Wang2 , " Analysis on Performance of Linear Induction Motor Basing on Winding Function Method", 978-1-4244-2800-7/09/$25.00 ©2009 IEEE.

[41] E.Levi Liverpool John Moores University School of Electrical Engineering Liverpool L3 3AF, UK, A.Boglietti, M.LazzariPolitecnico*h* Torino Dipt. diIngegneriaElettricaIndustriale 1012. Torino, Italy

[42] Yifan Tang, *Member, IEEE,* and LongyaXu, *Senior Member, IEEE, "*A Flexible Active and Reactive Power Control Strategy for a Variable Speed Constant Frequency Generating System," IEEE *Transactions On Power Electronics, Vol. Lo, No. 4, July 1995.*

[43] S. Rahman, B.E., M.Sc, Ph.D., and W. Shepherd, D.Sc.(Eng.), "Thyristor and diode controlled variable voltage drives for 3-phase induction motors",*IEE, Vol 124,No. 9, September 1977.*

[44] Takayoshi Matsuo,VladimirBlasko,Julio*C.* Moreira,and Thomas *A.* Lipo,*"*Field Oriented Control of Induction Machines Employing Rotor End Ring Current Detection," IEEE, *Transactions On Power Electronics, Vol. 9, No. 6, November, 1994*.

[45] M. A. Choudhury and M. AzizurRahman, *ZEEE, "*Determination of Operating Conditions of Submersible Induction Motors," IEEE *Transactions On Industry Applications, Vol. 28, No. 3, May/June 1992.*

[46] B.C.Ghosh and S.N.Bhadra, "Effects of flux level on a CSI-fed field-orientedinduction motor," *IEE Proc.-Electr. Power Appl., Vol. 144, No. 5, September 1997.*

[47] Xibo Yuan, Jianyun Chai, and YongdongLi,*"*A Converter-Based Starting Method and Speed Control of Doubly Fed InductionMachine With Centrifugal Loads," IEEE *Transactions On Industry Applications, Vol. 47, No. 3, May/June 2011.*

[48] V. S. S. Pavan Kumar Hari, and G. Narayanan, *"*Space-Vector-Based Hybrid PWM Technique to Reduce Peak-to-Peak Torque Ripplein Induction Motor Drives," IEEE *Transactions OnIndustry Applications.*

[49] ShuyingYang,PengpengCao,Xing Zhang,*"* Stability Analysis of q-axis Rotor Flux Based Model Reference Adaptive System Updating Rotor Time Constant in Induction Motor Drives,"CES *Transactions On Electrical Machines And Systems, Vol. 1, No. 2, June 109 2017.*

[50] *Deepak Ramasubramanian and Vijay Vittal1,"*Positive sequence induction motor Speed control drive model for time-domain simulations," IET*Generation, Transmission & Distribution*.

[51] Xibo Yuan, *Member*,Jianyun Chai, and YongdongLi,*"*AConverter-Based Starting Method and Speed Control of Doubly Fed Induction MachineWith Centrifugal Loads," IEEE *Transactions On Industry Applications, Vol. 47, No. 3, May/June 2011*.

[52] BidyutMahato,RaviRaushan,Kartick Chandra Jana, "Modulation and Control of Multilevel Inverter for an Open-end Winding Induction Motor with Constant Voltage Levels and Harmonics," IET *Power Electronics.*

[53] Jose Titus,JayendraTeja, KamaleshHatua, and Krishna Vasudevan,"An Improved Scheme for Extended Power LossRide-through in a Voltage Source Inverter fed Vector Controlled Induction Motor Drive using a Loss Minimisation Technique," IEEE *Transactions On Industry Applications*

[54] Jianghan Zhang, Jin Zhao, Dehong Zhou, and Chengguang Huang, "High-Performance Fault Diagnosis in PWM Voltage-Source Inverters for Vector-Controlled Induction Motor Drives," IEEE *Transactions On Power Electronics, Vol. 29, No. 11, November 2014.*

[55] TetsumaHoshino,*IEEE*, and Jun-ichiItoh,*"*Output Voltage Correction for a Voltage Source Type Inverter of an Induction Motor Drive," IEEE, *Transactions On Power Electronics, Vol. 25, No. 9, September 2010*

[56] K. S. Rajashekara, Member, VenkatachariRajagopalan, Senior Member, Ieee, Anatole Sevigny,And Joseph Vithayathil,"Dc Link Filter Design Considerations In Three-Phase Voltage Source Inverter-FedInduction Motor Drive System," IEEE*Transactions On Industry Applications, Vol. Ia-23, No. 4, July/August 1987 Dc.*

[57] Mohamed A. Abbas, Member,Roland Christen, And Thomas M.JahnsSix-Phase Voltage Source Inverter Driven InductionMotor", IEEE*Transactions On Industry Applications, Vol. Ia-20, No. 5, September/October 1984.*

[58] S. Hazra, And P. Sensarma, "Vector approach for self- excitation and control of induct stand-alone wind power generation," IET *Renewable Generation Received On 25th September 2010 Revised On 2nd March 2011*.

[59] AlfioConsoli, Giovanni Bottiglieri, Giuseppe Scarcella, and GiacomoScelba*, "*Flux and Voltage Calculations of Induction Motors Supplied by Low- and High- Frequency Currents," *IEEE Transactions On Industry Applications, Vol. 45, No. 2, March/April 2009*.

[60] Wubin Kong, RonghaiQu, Min Kang, Jin Huang, and Libing Jing, "Air-Gap and Yoke Flux Density Optimization for Multiphase Induction Motor Based on Novel Harmonic Current Injection Method," IEEE, *Transactions On Industry Applications.*

[61] Michele Mengoni,LucaZarri,AngeloTani,Leila Parsa, Giovanni Serra,andDomenicoCasadei,*"*High-Torque-Density Control of Multiphase Induction Motor Drives Operating Over a Wide Speed Range", IEEE, *Transactions On Industrial Electronics, Vol. 62, No. 2, February 2015*

[62] Yu Liu,andLongyaXu,*"*The Dual-Current-Loop Controlled Doubly Fed Induction Motor for EV/HEV Applications", IEEE, *Transactions On Energy Conversion, Vol. 28, No. 4, December, 2013*

[63] N.M.B. Abdel-Rahim,A. Shaltout, "Torsional vibration control of large induction motors using constant air gap flux scheme", IET *Electric Power Applications Received On 6th May 2011 Revised On 26th January 2012.*

[64] Shonin O.B., Novozhilov and N.G., Kryltsov S.B., "Sensorless Estimation of the Rotor Speed for the Usein V/f Control Systems of IM Drives",International Conference on Industrial Engineering, Applications and Manufacturing (ICIEAM) 978-1-5090-1322-7/16/$31.00 ©2016

[65] Michael Bierhoff, and Manuel Gollner, "A Current Sensor Less Speed Control Algorithm for Induction Motors", IEEE 978-1-5090-3474-1/16/$31.00 ©2016.

[66] Ju-Suk Lee, TakaharuTakeshita,and Nobuyuki Matsui, "Optimized Stator-Flux- oriented Sensorless in Low-Speed Performance *R,+ PL, -wL, PMU 3 P 144* Drives of IM", 0-7803-3544-9/96 $5.00 *0* 1996 IEEE.

[67] By R. Bojoi, E.Levi, F.Farina, A.Tenconi,andF.Profumo, "Dual three-phase induction motor drive with digital current control in the stationary reference frame", IET *Power Engineer | June/July 2006.*

[68] S. Rubino, R.bojoi, S.A. ODHANO, and P. ZANCHETA, "Model Protective Direct Flux Vector Control Of Multi Three Phase Induction Motors Drives", IEEE978-1-5090-2998-3/17/$31.00 ©2017.

[69] Mario-Bermudez,Ignacio-Gonzalez-Prieto,FedericoBarrero,Hugo Guzman, Xavier Kestelyn, and Mario J. Duran, "An Experimental Assessment of Open-Phase Fault-Tolerant Virtual Vector Based Direct TorqueControl in Five-Phase Induction Motor Drives", IEEE *Transactions On Power Electronics.*

[70] Omar Ellabban,Haitham Abu-Rub,andGeBaoming, *"*A Quasi-Z-Source Direct Matrix Converter Feeding A Vector control theory", IET *Electric Power Applications Controlled Induction Motor Drive", 2168-6777 (C) 2013*.

[71] *Shafiq Odhano1 , RaduBojoi, Andrea Formentini1, Pericle Zanchetta1, AlbertoTenconi,"*Direct flux and current vector control for induction motor drives using model predictive", *IET Electr. Power Appl., 2017, Vol. 11 Iss. 8, Pp. 1483-1491© The Institution Of Engineering And Technology 2017.*

[72] HSoumitra Das, Hang Gao, Bin Wu, Manish Pande, and David Xu, "A Space Vector Modulation Based Direct Torque Control Scheme for a Current Source Inverter fed Induction Motor Drive", IECON*2015-Yokohama November 9-12, 2015*.

[73] S.A. Odhano, R. Bojoi, A. Boglietti, S. G. Rosu and G. Griva, "Maximum Efficiency per Torque Direct Flux Vector Control of Induction Motor Drives", IEEE, *Transactions On Industry Applications.*

[74] Ahmed K. Abdelsalam,Mahmoud I. Masoud, Mostafa S. Hamad, and Barry W. Williams, "Modified Indirect Vector Control Technique for Current-Source Induction Motor Drive", IEEE *Transactions On Industry Applications, Vol. 48, No. 6, November/December 2012.*

[75] M. NasirUddin,Tawfik S. Radwan,and M. AzizurRahman, *"*Performances of Fuzzy-Logic-Based Indirect VectorControl for Induction Motor Drive", IEEE *Transactions OnIndustryApplications, Vol. 38, No. 5, September/October 2002.*

[76] Jitendra Kr. Jain, SandipGhosh,andSomnathMaity,*"*A Numerical Bifurcation Analysis of Indirect Vector Controlled Induction Motor", IEEE *Transactions On Control System Technology*.

[77] RamuKrishnan,andAravindS. Bharadwaj,*"*A Review of Parameter Sensitivity and Adaptation in Indirect Vector Controlled Induction Motor Drive Systems", IEFE *Transactions On Powfr Electronics Vol 6 No -1 Octobfr 1991*.

[78] Ahmed K. Abdelsalam,Mahmoud I. Masoud, Mostafa S. Hamad, and Barry W. Williams, "Modified Indirect Vector Control Technique for Current-Source Induction Motor Drive", IEEE *Transactions On Industry Applications, Vol. 48, No. 6, November/December 2012.*

[79] David C. Meeker,and Michael John Newman, "Indirect Vector Control of a Redundant Linear Induction Motor for Aircraft Launch", IEEE | *Vol. 97, No. 11, November 2009.*