A Literature Review on Speed Controlled Techniques of Induction Motor Drive

Jaswant Singh  
Asst. Professor,  
Department of Electrical Engineering,  
Arya College of Engineering & IT,  
Jaipur, India

Vikash Kumar  
B.Tech Student, EED,  
Arya College of Engineering & IT,  
Jaipur, India

Raja Kumar  
B.Tech Student, EED,  
Arya College of Engineering & IT,  
Jaipur, India

Ranjeet Kumar  
B.Tech Student, EED,  
Arya College of Engineering & IT,  
Jaipur, India

Abhishek Kumar Chopra  
Asst. Professor,  
Department of Electrical Engineering,  
Arya College of Engineering & IT,  
Jaipur, India

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 control methodologies, 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 converters pulse width modulation (PWM), shoot-through state, Z-source inverter.

I. INTRODUCTION

In modern industrialized countries, more than half the total electrical energy 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 speed due to facilitate of their speed control methods [1]. The conventional methods of speed control of an induction motor drive were either too extravagant or too inefficient thus limiting their application to only constant-speed 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 brief classification 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 MOTOR 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 $N_s$ is produced [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 the 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. 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 $N_r$ which is slightly less than the synchronous speed.

**Equivalent circuit**

In the vicinity of the rotor, the air gap flux can be given by,

$$\Phi_m = \frac{V_{m}}{\omega_s}$$

From the equivalent circuit, the approximate equivalent circuit can be obtained as Shown in fig. 3.5, where the core loss resistor $R_{m}$ has been dropped and the magnetizing inductance $L_{m}$ has been shifted to the input. This approximation is easily justified for an integral horsepower machine, where $(R_{s} + j \omega_s L_{m}) \ll \omega_s L_{m}$. The performance prediction by the simplified circuit typically varies within 5 percent from that of the actual machine.

In figure 2, the current $I_r$ is figured out by:

$$I_r = \frac{V_{m}}{\omega_s} (R_{s} + R_{f}/S)^2 + \omega_s^2 (L_{m} + L_{f})$$

Substituting equation (3.9) in (3.8) yields

$$T_e = 3 \left( \frac{P}{2} \right) \frac{V_{m}^2}{R_{f}} \omega_s \left( L_{m} + L_{f} \right)^2$$

A further simplification of the equivalent circuit of fig. 3.4 can be made by neglecting stator parameters $R_{s}$ and $L_{m}$. 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

$$T_e = 3 \left( \frac{P}{2} \right) \frac{V_{m}^2}{R_{f}} \omega_{si}^2$$

where $\omega_{si} = \frac{\omega_s}{3}$.

The air gap flux can be written by,

$$\Phi_m = \frac{V_{m}}{\omega_s}$$

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

$$T_e = 3 \left( \frac{P}{2} \right) \frac{1}{R_{f}} \omega_{si}^2$$

Where, $R_{f} >> R_{s}$, equation (3.11) is important because it indicated that at constant flux $\Phi_m$, the torque $T_e$ is proportional to slip frequency $\omega_{si}$, or at constant slip frequency $\omega_{si}$, torque $T_e$ is proportional to $\omega_{si}$.

**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 speed, 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]:

$$S = \frac{N_r}{N_s}$$

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

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

(15)

Synchronous speed is given by $N_s = \frac{120f}{p}$

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

$$N_r = \frac{120f}{p} (1 - S)$$

(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 electronic converter it is possible to vary the speed of an induction motor. The fundamental elements needed in an Electric motor drive system include:

- 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 (QZSMC) 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 presented a 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. Pratibha Nagana, et al. [24], has discussed two 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 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 controlled phase control. Three-phase fully controlled bridge rectifier circuit shown in figure (3) is the, the widely used rectifier circuit, which consists of rectifier transformer, six Thyristor Bridge connected, load, trigger and synchronization aspects of the composition.

![Function diagram.](image)

Review on phase controlled induction motor using different techniques. B. Prathap Reddy, et al. [25], has suggested two 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 (FTC)-based direct torque control (DTC) method especially for improving steady-state motor torque performance and retaining the high dynamic performance. I. Gonzalez-Prieto, et al. [26], has presented the most serious and recent competitor to the standard field oriented control (FOC) for induction motors (IM) is the finite control set model predictive control (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 suggested Direct 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], [31]. Has discussed a 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 suggested 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 been analyzed in comparison with different rotor field-oriented control (ROFC) 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 Gonzalez-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 in electric 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 modern strategy 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 proposed a 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-power 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 voltage-source- 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 has been 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 torque 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. Has presented 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 discussed Variable-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 controllers, 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 suggested 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. 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 inverter 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 suggested proposes a simple method for single switchand double switches open-circuit fault diagnosis in pulse width modulated voltage-source inverters (PWM VSIs) for vector controlled induction motor drives, which also applies to secondaropen-circuit fault diagnosis. According to the phase angle of onephase current, the repetitive operation process of VSI is evenly divided into six operating stages by certain rules. At each stage, onlythree of the six power switches exert a vital influence on this operation and the others make a negligible influence[54]. Uses a disturbance observer for various types of induction motor control was evaluated. The disturbance observer is designed to have fast response that iest times faster than the current controller for vector control. The voltage error is efficiently corrected using the proposed method, and the current disturbance can be reduced by approximately 1/3[55]. Has discussed de-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:
Presented in 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 topologies 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 comprehensive 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 suggested 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 current stress of the semiconductor devices decreases proportionally with the phase number, torque ripple is reduced, rotor harmonic currents are smaller, and power per rms amperes ratio is higher for the 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 multilotted 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 been analyzed in comparison with different rotor field-oriented control (RFOC) strategies [69]. The control strategy, which is 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 source inverter (CSI) fed IM drive, there is no direct relation between the stator flux amplitude 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 motor drives to ensure maximum efficiency operation for a given torque demand. The proposed strategy directly regulates the machine stator flux according to the desired torque, 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 decoupling 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 decoupling 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

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<th>Literature Review</th>
<th>Speed Control Techniques of IM Drive</th>
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![Pie Chart 1. VSI, CSI and number of literatures survey](image)

Table 2. Voltage and number of literatures survey

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<th>Voltage Source Drive</th>
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<td>Voltage Source Drive</td>
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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 method such 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).

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[41] E. Levi Liverpool John Moores University of School of Electrical Engineering Liverpool L3 3AF, UK, A. Boglietti, M. LazzarinPolitecnico di Torino Dept. diElettricitaindustriale 1012. Torino, Italy


