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An Overview on Performance Improvement of an Induction Motors (IM) – A Review

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Abstract:Several technologies of motors are available in the market, since the most affordable in terms of cost up to the most efficient or compact one. Besides that, motors have to be able to meet many specific application requirements, like speed range, installation, safety, reliability, low level of noise and vibration, long life, maintenance etc. Induction motors account for approximately 50 % of the overall electricity use in industrialized countries. In the agricultural and commercial sectors also, power consumption by ac motors is quite substantial. On an average, the energy consumed by a motor during its life cycle is 60-100 times the initial cost of the motor. However, in spite of all motor technologies, induction motors remain the most used in the market, especially when variable speed is not necessary. This paper presents a review on performance improvement factors of the Induction Motor (IM) operation. This paper discussed the factors are follows: (a) Efficiency improvement of IM (b) Torque control techniques of IM, and (c) Speed control techniques of IM.

Keywords: Performance improvement, Induction motor, Efficiency, Torque control, Speed control.

I. INTRODUCTION

The electric motor has a long history of development since its invention by Nicola Tesla in 1888, with earlier effort aimed at improving power and torque and reducing cost. The need for higher efficiency became apparent during the late 1970's and by the early 1980's and at least one British manufacturer had started to market a premium range of motors with improved efficiency. Now the trend is towards the design and manufacturing of motors with a small improved efficiency at a small extra cost. It is needless to state that this extra cost could be realized in the savings in the operating cost [36]. Induction motors are electro-mechanical devices used in most of the industrial applications. Three phase induction motors are considered the universal work horses of industry, converting up to 80% of all electrical power into mechanical energy and cover up many heavy industrial applications such as fans, blowers, compressors, mixers, conveyors…etc. These motors are robust machines used not only for general purposes, but also in hazardous locations.

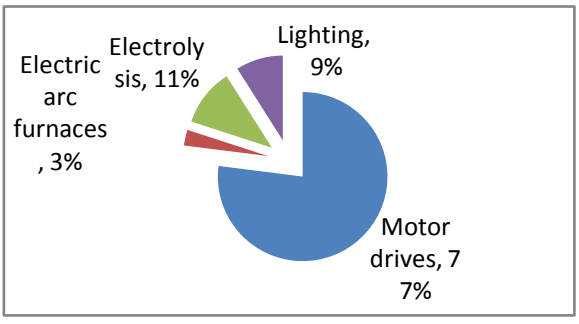

Fig.1. Induction motors in industrial applications.

In many variable speed drive applications, torque control is required, but precise, closed-loop control of speed is not necessary. The advantages of torque control in this type of application include greatly improved transient response, avoidance of nuisance over current trips, and the elimination of load-dependent controller parameters [8].

A. EFFICIENCY IMPROVEMENT

There are several significant power quality and performance issues relating to Energy Efficient (EE) motors. The voltage unbalance results in a larger % current unbalance in EE motors. This is primarily due to the lower negative sequence impedance associated with EE motors [7]. This paper discusses the influence of each individual loss on the efficiency of induction motors and proposes means to mitigate them in order to reach the level of efficiency IE4 (IEC 60034-30). General rules, guidelines and best practices to reduce all kinds of losses in induction electric motors are presented. Even though an induction motor is already built, it is still possible to increase the efficiency in a Variable Speed Drive (VSD) application especially at low speed by controlling properly the magnetic flux (Voltage/frequency ratio) in order to maintain the total losses in a minimum value. This is known as Optimal Flux [5]. Knowing exactly where the losses are located is the key to propose modifications in the design and manufacturing process to reduce them. The losses to be considered are: Pj1– Joule losses in the stator windings, Pj2 – Joule losses in the rotor, Pmechj2 – mechanical losses (friction and ventilating losses), Pfe – iron losses, Padd – additional losses and Pharm – harmonics losses. For instance, the percentage losses distribution for a WEG, IE4, W22, 30kW, 4-pole

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induction motor is: Pj1 = 43.7%, Pj2 = 20.4%, Pmech = 3.53%, Pfe = 26,7%, Padd = 4.91% and Pharm =0,67%. Particularly for this motor, it is clear that the most relevant losses are Joule losses and iron losses. Obviously, the reduction of each individual loss tends to increase the cost of the motor. Besides that, in some cases, to reduce mechanical losses, temperature rise can be increased. In other situations, starting current, starting torque or power factor are also affected. So, the challenge for induction motor designers and researchers is to reduce losses with a minimum cost increase and general motor performance improvement, not only in terms of efficiency but also noise, vibration, temperature rise, starting current and torque, and power factor among others.

B. Torque control

Direct Torque Control (DTC) was proposed by M. Depenbrock and Takahashi [1, 2]. This method presents the advantage of a very simple control scheme of stator flux and torque by two hysteresis controllers, which give the input voltage of the motor by selecting the appropriate voltage vectors of the inverter through a look-up-table in order to keep stator flux and torque within the limits of two hysteresis bands as shown in Fig.2.The application of this principle allows a decoupled control of flux and torque without the need of coordinate transformations, PWM pulse generators and current regulators [6],[11-14].

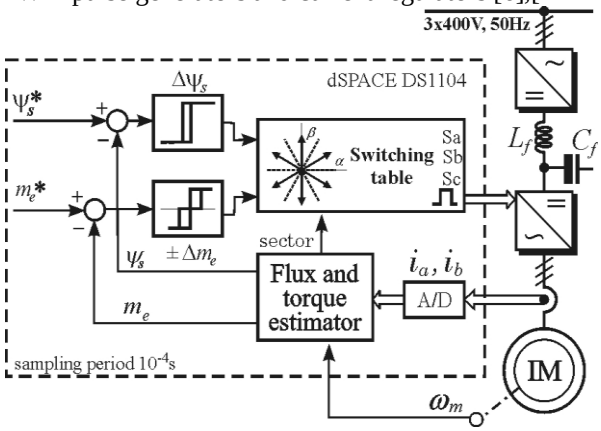

Fig.2. Basic Direct Torque Control scheme for ac motor drives

C. Speed control

We have seen the speed torque characteristic of the machine. In the stable region of operation in the motoring mode, the curve is rather steep and goes from zero torque at synchronous speed to the stall torque at a value of slip s = ˆs. Normally ˆs may be such that stall torque is about three times that of the rated operating torque of the machine, and hence may be about 0.3 or less. This means that in the entire loading range of the machine, the speed change is quite small. The machine speed is quite stiff with respect to load changes. The entire speed variation is only in the range n_s to (1 - ˆs)n_s, n_s being dependent on supply frequency and number of poles. The foregoing discussion shows that the induction machine, when operating from mains is essentially a constant speed machine. Many industrial drives, typically for fan or pump applications, have typically constant speed requirements and hence the induction machine is ideally suited for these. However, the induction machine, especially the squirrel cage type, is quite rugged and has a simple construction. Therefore it is good candidate for variable speed applications if it can be achieved [4].

II. EFFICIENCYIMPROVEMENT OF IM

Motor efficiency is the ratio of mechanical power output to the electrical power input, usually expressed as a percentage. Considerable variation exists between the performance of standard and energy-efficient motors (see Figure 3). Improved design, materials, and manufacturing techniques enable energy-efficient motors to accomplish more work per unit of electricity consumed [32].

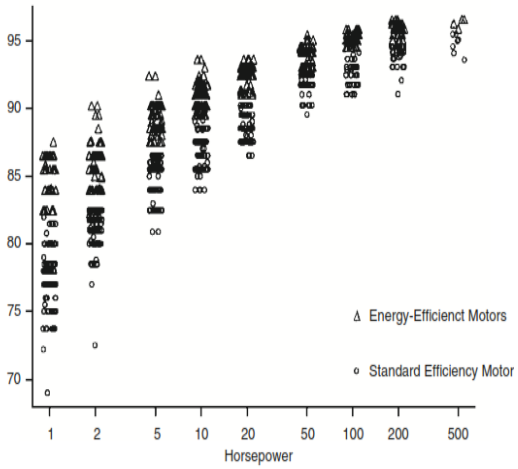

Fig.3. Standard and Energy-Efficient Motor Performances

The need to increase overall motor system efficiency has never been greater. With the rising costs of energy and the substantial concerns about global CO_2 emissions, achieving the highest possible motor system efficiency has become a critical priority. In almost all cases, the addition of a variable-speed drive to an electric motor system leads to substantial energy savings by allowing motor speed and load to be optimized to the system requirements. The efficiency of the variable-speed electronic drive portion of a modern motor system is very high: almost always above 95 percent, often 97 percent, and recent improvements are pushing drive efficiencies to 98 percent and higher. These high efficiencies for variable-speed drives can be achieved over a wide range of motor speeds and loads. However, even at these high efficiencies, the addition of a drive to a line-operated motor still reduces the peak efficiency of the motor system. Efficiency over 90% over such a wide operating range of speeds and torques is exceptional for a motor of this size. Most motor designs provide such high efficiencies only near their rated load, and display a significant decrease in efficiency at lower speeds and torques [22].

A. Soft Starter with energy savers

When starting, AC Induction motor develops more torque than is required at full speed. This stress is transferred to the mechanical transmission system resulting in excessive wear and premature failure of chains, belts, gears, mechanical seals, etc. Additionally, rapid acceleration also

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has a massive impact on electricity supply charges with high inrush currents drawing +600% of the normal run current. Soft starter provides a reliable and economical solution to these problems by delivering a controlled release of power to the motor, thereby providing smooth, step less acceleration and deceleration. Motor life will be extended as damage to windings and bearings is reduced. However, as the % loading increases, the % savings decrease. Energy savings are of appreciable quantity only if the time period is more than 5yrs [33, 34].

B. Fault control

In recent years, many researchers have been focused on fault tolerant control of nonlinear system, namely: control systems able, on the one hand to detect incipient faults in sensors and/or actuators and on the other one, to promptly reconstruct the control law so as to maintain performances in terms of both production quality and safety[23]. Industrial induction motor drives (IM) are used in numerous applications such as conveyers, cranes and ventilation systems. However, IM are subjected to various faults, such as stator short circuits, broken bars or rings, eccentricity, sensor and actuator faults. In [24-26] the authors propose active fault- tolerant control systems for induction motor that can adaptively reorganize themselves in the event of sensor loss or sensor recovery to sustain the best control performance, given the complement of remaining sensors. Multi-sensor switching control strategy for fault tolerant direct torque and flux control of the induction motor is proposed in [27]. In [28, 29] the authors present a fault tolerant strategy based on multi-controller and wavelet index. The IM tolerance for unexpected fault such as stator winding fault, and switch itself from nominal controllers to robust controllers designed for faulty conditions. In order to get better performance against fault conditions, two robust controllers were tested: back stepping controllers and sliding mode controllers. The sliding mode controllers were more interesting on maintaining control performance and equilibrium of IM [30].

C. Phase conversion

Motor drives constitute a predominant load for the agricultural sector. As most rural communities in the India are supplied with single-phase ac power, these drives have to be realized with single-phase motors, or with three phase motors (Induction Motors) driven by phase converters. Autotransformer capacitor phase converters and rotary phase converters have been usedfor several decades [18].Both have the advantages of simple structure and reasonably low cost. Autotransformer capacitor phase converters, however, cannot easily obtain balanced output voltage with reasonable cost, and rotary converters are heavy and have significant no-load losses, also both topologies have high inrush current during motor start up [19]. The three-phase induction motors have some advantages in the machine efficiency, power factor, and torque ripples compared to their single-phase counterparts [20]. Though the precise control of single phase induction motor is less complex in comparison to the three phase induction motor, but when the torque requirement is considered then three phase induction motor is the best choice.A 3-phase, 415V, 1440RPM, 1.5HP Induction motor is used as load for testing the developed hardware. Textronics TDS2024B storage oscilloscope is used to store the gate pulses and waveforms. The experimental result showed that PWM pulses produced remained approximately constant with increase in load and the developed hardware has satisfactory converted the single phase power to three phase power [21].

III. TORQUECONTROL TECHNIQUES OF IM

The two most popular sensor less control methods of IM are Field oriented control (FOC) and direct torque control (DTC). Unlike FOC, DTC does not require coordinate transformation, pulse width modulator (PWM) signal generators, current controllers and a position encoder, which introduces delays and requires a mechanical transducer. In spite of its simplicity, DTC provides fast instantaneous torque control in the steady state and under transient operating conditions with simple control structure [42, 43]. Since an EV drive system must feature a fast torque response, reasonable cost, reliability and robustness, the DTC of IM appears to be very convenient for EV applications [44–46].

A. Direct torque control (DTC):

DTC offers a much simpler structure than the FOC system. The problem of decoupling the stator current [2] for induction motordrives in the mid-1980s. The basic principle of DTC is to directly select stator voltage vectors (switching states) according to the differences in a dynamic fashion in the FOC is avoided in DTC. This method was proposed by Takahashi [1] and Depenbrock between the reference and the actual values of torque and stator flux linkage. The DTC can provide a very quick and precise torque response without the need for a complex field orientation block and inner current regulation loop. Hence, DTC is very well suited for operation at saturated voltage.

B. The major problem in basic DTC scheme

In spite of its simplicity, the basic DTC scheme based on hysteresis controllers causes some quite major drawbacks such as variable inverter switching frequency, high torque ripple and hence high sampling requirement to minimize the problems for digital implementation [47-52]. The problems are list out below: (1). Variable inverter switching frequency, (2). High torque ripple, (3). The need for high-speed processor.

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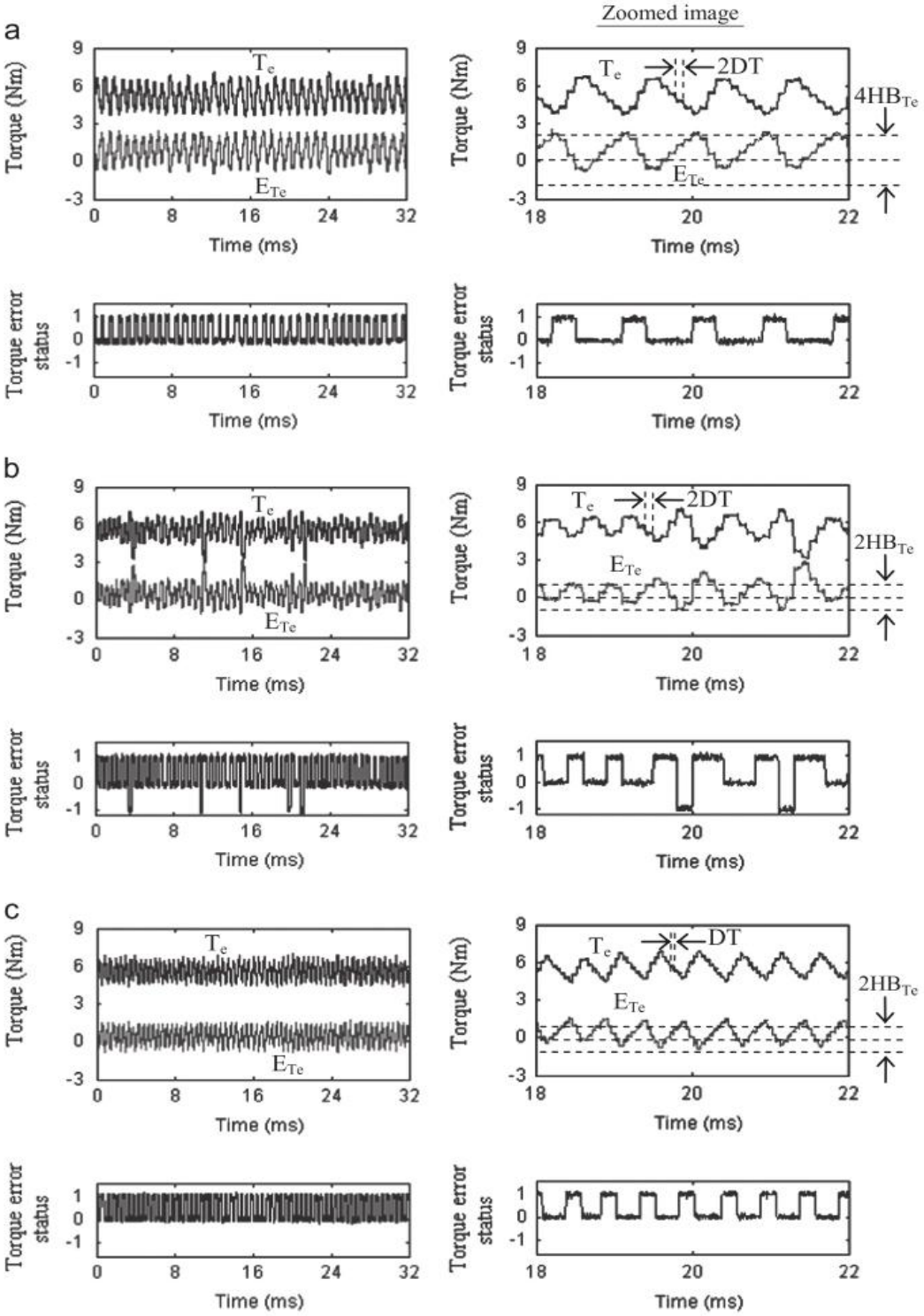

Fig. 4. Experimental results of control of output torque utilizing three-level hysteresis comparator (in hysteresis based-DTC). (a) Hysteresis band=$2HB_{Te}$, sampling time=2DT, (b) hysteresis band=HB_{Te}, sampling time=2DT and (c) hysteresis band¼HB_{Te}, sampling time=DT_{Te} [53].

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C. Some DTC improvements to solve problems:

As seen in the above overview, the basic DTC has some disadvantages. Several variations to its original structure (which referred to DTC as hysteresis-based) were proposed to improve the performance of DTC of induction machines. Noticeably, most research projects in recent decades have aimed to overcome the inherent disadvantages of hysteresis-based DTC schemes, such as variable switching frequency and high torque ripple. Some of those improvements are: (1) Switching control strategies, (2) DTC based on space vector modulation, (3) Constant switching frequency of torque controller, (4) Predictive control scheme, (5) Intelligent control techniques.

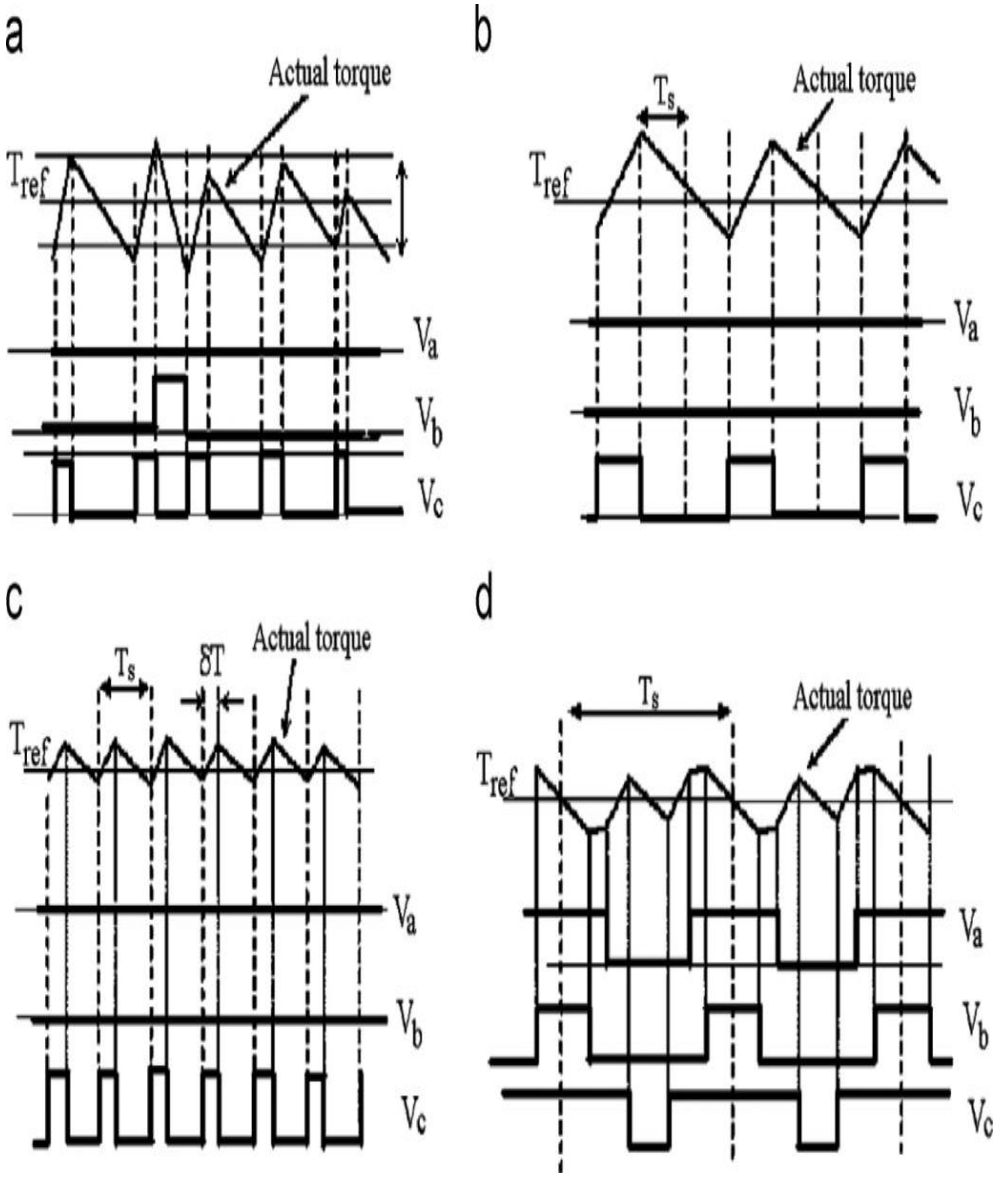

Fig.5. Typical torque waveforms in various switching strategies of DTC. (a) Hysteresis-based controller. (b) Fixed switching torque. (c) Fixed switching torque with controlled duty ratio. (d) Fixed switching torque with space-vector modulation [54].

D. Reliability

In recent years DTC as an innovative control method has gained the attraction for EV application, because it can also produces fast torque control of the induction motor and does not need heavy computation on-line, in contrast to FOC. DTC is low cost due to without mechanical speed sensors at the motor shaft. The rotor speed is estimated from sensed stator voltages and currents at the motor terminal. Hence, it can reduces hardware complexity and size of the drive machine, elimination of the sensor cable, improved noise invulnerability, increased reliability, and less maintenance requirements in EV applications [55-57].

IV. SPEEDCONTROL TECHNIQUES OF IM

Throughout the twentieth century, most of the drives for industrial processes, commercial equipment, and domestic appliance have been designed to operate at essentially

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constant speed, mainly because of the ready availability of economical induction motor operating on the available constant frequency ac power supply. For much mechanical system, it is well known that a variable speed drive provides improved performance and energy efficiency. However, until recently, the provision of a continuously variable speed has been considered too expensive for all but special applications for which the compromise of constant speed was not acceptable e.g. elevators, mill drives, machine tools. [60]. For many industrial applications an exact speed control is not needed, because of a great inertia of the mechanical system, a fast response to change in the reference, or due to fact that a precise control of the motor developed torque is not necessary. In these applications the main objective is to maintain the speed at a fixed reference value, and the use of constant V/f control method offers good results [61]. The V/f control method is, in principle a control method for keeping the air-gap flux constant bycontrolling stator voltage V and stator frequency f so that the ratio V/f is kept constant. However, as the frequency f approach zero near zero speed, the stator voltage V will also approaches zero and it will be absorbed by the stator resistance, causing the air gap flux, and consequently the developed torque, to decrease [59,62].domestic appliance have been designed to operate at essentially constant speed, mainly because of the ready availability of economical induction motor operating on the available constant frequency ac power supply. For much mechanical system, it is well known that a variable speed drive provides improved performance and energy efficiency. However, until recently, the provision of a continuously variable speed has been considered too expensive for all but special applications for which the compromise of constant speed was not acceptable e.g. elevators, mill drives, machine tools. [60].

A. Speed control of three phase induction motor

The motor used for domestic fans is a capacitor-run single-phase induction motor with squirrel cage rotor. The rotor resistance in these motors is higher and is therefore, quite suitable for wide range of speed control using stator voltage control. The commonly employed method of speed control in domestic fan motors is the use of a variable resistance in series with the stator of the motor [65]. Stator frequency control of variable speed induction motor drives using solid state device using solid state devices has been widely applied. This method provides better control properties and higher efficiency than other techniques in adjusting the speed of induction motors over a wide range [74]-[76]. The major disadvantage of these solid state drivers are their relatively high cost and complexity, as well as the harmonic distortion introduced on both supply on motor sides [77, 78]. As this scheme is cheaper, it is popular even today.

However, this is an inefficient method of speed control due to the power loss in the series resistance. In the alternative schemes, the triac is inserted either between the ac mains and the fan motor or in series with the main winding. The triac based schemes are simple, reliable, cost effective and superior in power savings [66-68]. The focus of the study in literature [67,68]was to improve energy saving rather than the aspects of power quality. A pulse width modulated (PWM) ac chopper has been suggested [69, 70]as an alternative to an ac voltage controller. The ac chopper employs forced commutated devices or self-commutated devices. The performance characteristic of a symmetrical PWM ac chopper controller-fed single-phase induction motor is available in literature [71]. In industrial applications D.C. drives are preferred in many cases where wide range and smooth speed control has to be provided. For these reasons preference is often given to adjustable speed induction motor drives as the induction motor is cheaper, robust in construction and more economical to operate and maintain. But the plain induction motor is essentially a constant speed, shunt characteristic machine, as its stable operation is restricted within a small range of speed. Apart from this, another major disadvantage of induction motor is its low operating power factor [63, 64]. The chief methods of speed control are: -

a)Variable-Voltage, Constant-Frequency Operation
b)Variable-Frequency Operation
c)Constant Volts/Hertz Operation
d)Variation of Number of Poles
e)Variation of Motor Resistance
f)Variation of Motor Reactance

B. Scalar control

In this type of control, the motor is fed with variable frequency signals generated by the PWM control from an inverter. Here, the *V/f* ratio is maintained constant in order to get constant torque over the entire operating range. Since only magnitudes of the input variable-frequency and voltage- are controlled, this is known as "Scalar Control". Generally, the drives with such a control are without any feedback devices (open- loop control). Hence, a control of this type offers low cost and is an easy to implement solution. In such controls, very little knowledge of the motor is required for frequency control. Thus, this control is widely used. A disadvantage of such a control is that the torque developed is load dependent as it is not controlled directly. Also, the transient response of such a control is not fast due to the predefined switching pattern of the inverter. Scalar control, as the name indicates, is due to magnitude variation of the control variable only, and disregards the coupling effect in the machine. The voltage of a machine can be controlled to control the flux, and frequency or slip can be controlled to torque. However flux and torque are also functions of frequency and voltage respectively. The most popularly used scalar control methodology is Volts/Hertz method of

a)Open Loop Constant *V/f* speed control.
b)Closed Loop Constant *V/f* speed control.

C. Vector control

This control is also known as the "field oriented control", "flux oriented control" or "Indirect torque control". Using field orientation (Clarke- Park transformation), three-phase current vectors are converted to a two-dimensional rotating reference frame (d-q) form a three-dimensional

stationary reference frame. The "d" component represents the flux producing component of the stator current and the "q" component represents the torque-producing component. Passing through separate PI controllers can independently control these two decoupled components. The outputs of the PI controllers are transformed back to the three-dimensional stationary reference plane using the inverse of the Clarke Park transformation [72]. The transformation from the stationary reference frame to the rotating reference frame is done and controlled with reference to a specific flux linkage space vector (stator flux linkage, rotor flux linkage or magnetizing flux linkage). In general, there exists three possibilities for such selection and hence, three different vector controls. They are:

1. Stator flux oriented control
2. Rotor flux oriented control
3. Magnetizing flux oriented control

The vector control is divided into two subcategories:

a) Open Loop Indirect vector control
b) Closed Loop Indirect vector control.

V. CONCLUSION

All over the world a significant amount of energy has always been consumed by the induction motor drives. Thus, global electricity financial savings can be carried out when ASD is utilized to replace the majority of the existing nonadjustable drive systems for IM. Proper control of the motor can reduce loss as well as improve the efficiency of the drive system. An extensive review of performance improvement schemes for IM drives is presented, in this paper there are three factors are discussed briefly in that the torque control method DTC is cost effective compared to FOC because of its simplicity and robustness, there are some drawbacks, such as flux and torque ripple. From the survey it can be seen that although many DTC schemes have been proposed to improve the drive performance, to date, there are still some limitations. Efficiency optimization of three-phase induction motor through optimal control and design techniques. Optimal control covered both the broad approaches namely, loss model control and search control. Optimal design covers the design modifications of materials and construction in order to optimize efficiency of the motor. The use of Artificial Intelligence techniques such as artificial neural network, fuzzy logic, expert systems and nature inspired algorithms; Genetic algorithm and differential evolution. improvement in performance with respect to power factor and total harmonic distortion an appreciable amount of energy saving is also obtained in the electronic transformer based scheme of speed control of capacitor-run. Even though the saving in input power is only a few watts with a single motor, the use of a large number of capacitor-run fans in domestic and small-scale industries will result in increased energy saving over a period of time.

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