Original Research Article

IMPROVEMENT OF THREE PHASE INDUCTION MOTOR PERFORMANCE USING VOLTAGE AND FREQUENCY SPEED CONTROL TECHNIQUES

ABSTRACT

Inductions motors are the most commonly used electric motors because of their robustness, durability, reliability and low cost, and essentially lack the ability to run at variable speed operation. However, the first DC motors were applied to most of electric drives. The advent of power electronics has drastically made a lot of improvement, where alternating current drive is used to control and run the performance of induction motor. This research work presents the use of voltage and Frequency control technique to improve the performance of speed control of three phase 4-pole induction motor. Controlling the speed of motor using traditional method such as controlling the supply voltage ,changing the stator pole and others incurs running motor at full speed ,speed instability, and the efficiency of the motor drop when motor speed is varied but the voltage and frequency ratio method of speed control solves this problem .A model and simulation in MATLAB for various method of speed control was analysed with constant voltage and frequency method showing much improvement on electromagnetic torque and the speed characteristic of the induction motor compared to other method such as change in stator resistance ,rotor resistance, number of poles, stator leakage resistance and others. Varying the line frequency at a maintained constant 8V/Hz V/F ratio and the effect of the torque-speed characteristics performance of the three phase 4-pole induction motor for line frequencies were investigated: (40Hz, 50Hz, 60Hz, 70Hz, and 80Hz). The result shows that as the line frequency increases, the torque decreases and the speed increases (or slip decreases), and for a line frequency of 40Hz, the torque observed is 43.6Nm while the rotor speed is 1076rpm. But for a line frequency of 80Hz, the peak torque was observed at 22Nm while the corresponding rotor speed was 2152rpm, thereby improving the speed control performances of the three phase 4-pole induction motor and its voltage frequency characteristics.

Key Words: induction motor; Matlab; Improvement; Supply Voltage; Frequency Variation; Speed Control; sensorless; V/F ratio; Cyclo Converter; Stator and Rotor.

INTRODUCTION

In several industrial areas, three phase induction motor drives are employed with a good power, ranging from few 100W to many MW. In an industrial-orientation country, more than half of all electrical energy used is converted to mechanical energy through AC induction motors. Induction motors have industrial and household applications and expend over 50% of the total generated electrical energy. Induction motor (three phase) popularity on board ship is due to their high reliability factor simplicity in design, robustness in construction, low cost and high efficiency. Different application can be used by three phase induction motor with their various load requirement and speed, and its significant is to ensure cost effective operation [1]. Enlistment engines exhaust more than half of the complete produced electrical energy and have modern and family applications. One-staged enlistment engines are generally used in modern control and home machines and. During the most recent couple of years, speed and force control guideline are offbeat with engine drives which acquired critical prominence. It is feasible to consolidate the acceptance engine underlying vigour with the control effortlessness and effectiveness of an immediate current engine. This development came about to the substitution of the DC machines by acceptance engines in numerous applications over the most recent couple of years. Prior just DC engines were utilized for drives requiring variable velocities due to work with of their speed control techniques [2]. The ordinary techniques for speed control in an enlistment engine are pricey or too wasteful hence limiting their degree of utilization to just consistent speed drives. Models incorporate to drive siphons, fans, blowers, blenders, fomenters, factories, transports, smashers, machine instruments and cranes. They are extremely basic, dependable, low upkeep and minimal expense. Today, with progressions in power gadgets, microcontrollers, and computerized signal processors (DSPs), electric drive frameworks have improved definitely. At first the rule of speed control depended on consistent state thought of the enlistment engine. V/F control was reasonable for the open-circle speed control of drives with low powerful necessities.

There are various techniques for controlling enlistment engine for mechanical application. Be that as it may, the primary point of this work is to complete an examination on the voltage/recurrence proportion strategy for enlistment speed control method. This technique offers a simple method to control both the recurrence and size of the voltage applied to an engine. Nonetheless, better effectiveness can be gotten by these engine drives with less commotion. The most uncontrolled method is the consistent V/Hz rule which necessitates that recurrence and the greatness of the voltage applied to the stator of an engine keep a steady proportion. Thus, by this, the attractive field in the stator is saved practically steady for every working point. Along these lines, consistent force is kept up with. Additionally permits the engine to accomplish quicker powerful reaction [3]. Voltage and frequency control was suitable for the open-loop speed control of drives as shown in Figure 1, with low dynamic requirements. Developments of several techniques for control speed of induction motor includes: pole changing, frequency variation, variable rotor resistance, variable stator voltage, constant V/F control, slip recovery method etc. Using traditional methods to control the speed of a motor involve running the motor at full speed and then using mechanical means such as gears, hydraulic couplings or pulleys. This consumes tons of energy and also expensive. There are many means of controlling induction motor speed, but the most popular problem discovered in them is that the efficiency of the motor drops when the motor speed is varied and the motor used to experience speed instability. The aim of this research work is to enhance the performance and efficiency of speed control of three phase induction motor using voltage and frequency ratio method. It also explained the best techniques for controlling the speed of electric motor and designed to be of immense benefit to all the users of electric motor most especially in industries and serve as a useful piece of information for both producers and users of electric motor speed controller.

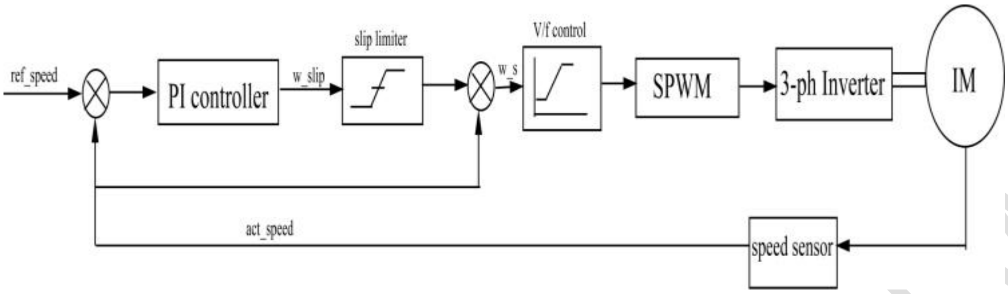

Figure 1: Block diagram of closed loop v/f control of induction motor

2. THE USE OF INDUCTION MOTOR

More than half of the electricity used is converted to energy through induction motors in modern countries. Induction motors consume more than 50% of the entire generated electricity and are extensively utilized in industrial and household appliances. Single-phase induction motors are widely utilized in home appliances and industrial control. The concept of speed and torque control of asynchronous motor drives has gained significant popularity during the previous couple of years. In this way, it is possible to mix the induction-motor structural robustness with the control simplicity and efficiency of an immediate current motor. This evolution resulted to the replacement of the direct current machines with induction motors in many applications within the previous couple of years. DC motors were employed earlier only for drives requiring variable speeds due to facility of their speed control methods.

The applications of speed control of induction motor were limited to only constant speed drives because it were either too extravagant. They are used to drive pumps, fans, compressors, mixers, agitators, mills, conveyors, crushers, machine tools, cranes, etc. the electric motors are so popular thanks to its simplicity, reliability, less maintenance and low cost. Today, with advancements and improvement in digital signal processors (DSPs), power electronics, microcontrollers, and electric drive systems have improved drastically. Consideration of the induction motor, V/F control was the commonly used method for the open-loop speed control of drives with low dynamic requirements which is the focus of this research work.

Replacement of current- limiting soft-starter for a three-phase induction motor drive system using pulse width modulation (PWM) chopper unique in configuration with three-phase has been presented [4] A good AC-chopper using only four insulated gate bipolar transistors (IGBTs) is additionally proposed. It requires just one current sensor. The duty ratio of the chopper IGBTs from the closed loop current control is to limit the motor starting current at a preset value. Only two complementary gate pulses are obtained from the negative feedback circuit to regulate the four IGBT switches. Posit that phased two-level inverters voltage space vector for the three-level inverter-cont4olled induction motor with cascades [5]. This study proposes a five-level torque controller (FLTC)-based torque control technique to retain the high dynamic performance and boost the steady-state motor torque performance. The quality field oriented control (FOC) for induction motors (IM) is that the finite control set model predictive control (FCS-MPC) presented the foremost serious and up to date competitor [6], the study shows that Direct torque control (DTC) has been widely used as an alternate to traditional field-oriented control (FOC) methods for three-phase drives. They also suggested that Direct torque control (DTC) has been recently used for the event of high efficiency in five-phase induction motor (IM) drives. This work analyzes the fault-tolerant capability of six-phase drives with parallel converter supply. Scenarios of up to 3 faults for single and two neutral configurations are examined, optimizing off-line the post- fault currents and modifying accordingly the control strategies. Evaluation of a model to control scheme for multiphase induction machines with multi three-phase. Complete details about the predictive control scheme and adopted flux observer are included, has been suggested Direct torque control (DTC) has been recently used for the event of high performance five-phase induction motor (IM) drives in normal operation of the system and therefore the ability of DTC to manage things has been analyzed as compared with different rotor field-oriented control (RFOC) strategies [7], discussed three-phase machines are the industry standard for electrical drives, but the inherent fault tolerance of multiphase machines makes them a beautiful alternative in applications requiring high reliability. This novel strategy is then combined with minimum losses and maximum torque criteria to urge a variable current injection method that minimizes the drive derating, reduces the copper losses and improves the braking transients. It was observed that the six-phase induction motor drive can perform successfully within the different zones.

The reviewed high order of the dynamics and nonlinearity of an induction motor estimation of the angle speed and rotor position becomes a challenging problem without the measurement of mechanical variables [8]. The benefits of position and more so speed of a sensorless induction motor drives are to be optimised in order to minimised hardware complexity and lower cost, increasing reliability,reduce size of drive machine, eliminate of sensor cable, better noise immunity and fewer maintenance requirements. The presentation of sliding mode controller with rotor flux estimation for induction motor drives [9, 10], the rotor flux was also estimated using a sliding mode observer. Most methods are basically supported the Model Reference Adaptive System schemes (MRAS). Confirmed reactive-power-based-reference model was confirmed and derived in both motoring and generation modes but one among the disadvantages of this algorithm is its sensitivity to detuning within the stator and rotor inductances [11] An MRAS pattern is so simple but its greatest drawback is that the sensitivity to uncertainties within the motor parameters.

Another method based on the Extended Kalman Filter (EKF) algorithm was proposed [12]. The EKF may be a stochastic state observer where nonlinear equations are linearized in every sampling period. An interesting feature of the EKF is its ability to estimate simultaneously the states and therefore the parameters of a dynamic process. This is generally useful for both the control and therefore the diagnosis of the method.

The advancement of microprocessor and power electronics which provides and permit the implementation of modern techniques for induction machines like field-oriented control also referred to as vector control [13]. This reduces the value of drive components and provision of higher efficiency; lower operating costs. In sensor-less field with oriented control, the speed or position cannot be estimated, their values are estimated using other parameters like phase voltages and current, that are directly measured. Sensor-less drives are getting more and more important as they will eliminate speed sensors maintaining accurate response. While observing only the stator current and voltages, it is possible to estimate the necessary control variables. There is other sort of methods for state estimation that's supported the intelligent techniques is employed within the recent years by many authors. The discussion Variable-speed constant- frequency generating systems are used in wind power, hydro power, and aerospace and naval power generations to enhance efficiency and reduce friction [14]. In these applications, the slip power recovery system comprising of doubly excited induction machine or doubly excited brushless reluctance machine and PWM converters with a dc link. Thus from the working rule of three phase induction motor, it is going to be observed that the rotor speed should not reach the synchronous speed produced by the stator. If the speeds become equal, there would be no such relative speed, so no EMF induced within the rotor, and no current would be flowing, and thus no torque would be generated. Consequently, the rotor cannot reach the synchronous speed. The difference between the stator (synchronous speed) and rotor speeds is named the slip. The rotation of the magnetic flux in an induction motor has the advantage that no electrical connections got to be made to the rotor.

3. METHODOLOGY

The data used for this research work comprises of machine parameters gotten from Cummins induction motor manufacturer, Vein Road Onitsha, between January and April 2019 as shown in Table 1. The simulation sequence of the developed models for the three phase 4-pole induction motors in Matlab is given in the flow sequence take to write a program in a more interactive language as shown in Figure 2. The simulation sequence was modelled and developed in Matlab using equation (2.5). Nine (9) script files and codes were written to accommodate the nine sensitivity analyses performed on the investigation of the effect of changing parameters on the three-phase induction motors. Figure 5, 6, 9 and 10 shows the effect of varying supply voltage, line frequency, frequency at constant V/F ratio and frequency at varied V/F ratio of the torque-speed characteristics performance of the three-phase induction motor. Figure 3 and 4 shows the hardware design and implementation.

From Figure 2, TR1 and TR2 is a step down transformer from 220V to 12V, BR1 is bridge rectifier which rectifiers the out coming voltage from TR1, C_1 filter the rectified voltage, R1 and R2 forms a voltage divider, this sub circuit create a power supply to the microcontroller which is used to control V/F of the induction motor. Also from Figure 4, the main of 220V AC passes through bridge rectifier BR_2 which rectifies the incoming AC into a pulsating DC. C_2 filters the rectified voltage form BR_2. TR_1 is a step-down transformer, which steps down the main of 220V into 12V aAC, BR_1 rectifies the 12V ac form TR_1 into pulsating DC C_1 filters BR_1. U_1 is 7805 regulator which regulate the input DC volt 12V to 5V DC, C_4 filters the regulated voltage to U_2. U_2 is the heart beat of the control circuits which control the voltage and frequency and also generate pulses to fire U_3, U_4 and U_5. U_2 pin 15 and pin 16 is connected to a crystal oscillator which oscillates at $20MH_Z$ driving U_2 into oscillation. U_2 pin 2, pin 3, pin 8 and pin 9 are used for controlling the frequency and voltage. U_3, U_4, and U_5 are opta isolated drivers. R_7, R_8 and R_9 are current limiter which protects U_3 to U_4 from excess current. V_6, V_7 and V_8 are power amplifiers which amplify the signal form U_3, U_4 and U_5 to the induction motor.

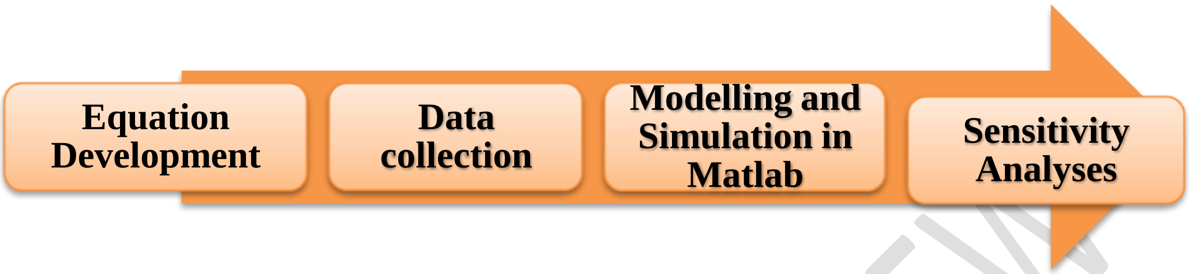

Figure 2: Block Diagram of Flow Sequence

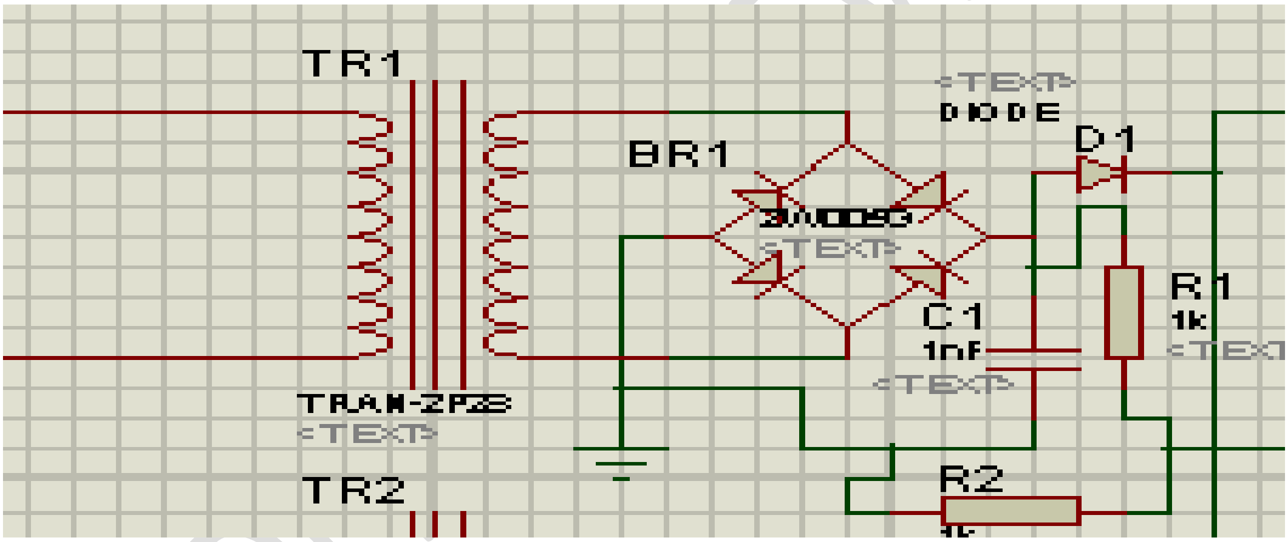

Figure 3: Transformer Rectification.

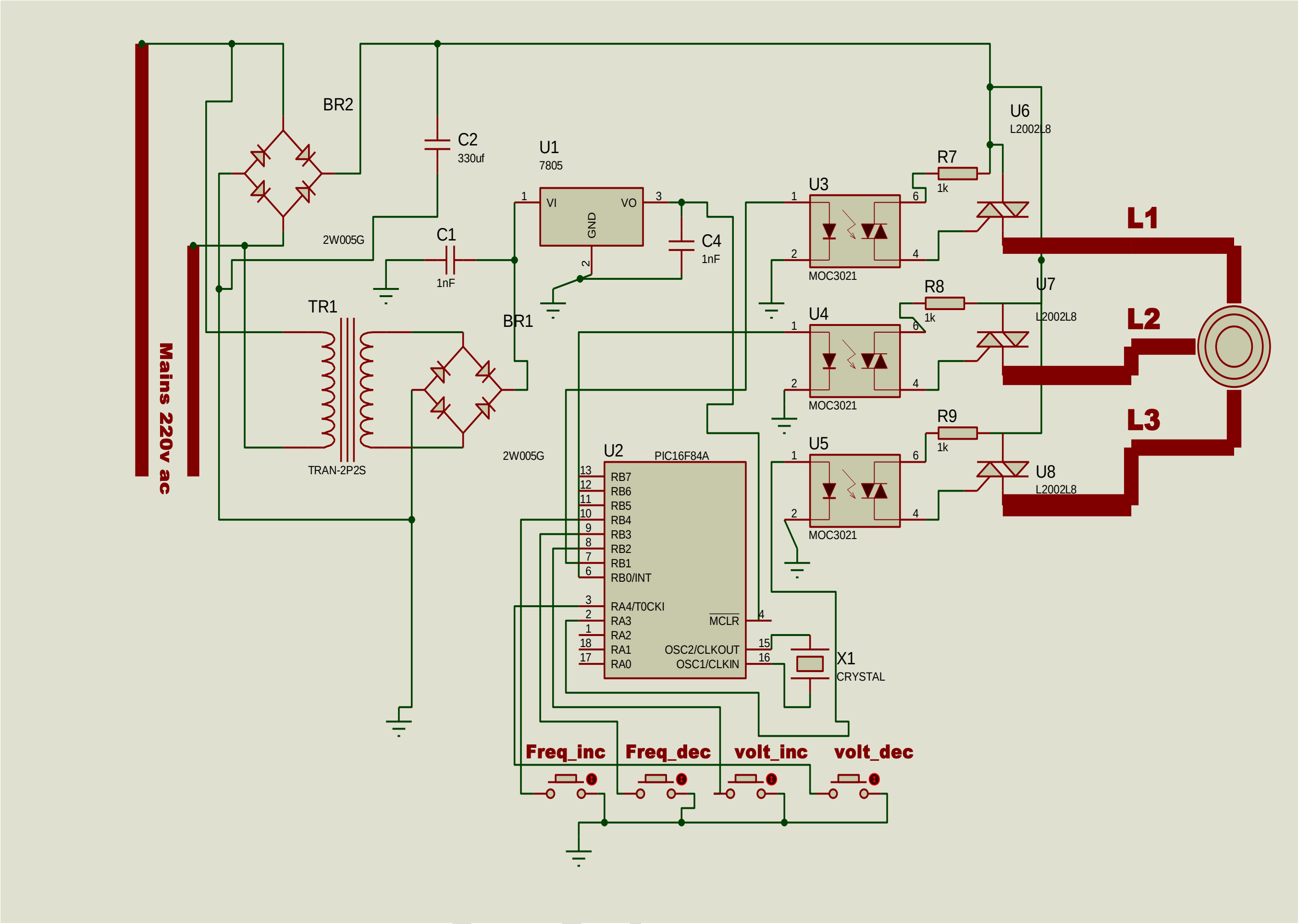

Figure 4: Circuit Diagram and Analysis

Table 1: Simulation Parameter

Parameter	Value	
	Base	Sensitivity
Line to Line supply voltage (RMS value)	400 V	400V, 440V, 480V, 520V, 560V
Stator Resistance	0.1 ohm	0.1ohm, 0.15ohm, 0.2ohm, 0.25ohm, 0.3ohm
Rotor Resistance	0.15 ohm	0.35ohm, 0.3ohm, 0.25ohm, 0.2ohm, 0.15ohm,
Number of poles	4	4, 6, 8, 10, 12
Frequency	50 Hertz	80 Hertz, 70 Hertz, 60 Hertz, 50 Hertz, 40 Hertz.
Stator leakage resistance @ 50 Hz	0.75 ohm	0.55ohm, 0.65ohm, 0.75ohm, 0.85ohm, 0.95ohm
Rotor leakage resistance @ 50 Hz	0.75	0.55ohm, 0.65ohm, 0.75ohm, 0.85ohm, 0.95ohm

V/F ratio	8 V/Hz	6V/Hz, 7V/Hz, 8V/Hz, 9V/Hz, 10V/Hz
Power Rating	1.8 kw	

4. INDUCTION MOTOR SPEED CONTROL TECHNIQUES

There are many techniques involve in controlling the speed of induction motor, but here are discussed the techniques related to this research work and they are as follows:

4.1. Varying Supply Voltage Speed Control

The speed of induction motor can be varied by changing supply voltage. The torque developed during this method is proportional to the square of the availability voltage ($T \propto V^2$). This is the most cost effective and simplest way, but it's rarely used due to the below reasons. A small change in speed requires an outsized change in voltage. This large change in voltage will end in an outsized change within the flux. The torque produced by running three phase induction motor is given by:

$$T \propto \frac{sE_2^2 R_2}{R_2^2 + (sX_2)^2} \tag{1.0}$$

$$T \propto \frac{sE_2^2}{R_2} \tag{1.1}$$

The low slip region $(sX)^2$ is extremely small as compared to R^2. So, it can be neglected. Since rotor resistance, R_2 is constant so the equation of torque further reduces to

$$T \propto sE_2^2 \tag{1.2}$$

the rotor induced EMF E2 $\propto$ V. So,$T \propto sV^2$. The equation above clears that if we decrease supply voltage torque also will decrease. But for supplying an equivalent load, the torque must remain an equivalent, and it's only possible if we increase the slip and if the slip increases the motor will run at a reduced speed. This method of speed control is never used because a little change in speed requires an outsized reduction in voltage, and hence the present drawn by motor increases, which cause overheating of the induction motor.

4.2. Speed Control by Frequency Variation

Control of Frequency variation is a method which is employed for the regulation of an induction motor speed. The synchronous speed and therefore, the speed of the motor can be controlled by varying the supply frequency. The variation of the supply frequency (on small amount), the speed will be varied also. But a decrease in supply frequency decreases the speed and increases the flux, core losses which lead heating and low efficiency. Increase in frequency increases the speed and reduces the torque. Separate costlier auxiliary equipment is required to provide a variable frequency. The synchronous speed of an induction motor is given by:

$$N_s = \frac{120f}{P} \tag{1.3}$$

Where, f = frequency of the availability and P = number of stator poles.

Therefore, the supply frequency changes with change in synchronous speed. Actual speed of an induction motor is given as

$$N = Ns\ (1 - s). \tag{1.4}$$

Where N = Actual speed, N_S = Synchronous speed, S = Slip.

Equation (1.4) present the EMF induced in the stator of the induction motor and is given by:

$$E_1 = 4.44k_{w1}f\varphi T_1 \tag{1.5}$$

Therefore, if the availability frequency is modified induced EMF also will change to take care of an equivalent air gap flux. The terminal voltage V1 is equal to the induced EMF E1 if the stator voltage drop is neglected. In order to avoid saturation and minimize the losses, the motor is operated at rated air gap flux. This condition is obtained maintaining (V/f) ratio constant at the speed value and by varying the terminal voltage with frequency. This type of control is understood as Constant Volts per Hertz. Thus, the speed control of an induction motor using variable frequency supply requires a variable voltage power source. The variable frequency supply is obtained by the subsequent converters such as: voltage source inverter, current source inverter and cyclo converter. An inverter converts a hard and fast voltage DC to a hard and fast or variable voltage AC with variable frequency. Cyclo converter converts a hard and fast voltage and glued frequency AC to a variable voltage and variable AC frequency. The variable frequency control allows good running and transient performance to be obtained from a cage induction motor. Cyclo converter-controlled induction motor drive is suitable just for large power drives and to urge lower speeds.

4.3. Changing the Number of Stator Poles

From the above condition of coordinated speed, it tends to be seen that simultaneous speed (and henceforth, running rate) can be changed by changing the quantity of stator posts. This technique is typically utilized for confine enlistment engines, as enclosure rotor adjusts for quite a few stator posts. Change in stator shafts is accomplished by at least two autonomous stator windings twisted for different number of posts in same spaces. For instance, a stator is twisted with two 3phase windings, one for 4 shafts and other for 6 posts for supply recurrence of 50 Hz: synchronous speed when 4 post winding is associated, Ns = 120*50/4 = 1500 RPM and synchronous speed when 6 shaft winding is associated, Ns = 120*50/6 = 1000 RPM

4.4. Control from Rotor

This method involves using rotor rheostat control and by injecting EMF in rotor circuit as follows:

(a) Rotor rheostat control; this method is analogous thereto of armature rheostat control of DC shunt motor. But this method is merely applicable to slip ring motors, as addition of external resistance within the rotor of cage motors isn't possible. Also, in this method of speed control, two motors are used. Both are mounted on a same shaft so that both run at the same speed. One motor is fed from a 3phase supply and therefore the other motor is fed from the induced EMF in first motor via slip-rings as shown in Figure 4.

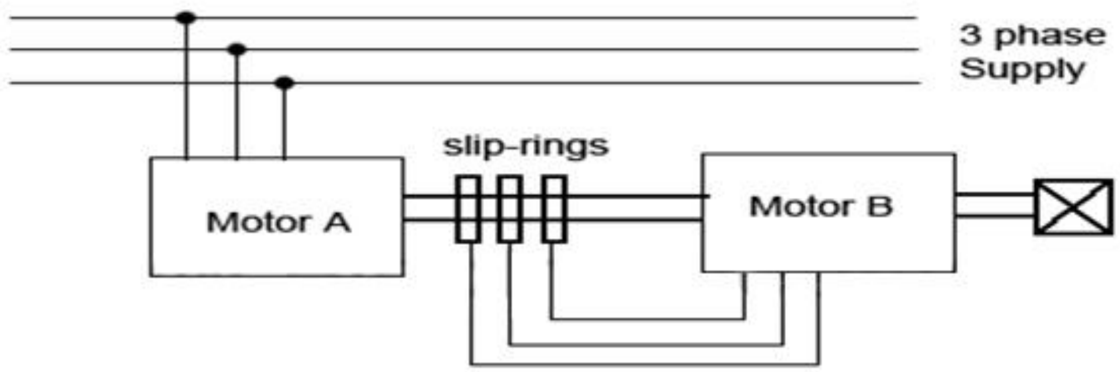

Figure 5: Motor Arrangement.

Motor A is called the main motor and motor B is called the auxiliary motor. Let, N_{s1} = frequency of motor A, N_{s2} = frequency of motor B, P_1 = number of poles stator of motor A, P_2 = number of stator poles of motor B, N = speed of the set and same for both motors and f = frequency of the supply. Now, slip of motor A, $S_1 = (N_{s1} - N) / N_{s1}$.

Frequency of the rotor induced EMF in motor A, $f_1 = S_1 f$. Now, auxiliary motor B is supplied with the rotor induce EMF. Therefore, $N_{s2} = (120f_1)/P_2 = (120S_1 f)/P_2$. Now putting the value of $S_1 = (N_{s1} - N) / N_{s1}$ gives equation (1.6).

$$N_{s2} = \frac{120f(N_{s1} - N)}{P_2 N_{S1}} \tag{1.6}$$

At no load, speed of the auxiliary rotor is almost same as its synchronous speed. i.e. $N = N_{s2}$. from equation (1.6) it can be obtained that:

$$N = \frac{120f}{P_1 + P_2} \tag{1.7}$$

with this method, four different speeds can be obtained: When only motor A works, corresponding speed = .Ns1 = 120f / $P_{1,}$ when only motor B works, corresponding speed = Ns2 = 120f / P_2, if commutative cascading is done, speed of the set = N = 120f / (P_1 + P_2) and if differential cascading is done, speed of the set = N = 120f (P_1 - P_2).

(b) By injecting EMF in rotor circuit; in this method, speed of an induction motor is controlled by injecting a voltage in rotor circuit. It is necessary that voltage EMF being injected must have same frequency as of the slip frequency. However, there is no restriction to the phase of injected EMF. If we inject EMF which is in opposite phase with the rotor induced EMF, rotor resistance will be increased. If we inject EMF which is in phase with the rotor induced EMF, rotor resistance will decrease. Thus, by changing the phase of injected EMF, speed are often controlled. The main advantage of this method may be a wide range of speed control (above normal also as below normal) is often achieved. The EMF is often injected by various methods like Kramer system and Scherbius system.

4.5. Sensor-less Control Method; There is escalated research overall committed to sensor-less strategies. Engine drives without a speed or position sensor have gotten a lot of examination consideration as of late, both for IMs and PM brushless sorts. Such strategies commonly measure stator amounts, generally current, straightforwardly through existing transducers typically present inside the inverter and voltage, albeit seldom with a prompt estimation. SI techniques are likewise utilized. Figure 6 shows a common schematic of a sensor-less plan. Benefits of such "sensor-less" plans incorporate more minimal drive with less upkeep: no link to machine transducers, simpler application especially to existing machines, decreased electrical commotion and transducer cost is kept away from suitable threatening conditions, including temperature. In spite of much exertion and progress, activity at extremely low speed stays hazardous especially for an IM sensor-less drive. Appropriate relative examination of the numerous variations in the broad writing on this subject is troublesome. This is predominantly on the grounds that a normal arrangement of tests or benchmarks has not been concurred. Indeed, even very basic plans can give results which are sufficient for undemanding applications. Benchmark tests are proposed in four classifications, including a flight of stairs speed transient more than 150 r/min in ten stages, i.e., of 30 r/min, with drive information to be completely indicated, including snapshot of dormancy since huge qualities can make results look amazing. Affectability to boundary change is likewise fundamentally significant.

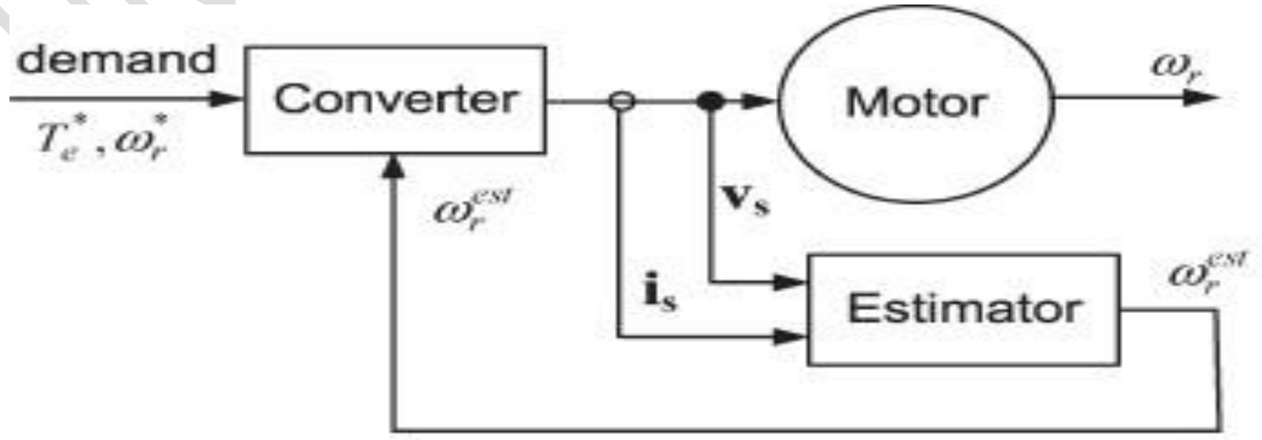

Figure 6: Schematic of a speed sensor-less.

4.6. Equation development

Three-phase induction motors are represented by set of equations. The slip is given b

$$S = \frac{N_s - N_r}{N_s} \tag{1.8}$$

Where$S = slip$,$N_s = synchronous\ speed$, $N_r = Rotor\ speed$.

The rotor speed can otherwise be written as:

$$N_r = N_s(1 - S) \tag{1.9}$$

The Synchronous speed is given as:

$$N_s = \frac{120f}{P}, \qquad rpm \tag{2.0}$$

or

$$N_s = \frac{2f}{P}, \qquad rps \tag{2.1}$$

Where, if the unit of the synchronous speed is to be determined in radians, then the speed has to be multiplied by the factor (2π).

$$\omega_s = 2\pi N_s \tag{2.2}$$

Similarly, the angular value of the rotor speed is give as:

$$\omega_r = 2\pi N_r \tag{2.3}$$

The rotor current is given as:

$$I_2 = \frac{V_0}{\left[\left(R_s + \frac{R_r}{S}\right)^2 (X_s + X_r)^2\right]^{0.5}} \tag{2.4}$$

The electromagnetic torque is given as:

$$T = \left[\frac{3}{\omega_s}\right]\left[\frac{R_s}{S}\right]\left\{\frac{V_0}{\left[\left(R_s + \frac{R_r}{S}\right)^2 (X_s + X_r)^2\right]^{0.5}}\right\} \tag{2.5}$$

Where, T is the electromagnetic torque [Nm], $\omega_s = is\ the\ synchronous\ speed, rads/sec.$

If the synchronous speed is in revolutions per minute then the torque is given by:

$$T = \left[\frac{3}{N_s}\right]\left[\frac{R_s}{S}\right]\frac{V_0}{\left[\left(R_s + \frac{R_r}{S}\right)^2 (X_s + X_r)^2\right]^{0.5}}$$ 2.6)

The power analyses of the circuit are given as follows: the power transferred across the air gap to the rotor is given as:

$$P_g = 3E_2I_2\cos\theta_2 = \frac{3I_2r_2}{s} \tag{2.7}$$

The rotor copper loss is given as:

$$P_{cu} = 3I_1^2r_1 \tag{2.9}$$

$$P_m = P_g - P_{cu} \tag{3.0}$$

$$P_o = P_m - (Frictional\ losses, windage\ and\ stray\ losses) \tag{3.1}$$

Thus, torque is given as:

$$T = \frac{P_m}{\omega_r} = \frac{P_m}{2\pi N_r} \tag{3.2}$$

The torque developed is proportional to the air gap power Pg. The air gap power Pg is usually known as torque measured in synchronous watts.

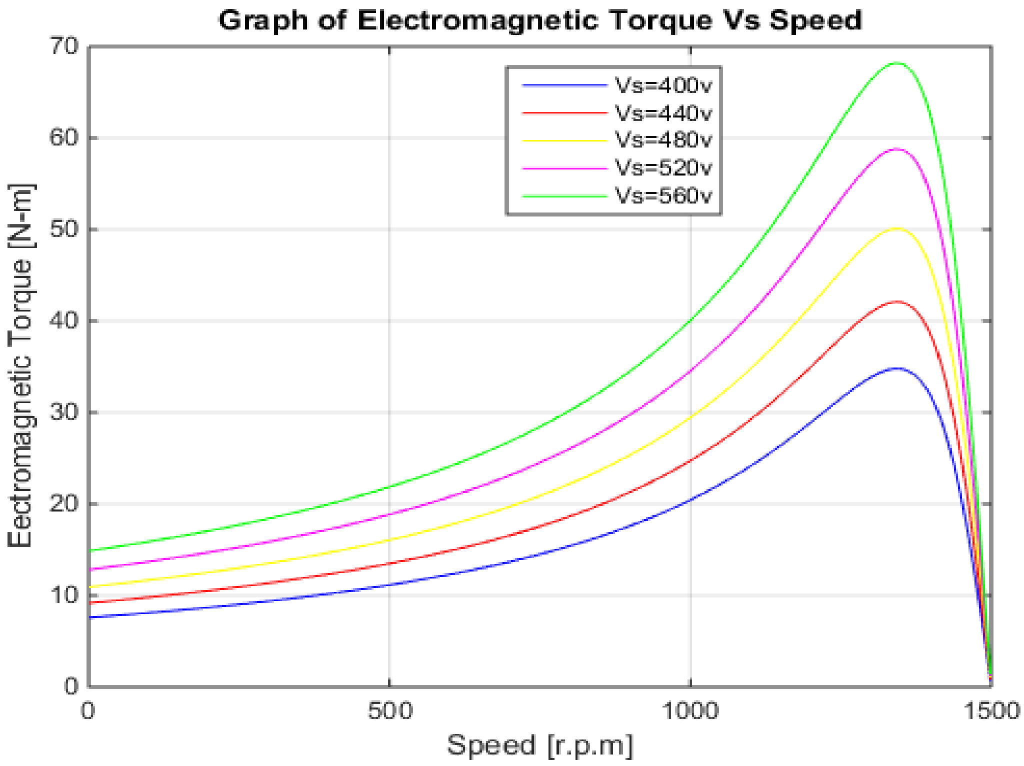

Figure 7: Torque -speed at varied supply voltage

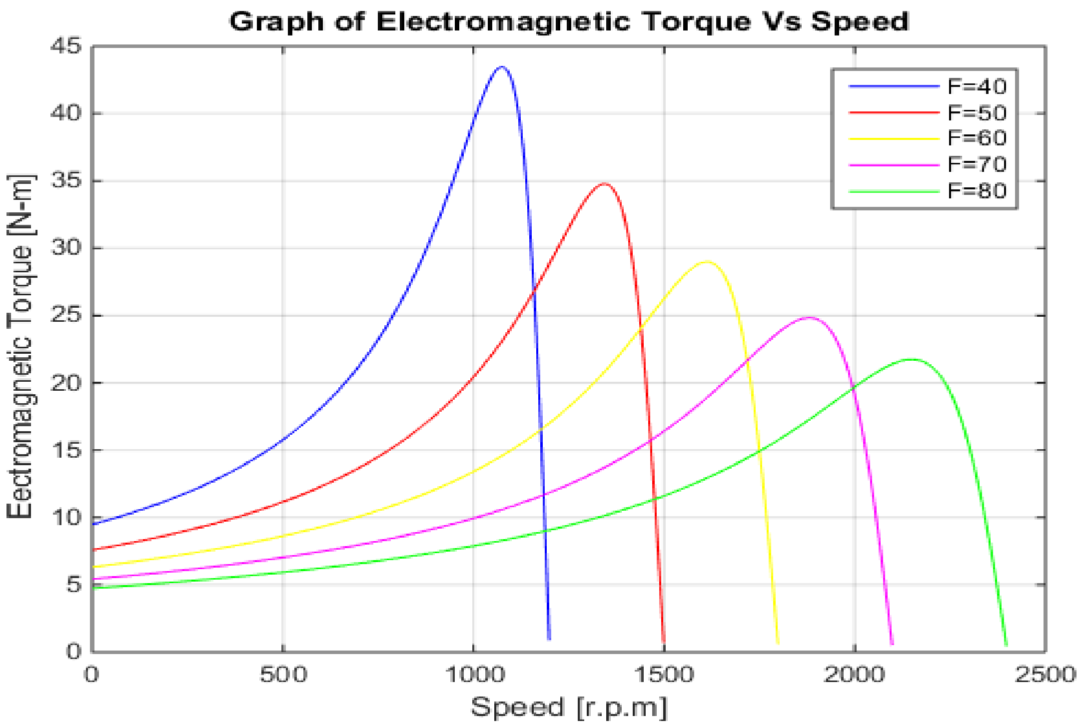

Figure 8: **Torque -speed at varied line frequency**

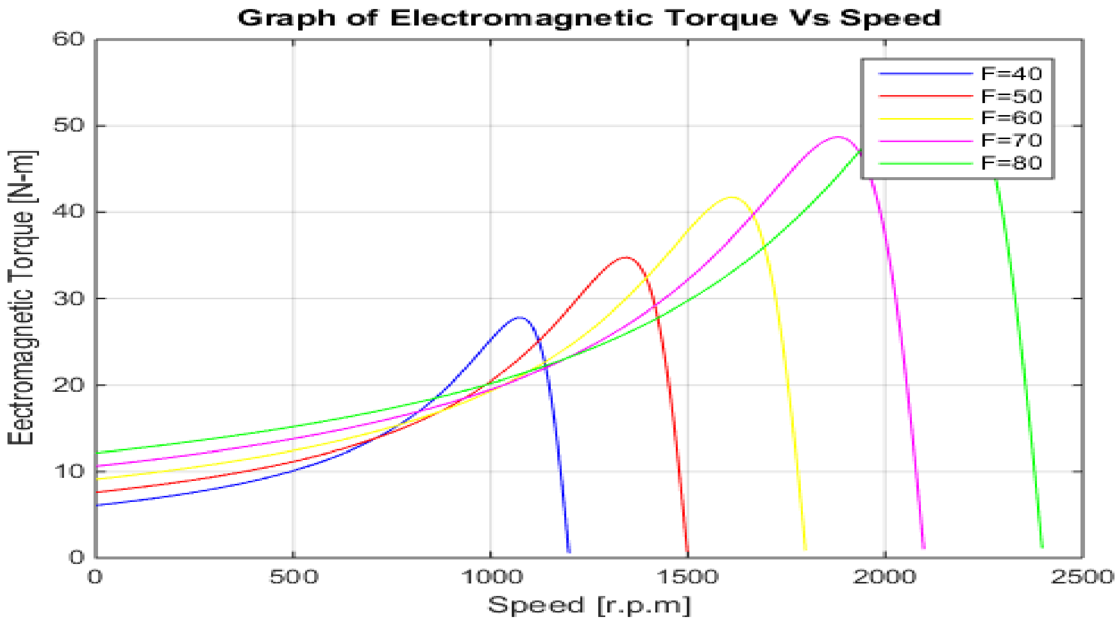

Figure 9: Torque -speed at varied frequency and constant V/F ratio

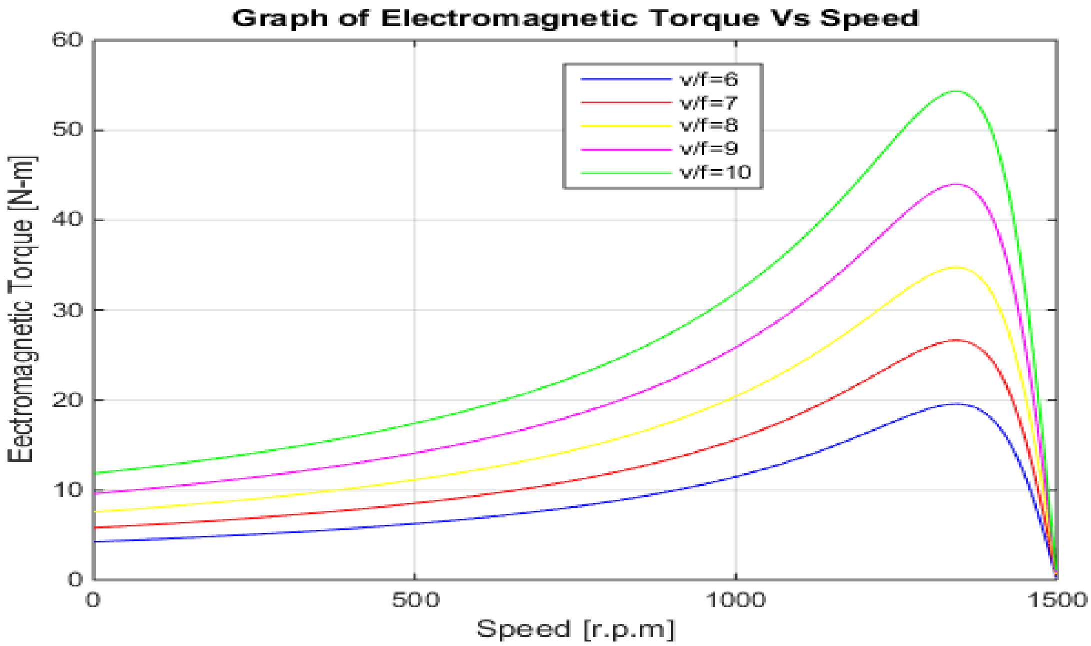

Figure 10: Torque -speed at varied V/F ratio

5. RESULTS AND DISCUSSION

The result for the effect of the changing parameters on the torque-speed value for the three-phase induction motors are presented in Figure 4, 5, 8 and 9, and they represent the steady state behaviour of the three-phase induction motor. The varied supply voltage and the effect of the torque-speed characteristics performance of the three-phase induction motor for line-to-line RMS voltage were investigated: (400V, 440V, 480V, 520V, 560V). It was observed from Figure 4 that as the supply voltage increases, the torque increases and the speed remains constant, and for a voltage of 400V, the torque peaked at 35Nm corresponding to 1350rpm. While for 560V, (green line) the torque peaked at 68.2Nm corresponding to 1350rpm. Thus as the voltage increases, the torque increases while the rotor speed remains constant (i.e. at the same slip). Varying the line frequency at a maintained constant 8V/Hz V/F ratio and the effect of the torque-speed characteristics performance of the three-phase induction motor for line frequencies were investigated: (40Hz, 50Hz, 60Hz, 70Hz, and 80Hz). The result shows that as the line frequency increases, the torque decreases and the speed increases (or slip decreases), and for a line frequency of 40Hz, the torque observed from figure 5 is 43.6Nm while the rotor speed is 1076rpm. But for a line frequency of 80Hz, the peak torque was observed at 22Nm while the corresponding rotor speed was 2152rpm. It was also observed from Figure 8 that as the line frequency increases at constant V/F ratio, the torque increases and the speed also increases (or slip decreases). For a line frequency of 40Hz, the torque observed from figure 8 is 27.9Nm while the rotor speed is 1080rpm. But for a line frequency of 60Hz, the peak torque was observed at 42Nm while the corresponding rotor speed was 1614rpm. Thus increasing the line frequency at constant V/F ration increases the electromagnetic torque and also increases the rotor speed (decreased slip).

The effect of varying V/F ratio as shown in Figure 9 shows that as the V/F ratio increases, the torque increases and the speed remains constant. For V/F ratio of 6V/Hz (the blue line), the torque peaked at 19.8Nm corresponding to 1350rpm. While for 10V/Hz, (green line) the torque peaked at 54.8Nm corresponding to 1350rpm. Thus as the voltage increases, the torque increases while the rotor speed remains constant (i.e. at the same slip). It is pertinent to note that the speed control of the three-phase induction motor was enhanced and the evaluations made herein are geared towards improvements in characteristics of the voltage frequency.

6. CONCLUSION

It can be concluded that using constant V/F ratio control, the voltage supply control and the supply frequency control techniques, constant flux can be achieved in order to get different operating zone for various speeds and torques. Different synchronous speed can be achieved with almost the same maximum torque that can makes the motor completely utilized and also has a good range of speed control. To maintain the V/F ratio helps us to maintain a constant maximum torque while controlling the speed. It is therefore recommended that the ratio of the change in voltage and frequency must be constant in order to keep the flux content. Thus by maintaining a constant V/f ratio maximum torque of the motor becomes constant for changing speed and the initial starting load torque should be zero. This will make the motor speed to move from the incremented of zero to the synchronous speed.

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