A Review on Speed Control Techniques of Single Phase Induction Motor

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Abstract: ***In this paper, different types of speed control methods for the single phase induction motor are described. This research paper review speed control of single phase induction motor by means of V/F control, PWM technique and direct flux and torque control. In V/F control, maintain ratio V/F constant. Different types of PWM strategies have been used in speed control of SPIMD's [sinusoidal pulse induction motor drive], most widely sinusoidal PWM & space vector PWM strategies [7]. The proposed paper describes the several PWM strategies with an AC chopper to control the speed of single phase induction motor and reduce the harmonic present in motor current [2]. PWM technique has been used to operate the power electronics switches (IGBT) of an AC chopper. IGBT is used as power switching device because of having advantage of other power switch (MOSFET, Thyristor ext). The voltage Controller achieves an almost linear response and the motor speed is smoothly regulated within the full dynamic range of the control input [3]. Direct flux and torque control (DTC) based speed control of induction motor (IM) drive and effect of flux and torque Hysteresis band amplitude on this strategy is presented. This scheme is simple and provides a good dynamic response, but the major problem associated with this DTC drive is high torque along with stator flux ripples. The direct torque control of induction machine is based on the use of two hysteresis controllers [8].***

Keywords: speed control, asymmetrical PWM, *induction motor, V/F,* stator flux ripples, *torque ripples*

1. Introduction

Single phase induction motor is in very wide use in industrial, especially in the fractional kilowatt range. They are extensively used for electric drive for low power constant speed apparatus such as machine tools, domestic apparatus, and agricultural machinery in circumstances where a three phase supply is not available. There is a large demand for single phase induction motor in size ranging from a fraction of a kilowatt power up to about 3.7 KW. Through these machines are useful for small outputs, they are not used for large power as they suffer from many disadvantage and are never used in cases where three phase machines can be adopted. Chief among the disadvantages of IM are

(1) Their output is only 50% of three phase motor for given size and temperature rise;
(2) They have low power factor;
(3) Low efficiency;
(4) These motor have no inherent torque

And some special device have to be employed to make them self-starting [1].

The market for power electronics and power-electronic controlled electrical drives is rapidly growing. Often, the application of power electronic and electrical drive (PE & ED) systems require careful engineering because PE &E D systems are utilized as energy converters or as actuators embedded in larger engineering systems. Control systems are required to obtain the desired characteristics of the PE & ED systems and the entire application. The diversity of applications is reflected in a correspondingly wide range of control methods [8].

The advantages of IM motor are their ability to operate from a single phase power supply. Therefore, they can be used whenever a single phase power is available. There are also other aspects for their popularity, low manufacturing cost, reliability and simplicity. In many applications, it may be desirable to change the speed of motor, and then it is useful for varying AC induction motor speed. Generally, speed control of motor can be achieved by varying the input parameters of motor such as current, voltage etc. This can be achieved by various methods such as

a) PWM method
b) V/F method
c) Direct Flux and torque control

2. Speed Control

Synchronous speed and rated speed are the two speed of electric machine. Synchronous speed is the speed at which a motor's magnetic field rotates. Synchronous speed is the motor's theoretical speed if there was no load on the shaft and friction in the bearings. The two factors affecting synchronous speed are the frequency of the electrical supply and the number of magnetic poles in the stator. The synchronous speed is given by

$$Ns = \frac{120f}{p} \qquad \text{.......... (1)}$$

Where,
f = Frequency in Hz
P = Number of Poles
Ns=synchronous speed

The rotor speed of an Induction machine is different from the speed of Rotating magnetic field. The shaft speed of induction motor when driving load will always be less than the synchronous speed. The percentage difference in synchronous speed and shaft speed is called slip as shown in equation

$$S = \frac{Ns-Nr}{Ns} \qquad \text{.......... (2)}$$

Ns = Synchronous speed
Nr = Rotor speed

Equation (3) states that synchronous speed of induction motor is directly proportional to the frequency and inversely proportional to the number of poles of the motor .Since the number of poles is fixed by design, the best way to vary the speed of the induction motor is by varying the supply frequency.

$$Ns\ \alpha\ \frac{f}{p} \quad \text{……….} (3)$$

The speed of the motor shaft with rated voltage and line frequency applied at full load is so called base speed. By changing the frequency to the motor above or below 50Hz; the motor can operate above or below base speed [5].

A: PWM Method

Now a day, by improvement of the power electronic device, flow of power to the motor is control by the switching action of power switch. The most popular technique of supplying single phase AC motor is the conduction angle control. To carry out this control a tric device is used. It's done by changing the instant of the tric device. This method represents of cost effective solution but it produce very high harmonic content in both motor and supply current wave form [3]. There are different methods of speed control of IM using PWM, but PWM method using AC chopper is most preferable.

- Concept of AC chopper
- PWM AC chopper control schemes
- Concept of AC chopper

The concept used in this motor control is to implement the power switching device to chop the input voltage. This method will cause the pulse-width of the AC voltage waveform to change. So, this method of AC voltage control is called symmetrical PWM. Fig (1) shows the circuit diagram. The current in the induction load always has a continuous path to flow regardless of its direction. To explain the operation of this circuit, three operating modes are proposed, namely active mode, freewheeling mode and dead time mode.

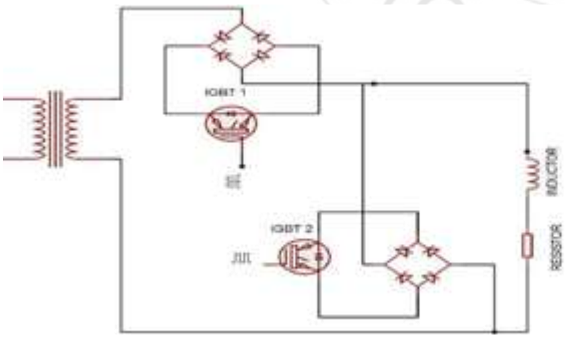
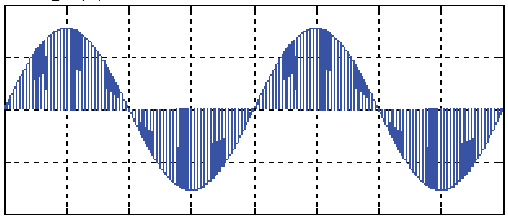


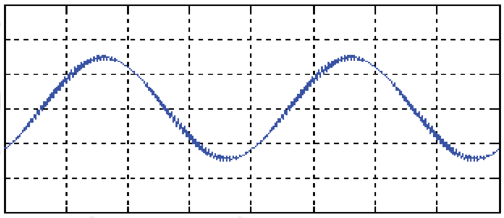
Figure 1: circuit diagram of symmetrical PWM AC chopper

a) **Active mode: -** The active mode occurs when switch 1 is close and the current is flowing across the load. During this stage switch 2 is opened. Power flows from the supply to the load.
b) **Freewheeling mode: -**As for the freewheeling mode, IGBT1 is opened and the load is disconnected from the supply. At that time IGBT2 is close. The load current freewheels and naturally decays through the freewheeling path according to the direction of the load current. The current can flow until energy in the inductor is fully depleted. The trapped energy in the inductor is dissipated in the resistance of the freewheeling path [3].

The advantages of AC chopper are simplicity, ability to control large amount of power, low waveform distortion, high power factor and high response. The motor voltage can be varied by controlling duty ratio of PWM signals to turn-on and off bidirectional IGBT1 and IGBT2. Note that both switches operate alternately. The voltage and current waveforms of PWM AC chopper control technique are shown in fig. (2)

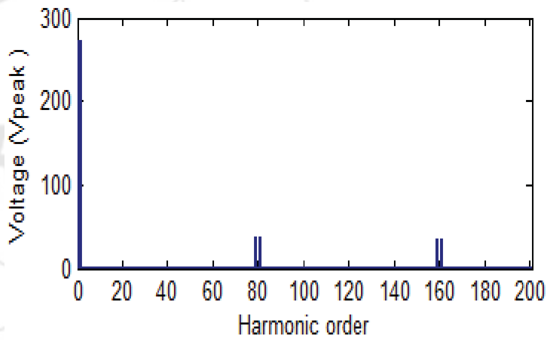


Voltage

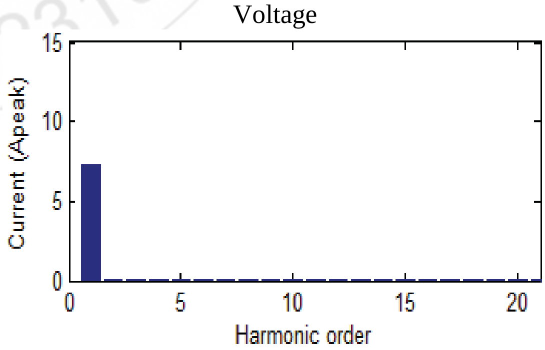


Current

Figure 2: Voltage and current waveform of PWM AC chopper control technique



Voltage



Current

Figure 2: Voltage and current spectrum of PWM AC chopper control technique

Fig (2) shows the voltage and current wave form of PWM as chopper control technique. The voltage waveform contain high order harmonics depending on switching frequency of PWM signal without low order harmonics as the current waveform is nearly sinusoidal due to eliminated low order harmonics voltage. The voltage and current spectrum of PWM technique is show in fig (3) [4].

- PWM AC chopper control schemes

The bidirectional switch 1 and 2 is controlled by T_{on} and T_{off}. A duty ratio (D) can be expressed as equation (4). Then the fundamental voltage supply to the motor can be derived,

$$D = \frac{Ton}{Ts} = \frac{(Ton)}{Ton + Toff} \quad \text{.........(4)}$$

$$VL\,(t) = (D) * (Vm\ Sin(wt)) \quad ..(5)$$

The main winding stator current (I_m) is used to feedback for minus with the appropriate current obtain from the multiple the auxiliary winding stator current (Ia) and the appropriate constant (K1), then the error is sent to the PI controller. The output of controller (Vcontrol) will be compare with a carrier (Vtri) to generate PWM signal to control bidirectional switch. The control scheme is show in fig (4) [4].

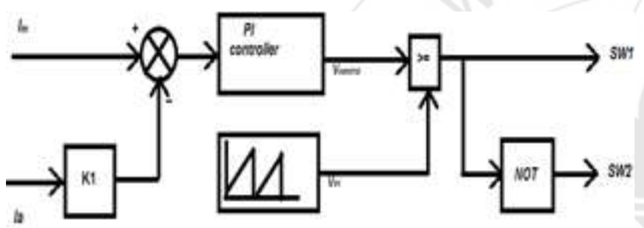


Figure 4: PWM AC Chopper control scheme.

B: V/F Method

Speed control method of induction motor can be broadly classified into two types: scalar control & vector control. By using scalar control method, we can control the magnitude of voltage or frequency of the I.M, to maintain torque of the motor closer to the rated torque at any frequency, the air gap flux (φag) is maintained constant. Any change in the supply frequency i.e. reduction in Supply frequency without changing the supply voltage will increase the air gap flux and the motor may go to saturation. This will increase the magnetizing current and increases the core losses and copper losses, due to which, system becomes noisy. So to avoid these problems, we are changing the supply voltage as well as supply frequency [6].

- Selection of V/F control method
- Speed control using electronics devise
- V/F control method

Selection of V/F control method

V/F control method is mostly used rather than the other conventional methods of speed control. Various advantages is given below:

a) It provides wide range of speed.
b) It has low starting current requirement.
c) It is economical & easy to implement.
d) It gives good running & transient performance.
e) Voltage and frequency reach rated value at base speed

Speed control using electronics devise

In I.M we convert AC supply in to DC supply by using rectifier and then fed to the inverter via the DC bus filter. Inverter circuit having switching device likes MOSFET, IGBT. The output is connected to the I.M whose speed is to be control as show in fig (5). The DC bus filter is used to take out the ripple from the supply which is coming out from the rectifier [6].

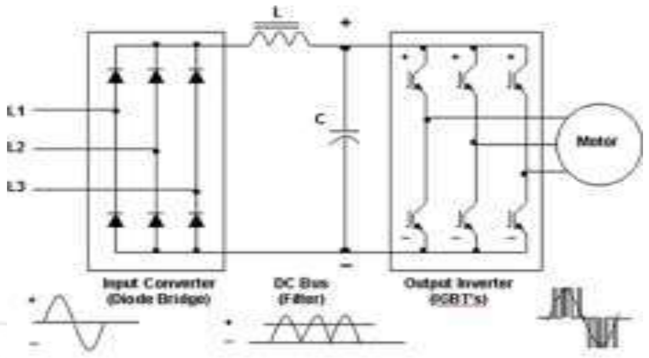


Figure 5: Block diagram of speed control drive

V/F control method:

As the synchronous speed is denoted as;

$$Ns = \frac{120f}{p} \quad \text{.......... (6)}$$

Where,
f=supply frequency
p=number of pole

From equation (6) say that supply frequency is directly proportional to the synchronous speed. The air gap voltage is related to $\emptyset_{ag}$ & the frequency f as,

$Eag\ = K1\ \emptyset ag\ f$... (7)

Input voltage, $Vs = K1\ \emptyset ag\ f$ … (8)

$\emptyset_{ag}$ = constant = V_s

Where,
K_1=constant
$\emptyset_{ag}$ = air gap

The torque developed by the motor is directly proportional to the magnetic field produced by the stator. So the voltage applied to the stator is directly proportional to the product of stator flux and angular velocity. This makes the flux produced by the stator proportional to the ratio of applied voltage and frequency supply. By varying the voltage and frequency by the same ratio, flux and hence, the torque can be kept constant throughout the speed range. This makes constant V/F ratio the most common speed control of an induction motor [6].

$V\alpha\ (\varphi) * (\omega)$ ……….(9)

Where,
V = stator voltage
φ =stator flux
ω =angular velocity

$$V\ \alpha\ \varphi\ * \ 2\pi f$$
$$\Phi\ \alpha \frac{V}{F}$$

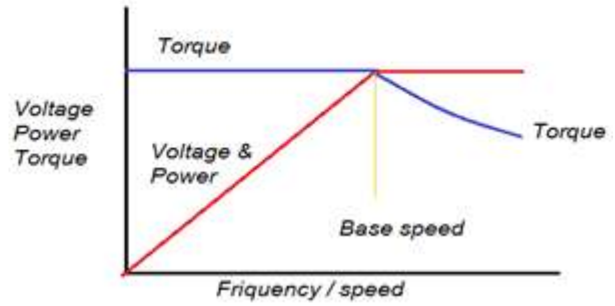


Figure 6: Torque – Speed characteristics

C: Direct Flux & Torque Control

The basic idea of direct torque control of induction motor is based on the relationship between slip and electromagnetic torque. In this type of control method speed control strategy of induction motor (IM) drive and the effect of flux and torque hysteresis band amplitude on this strategy is presented. This method is simple and provides a good dynamic response. It does not needed current controller, because it is selected for voltage space vector according to the error of flux linkage and torque. In direct torque controlled induction motor, it is possible to control directly stator flux linkage and electromagnetic torque. Direct torque control utilizes two and three levels hysteresis band comparators for flux and torque control respectively. The field-oriented control is scheme, doesn't need any coordinate transform. This scheme is less sensitive to motor parameter variation. It required only the stator resistance to estimate the flux and torque. The Direct torque control drive is the presence of steady state ripples in torque and flux. The flux and torque hysteresis band width is varied and the width of the hysteresis band influences the drive performance in terms of current harmonics, torque ripple and switching frequency of the device. In fixed torque hysteresis band, the flux is increased. The shape of flux is a hexagonal due to harmonic distortion. In a fixed flux hysteresis band if the torque hysteresis band, amplitude is increased the torque ripple increases. The operating scalar control is steady state and it controls the angular speed of current, voltage, and flux linkage in the space vectors [9].

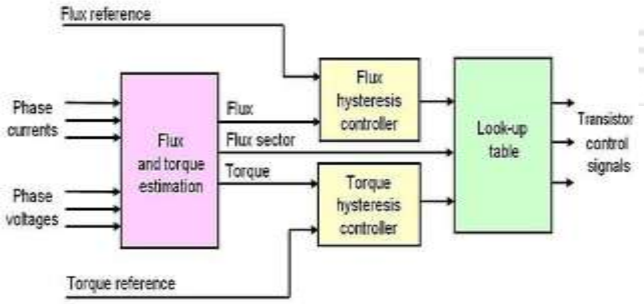
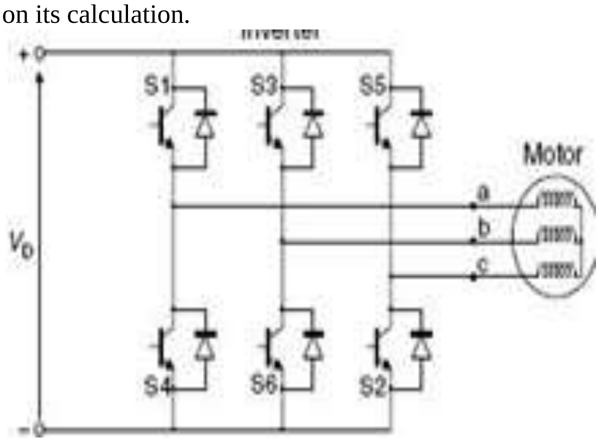


Figure 7: Block diagram of direct torque control scheme.

Flux and torque estimation

Stator flux based calculation methods are used for calculating the electromagnetic torque. It used only the stator flux linkages and stator currents. Only the stator resistances are employed, therefore removing the dependence of mutual and rotor inductances of the machine on its calculation.



As from Fig,

The three phase inverter output voltages V_{as}, V_{bs}, V_{cs} and Currents I_{as}, I_{bs}, I_{cs} are transformed into two phase.

$$Vds = \left(\frac{1}{3½}\right)(Vcs - Vbs)$$

$$iqs = ias$$

$$ids = \left(\frac{1}{3}½\right)(ics - ibs)$$

$$\lambda qs = \int(Vqs - RsIqs)dt$$

$$\lambda ds = \int(Vds - RsIqa)dt$$

$$\lambda=(\lambda qs^2 + \lambda ds^2)^{½} < \theta_{fs}$$

$$\theta fs=\tan^{-1}(\lambda qs/\lambda ds)$$

$$Te = \left(\frac{3}{2}\right) * \left(\frac{p}{2}\right)(iqs\lambda ds - ids\lambda qs)$$

Direct torque control

The resultant flux λ_s is compared with reference flux magnitude. The difference between reference value and the estimated value that gives flux error. It is given as input to the flux hysteresis comparator. In Direct Torque Control method the stator flux

is forced to follow a circular locus by limiting its magnitude within the hysteresis band. if the stator flux touches its upper or lower hysteresis band, a suitable voltage vector is selected to reduce or increase it respectively [9].

Direct Flux Control

The estimated stator torque and stator current is compared with the command torque. Depending on the torque error, the torque can be increased or decreased by selecting suitable voltage. The torque error

3. Conclusion

Can to be limited within its hysteresis band. The output of the torque hysteresis comparator is the torque error status. If it is 1, it calls for control action to increase torque, if it is -1, to decrease and if it is 0, to maintain as it is [9].

Parameter	PWM technique	Direct Flux and Torque method	V/F method
Switching loss	Very low	Low	High
Power factor	Input power factor is High		High during Starting and lagging due to inductive reactance
Cost	Expansive	Low	Cheap
Harmonics	Low	Low	Voltage harmonic high compare to current harmonics
Control	Simple	Simple	Simple
Thermal parameter	Little		
Switching frequency	Very High (50-100 KHz)	Varies widely around average frequency.	2-15 KHz
Efficiency	High	High	Decrease due to switching losses
Dynamic response behavior		Very fast	High
Complexity	Less	Less	
Power consumption	Low		Low
PI controller	Not use	No PI controller	Use to keep the measured current component at reference values
Noise in machine		Low	

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