Speed Control of Induction Motor by using Closed Loop Inverter Circuit

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Abstract— *In this paper, speed control method of single phase induction motor by using feedback based closed loop inverter circuit or closed loop v/f control method is described. This research paper explains speed control of single phase induction motor by means of frequency ,its implementation and test result also the power conversion section in the given speed drive is consisting IRFZ44 N-channel MOSFET as a switching element. These MOSFET (two in number) are used to form inverter to supply AC current to the motor. The driver circuit for this inverter is made up of 2N2369 NPN transistors and 2N3055 NPN transistors. Here, IC SG3524A is used as pulse width modulation IC for frequency control purpose.*

Keywords— Closed Loop Inverter Circuit, Speed Control of Induction Motor

I. Introduction

Induction motor are widely used for appliances, industrial control, and automation, they are often called the workhorse of the motion industry. They are robust, reliable, and durable. When power is supplied to an induction motor at the recommended specifications, it runs at its rated speed. However, many applications need variable speed operations. Historically, mechanical gear systems were used to obtained variable speed. Recently, electronic power and control system have matured tallow these component to be used for motor control in place of mechanical gears. These electronics not only control the speed, but can improve the motor’s dynamic and steady state characteristics. In addition, electronics can reduce the system’s average power consumption and noise generation of the motor. Induction motor control is complex due to its nonlinear characteristics. While there are different method for control, variable voltage variable frequency or volts/hurtz to the most common method of speed control in close loop. This method is most suitable for applications without position control requirements or the need for high accuracy of speed control. For this purpose the generated 220 volts ac is fixed or sometimes is dependent on output load or battery voltage. We will regulate the output ac for induction motor so as to control the speed of induction motor by getting the sample of output and feeding it to the input as reference so that by fixing a fix voltage as comparator voltage we will regulate the speed of induction motor.

II. Speed control

There are two speed terms are synchronous speed and rated speed used in the 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

$$Ns = \frac{120f}{p}$$

Where,

f = Frequency in Hz

P = Number of Poles

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

$$S = \frac{Ns - Nr}{Ns}$$

Ns = Synchronous speed

Nr = Rotor speed

Below relation 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.

$$Ns \propto \frac{f}{p}$$

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. Volts - Per - Hertz Ratio This term describes a relationship that is fundamental to the operation of motors using adjustable frequency control. An ac induction motor produces torque by virtue of the flux in its rotating field. Keeping the flux constant will enable the motor to produce full load torque. Below base speed, this is accomplished by maintaining a constant voltage-to-frequency ratio applied to the motor when changing the frequency for speed control. For 460 and 230 Volt motors, the ratio is 460/60 = 7.6 and 230/60 = 3.8. If this ratio rises as the frequency is decreased to reduce the motor speed, the motor current will increase and may become excessive. If it reduces as the frequency is increased, the motor torque capabilities will decrease. There are some exceptions to this rule which are described below. The base speed of the motor is proportional to supply frequency and is inversely proportional to the number of stator poles. So, by changing the supply frequency; the motor speed can be changed. Above base speed, this ratio will decrease when constant voltage (usually motor rated voltage) is applied to the motor. In these cases, the torque capabilities of the motor decrease above base speed. At approximately 30 Hertz and lower, the Volts-per-Hertz ratio is not always maintained constant. Depending on the type of load, the voltage may be increased to give a higher ratio, in order for the motor to produce sufficient torque, especially at zero speed. This adjustment is usually called "Voltage Boost". At base speed and below, the Volts-per-Hertz ratio can be adjusted lower to minimize motor current when the motor is lightly loaded. This adjustment, which lowers the voltage to the motor, will reduce the magnetizing current to the motor. Consequently, the motor will produce less torque which is tolerable. This control is the most popular in industries and is popularly known as the constant V/f control. The VFD is a system made up of active/passive power electronics devices; figure 1 shows electronic speed control of the motor supply frequency. The basic concept of these drives, figure 1, is that a rectifier converts the fixed frequency supply to d.c. (which converts commercial power into a direct current). A d.c. link stage smoothes the rectified output to a stable d.c. voltage (or current).This d.c. is then inverted to provide a synthesized a.c. waveform at the motor terminals. The frequency and power of the a.c. supply delivered to the motor is controlled by inverter [3].

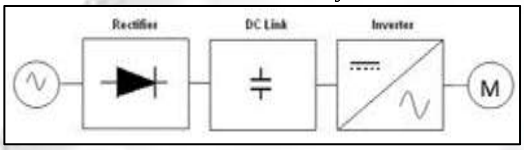

Fig. 1: Basic Block Diagram of VFD

III. Motor Driven Load Characteristics

The behavior of torque and horsepower with respect to speed partially determine the requirement of motor drive system.

$$Horsepower\ (Hp) = \frac{speed \times Torque}{5250}$$

$$1\ Horsepower\ (Hp) = 746\ Watts$$
$$= 0.746\ kwatts$$

$$Power\,(KW) = \frac{RPM \times Torque\,(kgfm)}{5250}$$

$$= \frac{RPM \times Torque\,(Nm)}{9555}$$

This torque formula implies that the torque is directly proportional to the horse power rating and inversely proportional to the speed.

In real applications, various kinds of loads exist with different torque-speed curves. The type of load that a motor drives is of the most important one application considerations when applying any type of inverter. Generally, loads can be grouped into three different categories explain below

A. Constant Torque Load

Constant torque loads require the same amount of torque at low speeds as at high speeds. Torque remains constant throughout the speed range and the horsepower increases and decreases in direct proportion to the change in speed. Figure 2 shows the constant torque load characteristics of induction motor. If the speed drops to 50 percent, then the power required to drive the operation will drop to 50 percent while the torque remains constant.

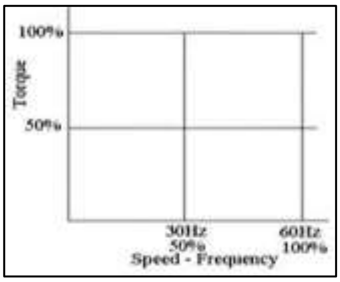

Fig. 2: Constant Torque Load Characteristic

This type of load characteristics includes most compressors, conveyors, reciprocating pumps.

B. Constant Horsepower Load

This is characteristic of grinders, turret lathes and winding reels. Specifically, the torque required of the load will decrease as the speed is increased**,** or vice versa. Hence, the product of torque and speed, which is horsepower, is approximately constant as the speed changes. This type of loading is usually applied above base speed. Figure 3 shows the constant horse power load characteristics of induction motor. As an example, an empty reel winding a coil will require the least amount of torque, initially, and will be accelerated to the highest speed.

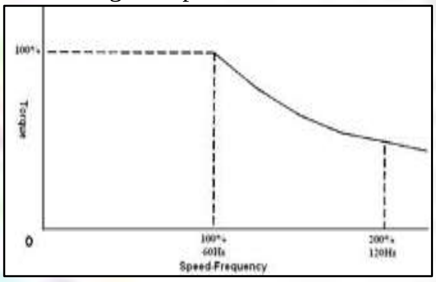

Fig. 3: Constant Horsepower load characteristics

As the coil builds up on the reel, the torque required will increase' and the speed will be decreased. Energy savings can be achieved by varying the speed of the motors and the driven load using a commercially available variable frequency drive.

C. Variable Torque Load

With a variable torque load, the loading is a function of the speed. This is a characteristic of centrifugal pumps and fans. Specifically, as the speed is increased or decreased, the torque required of the load will change with the square of the speed, while the power is the cube of the speed. Figure 3 shows the variable torque load characteristics of induction motor. As an example, with a 100% torque load at 100% speed, when the speed is reduced to 50%, the square of the speed is 0.5 x 0.5 or 0.25 and the load torque will be 25% of full load torque in Fig. below

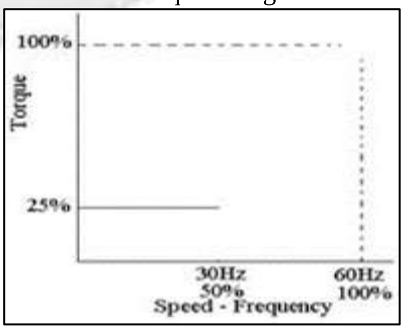

Fig. 4: Variable Torque Load Characteristics

D. Closed Loop v/f Control

The basis of constant V/F speed control of induction motor is to apply a variable magnitude and variable frequency voltage to the motor. Both the voltage source inverter and current source inverters are used in adjustable speed ac drives. The following block diagram shows the closed loop V/F control using a VSI. A feedback is used to obtain the actual speed of the motor. It is then compared to a reference speed

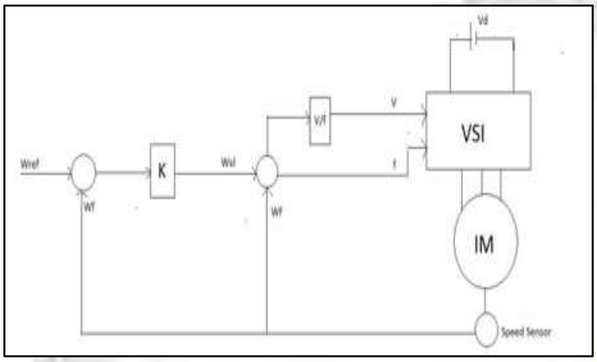

Fig. 5: Block diagram for closed loop V/F control for an IM

The difference between the two generates an error and the error so obtained is processed in a Proportional controller and its output sets the inverter frequency.

IV. V/F CONTROL THEORY

The induction motor draws the rated current and delivers the rated torque at the base speed. When the load is increased (overrated load), while running at base speed, the speed drops and the slip increases. The motor can take up to 2.5 times the rated torque with around 20% drop in the speed. Any further increase of load on the shaft can stall the motor. 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 of supply. By varying the frequency, the speed of motor can be varied. Therefore by varying the voltage and frequency by same ratio, fiux and hence, the torque can be keep constant throughout the speed range.

A. Equation

Stator Voltage (V) ∝ [Stator Flux (Φ)] x [Angular Velocity (w)]

$$V \propto \phi * (2 \pi F)$$

$$\Phi \propto V/F$$

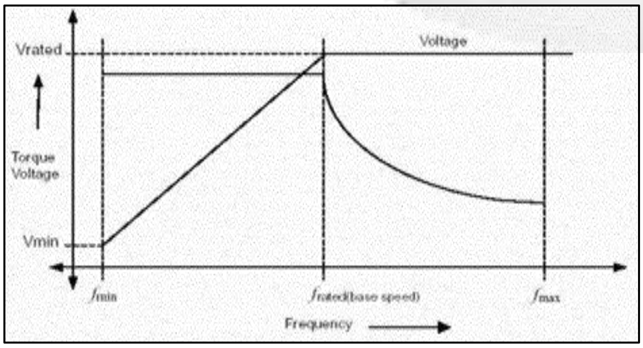

Fig. 6: Speed Torque characteristics with v/f control

V. CONTROL PLATFORMS

Various speed control techniques implemented by modern-age VFD are mainly classified in the following two categories

A. Scalar Control (V/f 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 variables – 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.

B. Vector Control

This control is also known as the "field oriented control", "flux oriented control" or "indirect torque control". In general, there exists three possibilities for such selection and hence, three different vector controls. They are:

– Stator flux oriented control
– Rotor flux oriented control
– Magnetizing flux oriented control

As the torque producing component in this type of control is controlled only after transformation is done and is not the main input reference, such control is known as "indirect torque control". The most challenging and ultimately, the limiting feature of the field orientation, is the method whereby the flux angle is measured or estimated. Depending on the method of measurement, the vector control is divided into two subcategories: direct and indirect vector control.

In direct vector control, the flux measurement is done by using the flux sensing coils or the Hall devices. This adds to additional hardware cost and in addition, measurement is not highly accurate. Therefore, this method is not a very good control technique. The more common method is indirect vector control. In this method, the flux angle is not measured directly, but is estimated from the equivalent circuit model and from measurements of rotor speed, the stator current & the voltage.

C. Advantages

1) Large energy savings at lower speed.
2) Increased life of rotating components due to lower operating speed.
3) Reduced noise and vibration level.
4) Reduction of Thermal and mechanical stresses.
5) Lower KVA
6) High power factor
7) Extended Machine Life and Less Maintenance
8) Improved load control.

D. Application

1) FWD/ Rev operations
2) You can maintain torque V/s Speed characteristics

3) variable acceleration deceleration options
4) It acts as safety device for motor, it controls voltage, currents and torque.
5) They are also used in modern lifts, escalators and pumping systems.

VI. CONCLUSION

The use of a Variable Speed Drive for a speed control application usually offers an energy efficient and environmentally friendly solution. The best opportunities for energy savings, with subsequent economic savings, arise through the laws which govern the operation of centrifugal fans and pumps. Speed control of induction motor for full load, is carried out by using closed loop inverter circuit, And the results are checked. From the above experiment and results we concluded that the closed loop V/F control gives better response and better result as compared to open loop V/F control of induction motor.

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