Speed Control of AC Motor Using VFD

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ABSTRACT

This paper discusses speed control of AC motor using Variable Frequency Drive (VFD). The speed of AC motors remains constant because it takes rated power from supply and therefore it causes problems when less motor speed is needed. The VFD mechanism provides an approach for variation in speed of AC motors. The paper presents the working principle of VFD, its performance and the use of Pulse Width Modulation (PWM) in the three phase inverter to control or maintain the ratio of voltage to frequency. The model is simulated using spice models and the results are analyzed. This paper is intended to provide the basic understanding of VFD terms, VFD operations and Power factor improvement.

Keywords: Variable Frequency Drive (VFD), Rotating Magnetic Field (RMF), Electromagnetic Interference (EMI), Pulse Width Modulation (PWM), Insulated Gate Bipolar Transistor (IGBT), Gate Driver, Inverter.

I. INTRODUCTION

A. Motor types and VFD

AC motor is an electric motor driven by an alternating current (AC). There are two types. The first type is the induction motor or asynchronous motor that relies on small difference in speed between the Rotating Magnetic Field (RMF) and the rotor to induce a rotor current. The second type is synchronous motor. It does not rely on induction and hence, it can rotate exactly at the supplied frequency. The current that is delivered generates magnetic field on the rotor through slip rings or by permanent magnet \cite{12}.

Variable Frequency Drive (VFD) is a type of adjustable speed drive. It is used to control speed and torque of the motor. This is done by varying motor input frequency and voltage. VFD basically controls the speed and torque of Standard induction AC motors. The frequency as well as the amplitude of AC waveform which is delivered is varied thereby saving money and electricity. VFD consists of three main sub-systems: AC motor, main drive controller assembly and a drive operator interface. The application of VFD is usually in three phase induction motor. Some types of single phase induction motors can be used. The VFD controller comprises of bridge rectifier, Direct Current (DC) link, and an inverter. The bridge rectifier is a three phase, six phase full wave diode bridge. The DC link consists of a capacitor which smooths out the bridge rectifier’s DC ripple output. Thus it provides a stiff input to the inverter. The inverter converts the DC input voltage to a sinusoidal AC output voltage using inverter’s Switching elements. The switching elements are the power semiconductor devices. IGBT’s (Insulated Gate Bipolar Transistor) are usually used as inverter’s switching elements. Figure 1 shows the basic block diagram of VFD.

B. Literature Survey

Dennis P. Connors \cite{3}, illustrated various types of Variable frequency drives (V.F.D) with their limitations and described basic relationships among drive voltage, frequency, torque, speed of the motor along with harmonic effect.

Thomas A. Lipo \cite{5}, summarized various stages of developments of VFD, which linked technological innovations in power components, like silicon controlled rectifier (SCR), gate turn off thyristor (GTO), insulated gate bipolar transistor (IGBT), Pulse width modulation (PWM) controlled.

Figure 1. Basic Block Diagram
Paresh C. Sen [7], described the substitute of DC drive performance by AC frequency drive, as a result of sustained research work in area of power electronic components and micro-controllers.

P. Y. Keskar [13], based on IEEE 519-1992 standard on Variable frequency drives (VFD) showed voltage and current harmonic order and their magnitude calculation methods. Before installation of VFD, appropriate harmonic analysis and mapping on impedance line diagram of plant could be powerful tool in deciding VFD hardware and other filters location.

James Will Gray and Frank J. Haydock [8], presented fundamental concept of harmonics and probable frequencies of harmonics, based on theory of energy balance and Fourier series analysis. A harmonic current for a six- pulse convertor ($6n \pm 1$) will be generated and their magnitude is inversely proportional to harmonic number for ideal square wave. The switching pulses and harmonics are superimposed on fundamental wave and produce distortion.

Thomas M. Jahns and Edward L. Owen [9], gave historical review on development of AC drive beginning from 1920, when devices like mercury arc rectifier, thyatron and ignition were used.

In 1901, Mr. Peter Cooper Hewitt demonstrated brief development progress on devices like thyatron, ignition. Wound rotor induction motor with external slip rings, were the basis of speed control by varying the voltage at wound rotor using normal voltage controller. Variable speed drives (VSD) are considered to be having highest energy saving potential and are widely replacing mechanical, hydraulic and DC motor speed control system. VSD performance is proved useful in process control with minimum wear and tear in driven equipment.

Jose Rodriguez [10], presented a review on development of high power converters. Insulated gate-bipolar transistors (IGBT) and Gate commutated thyristor (GCT) came into existence in 1980 and 1990, with reduced power losses, simple gate control without using snubbers and better switching functions. IGBT modules up to 3.3/4.5/6.5 KV are available by cascading in series with common gate control.

Joseph Song-Manguelle [11], discussed the development of pulsating torque within motor air gap which is one of major factors, causing torsional resonance and vibration in driven shaft couplings. A test was conducted on compressor test bed coupled to a motor and driven by PWM inverter. The results were compared with theoretical model and found to be in order. Further, it was observed that mechanical shaft failure is due to frequency of PWM drive’s pulsating torque and not the magnitude. The air gap flux pulsations are the result of current harmonics, so generated from inverter and flowing into motor windings.

II. OPERATION OF VFD

A. Basic Operation

VFD operation requires three basic sections: the rectifier, dc link, and Inverter. The AC power supply produces a sinusoidal wave. The positive voltage causes a current to flow in one direction and a negative voltage causes a current to flow in opposite direction. A large amount of energy is transmitted efficiently over great distances.

Before rectifier, line filtering is done to reduce the noise entering the equipment from commercial power lines or noise generated from electronic equipment. Common mode chokes, line bypass capacitors and Metal Oxide Varistors (MOV’s) are generally used as filter devices for suppressing AC Electromagnetic Interference (EMI). There are two modes, common mode (line to ground) and differential mode (line to line). Filters are designed to suppress Radio Frequency Interference (RFI) and EMI that exists in these modes. The most frequently encountered is Common mode interference and hence common mode chokes are used most often. Common mode chokes suppress common mode noise and thereby influence the performance of the filter block.

The rectifier which is in the form of bridge comprising of six diodes (full wave) converts the incoming AC voltage (power) from the power supply into a pulsating DC voltage (power). This rectified DC voltage flows and the DC link block that contains a capacitor. The capacitor accepts this voltage (power) from the rectifier stores it and delivers a smooth voltage to the inverter block. Inductors, chokes or similar things add inductance and provide more smoothening to output voltage.

The final section of VFD is an inverter. The inverter requires a stable dc voltage at its input. A voltage regulator circuit provides this stable voltage. A voltage regulator converts the unregulated dc voltage obtained from the bridge rectifier into regulated dc voltage. It provides a constant dc output voltage and contains a circuitry that continuously holds the output voltage at the desired value. The control circuitry is basically a feedback loop between the input and output of the voltage regulator circuit that monitors the output voltage.

The inverter contains power transistors that deliver power to the motor. IGBT is a common choice in modern VFDs. It can switch ON and OFF several thousand times per second. The IGBT uses PWM (Pulse Width Modulation) technique to simulate a sinusoidal current at the desired frequency to the motor. The inverter requires a stable dc voltage at its input. Hence, the rectified output of the bridge rectifier which is filtered using DC link is made constant using a voltage regulator circuit.

A driver circuit is used to drive the gate of the IGBT’s. This circuit comprises of TLP250 and IR2110. TLP250 is an 8 pin power MOSFET or IGBT gate drive optocoupler consisting of an LED and photo detector. IR2110 is a high voltage; high speed Power MOSFET/IGBT driver with independent high and low side output channels. The drain terminal is connected to high voltage in the system and hence the driver circuit is introduced to boost the gate of IGBT, as the gate terminal must be at least 10 volts higher than drain terminal for the IGBT to conduct. Figure2 is the modified block diagram shown below.
B. Pulse Width Modulation (PWM) Inverter
Pulse Width Modulation (PWM) is the process that modifies the width of the pulses in a pulse train in a direct proportion to a small control signal. For a PWM circuit, a sinusoid of desired frequency is used as a control voltage. Thus, it is possible to produce a high power waveform. The average voltage is varied sinusoidally in a manner suitable for driving AC motors. The motor speed is fixed when the motor is connected directly to the AC line. The speed is calculated as follows:

\[ n_s = \frac{120f}{p \cdot \text{slip}} \]

- **ns** = Motor speed (Hz)
- **f** = fundamental frequency
- **p** = no. of poles

The fixed speed is a problem as many applications require change in speed of the motor which was traditionally achieved reducing the voltage across the windings of the motor. This in turn reduced the current through the windings thereby reducing the motor torque. If the load on the motor remains same then, the speed of the motor reduces proportionally with the voltage. But, since the load is not constant this technique is not ideal. Also, the efficiency of the motor is significantly reduced as the slip on a motor is too great.

A full control over the motor is achieved via the microcontroller and IGBT pair in the inverter stage. The inverter consists of six IGBT’s, two IGBT’s for each motor winding. phase. The microcontroller sends gate signals and the IGBT’s are switched on and off creating an average AC voltage close to a sinusoidal waveform. The duty cycle of the IGBT is varied which provides equivalent sine wave output. The modulation of duty cycle is phase shifted by 120 degrees for each phase. An effective control over fundamental frequency and voltage of the output is achieved. When the IGBT’s are switched off, a back emf is produced in the motor winding that generates a very high and potentially damaging voltage across the IGBT. To overcome this problem, the inverter has antiparallel diodes connected across each IGBT that will allow current flow from the motor winding to the dc link when the IGBT’s are switched off. The back emf is directly proportional to the rotational velocity and opposite in polarity to the voltage applied across inverter. To drive the current through the motor windings and to increase motor speed and torque, both modulating frequency and voltage must be increased. The back emf and the motor speed are proportional to each other. Therefore, to maintain the current flow the supply voltage to the motor winding must be above this emf.

III. CONCLUSIONS
Thus, we conclude that less energy is utilized when the motor works at lower speeds. The cost required to run the mechanism is low. VFDs can increase productivity, improve product quality and process control, and reduce maintenance and downtime.

The mechanism find its application in fields such as: Motor driven centrifugal pumps, fans and blowers. In conveyers, where the benefits of accurate speed control are the primary consideration.

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