Speed Controlling of Three-Phase Induction Motor Using VFD

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Abstract- This paper explains how Variable Frequency Drives (VFDs) work and talks about their performance. It also discusses a simulation model made using MATLAB Simulink and analyzes the results. It looks at something called Total Harmonic Distortion (THD) in waveforms. VFDs are being used more and more in heating, ventilation, and air conditioning (HVAC) systems, like air handlers, chillers, pumps, and tower fans. Understanding VFDs better can help choose and use HVAC equipment and systems more effectively. This paper aims to explain VFD terms, how they work, how they improve Power Factor, how they deal with Harmonics, and includes a simulation project showing how VFDs can save energy. It also compares VFDs with other technologies according to industrial standards.

Keywords: Working Principle of VFD, Simulation Circuit, and Analysis of Results.

1. INTRODUCTION

The Variable Frequency Drive (VFD) industry is booming, making it crucial for technicians and maintenance personnel to keep VFD installations running smoothly. VFDs adjust the speed of motors by changing the voltage and frequency of the power supplied to them. Maintaining the proper volts/hertz ratio, as indicated on the motor's nameplate, is essential for maintaining the power factor and preventing excessive motor heating. VFDs, also known as AC drives, are primarily used for smoothly controlling the speed of induction motors in process plants, known for their durability and long maintenance-free lifespan.

VFDs work by adjusting the motor's speed through a sophisticated microprocessor-controlled electronic device. They consist of two main units: the rectifier and the inverter. The rectifier converts AC power into DC voltage, while the inverter converts this DC voltage back into AC voltage.

1. VFD Operation

To understand how Variable Frequency Drives (VFDs) work, let's break it down into three main parts: the Rectifier unit, the DC Bus, and the Inverter unit.

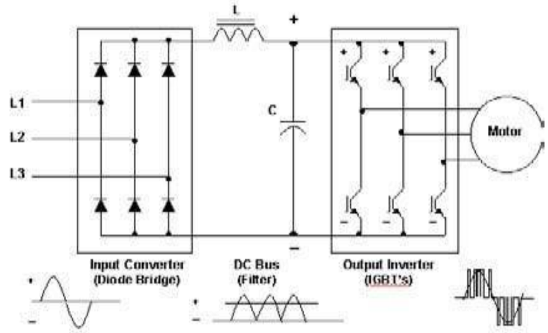

Figure 1: VFD Circuit Diagram

2. Rectifier Unit: This is where the supply voltage is first converted from AC to DC. In this unit, the three-phase AC supply is passed through diodes, which turn it into a DC supply.

3. DC Bus: The DC Bus is a crucial part of the VFD where the DC supply is stored and filtered. Here, any harmonics generated during the AC to DC conversion are removed.

4. Inverter Unit: The Inverter unit takes the altered DC supply from the DC Bus and converts it back into AC power. This AC power, which is now a quasi-sinusoidal wave, is then supplied to the induction motor connected to the VFD. This unit typically consists of six Insulated Gate Bipolar Transistors (IGBTs).

5. By adjusting the frequency of the power supply through the VFD, we can control the speed of the synchronous motor. The formula to calculate motor speed (in rpm) is:

6. Speed (rpm) = Frequency (Hertz) × 120 / No. of Poles

7. Here, Frequency represents the electrical frequency of the power supply in Hertz, and No. of Poles refers to the number of electrical poles in the motor stator.

8. VFDs provide a convenient way to adjust motor speed without physically changing the motor's poles. They achieve this through Pulse Width Modulation (PWM) drives, which vary both the frequency and voltage output to the motor.

9. Because frequency can be easily adjusted compared to changing the motor's poles, drives that control speed through frequency adjustments are called Variable Frequency Drives (VFDs).

2. Constant V/F Ratio Operation

Variable Frequency Drives (VFDs) keep the voltage-to-frequency (V/f) ratio constant at all speeds to maintain motor performance. If the voltage is reduced without adjusting the frequency, it can cause the magnetic flux in the motor to increase, potentially saturating the core and disrupting performance. By maintaining a constant flux, VFDs ensure consistent motor torque at all speeds.

3. How Drive Changes Motor Speed

To change motor speed, VFDs use Pulse Width Modulation (PWM) drives. PWM generates pulses of varying widths to create the necessary waveform for the motor. This method helps reduce undesired heating and allows for an almost constant power factor, which is close to unity, at all speeds. Additionally, PWM drives can operate multiple motors on a single drive, making them versatile and efficient.

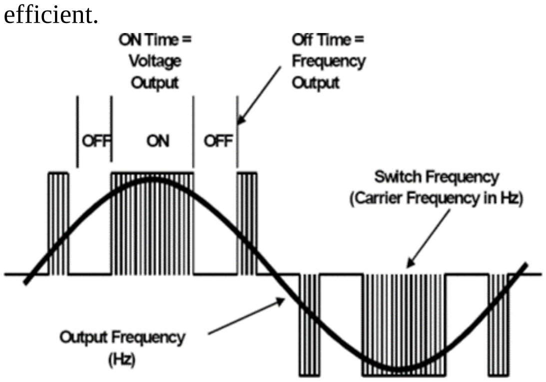

Figure 2: Drive Output Waveform Components

4. Advantages of VFD

Lowering the speed of AC electrical machines using Variable Frequency Drives (VFDs) offers significant benefits:

1. Energy Savings: Operating at lower speeds can result in large energy savings.
2. Extended Component Life: Lower speeds can prolong the lifespan of rotating components.
3. Reduced Noise and Vibration: Lower speeds lead to quieter operation and reduced vibration levels
4. Less Thermal and Mechanical Stress: Slower operation reduces stresses on both thermal and mechanical components.
5. Lower KVA Requirement: Lower speeds mean lower KVA (Kilovolt-Ampere) requirements.
6. Improved Power Factor: VFDs often maintain a high-power factor, contributing to efficient operation.

6. Simulation Circuit

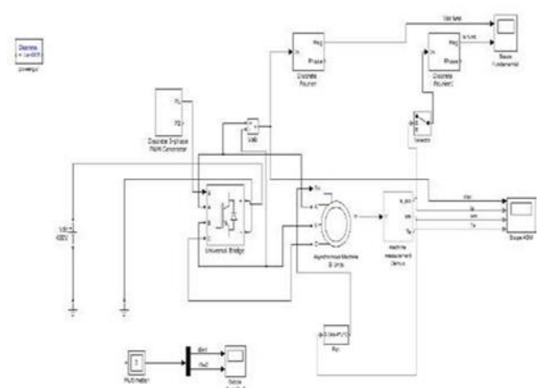

Figure 3: Simulation Circuit of VFD

In simulations, various power electronics switches like IGBTs, MOSFETs, and GTOs are employed for forced commutation.

Traditional methods like DC motors and Thyristor Bridges have been replaced with newer Voltage Converters (VSC) powered by Pulse Width Modulation (PWM) for controlling asynchronous machines.

Modern control techniques like Field Oriented Technique or Direct Torque Control are combined with PWM for flexible speed and torque control.

The simulation circuit includes common three-phase machines like asynchronous, permanent magnet synchronous, simple ed, and complete synchronous machines, which can operate in generating or motoring mode.

These machines can simulate electromechanical transients when combined with linear and nonlinear elements like transformers and loads. For drive simulations, they're connected with power electronics devices like diodes, thyristors, GTOs, MOSFETs, and IGBTs, forming Three Phase Bridges.

In a specific simulation of a 3 HP, 4-pole motor, an inverter utilizing PWM techniques adjusts the frequency and amplitude of the output voltage, controlling the motor's speed

Waveform Analysis

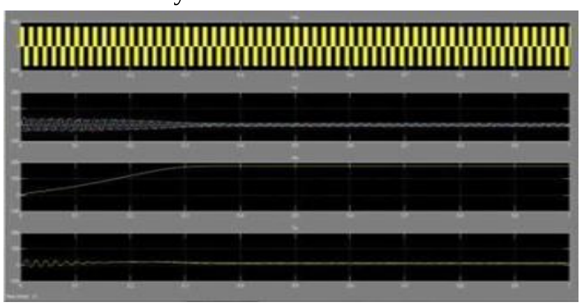

Figure 4: Waveforms of Voltage Current, Speed, and TorqueThe voltage, current, speed, and torque waveforms are analyzed

7. Performing Harmonics Analysis using theFFT Tool

To analyze voltage, current, speed, and torque waveforms, we can use the FFT (Fast Fourier Transform) Tool for Harmonics Analysis.

During simulation, the fundamental components of voltage and current are captured by two Discrete Fourier Blocks. However, to observe harmonic components, a Discrete Fourier Block would be needed for each harmonic, which isn't practical.

Instead, to display the frequency spectrum of current and voltage waveforms, we use the FFT tool in Powergui. This tool requires time-variable signals generated by the scope block. These signals are stored in the ASM structure, and the sampling is done at a fixed step to meet the requirements of the FFT tool.

To utilize the FFT analysis, we open the Powergui and select FFT analysis. A new window opens where we set parameters such as the analyzed signal, the time window, and the frequency range.

Table 1: Parameters of FFT present in Powergui block

Structure	*ASM*
Input	Vab
Signal number	1
Start time	0.7 s
Number of cycles	2
Fundamental frequency	60 Hz
Max frequency	5000Hz
Frequency axis	Harmonic order
Display style	Bar (relative to Fund or DC)

8. FFT Analysis of Motor Line-to-Line Voltage

After clicking the Display option, the analyzed signal is shown, and at the bottom window, the frequency spectrum is displayed.

The FFT analysis of the motor's line-to-line voltage reveals both the fundamental component and the Total Harmonic Distortion (THD) of Vab in the spectrum window.

The magnitude of the inverter voltage fundamental is measured at 312V, which is compared to the theoretical value of 311V for a modulation index (m) of 0.4.

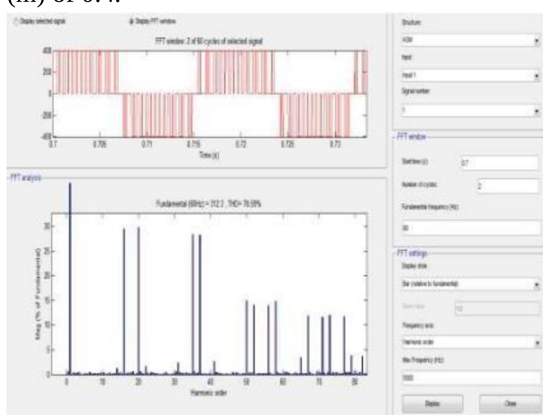

Figure 5: FFT analysis of Asynchronous motor

9. Result

The simulation results are obtained from a 4-pole Asynchronous motor rated at 3 HP. The Harmonics analysis was performed using the FFT tool with a maximum frequency of 5000 Hz.]

Table 2: Data Analysis of Frequency

Fundamental Frequency	*Speed (RPM)*	*Order of Harmonics*	*THD of Voltage*	*THD of Current*
80	2400	62.5(even)	106.25%	30.49%
75	2250	66.66(even)	81.86%	19.65%
70	2100	71.42(odd)	67.89%	14.91%
65	1950	76.92(even)	55.46%	12.20%

60	1800	83.33(odd)	78.59%	11.46%
55	1650	90.90(even)	55.85%	18.72%
50	1500	100(even)	76.85%	32.86%
45	1350	111.11(odd)	126.29%	37.35%

a) As the fundamental frequency of the voltage increases beyond 70Hz or decreases below 45Hz, the Total Harmonic Distortion (THD) level also increases. Therefore, it's important to keep the range of fundamental frequency variations between 70Hz and 45Hz.

b) At frequencies like 70Hz, 60Hz, and 45Hz, the THD (V) values tend to be high compared to frequencies in between. This is because these frequencies contain more harmful ODD harmonics, which promote distortion in the circuit more than EVEN harmonics. Since the maximum frequency is set at 5000Hz, the order of harmonics can be easily calculated.

c) Energy consumption depends on the load requirement, but varying the frequency can lead to harmonic distortion. This distortion can be managed using various harmonics mitigation techniques.

d) THD levels change with variations in fundamental frequencies, affecting energy savings calculations and motor speed control. Introducing laser techniques could help mitigate harmonic levels, and the application of Band Pass Active Filters could be explored as future research to mitigate harmonics effectively.

10. CONCLUSION

1) T the analysis of the table reveals that varying the frequency leads to changes in harmonics within the machine. As the speed decreases, the Total Harmonics Distortion (THD) in both voltage and current increases, with THD in voltage typically lower than in current. Excessive frequency variation also raises THD voltage and current levels. Variable Frequency Drives (VFDs) can effectively control motor speed and save energy.

2) However, achieving high performance with VFDs for maximum process productivity requires complex engineering considerations. Advances in AC control technology, along with the availability of standard fixed-frequency AC motors, offer numerous solutions. Pulse width modulation enables setting the frequency to control induction motor speed, aligning energy consumption with load requirements. Harmonic distortion resulting from frequency variation can be mitigated using various techniques.

3) Harmonics elimination techniques typically target the lowest harmonic due to practicality and cost-effectiveness. Multilevel inverters offer another approach to harmonic cancellation. Active filters like Band Pass Active Filters are necessary for inverter circuits to mitigate harmonics effectively.

4) Through the study of Variable Frequency Drives, it's possible to control motor speed and conserve electrical energy, addressing the global importance of energy conservation. Efficient energy use and reduced consumption from conventional sources contribute to overall energy conservation efforts.

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