



INTERNATIONAL JOURNAL OF CREATIVE RESEARCH THOUGHTS (IJCRT)

An International Open Access, Peer-reviewed, Refereed Journal

Study And Design Of Variable Frequency Drive For Induction Motor Control

Dr. S. S. Ambekar¹

Prof & HOD Of Electrical Engineering,
K.D.K. College of Engineering,
Nagpur, Maharashtra, India

Toshika Pande²

Department Of Electrical Engineering,
K.D.K. College of Engineering, Nagpur,
Maharashtra, India

Rohini Nimbarte³

Department Of Electrical Engineering,
K.D.K. College of Engineering, Nagpur, Maharashtra, India

Gayatri Nimje⁴

Department Of Electrical Engineering,
K.D.K. College of Engineering, Nagpur,
Maharashtra, India

Harsh Kinekar⁵

Department Of Electrical Engineering,
K.D.K. College of Engineering, Nagpur,
Maharashtra, India

Abstract:

This study is about the use of Variable Frequency Drives in Direct Current to Alternating Current applications. A Variable Frequency Drive (VFD) primarily manages the speed and torque of an AC motor by modifying the frequency and voltage it receives. However, their role in DC-to-AC conversion presents new concepts of power control for improvement in system efficiency and adaptability in systems that demand versatility within electrical outputs.

A Variable Frequency Drive (VFD) is a key component in modern electrical systems, used to regulate the speed and torque of motors by altering the input frequency and voltage. This study focuses on the design and selection of VFDs, particularly for industrial applications, with emphasis on the key components such as diodes in the rectifier stage and IGBTs in the inverter stage. The paper also includes the detailed calculation for selecting VFD components based on motor specifications, using a 5 HP (3.73 kW) motor as a case study. The main objective is to offer insights into the appropriate VFD ratings, component selection, and the application of VFDs for controlling motors efficiently.

Keywords: Variable Frequency Drive, VFD applications, energy efficiency, motor control, PWM, vector control, fault detection, industrial automation, AC drive, inverter technology.

1. Introduction

In today's electrical systems, a Variable Frequency Drive (VFD) plays a vital role by adjusting the voltage and frequency to control the speed and torque of electric motors. The use of VFDs has become widespread in industries such as HVAC, pumps, fans, and conveyors due to their ability to enhance energy efficiency, provide precise motor control, and reduce mechanical wear.

A VFD system primarily comprises a rectifier that converts AC to DC, and an inverter that converts the DC back to AC with variable frequency and voltage. Diodes are commonly used in the rectifier stage, while the inverter stage relies on IGBTs (Insulated Gate Bipolar Transistors) for switching operations. This paper addresses the key parameters involved in selecting the correct VFD, with a focus on motor specifications and the required component ratings.

2. Operation of VFD:

Understanding the fundamental operation of a Variable Frequency Drive (VFD) involves examining its three core sections: the rectifier unit, the DC bus, and the inverter unit. The input voltage is firstly passed through a rectifier unit as above are the functions of all the units.

1. Rectification: The AC input is converted into DC using a rectifier made up of diodes.
2. DC Link: The Direct Current (DC) voltage is filtered and smoothed by capacitors, which is use to form a stable DC bus voltage.
3. Inversion: The Direct Current (DC) voltage is then converted back into an Alternating Current (AC) using IGBTs. The AC output's frequency and voltage are regulated with the help of VFD to precisely control the electric motor's speed and torque.

The supply voltage is first passed through a rectifier unit where it gets converted into AC to DC supply, the three-phase supply is fed with a three-phase full wave diode where it gets converted into DC supply.

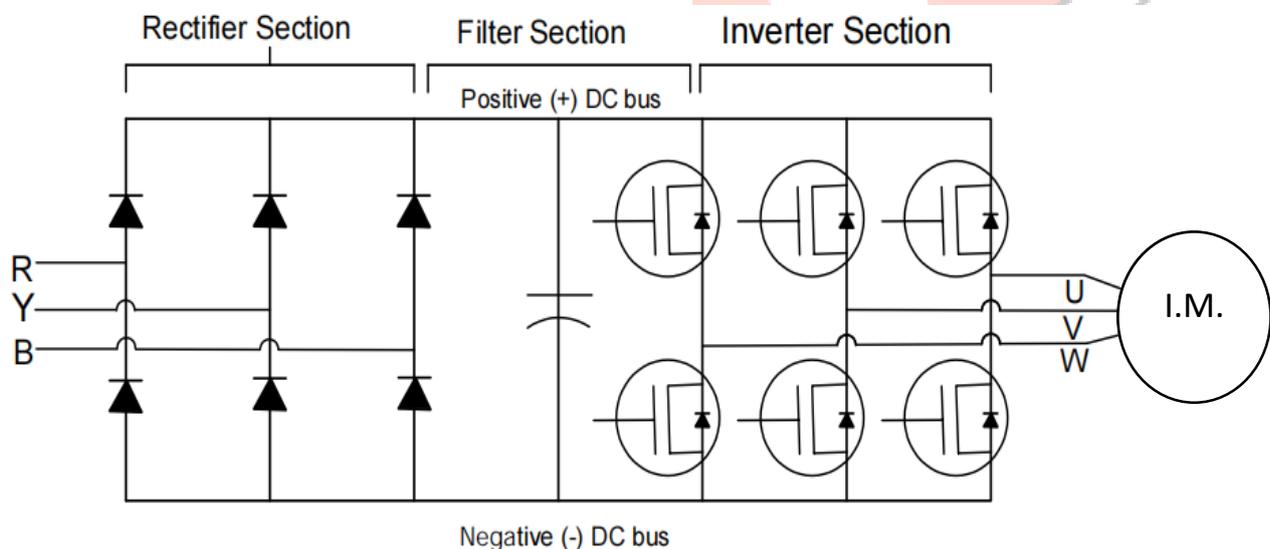


Fig.1 VFD Circuit Diagram

The DC bus comprises a filter section where the harmonics generated during Alternating Current into Direct Current conversion are filtered out. The inverter section contains a circuit made up of six IGBTs (Insulated Gate Bipolar Transistors) that convert the filtered DC power into a quasi-sinusoidal AC waveform, which is then delivered to the connected induction motor.

This part involves converting stored DC voltage back to AC voltage through an inverter. Table 1. includes a detailed electrical equivalent of the switching circuit, which demonstrates how the inverter utilized IGBTs (Insulated Gate Bipolar Transistors) or similar switching devices to turn DC voltage on and off quickly to produce an AC waveform. The output Alternating Current (AC) is used to vary the speed and torque of the electric motor as it can vary the frequency and voltage simultaneously.

The output frequency f_{out} of the inverter is determined by the VFD's control circuit, and the equation for this:

$$f_{out} = VDC * \text{PMW frequency} / VAC$$

Where,

f_{out} = The output frequency (in hertz, Hz)

V_{DC} = The desired output AC voltage

V_{AC} = The desired output AC voltage

PWM = Pulse Width Modulation. a technique used to simulate the smooth Alternating Current wave from the Direct Current voltage.

For DC to AC Conversion in VFD:

Inversion to AC: The VFD will then use PWM to convert the DC into an AC voltage. To achieve an output of 440V at 50Hz, the VFD must be set to provide that specific voltage and frequency level. Inverter Output Frequency: 50Hz (as desired)

Inverter Output Voltage: 440V (as desired) If the desired output is 440V at a frequency of 50Hz, the system must be configured accordingly to deliver that specific voltage and frequency.

Because a VFD operates using Pulse Width Modulation (PWM), the resulting AC output is not a true sine wave but an approximated version that mimics its shape. The modulation index is determined by the ratio between the DC input voltage and the required AC output voltage. The control logic in the VFD will adjust the pulse width to achieve the desired AC waveform.

METHODOLOGY

Connecting the Power Supply: The VFD needs to be connected to an electrical power source, usually a 3-phase AC supply (though some VFDs are designed for single-phase). by making the connection of the power wires (L1, L2, L3 for 3-phase, or L1 and L2 for single-phase) to the VFD's input terminals. This is like plugging the VFD into the wall, but it's for the motor's power.

Connecting the Variable Frequency Drive to the Motor: The VFD will then send power to the motor, but with the special ability to control the motor's speed. The VFD has output terminals (usually marked U, V, and W for 3-phase motors) that you will connect to the motor's corresponding terminals. By adjusting or varying the output power (voltage and frequency), the VFD controls how fast the motor spins.

Grounding the System: The proper grounding is really important to both the VFD and the motor to avoid electrical hazards. There are specific grounding terminals for this purpose on both the VFD and the motor.

Protection: for the protection, we can use fuses or circuit breakers between the power supply and the VFD to protect the system from power surges or overloads.

How the Wires Connect:

1. Power Supply to VFD:

L1, L2, L3 → VFD's input terminals

Ground → VFD grounding terminal

Positive (+) → DC positive

Negative (-) → DC negative

2. VFD to Motor:

U → Motor's U terminal

V → Motor's V terminal

W → Motor's W terminal

Ground → Motor grounding terminal

3. Control Inputs (Optional):

For start/stop controls, wire a button to the VFD's control input terminals.

For speed control, connect a potentiometer to the VFD's analog input terminals.

3. Motor Specifications and Current Calculations

To design a VFD for a specific application, it is essential to understand the motor's rated specifications, including:

- **Motor Power (P):** The output power of the induction motor.
- **Motor Voltage (V):** The voltage at which the motor operates.
- **Motor Current (I):** The current required by the motor.
- **Motor Frequency (f):** The frequency at which the motor operates (typically 50 Hz or 60 Hz).

For this study, a **5 HP motor** with the following specifications is considered:

- **Motor Power (P)** = 5 HP = 3.73 kW
- **Motor Voltage (V)** = 400 V (3-phase)
- **Power Factor (PF)** = 0.85
- **Efficiency (η)** = 0.9
- **Motor Current (I)** = Calculated below

The motor current is determined using the following formula:

$$I = \frac{P}{\sqrt{3} \times V_{line} \times \text{Power Factor (PF)} \times \eta}$$

Substituting values:

$$I = \frac{P}{\sqrt{3} \times 400 \times 0.85 \times 0.9} = \frac{3730W}{522.6} \approx 7.13A$$

Thus, the motor current is approximately **7.13 A**.

4. Diode Rating for Rectifier Stage

The diodes in the rectifier stage of the VFD convert Alternating Current to Direct Current. When selecting diodes for this stage, we must ensure they can handle the peak voltage and current experienced during rectification.

1. Diode Voltage Rating

For a motor rated at 400 V (3-phase), the peak AC voltage is

$$V_{diode} = 400 \times \sqrt{2} = 565.7V$$

To ensure safe operation, the diode voltage rating must be at least 1.2 times the peak voltage:

$$V_{diode} = 1.2 \times 565.7 \approx 678.8V$$

Therefore, the minimum diode voltage rating should be 700 V to 800 V to accommodate any voltage spikes or transients.

2. Diode Current Rating

The diode must carry the full current of the motor during each half-cycle of the AC waveform. As calculated earlier, the motor current is 7.13 A. The diode current rating should be:

$$I_{diode} = 1.5 \times I_{motor} = 1.5 \times 7.13 \approx 10.7A$$

Thus, the minimum diode current rating should be 12 A to ensure reliable operation.

5. IGBT Rating for Inverter Stage

The IGBTs are used in the inverter stage to convert Direct Current to variable frequency Alternating Current. The IGBT ratings need to match the DC bus voltage and motor current.

1. IGBT Voltage Rating

The IGBT voltage rating must be 1.5 times the DC bus voltage. The DC bus voltage is approximately the peak AC voltage, which is 565.7 V. Therefore, the IGBT voltage rating should be:

$$V_{IGBT} = 1.5 \times 565.7 \approx 848.5V$$

To ensure safety, a 1,000 V IGBT would be selected, providing a good margin for transient voltages.

2. IGBT Current Rating

The IGBT current rating must be at least 1.5 times the motor current, as the IGBTs must handle the motor's current and any transient spikes. From earlier calculations, the motor current is 7.13 A, so:

$$I_{IGBT} = 1.5 \times I_{motor} = 1.5 \times 7.13 = 10.7A$$

Therefore, a 12 A to 15 A IGBT should be selected for the inverter stage.

6. Summary of Component Ratings:

Component	Rating
Motor Power	5 HP (3.73 kW)
Motor Voltage	400 V (3-phase)
Motor Current	7.13 A
VFD Power Rating	4 kW
VFD Voltage Rating	400 V (3-phase)
VFD Control Mode	V/f or Vector Control
Diode Voltage Rating	700 V to 800 V
Diode Current Rating	12 A or more
IGBT Voltage Rating	1,000 V
IGBT Current Rating	12 A to 15 A

Table 1. a detailed electrical equivalent of the switching circuit

7. Conclusion

This study paper provides an in-depth look at the selection and sizing of a Variable Frequency Drive (VFD) for a 5 HP (3.73 kW) motor. We discussed the key parameters, including motor specifications, current calculations, and the required ratings for diodes in the rectifier stage and IGBTs in the inverter stage. The appropriate selection of VFD components ensures efficient operation, protection, and longevity of the drive system.

The diode voltage rating should be 700 V to 800 V and the diode current rating should be at least 12 A.

The IGBT voltage rating should be 1,000 V, and the IGBT current rating should be between 12 A to 15 A.

A well-selected VFD can improve motor efficiency, provide precise speed control, and reduce energy consumption, making it a valuable asset in industrial motor-driven applications.

REFERENCE

- [1] Jeffrey Ewanchuk, John Salmon and Andrew M. Knight, "Performance of a high-speed motor drive system using a novel multilevel inverter topology", IEEE transactions on industry applications, vol. 45, no. 5, pp. 1706-1714, 2009. https://scholar.google.com/scholar?as_q=Performance+of+a+high-speed+motor+drive+system+using+a+novel+multilevel+inverter+topology&as_occt=title&hl=en&as_sdt=0%2C31
- [2] Guennegues et al., "A converter topology for high speed motor drive applications", Power Electronics and Applications 2009. EPE'09. 13th European Conference on, 2009. https://scholar.google.com/scholar?as_q=A+converter+topology+for+high+speed+motor+drive+applications&as_occt=title&hl=en&as_sdt=0%2C31
- [3] M. A. Perez, S. Bernet, J. Rodriguez, S. Kouro and R. Lizana, "Circuit Topologies Modeling Control Schemes and Applications of Modular Multilevel Converters", IEEE Trans. Power Electronics, vol. 30, no. 1, pp. 4-17, Jan. 2015. https://scholar.google.com/scholar?as_q=Circuit+Topologies%2C+Modeling%2C+Control+Schemes%2C+and+Applications+of+Modular+Multilevel+Converters&as_occt=title&hl=en&as_sdt=0%2C31
- [4] International Research Journal of Engineering and Technology (IRJET)chrome-extension://efaidnbmnnnibpcajpcglclefindmkaj/https://www.irjet.net/archives/V3/i3/IRJET-V3I3198.pdf
- [5] M. Hagiwara and H. Akagi, "Control and Experiment of Pulse Width-Modulated Modular Multilevel Converters", IEEE Transactions on Power Electronics, vol. 24, no. 7, pp. 1737-1746, July 2009. https://scholar.google.com/scholar?as_q=Control+and+Experiment+of+Pulse+Width-Modulated+Modular+Multilevel+Converters&as_occt=title&hl=en&as_sdt=0%2C31