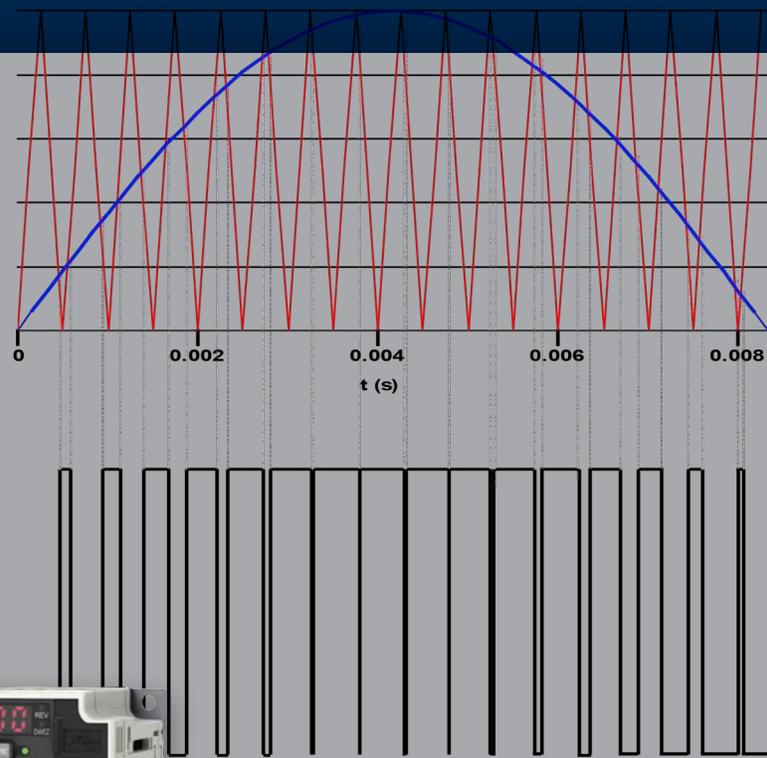


YASKAWA

THE ABCs AND 123s OF VARIABLE FREQUENCY DRIVES

A USER'S GUIDE TO VFD TERMINOLOGY



This document details 50 of the most important VFD terms that VFD users should understand to more effectively specify and maintain their drive.

Understanding VFD terminology helps users to ensure proper application in the field

INTRODUCTION

Keeping up on all of the terminology surrounding the usage of variable frequency drives can be daunting. Maybe if there was one place where you can look up definitions of these ever increasing terms it would make it easier to be a power user of variable frequency drives. We aim to make you the alpha drive user you always wanted to be.

Below you will find some real world definitions of many of the confusing terms thrown around in VFD (variable frequency drive) manuals and technical articles. This lesson contains 50 of the most important VFD terms for today's variable frequency drive users.

1. RECTIFIER/ CONVERTER

One of the three primary sections of a VFD's main power circuit, and first in terms of power flow. Incoming AC line voltage is rectified to DC voltage in the converter section, which consists of diodes, silicon-controlled rectifiers (SCRs), or insulated gate bipolar transistors (IGBTs) connected in a full-wave bridge configuration.

2. DC BUS

The second primary section of a VFD's main power circuit, it is chiefly comprised of capacitors that smooth and store power rectified by the converter. The DC bus section may also contain a pre-charge circuit (see #19 below) and a link choke (see #15 below).

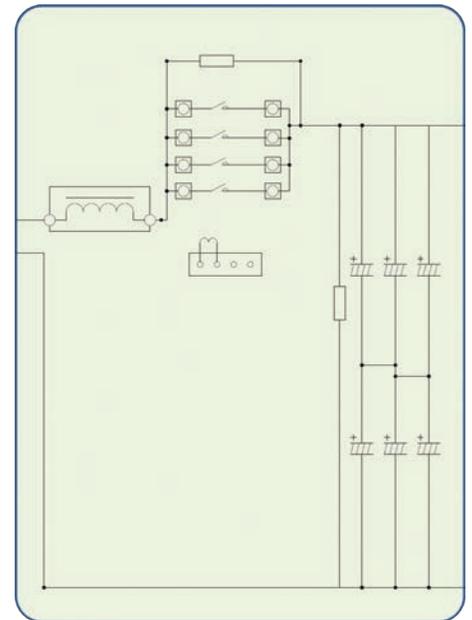


Figure 2: The DC bus section of a VFD

A VFD consists of 3 primary sections, the rectifier/converter, the DC bus and the inverter

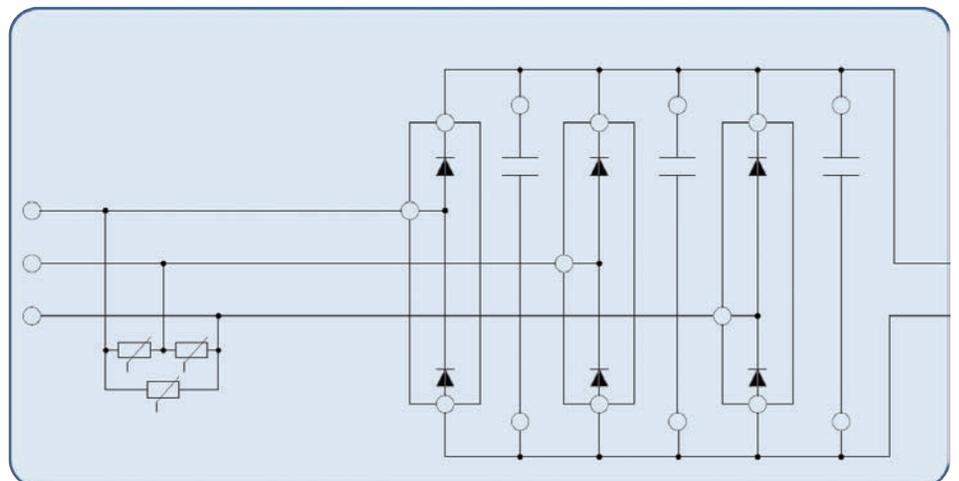


Figure 1: The rectifier/converter section of a VFD

The inverter section of a VFD is the primary difference between an AC drive and a DC drive.

3. INVERTER

The third and final primary section of a VFD's main power circuit. The inverter section is comprised of IGBTs that create sinusoidal output current using pulsed DC bus voltage, or pulse width modulation (PWM: see #5 below).

VFDs themselves are sometimes called inverters, as the presence of an inverter section is the primary difference between VFDs and DC drives.

4. IGBT

Isolated gate bipolar transistors (IGBTs) are very fast semiconductor switches that are actuated electronically.

By applying a small positive voltage between the gate and emitter points of the IGBT, current is allowed to flow from a collector point to an emitter point. IGBT switching rates in VFDs range from 2 to 15 kHz. (See #6 Carrier Frequency).

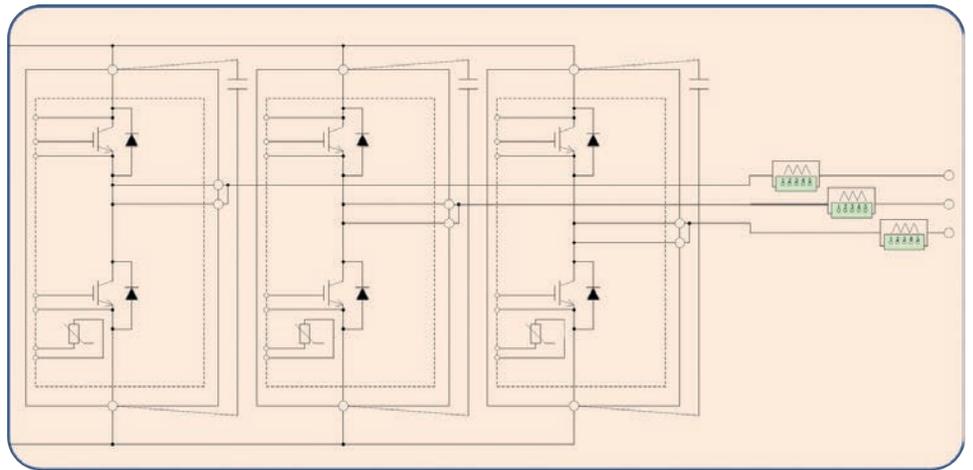


Figure 3: The inverter section of a VFD

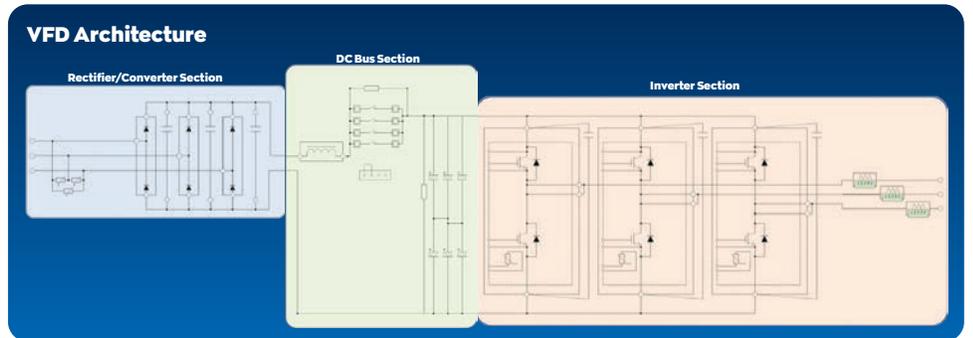


Figure 4: Assembling the 3 sections of a VFD

IGBTs are very fast semiconductor switches that are actuated electronically

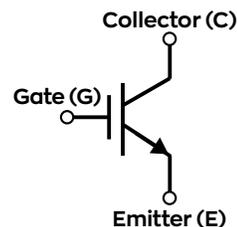


Figure 5: Diagram of an IGBT showing current flowing from collector to emitter.

Pulse width modulation uses a DC voltage to reconstruct a pseudo-AC voltage to produce a nearly perfect sinusoidal waveform

5. PWM

Pulse width modulation (PWM) is a VFD control scheme in which a constant DC voltage is used to reconstruct a pseudo-AC voltage waveform using a set of six power switches, usually IGBTs.

Varying the width of the fixed-amplitude pulses controls effective voltage. This pulse width modulation scheme works because the motor is a large inductor that does not allow current to pulse like the voltage. Sequenced correctly, PWM outputs motor current in a nearly perfect sinusoidal waveform.

6. CARRIER FREQUENCY

In PWM based VFDs, the carrier frequency is the rate at which output transistors are gated or turned on, usually 2 to 15 kHz. Higher values yield better current waveform, but greater VFD losses.

7. COMMON BUSING

Common busing is a method for connecting the DC bus sections of separate VFDs, or operating multiple independent inverter sections from a common DC source.

The advantage of this method is that motor operation sequencing can be used to balance motoring and regenerating so that little or no dynamic braking is necessary.

8. DYNAMIC BRAKING

In VFDs, dynamic braking refers to connecting resistors to the DC bus through a transistor.

The transistor is closed and shunts power to the resistors only when the DC bus voltage exceeds a predetermined level, which usually occurs when the load is quickly decelerated.

Dynamic braking is often used for quickly decelerating loads

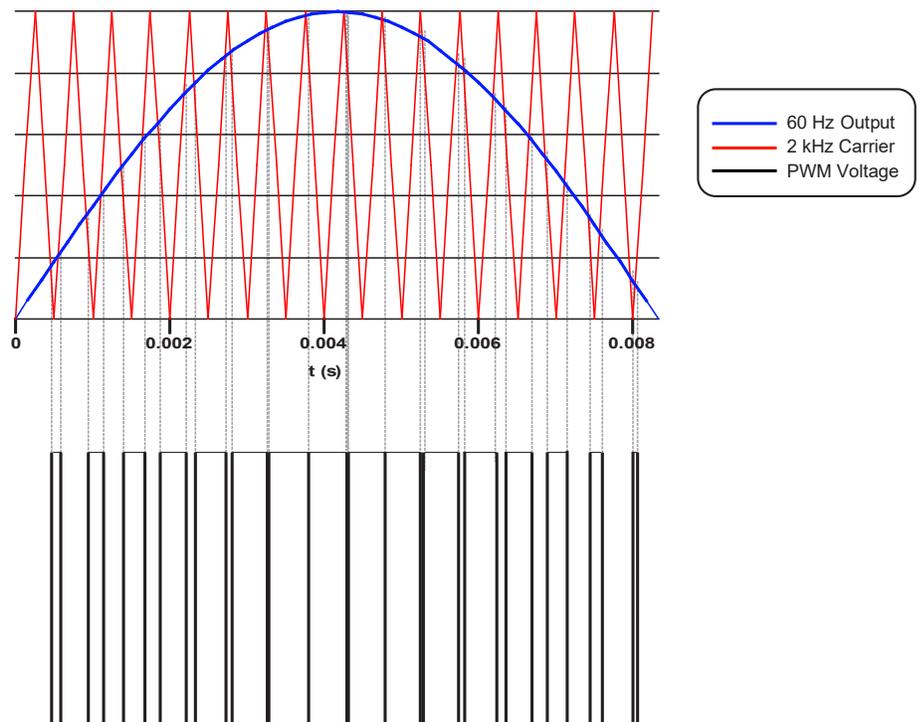


Figure 6 In pulse-width modulated (PWM)-based VFDs, the carrier frequency is the rate at which output transistors are gated or turned on, usually 2 to 15 kHz

An induction motor's power capability is not just dependent on volts and amps, but horsepower, as well

Higher operating currents and frequencies can magnify the effect of leakage inductance

9. GROUND

Also known as earth, ground is the input AC power supply's reference point. If a power supply conductor accidentally touches the ground, then an AC source protection circuit immediately acts to electrically isolate the AC source from the point of contact.

To create the ground point, a rod is normally driven into the earth, and all grounded circuits are connected to that point. When a VFD chassis ground is connected back to this ground, a safe conduction path is created in case a conductor accidentally shorts to a metal portion of the enclosure.

10. kVA

kVA refers to effective size of a VFD based on the output volts and amps it supplies.

$$\text{kVA} = \text{Volts} \times \text{Amps} \times \sqrt{3} \\ \text{(for a three-phase output)}$$

Multiplying output VA by the load power factor yields output power.

Knowing the rated input kVA is useful when sizing components used with VFDs, such as transformers and fuses.

11. kW/HP

kW/HP refers to the power measurement of the motor, where:

$$\text{kW} = \text{HP} \times 0.746$$

Due to a reactive component of the current drawn by induction motors, a motor's power capability is not just dependent on volts and amps, but horsepower, as well.

12. LEAKAGE CURRENT

Leakage current is the derivative of common-mode voltages over time (dv/dt) generated by PWM pulses interacting with parasitic capacitances found between motor cables and the ground conductor, and between the motor's stator and rotor.

Leakage current produced in this way is found on the ground circuit and can present problems for sensitive equipment attached to the same ground.

13. LEAKAGE INDUCTANCE

Leakage inductance is a portion of a motor's inductive properties, synonymous with flux or voltage losses.

Voltage loss results from voltage that is dropped across the motor's conductors, yet produces no flux to link stator and rotor.

A typical example of leakage inductance is the flux created at each turn of the stator winding that occurs outside of the core, created by the stator poles and not linked to the rotor.

Higher operating currents and frequencies magnify the influence of leakage inductance.

Line reactors and link chokes improve power quality for VFDs

14. LINE REACTOR

A line reactor is a device comprised of a conductor coiled around a magnetic core. When current flows through the coils, a magnetic field is established in the core. Any change to current amplitude or direction is opposed by the existing magnetic field in the core until equilibrium is achieved.

A line reactor reduces discontinuity of the current drawn by a VFD's converter section. Reducing this discontinuity or current draw distortion reduces the harmonic current created by the VFD.

Because the line reactor is installed in front of the VFD, it also helps protect the drive from most voltage transients by dropping voltage by an amount proportional to the current flowing through it. The terms reactor and inductor are often used interchangeably and refer to the same device, although reactance and inductance are not interchangeable terms..



Figure 7: Line Reactor

15. LINK CHOKE

A link choke is a single reactor electrically placed ahead of the DC bus capacitors in a VFD.

A link choke reduces harmonics created by the VFD (due to its distorted input current draw) in the same way as a line reactor, but provides less protection against voltage transients.

Unlike a line reactor, a DC link choke doesn't have a current-dependent voltage drop.

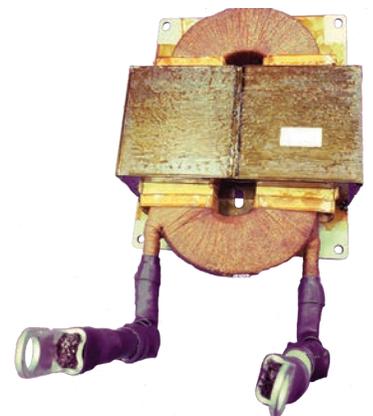


Figure 8: DC Link Choke

Matrix drives convert power using a completely different method than most commercially available drives

16. CONSTANT AND VARIABLE TORQUE

Constant Torque: A torque requirement that does not naturally change with speed, and sometimes requires intermittent overload

Variable Torque: A torque requirement that naturally increases with speed (i.e fan or pump), and does not require intermittent overload.

17. MATRIX CONVERTER

A Matrix converter is an AC-to-AC VFD that doesn't have a rectifier/converter or a DC bus section to convert AC to DC to AC, as in most commercially available drives.

Nine bi-directional switches are controlled depending on target output voltage and frequency. Benefits include four-quadrant operation in a small footprint, low input current harmonic distortion, and lower common mode voltage and common mode current.

A Matrix drive's output voltage is, however, limited to approximately 90% of input voltage.

18. MOTOR POLES

In an induction motor, the stator is used to create the magnetic fields inside the motor that magnetize its rotor and cause shaft rotation. Coils are wrapped around symmetrical iron cores, in turn, arranged around the stator's inner diameter.

Electromagnets are created when current is passed through the coils. In a single-phase motor, each of these electromagnets is matched by another one located 180° away with the opposite polarity, thus creating a magnetic field.

In a three-phase AC motor, three of these electromagnets constitute a motor pole. The number of poles in a motor is one of the factors used to determine the motor's torque per hp and rpm per Hz.

The number of poles in a motor is one of the factors used to determine the motor's torque/hp and rpm/Hz.

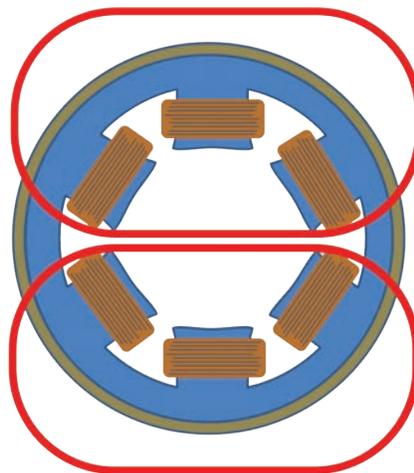


Figure 8 Diagram of a 2-pole motor

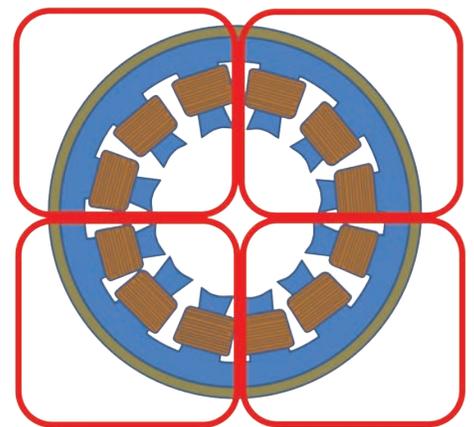


Figure 9 Diagram of a 4-pole motor

A pre-charge circuit limits the inrush current while the capacitors begin to charge

To avoid VFD faults during regeneration, some form of power dissipation is used, such as dynamic braking or line regeneration

19. PRE-CHARGE CIRCUIT

When line power is first applied to a VFD, the dc bus capacitors are in an uncharged state and behave much like a short circuit.

The large inrush of current caused by this shorted state can damage the capacitors and other VFD main circuit components. A pre-charge circuit limits the inrush current while the capacitors begin to charge. Once the capacitors charge to the target voltage, a contactor bypasses the pre-charge circuit.

20. REFLECTED WAVE

All PWM-based VFDs produce output voltage pulses with short rise and fall times. These high dv/dt pulses interact with cable inductance and capacitance and produce a reflection of the incoming voltage pulses at the motor terminals.

If the distance between the motor and drive exceeds the allowable distance, reflected waves can make the line-line peak value of the voltage at the motor terminals nearly twice the dc bus voltage. This high voltage can exceed the voltage rating of the motor's insulation.

21. REGENERATION

A motor can become a generator and send power back to the main line whenever the rotor is rotating faster than the stator field.

Under such a condition, the load is said to regenerate. This may occur whenever the VFD attempts to decelerate the motor, or when the load overhauls the motor.

In this state, the motor's back electromagnetic field is greater than applied voltage, which causes increasing bus voltage and probable VFD fault. To avoid VFD faults during regeneration, some form of power dissipation is used, such as dynamic braking or line regeneration.

22. SATURATION

In a VFD, saturation refers to the state at which voltage applied to the motor is more than what is necessary to produce sinusoidal magnetic field density. Increasing voltage once in the saturation state produces no extra mechanical torque, but does increase motor heating due to increased current.

23. SINGLE-PHASE

A typical 230 VAC single-phase electrical system uses two hot wires and a neutral to transmit power. Such a system is mainly used in residences where three-phase power isn't needed, or in remote areas where three-phase power transmission is too costly.

24. THREE-PHASE

Mainly used in commercial and industrial facilities, a three-phase electrical system uses a neutral or ground, and three hot wires that each transmit one AC phase.

Each phase is a sine wave offset by 120 electrical degrees, or one third of the period. Each phase peaks at a different time, giving the total power supplied the appearance of continuous dc power.

Slip is necessary to create torque in an induction motor

12-pulse and 18-pulse rectification are methods used to reduce input current harmonic distortion

25. SINKING AND SOURCING

Sinking and sourcing pertains to current flows through digital inputs and outputs of VFDs and other components. In a sinking circuit, current flows from the voltage supply, through the load, to the switch, and then to ground. NPN transistors are usually associated with sinking circuits.

In a sourcing circuit, current flows in the opposite direction. PNP transistors are usually associated with sourcing circuits.

26. SLIP

Slip is the speed difference between the motor's rotating magnetic field (created by the stator) and motor-shaft rotation. Slip is necessary to create torque in an induction motor.

27. 12-PULSE RECTIFICATION

This is a method used to lessen the input current total harmonic distortion (THD). Voltage distortion is also reduced, as current distortion causes voltage distortion.

12-pulse rectification requires a dual diode bridge input (six pulses each) and a multi-phase transformer.

The latter offsets the voltage waveform by 30° through one of the six-pulse input diode bridges. This offset causes the fifth and seventh harmonics to be eliminated. These account for about 75% of THD, so input current THD is decreased to about 10% of rated current at the rated operating point.

28. 18-PULSE RECTIFICATION

Similar to 12 pulse rectification, 18-pulse rectification, requires a three-diode bridge input (six pulses each) and a multi-phase transformer.

But in this case, the transformer offsets the voltage waveform by 20° through each of the six-pulse input diode bridges.

This offset causes the fifth, seventh, eleventh, and thirteenth harmonics to be eliminated. These four harmonics account for about 90% of THD, so the input current THD is decreased to about 5% of rated current at the rated operating point.

29. CONTROL BOARD

The control board is a printed circuit board (PCB) that is the main interface component used to connect external equipment and operator interface components to and from the VFD.

Acting as the VFD's brain, the PCB accepts real-world commands such as "Run" or "Speed Up" and executes the target function. The control PCB generally interfaces to the VFD's main circuit via the gate drive board.

Permanent magnet motors are more efficient and smaller than induction motors

However, not all VFDs can operate PM motors

30. GATE DRIVE BOARD

The gate drive board is a PCB containing the circuitry necessary for operating (gating) the output transistors of the VFD. The gate drive board can also monitor main circuit temperature, current, and voltage.

Typically, smaller VFDs have no separate gate drive, but combine gating with logic power supplies to form a power board.

31. INTELLIGENT POWER MODULE (IPM)

An IPM is used as the output section of some VFDs. IPMs include IGBTs, gate circuitry, thermal sensors, and self-protection devices. An IPM is easier to include in a VFD package and takes up less space than if the IPM components were individually laid out on an external PCB.

32. COPY KEYPAD

The copy keypad is a VFD keypad that can store programming to the non-volatile RAM of the keypad itself. These stored parameters often can be loaded into another VFD requiring the same programming

33. AC PM MOTOR

Permanent magnet (PM) motors are a type of synchronous AC motor. Two main AC PM motor subtypes include surface-mount and interior. No slip occurs between the stator and rotor during normal operation of PM motors, unlike in induction motors.

There are no I²R losses in the rotor, either, giving PM motors higher efficiency ratings than induction motors. These energy savings and smaller sizes make PM motors a useful alternative to induction motors. However, not all VFDs can operate PM motors.



Figure 10: Surface-Mount PM Motor



Figure 11: Interior PM Motor

Two-contactor and three-contactor bypass setups provide energy savings by allowing the motor to run across the line during peak demand

34. TWO-CONTACTOR BYPASS

A two contactor bypass is a VFD setup that allows motor operation across the line or through the VFD. One contactor is installed between the incoming line and motor, while the other is installed between the VFD output and motor.

A two-contactor bypass allows the motor to be run directly from the incoming line, bypassing the VFD. The bypass can be used to run the motor at a constant speed directly from the incoming line in case of VFD failure.



Figure 12:
Two-contactor bypass setup

35. THREE-CONTACTOR BYPASS

This is another setup that allows motor operation across the line or through the VFD. One contactor is installed between the incoming line and VFD input. Another (bypass) is installed between the incoming line and motor. A third is installed between the VFD output and motor.

A three-contactor bypass allows the motor to be run directly from the incoming line, bypassing the VFD. This allows for VFD servicing while the motor is being run from the incoming line, and can also be used to run the motor at constant speed at a higher efficiency than with the VFD in circuit.



Figure 13:
Three-contactor bypass setup

In V/f mode, the volts per hertz ratio dictates the amount of torque that a machine produces at a given operating point.

Open and closed loop control allow VFDs to realize the best characteristics of DC drive control without the maintenance and high initial cost of DC motors

36. V/F MODE

Also known as volts-per-hertz mode, this is a simple control method for AC induction motors via a VFD. A ratio is established in accordance with the base voltage and motor base frequency ratings. This ratio yields a linear pattern that the VFD follows to produce rated motor torque. The ratio of voltage to frequency is the flux level in the machine, which in turn, dictates the amount of torque that the machine produces at a given operating point.

37. OPEN LOOP VECTOR

Open loop vector is a complex, but effective motor control method that allows VFDs to realize the best characteristics of DC drive control (accurate torque control over a wide speed range) without the brush maintenance and high initial cost of DC motors. For optimum performance, the position or detection of the motor's rotor must be known or accurately estimated.

The lack of actual shaft position feedback in open-loop vector control necessitates the calculation of rotor position by other means. But the cost savings of eliminating the feedback device, VFD input, and associated cabling offsets the slight loss of motor performance, as compared to closed-loop vector operation.

38. CLOSED LOOP VECTOR

Closed loop vector is another complex, but effective motor control method that allows VFDs to realize the benefits of DC drive control benefits without the physical limitations of DC motors.

Feedback devices such as encoders or resolvers supply necessary motor slip information to close the loop between VFD output frequency and actual motor shaft speed.

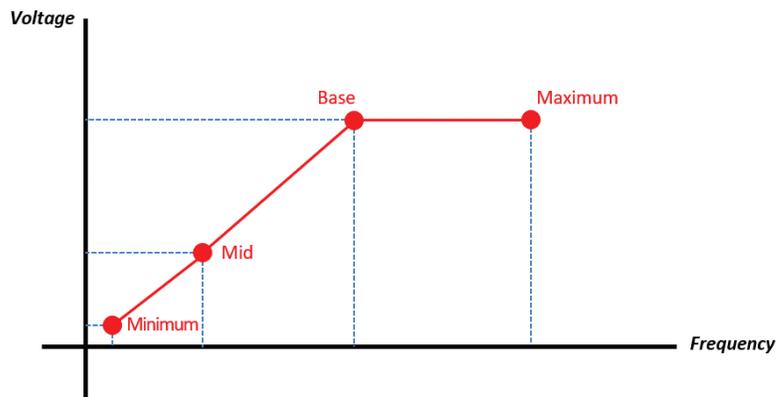


Figure 14: Volts-per-hertz (V/F) mode is a simple control method for AC induction motors via a VFD.

PID determines reaction to changes between a system set point and its actual state, as measured by feedback

39. PID

The Proportional, Integral, and Derivative (PID) control algorithm is widely used throughout industrial control. When a process loop is created by adding feedback (from a variable such as airflow, pressure, or level) and sent to the VFD, regulation of the process is possible via PID loop control.

The VFD's PID algorithm uses mathematical properties to determine reaction to changes between the system set point and its actual state as measured by feedback.

40. AUTO-TUNING

Auto-tuning is a process in which the VFD tests an attached and unloaded motor to determine the best tuning parameters.

41. SCCR

Short Circuit Current Rating (SCCR) is defined as the maximum current a device can endure during a short

circuit event without losing its external integrity. The SCCR of a device or combination of devices should be greater than the available fault current possible at its input.

42. AIC

Amps Interrupting Current (AIC) is defined as the amount of symmetrical amperage, at rated voltage, an over current protective device can safely stop by opening.

43. LET-THROUGH CURRENT

Over Current Protective Devices (OCPDs) typically open and allow a limited amount of current to flow through that is below the maximum fault current. The amount of current that an OCPD allows to flow through is called "let through" current.

Therefore the OCPD lowers the amount of fault current available downstream to its let-through current rating. The fault current must be within the range of the OCPD device.

The SCCR of a device or combination of devices should be greater than the available fault current possible at its input

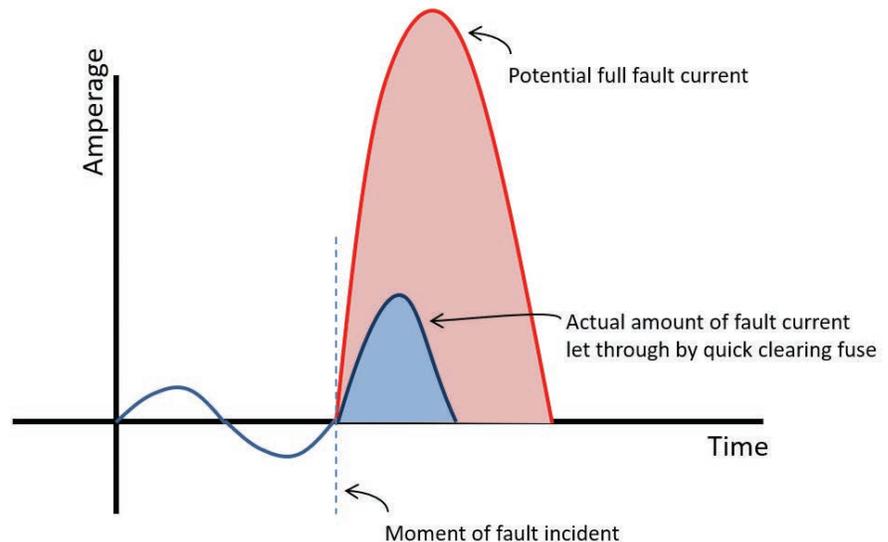


Figure 15: An over current protection device (OCPD) lowers the amount of fault current available downstream to its let-through current rating.

Every VFD needs to be configured as to where the command to start the motor will come from

44. FIELDBUS

Fieldbus is a term used for a communication network that can be used for automation and is defined by the physical means used to transmit messages along with how a message is structured. These networks are serial in nature.

A physical implementation of a fieldbus network can be comprised of RS-485 or Ethernet. Many VFDs have built-in fieldbus connections though some fieldbus protocols require option boards.

45. RS-485

RS-485 is a serial network standard defining the electrical and physical traits for transmitting and receiving messages in an industrial environment.

One of the main traits of RS-485 is that it is a multi-drop connection scheme that allows many devices to communicate over long distances using only two or four wires and a shield.

46. ETHERNET

This term defines the hardware and message transport specifications of networking devices, otherwise known as nodes.

It is comprised of the first two layers of the OSI model for the Physical Layer (e.g. cable, RJ45 connector) and Data Link Layer (i.e. defining how a message is moved from one device to another).

47. PROTOCOL

The term protocol is defined as a set of rules defining how messaging is created for use on fieldbus networks. The rules will detail how communication between devices (such as a VFD) is to be constructed and delivered.

Differing protocols generally cannot be mixed in a single network without use of a gateway device. Protocol is generally the software specification portion of “fieldbus protocol.” Examples of protocols are EtherNet/IP, DeviceNet, PROFIBUS, PROFINET, Modbus RTU, and Modbus TCP/IP.

48. RUN SOURCE

Every VFD needs to be configured as to where the command to start the motor will come from. Generally there are local (e.g. the keypad) and remote (e.g. a network command) sources of the start command. Choosing which source, local or remote, can usually be selected via the keypad itself. Warning: Generally only a single Run Source can be active at one time. All the other sources will be ignored.

49. REFERENCE SOURCE

The reference source specifies where the VFD's speed command will come from. It is also known as the Frequency Reference, since most VFDs default to using frequency in hertz as the default speed command unit. Sometimes, but not always, the reference source will come from the same source as the run source.

50. THREE-LEVEL OUTPUT

A three-level output is a modified output PWM pattern that uses extra IGBTs, a neutral point clamp, and custom switching patterns to achieve three possible output voltage levels ($E/2$, 0 , $-E/2$ with $E/2$ being the DC bus mid-point voltage). A three-level output from a VFD will naturally lead to lower common-mode voltage and noise and dramatically reduce bearing currents that cause premature motor bearing failures.

A three-level output from a VFD will naturally lead to lower common-mode voltage and noise and dramatically reduce bearing currents

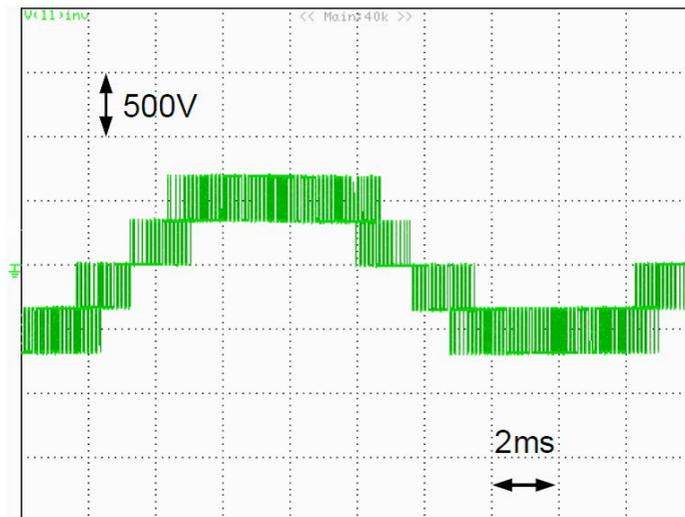


Figure 16: Three-level output is a modified output PWM pattern that uses extra IGBTs, a neutral point clamp, and custom switching patterns to achieve 3 possible output voltage levels, which can reduce bearing currents that lead to premature bearing failures.

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Yaskawa is the leading global manufacturer of low and medium voltage variable frequency drives, servo systems, machine controllers and industrial robots. Our standard products, as well as tailor-made solutions, are well known and have a high reputation for outstanding quality and reliability.

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