

AC DRIVE CHARACTERISTICS

AC DRIVE INTRODUCTION

The use of adjustable speed in industrial equipment is increasing due to the need for better equipment control and for energy savings where partial power is required.

ADJUSTABLE FREQUENCY DRIVE CONCEPTS

The principle of speed control for adjustable frequency drives is based on the following fundamental formula for a standard AC motor:

$$N_s = \frac{120 F}{P} \quad \text{where } N_s = \text{synchronous speed (rpm)}$$

F = frequency (cps)
P = no. of poles

The number of poles of a particular motor is set in its design and manufacture.

The adjustable frequency system controls the frequency (F) applied to the motor. The speed (Ns) of the motor is then proportional to this applied frequency. Control frequency is adjusted by means of a potentiometer or external signal depending on the application.

The control can automatically maintain the required volts/cycle (V/Hz) ratio to the motor at any speed. This provides maximum motor capability throughout the speed range.

The frequency output of the control is infinitely adjustable over the speed range and therefore the speed of the motor is infinitely adjustable.

BASIC CONTROL DESIGNS

Control Techniques produces two basic control designs; Pulse Width Modulation (PWM) and Six Step (6-Step). Both PWM and Six Step type inverters take an adjustable reference input and output a variable frequency and variable voltage to the connected AC motor. This varying output allows the operator to control the speed and direction of the AC motor.

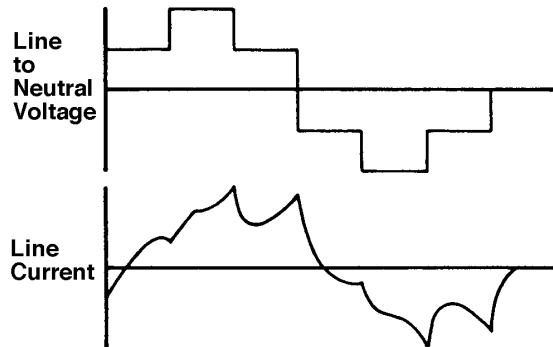
SIX STEP DESIGN (6-STEP)

The 6-Step type of inverter uses a two part conversion process to produce the variable frequency and voltage needed to control the AC motor. It takes the 3-phase input line voltage and rectifies it into a variable DC value which is later converted into six discrete steps per output cycle. Because there is no high frequency carrier, a 6-Step type of inverter produces no audio noise in the AC motor.

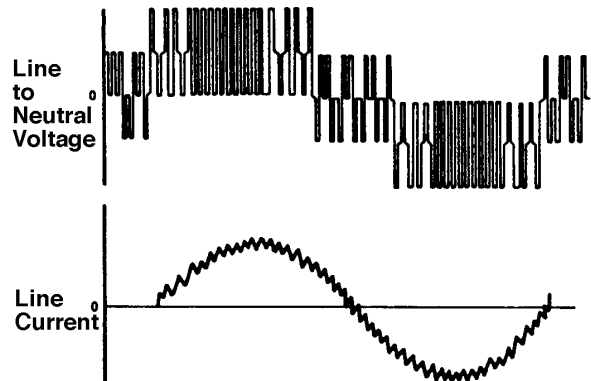
PULSE WIDTH MODULATION DESIGN (PWM)

The PWM type of inverter is the simplest of all the AC inverter designs. It takes the 3-phase input line voltage and rectifies it to a fixed DC value then modulates it to a variable frequency and voltage output. Since the DC bus of a PWM inverter is fixed at some value and does not vary, a simple 3-phase diode bridge is all that is needed for the conversion process.

SIX STEP WAVE FORM



PULSE WIDTH MODULATION WAVE FORM



AC APPLICATIONS

MOTOR CONSIDERATIONS

The Inverter is mainly used to operate one standard 3-phase, 60 Hz squirrel cage induction motor. Groups of motors may be connected to the drive provided the total load does not exceed the drive rating and that all motors can operate together. Reduced stall torque can be expected with multiple motors. The inverter should be selected on the basis of its current and KW ratings instead of nominal HP rating.

Synchronous induction or permanent magnet AC motors can also be operated except that due to lower power factors it may be necessary to use a higher rated inverter. Again, the inverter should be sized on the basis of its current and KW ratings.

When operating a motor at reduced speeds, the ability to dissipate heat is also reduced due to the slower cooling fan speed. Figure 12 is a conservative guide to follow for continuous operation at lower speeds, with a constant torque load.

However, most high-efficient and 1.15 service factor motors with Class F insulation will perform as shown in Figure 18 on page 15.

STANDARD SPEED RANGE

The inverter is factory set to provide constant torque from 6 to 60 Hz (Figure 13) and will operate any similarly rated 3-phase 60 Hz Induction, Synchronous, or AC Permanent magnet motor. The 60 Hz speed is determined by the number of poles (P). Motor current is essentially constant throughout the speed range when using a standard 60 Hz motor.

$$60 \text{ Hz Speed} = \frac{120 \times 60}{P} = \text{RPM}$$

EXTENDED SPEED RANGE

(shown for 460V models)

Extended speed range is available on the control at no additional cost. The frequency range is selectable by the user. The high speed limit potentiometer sets the maximum frequency between 60 and 120 Hz.

The drive provides constant voltage output (460V) as frequency increases above 60 Hz. (Figure 14) This is called "extended speed range" and corresponds to field weakening on DC drives.

Extended V/Hz (Constant Torque Range)

Curve B in Figure 14 provides 460V @ 120 Hz, and constant torque operation from 12 to 120 Hz. Motor is normally rated 230V @ 60 Hz but at 1/2 the Control HP rating.

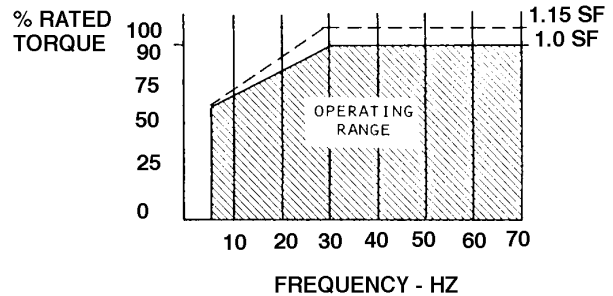


Figure 12
Operating Range

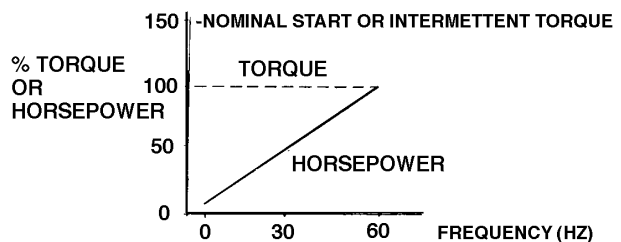


Figure 13
Torque and HP Range

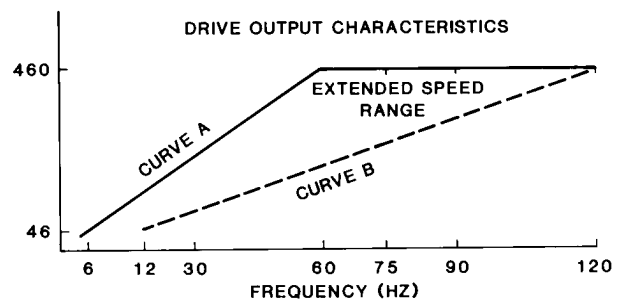


Figure 14
Extended Speed Range

AC APPLICATIONS

MOTOR TORQUE

Motor torque is defined at four points as shown in Figure 15.

1. Breakaway, starting, or stall
2. Minimum or "pull-up"
3. Breakdown or "pullout"
4. Full Load

The area under the curve represents the motor's accelerating torque from zero to full speed.

$$\text{Full-load torque} = \frac{\text{HP} \times 5250}{\text{RPM}}$$

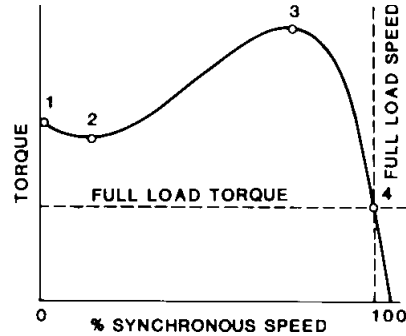


Figure 15
Motor Torque

INDUCTION MOTOR

A typical induction motor speed-torque curve at given frequency is shown in Figure 16. A family of such curves exists for all frequencies in the speed range. The speed at which the induction motor operates depends on the load imposed on the motor. For example, for a load of T_1 , the motor will operate at a speed of N_1 , and if the load is increased to T_2 , the motor will operate at speed N_2 . The regulation for such a system is dependent on the actual speed/torque curve of the particular motor.

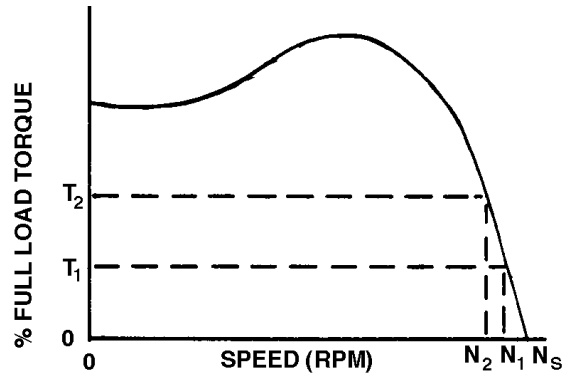


Figure 16
Induction Motor Speed/Torque Curve

SYNCHRONOUS-RELUCTANCE AND PERMANENT MAGNET SYNC MOTORS

A typical synchronous-reluctance motor speed/torque curve at a given frequency is shown in Figure 17. A family of curves exists for all frequencies in the speed range. This motor will operate at synchronous speed for all loads between points A and B. Thus, if the frequency is maintained constant, then the speed remains constant even though the load were to change. The precise speed control available with this type of motor and inverter is readily apparent. For such operation, the regulation error of the drive due to the load is zero.

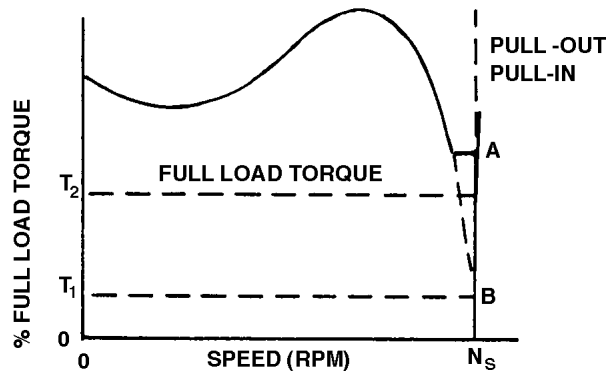


Figure 17
Synchronous-Reluctance Motor Curve

AC DRIVE APPLICATIONS

MOTOR PERFORMANCE (High Efficiency)

Typical motor performance is shown in Figure 18. This represents the maximum continuous capability of most AC induction motors when operated on the inverter. Operating in the extended speed range is possible to 90 Hz using an induction motor with the same rating as the inverter (e.g., 5 HP 60 Hz motor on 5 HP inverter) obtaining the same HP at 90 Hz as at 60 Hz. Above 90 Hz, horsepower drops off approximately as shown. If "up-framing" is necessary, use the next size inverter. At low speeds, most high efficiency and 1.15 SF motors will provide reduced torques approximately as shown in Figure 18.

Additional motor derating is necessary for operating over wide speed ranges with standard efficiency 1.0 service factored motors. A useful guide to motor selection is shown in Figure 19 for minimum speed operation.

MOTOR DERATING VS SPEED RANGE (Normal Efficiency)

Figure 1-8 is a useful motor derating guide for selecting the correcting motor for operation over a wide speed range. These curves are for constant torque loads. The nameplate HP of the motor must not exceed 1.5 times the constant torque rating of the inverter.

Variable torque loads do not require as much derating.

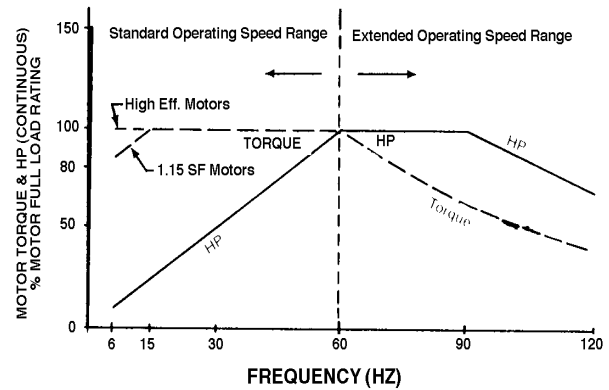


Figure 18
Motor Performance, Typical 60 Hz

Example 1 - A 20 HP motor over a 3:1 constant torque speed range can deliver 83% of the 20 HP full load torque ratings, and 77% for a 4:1 speed range.

Example 2 - A 40 HP motor over a 10:1 constant torque speed range can deliver 62% of the 40 HP full load torque ratings.

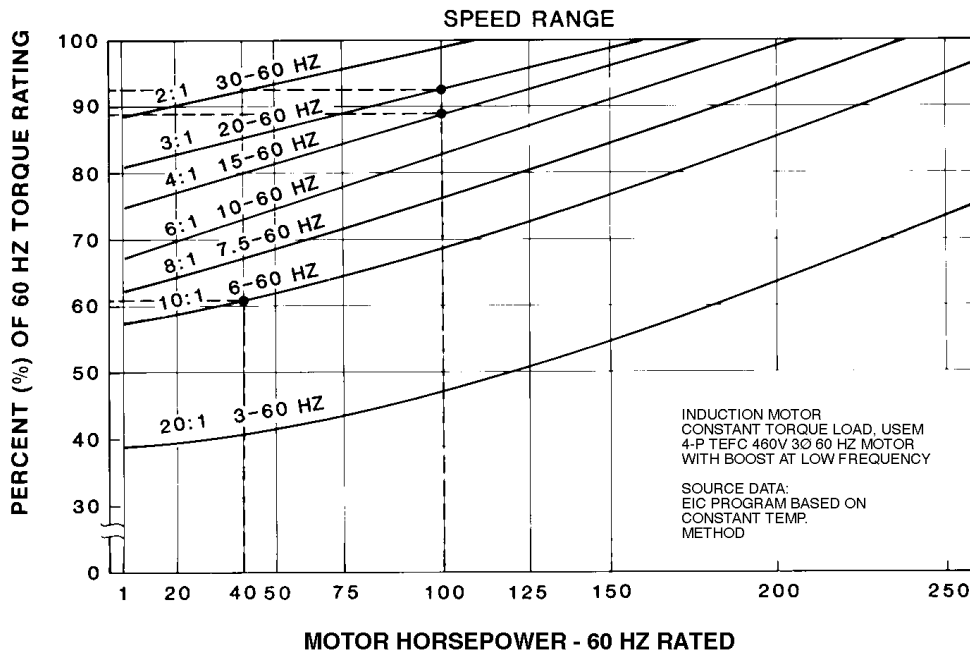


Figure 19
Motor Derating Curves vs Speed Range when applied to Adjustable Frequency AC Drives (6-step wave form or PWM)



AC and DC Drives Applications

AC APPLICATIONS

SELECTING THE AC CONTROL

After evaluating the type of load, constant torque (CT) or variable torque (VT) from page 2, and having considered speed range requirements and motor derating from Figure 19, the correct size control may then be selected.

When looking at the controller "rating" tables, the key parameters are "HP" and "Run Current". Larger motors or groups of motors can be run provided that in addition to the current rating, the KVA and KW ratings are not exceeded.

1. CONTINUOUS RUN CURRENT RATING

This is the maximum RMS current the control can safely handle under all operating conditions at 105°F. Motor full load sine wave currents must be equal to or less than the control rating.

2. OVERLOAD CURRENT RATING

This is the level (150% of full load rating) at which the control automatically reduces motor speed due to an overload condition by simultaneously reducing both voltage and frequency until the overload condition is cleared. Throughout this condition, full load torque is still available to the motor.

The relationship between overload current and time is an inverse function with continuous overload limited to approximately 105%.

In multi-motor applications with one or more of the motors starting across the line, the controller must be sized for the worst case RUN + START condition taking into consideration the locked rotor current of the motor(s) being started. The control should be sized so that it does not go into current limit.

3. START CURRENT RATING

This is a three to five second rating providing at least 175% of full load current for starting motors, usually with additional voltage boost. This feature permits setting of start frequency and boost for optimum start torque conditions.

Engineering assistance is available to help in sizing controllers for high start-torque applications.

NOTE:

Application engineering assistance is available on request for sizing information and custom engineered systems.

FACTORS FAVORING ADJUSTABLE FREQUENCY DRIVES

- Speed control accuracy
- Suggest, low-inertia, reliable AC motors
- Low maintenance costs
- Can be applied to most existing AC motors
- Large selection of motor enclosures for hostile environments - Safe, convenient, high-speed operation
- Can switch to plant power (at constant speed) should the control malfunction
- Large selection of base speeds - Multi-motor systems
- Need to soft-start motor due to power supply restrictions - Extended speed range beyond base speed
- Motor reversing without motor starters
- Accurate ratio control between machines
- Process controls - flow, pressure, level, temperature
- Inherent Energy Savings on centrifugal loads
- High Speeds

MOTOR PROTECTION

The most desirable motor protection is a thermal detector (N.C.) in the motor winding connected in the stop circuit. A separate thermal overload relay may also be used, but will not sense the additional heating at low speeds due to loss of fan action.

If the motor nameplate full load rating is matched to the control rating, the built-in inverse time over load feature will afford a similar type protection as standard thermal overload relays. The feature limits continuous overloads to approximately 105% full load. Thermal overloads should be used in applications where the control rating is much larger than the individual motor, it is powering or in multi-motor applications.



AC and DC Drives Applications

AC APPLICATIONS

MOTORS STARTERS

Motor starters may be used on the output of controls provided certain precautions are followed.

The motor starter option provides a positive disconnect of the control output leads to the motor. It also provides motor overcurrent sensing and overload protection from base speed down to approximately 50% speed for most motors. It should be noted that the control has an inverse time overload protection circuit. This circuit comes into operation when load current reaches 105% of control rated capacity. The effect of this circuit could negate the over current trip action of the O/L relays, since an over current condition is automatically corrected. If the control is rated higher than the motor, the overload relays may still work if properly sized. Another possibility would be to use an undersize set of overload heater elements. In multi-motor application, each individual motor should be protected with an O/L relay.

The recommended protection for all motor types and all speed ranges is an internal thermal sensor that can be connected to the control in order to shut it down in case the motor overheats.

RAPID DECELERATION OF HIGH INERTIA LOADS

When cycling from high speeds to low speeds on applications with large inertia loads, regeneration of power back into the control may occur. Downhill conveyors and elevators are also other applications where regeneration back into the control may occur. The drive will protect itself from damage by limiting the regenerative current and tripping out on bus over voltage. For those types of applications, switching a properly selected power resistor across the bus will keep the drive from tripping. Control Techniques does offer standard braking kits for certain models of control. For those controls that do not have standard kits, custom designs are available from the factory.