Product Data Bulletin
SC100 R5/95
May, 1995

Adjustable Frequency Controllers

Application Guide

Telemecanique

SQUARE D

TABLE OF CONTENTS

SECTION 1 – LOADS AND FORMULAS

SECTION 2 – MOTOR NAMEPLATE DATA

SECTION 3 – SPEED CONTROL RANGE & MOTOR HEATING

SECTION 4 – BREAKAWAY TORQUE REQUIREMENTS

SECTION 5 – ACCELERATION REQUIREMENTS

SECTION 6 – DECELERATION REQUIREMENTS

SECTION 7 – ENVIRONMENTAL CONDITIONS

SECTION 8 – MULTIMOTOR APPLICATIONS

SECTION 9 – AC LINE CONSIDERATIONS

SECTION 10 – AFC CONSIDERATIONS

SECTION 11 – SPECIAL APPLICATION CONSIDERATIONS

LIST OF FIGURES

LIST OF TABLES

Adjustable Frequency Controllers (AFCs) are often referred to as Inverters, Adjustable Frequency Drives (AFDs), AF Drives, Variable Frequency Drives (VFDs) or Power Converters. The term Adjustable Frequency Controller (AFC) is used in this publication.

Before selecting an AFC, you should evaluate all considerations addressed in the application flow chart on the next page, since additional equipment may be necessary to meet the application requirements.

The performance of an AFC can be affected by operating conditions, such as unusual application requirements or the condition of the mechanical equipment. The overall success of an application could be affected by other factors not considered in this application guide.

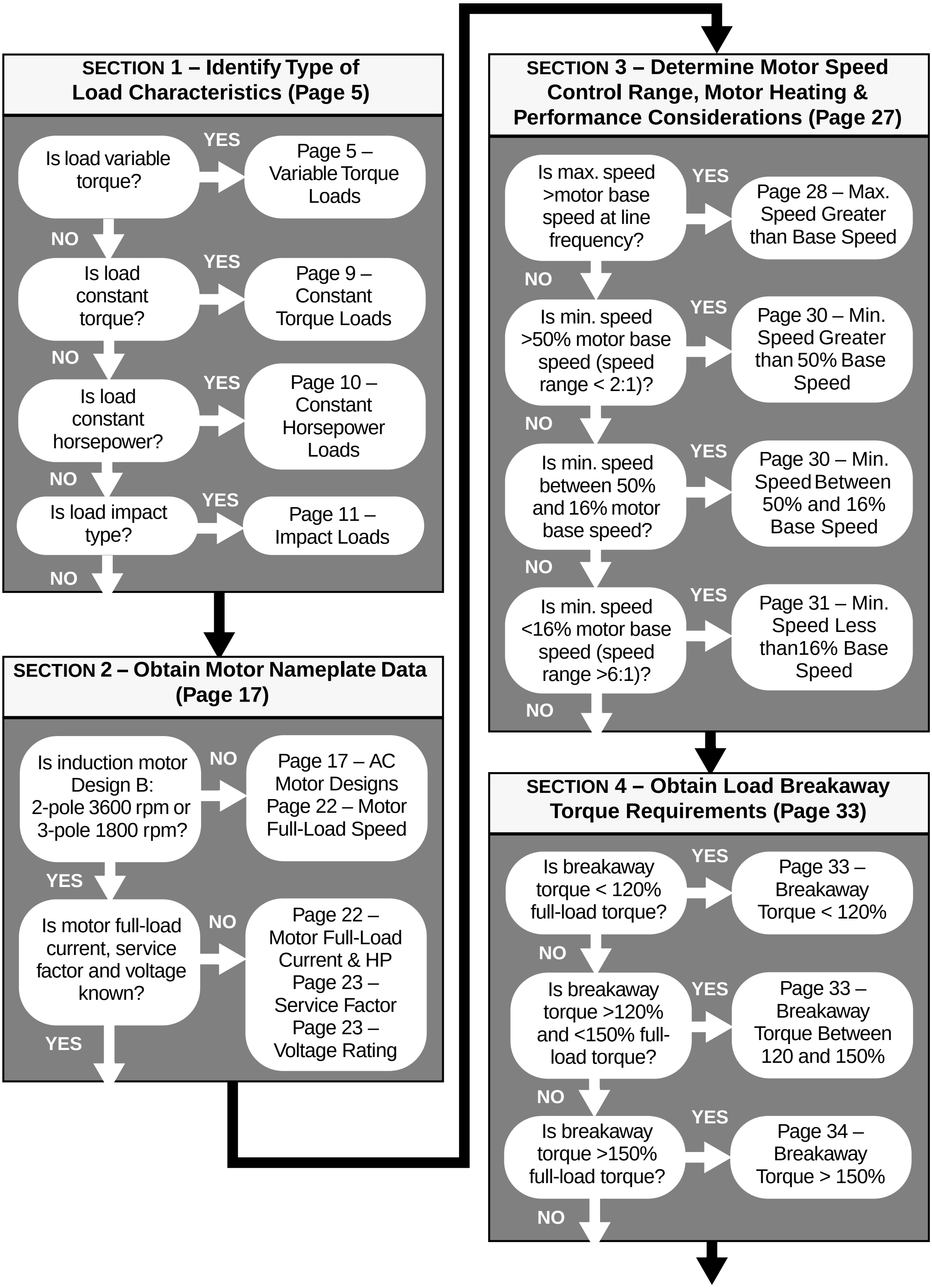
For some applications, you may have to adjust the AFC to attain the required performance. These adjustments are described in the instructional material supplied with the controller.

For more application information, refer to the documents listed below.

Table 1: Additional Reference Material

Bulletin No.	Title
C-862A	AC Motor Operation and Performance Characteristics
C-870A	Inverter Fundamentals
C-873A	Total Power Factor
C-877R	The Effects of Adjustable Frequency Controllers on the AC Line
C-879	Valve Sequencing Control with Adjustable Speed Pumping Drives
C-882R	Surge Voltages (IEEE Std. 587)
C-883	AC Line Disturbances (IEEE Std. 519)
8803PD9402	Power System Harmonics
8803PD9404	OMEGAPAK® AC Drive Order Processing
SC101	OMEGAPAK® AC Drive Application Data

Table 2: AFC Application Flowchart



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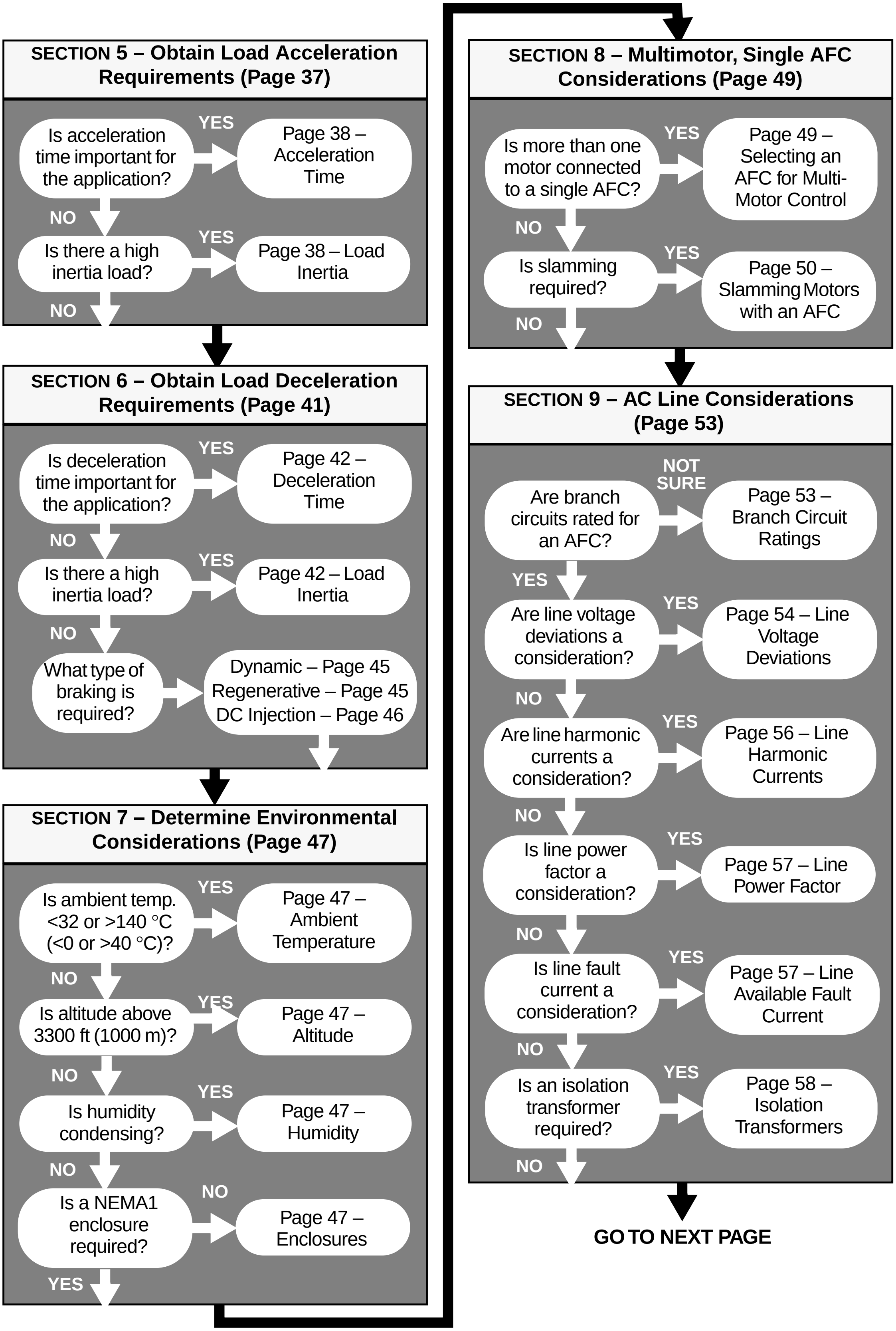
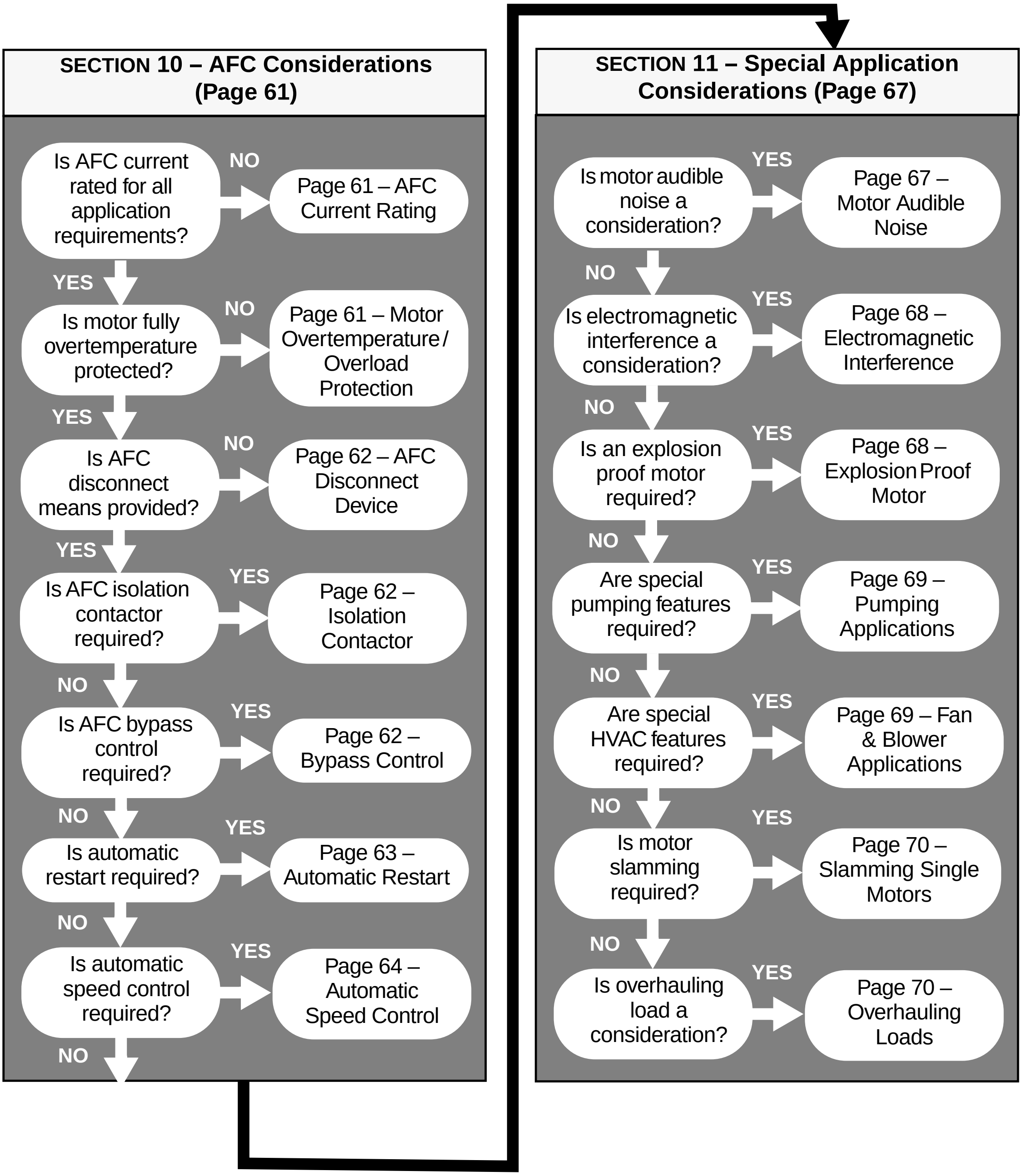

SECTION 5 – Obtain Load Acceleration Requirements (Page 37)
Is acceleration time important for the application?
YES
Page 38 – Acceleration Time
NO
Is there a high inertia load?
YES
Page 38 – Load Inertia
NO
SECTION 6 – Obtain Load Deceleration Requirements (Page 41)
Is deceleration time important for the application?
YES
Page 42 – Deceleration Time
NO
Is there a high inertia load?
YES
Page 42 – Load Inertia
NO
What type of braking is required?
Dynamic – Page 45
Regenerative – Page 45
DC Injection – Page 46
SECTION 7 – Determine Environmental Considerations (Page 47)
Is ambient temp. <32 or >140 °C (<0 or >40 °C)?
YES
Page 47 – Ambient Temperature
NO
Is altitude above 3300 ft (1000 m)?
YES
Page 47 – Altitude
NO
Is humidity condensing?
YES
Page 47 – Humidity
NO
Is a NEMA1 enclosure required?
NO
Page 47 – Enclosures
YES
SECTION 8 – Multimotor, Single AFC Considerations (Page 49)
Is more than one motor connected to a single AFC?
YES
Page 49 – Selecting an AFC for Multi-Motor Control
NO
Is slamming required?
YES
Page 50 – Slamming Motors with an AFC
NO
SECTION 9 – AC Line Considerations (Page 53)
Are branch circuits rated for an AFC?
NOT SURE
Page 53 – Branch Circuit Ratings
YES
Are line voltage deviations a consideration?
YES
Page 54 – Line Voltage Deviations
NO
Are line harmonic currents a consideration?
YES
Page 56 – Line Harmonic Currents
NO
Is line power factor a consideration?
YES
Page 57 – Line Power Factor
NO
Is line fault current a consideration?
YES
Page 57 – Line Available Fault Current
NO
Is an isolation transformer required?
YES
Page 58 – Isolation Transformers
NO
GO TO NEXT PAGE


SECTION 10 – AFC Considerations (Page 61)
Is AFC current rated for all application requirements?
NO
Page 61 – AFC Current Rating
YES
Is motor fully overtemperature protected?
NO
Page 61 – Motor Overtemperature / Overload Protection
YES
Is AFC disconnect means provided?
NO
Page 62 – AFC Disconnect Device
YES
Is AFC isolation contactor required?
YES
Page 62 – Isolation Contactor
NO
Is AFC bypass control required?
YES
Page 62 – Bypass Control
NO
Is automatic restart required?
YES
Page 63 – Automatic Restart
NO
Is automatic speed control required?
YES
Page 64 – Automatic Speed Control
NO
SECTION 11 – Special Application Considerations (Page 67)
Is motor audible noise a consideration?
YES
Page 67 – Motor Audible Noise
NO
Is electromagnetic interference a consideration?
YES
Page 68 – Electromagnetic Interference
NO
Is an explosion proof motor required?
YES
Page 68 – Explosion Proof Motor
NO
Are special pumping features required?
YES
Page 69 – Pumping Applications
NO
Are special HVAC features required?
YES
Page 69 – Fan & Blower Applications
NO
Is motor slamming required?
YES
Page 70 – Slamming Single Motors
NO
Is overhauling load a consideration?
YES
Page 70 – Overhauling Loads

The first important consideration when applying an AFC is to determine the type of load and its characteristics. To select the proper AFC parameters, you must know the speed and torque requirements. For some types of loads, the application considerations are minimal. For other types of loads, extensive review of the application is required.

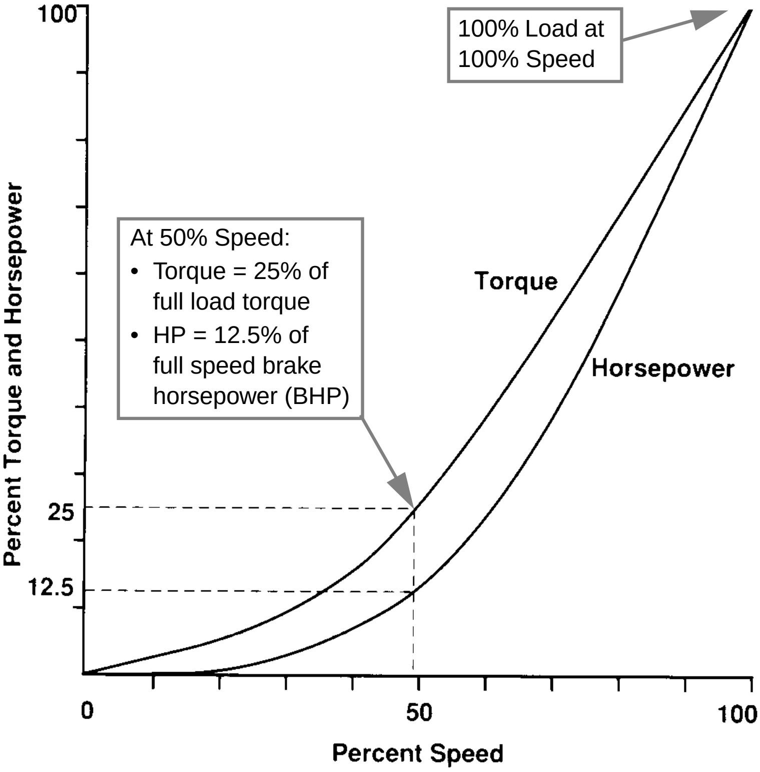
Generally, loads can be grouped into four different categories:

- Variable Torque Loads
- Constant Torque Loads
- Constant Horsepower Loads
- Impact Loads

To calculate load horsepower, see page 12. To calculate load inertia, see page 15.

VARIABLE TORQUE LOADS

Many types of loads require reduced torque when driven at speeds less than the base speed of the load. Conversely, such loads may require increased torque when driven at speeds greater than the base speed of the load. These are classified as variable torque loads. Many variable torque loads decrease with the square of the speed. This is characteristic of centrifugal pumps (page 7), and certain types of fans and blowers (page 8). Typically, as the speed decreases, the torque decreases with the square of the speed and the horsepower decreases with the cube of the speed (Figure 1).



100% Load at 100% Speed

At 50% Speed:
- Torque = 25% of full load torque
- HP = 12.5% of full speed brake horsepower (BHP)

Figure 1: Variable Torque Loads

These variable torque characteristics are a result of affinity laws that govern the performance of centrifugal machinery. Typically for pumps, these laws state:

- The **capacity** (Q) is directly proportional to the speed (S), with a fixed impeller diameter.

$$\frac{Q_1}{Q_2} = \frac{S_1}{S_2}$$

- The **head** (H) developed is directly proportional to the square of the speed, with a fixed impeller diameter.

$$\frac{H_1}{H_2} = \frac{S_1^2}{S_2^2}$$

- The **brake horsepower** (HP) required at a pump shaft is directly proportional to the cube of the speed, with a fixed impeller diameter.

$$\frac{HP_1}{HP_2} = \frac{S_1^3}{S_2^3}$$

- The **capacity** (Q) is directly proportional to the impeller diameter (D), at a fixed speed.

$$\frac{Q_1}{Q_2} = \frac{D_1}{D_2}$$

- The **head** developed is directly proportional to the square of the impeller diameter, at a fixed speed.

$$\frac{H_1}{H_2} = \frac{D_1^2}{D_2^2}$$

- The **brake horsepower** required at a pump shaft is proportional to the cube of the impeller diameter, at a fixed speed.

$$\frac{HP_1}{HP_2} = \frac{D_1^3}{D_2^3}$$

For additional information on pumping systems, see Product Data Bulletin C-876.

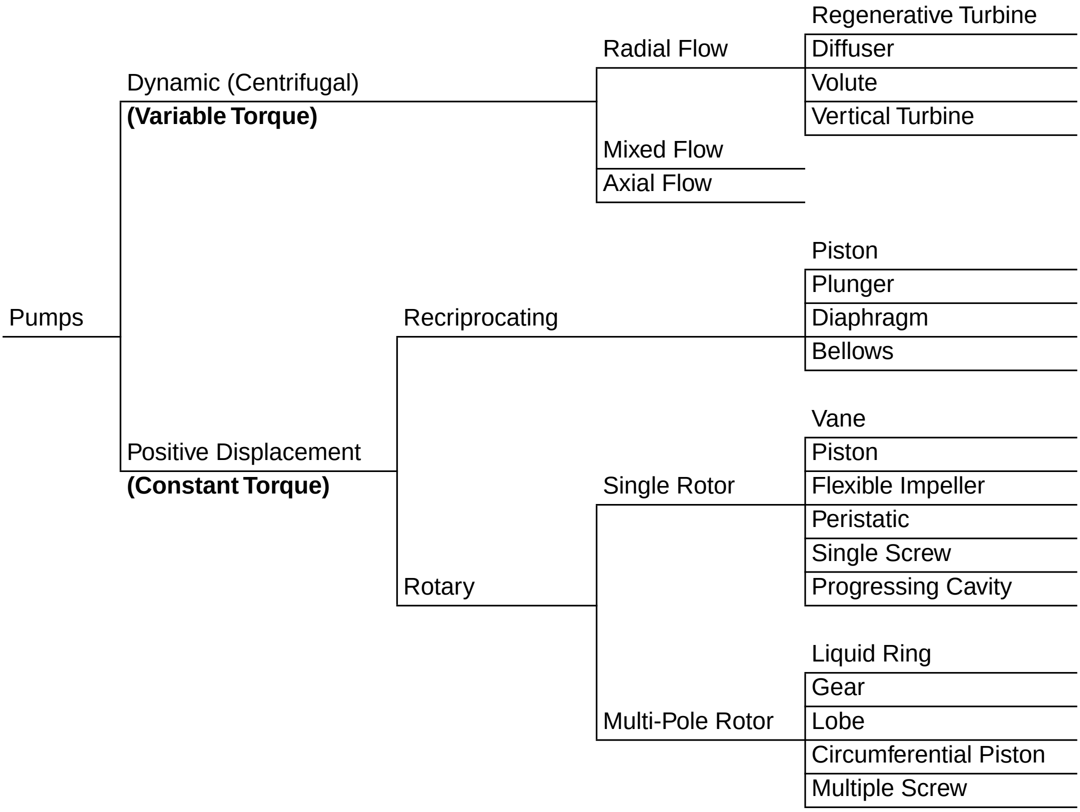
Pumps

Pumps can be grouped into two broad categories, positive displacement and dynamic (centrifugal). See Table 3.

Dynamic (centrifugal) pumps develop pressure and continuously impart energy to the liquid by a centrifugal force, dynamic lift or momentum exchange. These pumps usually present a variable torque load, except when the specific gravity of the fluid changes. In these cases, the torque required may be greater than the typical speed torque profile shown in Figure 1.

Positive displacement pumps discharge a given volume for each stroke or revolution of the pump. Energy is added in intermittent pulses. These pumps usually present, as an average, a constant torque load. However, there could be peak torque requirements greater than the motor full-load torque, which could affect motor and AFC sizing. If you are unsure about the load characteristics for a particular pump, consult the pump manufacturer.

Table 3: Typical Pumps and Types of Load



Air Movers

Air movers can be grouped into two broad categories (see Table 4):

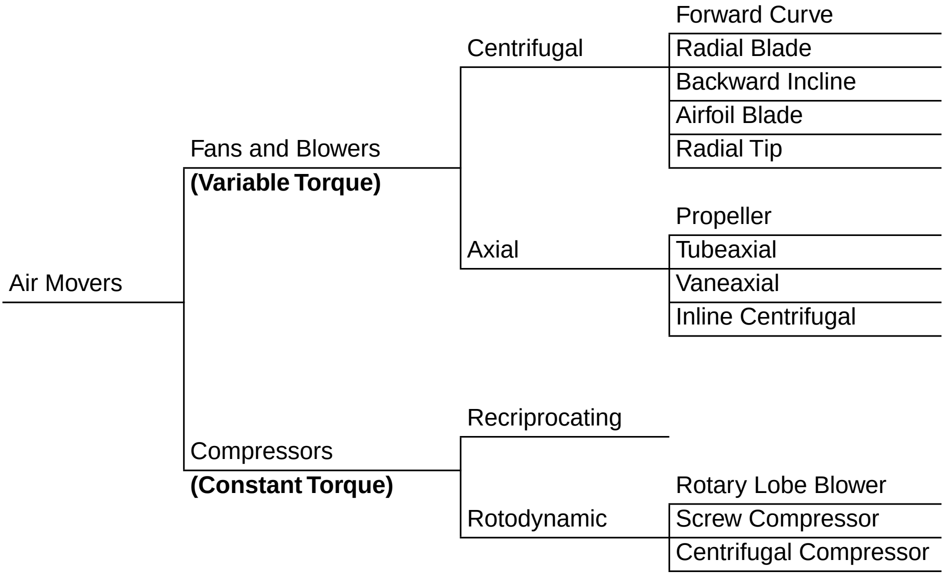
- Variable torque fans and blowers (typically produce less than 35 psi)
- Constant torque compressors (typically produce more than 35 psi)

Variable torque fans and blowers with centrifugal and axial designs develop static pressure and continuously pass on energy to the gas by a centrifugal force. These fans and blowers follow the fan affinity laws and usually present a variable torque load. The load varies drastically as a function of gas density (for example, hot air density vs. cold air density).

Constant torque compressors with reciprocating and rotodynamic designs develop static pressure by passing on energy to the gas in intermittent pulses. These types of compressor loads do not follow the fan affinity laws (even when the compressor is centrifugal), and should be considered a constant torque load. Peak torque requirements could affect the motor and AFC sizing.

Consult the manufacturer if you are unsure about the load characteristics for a particular air mover.

Table 4: Typical Air Movers and Types of Load



CONSTANT TORQUE LOADS

With constant torque loads, the torque loading is not a function of speed. Typical applications are:

- Traction drives
- Conveyors
- Positive displacement pumps
- Hoists

As the speed changes, the load torque remains constant and the horsepower changes linearly with speed (Figure 2).

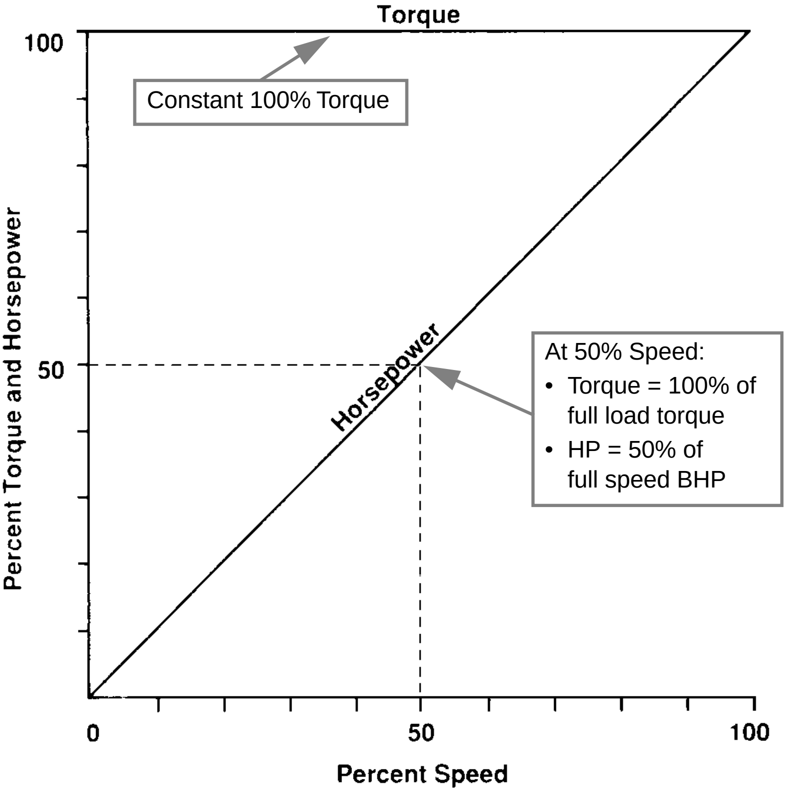
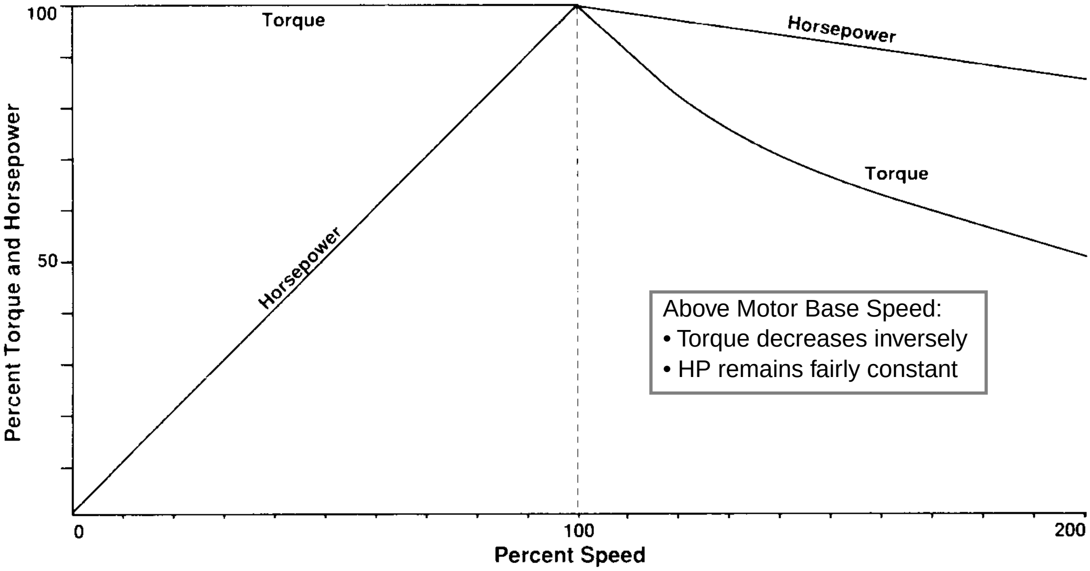


Figure 2: Constant Torque Loads

CONSTANT HORSEPOWER LOADS

With a constant horsepower load, the motor torque required above the motor base speed decreases inversely, while the horsepower remains fairly constant (Figure 3). Grinders and winders are constant horsepower loads.



Above Motor Base Speed:
- Torque decreases inversely
- HP remains fairly constant

Figure 3: Constant Horsepower Loads

IMPACT LOADS

With an impact load, the torque loading is intermittent and is not a function of speed (see Figure 4). Impact loads are exhibited by a punch press, which uses a large flywheel to deliver the energy needed for the load. It is also characteristic of loads that are driven through a clutch, which is cycled during the process operation. Press applications require that the motor and AFC combination produce sufficient accelerating torque to return the flywheel to the required speed prior to the beginning of the next work stroke. For clutch and other impacting applications, the peak torque requirements must be considered. Consult the AFC manufacturer when you are controlling impact loads.

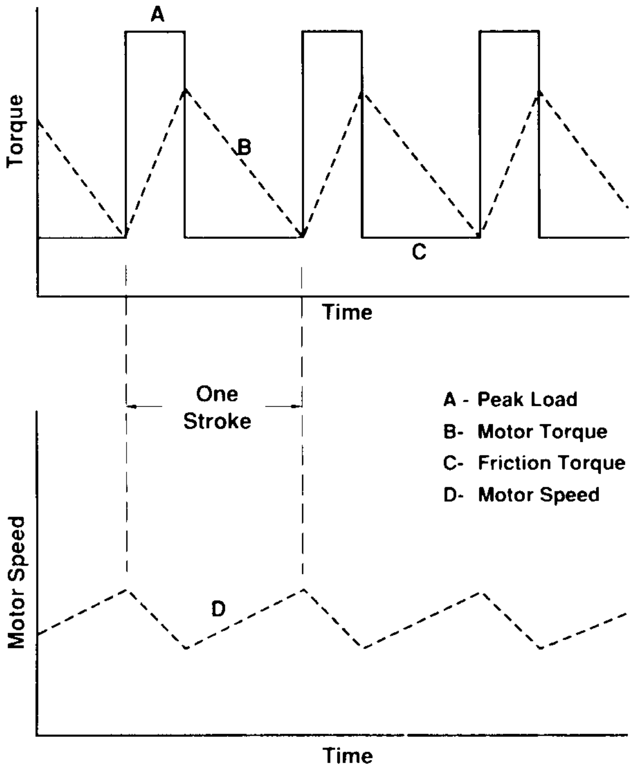


Figure 4: Impact Loads

APPLICATION CHARACTERISTICS OF TYPICAL LOADS

Table 5 lists the typical load characteristics – use it as a guideline only. If you have a question about the type of load for an installation, confirm this information with the machinery manufacturer.

Table 5: Application Characteristics of Typical Loads

Application	Load	Breakaway Torque	Application	Load	Breakaway Torque
Agitators			Machines		
Liquid	*VT	Moderate	Boring	CT	Moderate
Slurry	*VT	Moderate	Bottling	CT	Moderate
Blowers			Milling	*CHP	Moderate
Centrifugal	VT	Low	Mills		
Positive Displacement	CT	Low (Unloaded)	Rolling	*CT	Moderate
Calenders	CT	Low	Rubber	*CT	Moderate
Card Machines	CT	Moderate	Mixers		
Centrifuges	CT	Moderate	Chemical	CT	High
Chippers	*CT	High	Dough	CT	High
Compressors			Slurry	CT	High
Axial-Centrifugal	VT	Low	Planers	CT	Moderate
Reciprocating	*CT	Moderate	Plows-Conveyor	CT	Moderate
Rotary	CT	Moderate	Presses		
Conveyors			Printing	CT	Moderate
Belt	CT	Moderate	Punch	*CT	Moderate
Screw	*CT	High	Pullers-Car	CT	Moderate
Shaker	*CT	Moderate	Pumps		
Cranes			Centrifugal	VT	Low
Bridge	CT	Moderate	Positive Displacement	CT	Moderate
Trolley	CT	Moderate	Slurry	CT	High
Hoist	CT	Moderate	Roll Benders	CT	Moderate
Crushers	*CT	High	Sanders	CT	Low
Drill Presses	CHP	Moderate	Saws	*CT	Moderate
Elevators	CT	Moderate	Shakers	*CT	High
Extruders	CT	Moderate	Shears	*CT	Low
Fans-Centrifugal	VT	Low	Tension Drives	CHP	Moderate
Frames-Spinning	CHP	Low	Tool Machines	CHP	Moderate
Grinders	CHP	Moderate	Walkways	CT	Low
Kilns	CT	High	Winches	CT	Moderate
Looms	CT	Moderate	Winders	CHP	Moderate
Lathes	*CHP	Moderate	Washers	CT	Moderate

VT = Variable Torque
CT = Constant Torque
CHP = Constant Horsepower

High = Greater Than 150% Torque
Moderate = Between and Including 100% to 150% Torque,
Low = Less Than 100% Torque

* = Potential Impact Load

TYPICAL HORSEPOWER FORMULAS

You can use the formulas in this section to calculate the horsepower and torque requirements for a load. The results of these formulas are used to select the horsepower, torque and speed rating for the motor (see “Mechanical Parameters” on page 13).

Pump Horsepower

$$HP = \frac{Q \cdot H \cdot s}{3960 \cdot Eff}$$

- Q = liquid flow (gal/min)
- H = head (ft)
- s = specific gravity (water = 1)
- Eff = per unit efficiency of the pump (consult pump manufacturer or refer to pump performance curves)

Fan and Blower Horsepower (at a given air temperature)

$$HP = \frac{Q \cdot P}{229 \cdot Eff}$$

- Q = air flow (cubic ft/min)
- P = pressure (lb/in^2)
- Eff = per unit efficiency of the fan (consult fan manufacturer or refer to fan performance curves)

Lifting Horsepower

$$HP = \frac{W \cdot H}{550 \cdot t}$$

- W = weight (lb)
- H = height (ft)
- t = time (sec)

Linear (Sliding or Rolling) Horsepower

$$HP = \frac{W \cdot K \cdot d}{550 \cdot t}$$

- W = weight (lb)
- K = coefficient of friction (refer to handbook supplied with machinery)
- d = distance (ft)
- t = time (sec)

Rotating Horsepower

$$HP = \frac{T \cdot rpm}{5250}$$

- T = torque (lb-ft)
- rpm = speed (rev/min)

Mechanical Parameters

The horsepower requirements calculated for a load from the above formula are the horsepower requirements for the motor also, with additional horsepower required for the friction and windage losses in the mechanical parameters between the motor and the load. This is usually defined as efficiency in the system, and is determined by the type of mechanical parameters. For example, a gear box nameplate includes an efficiency value, and an efficiency can be determined for each sheave or pulley, depending on the type of bearing.

When sizing a motor for a load, the horsepower requirement alone is not sufficient. First you must determine the running torque and speed requirements at the load, and then you can translate these torque and speed requirements to the motor.

Torque Requirement for the Load

If the torque requirement for the load is not known, you can calculate it from the following formula:

$$T = \frac{HP \cdot 5250}{rpm}$$

- HP = horsepower required at the load
- T = torque (lb-ft) at the load
- rpm = speed (rev/min) required at the load

Determining Speed (rpm) of the Load

Use the following methods to determine the speed of the load:

For pumps and fans: refer to the specific performance curves for the pump or fan. These curves show the speed needed to meet the required output (for pumps – liquid flow at a specified head; for fans – air flow at a specified pressure).

To convert linear speed to rotary speed (rpm) at the load:

$$rpm = \frac{FPM}{3.14 \cdot D}$$

- rpm = speed (rev/min)
- FPM = speed (ft/min)
- D = diameter of pulley or sprocket (ft)

Torque Requirement for the Motor

After determining the torque and speed requirements at the load from the instructions above, you can determine the torque and speed requirements at the motor as follows:

- *For direct coupling:* (typical for most pumps) the motor speed and torque requirements are the same as the load. Fans may or may not be belt driven.
- *When mechanical parameters (gear box or pulleys) interface with the load and the motor:* use the following formulas for torque and speed.

$$T_m = K \cdot T_L$$

$$S_m = \frac{1}{K} \cdot S_L$$

- T_m = motor torque
- T_L = load torque
- S_m = motor speed
- S_L = load speed
- K = total ratio of the mechanical parameters (ratio of output shaft speed to input shaft speed)

The mechanical parameters usually result in the motor speed rpm higher than the load rpm, and the motor torque value lower than the load torque value.

TYPICAL INERTIA FORMULAS

To determine the motor horsepower and torque needed to satisfy the load acceleration and deceleration requirements, you must consider the inertia of the load. The following formula is typical:

$$T = \frac{WK^2 \cdot \Delta rpm}{308 \cdot t}$$

- T = torque to accelerate or decelerate a load (lb-ft at motor)
- WK^2 = inertia of load (lb-ft^2 equivalent at motor)
- Δrpm = change in motor speed
- t = time (seconds) required to achieve speed change

Acceleration torque is the difference in the total torque available from the motor and the torque required to drive the load, which includes the friction and windage losses. The torque required to drive the load may or may not be a function of the speed. For example, with a variable torque load, the load torque increases as the speed increases and hence the torque available for acceleration decreases as the speed increases.

Deceleration torque is the sum of the braking torque available from the motor and the friction and windage torque losses. During deceleration, friction and windage will help to decelerate the load and add to the motor braking torque. This is in contrast to acceleration, where the motor must provide additional torque to overcome losses.

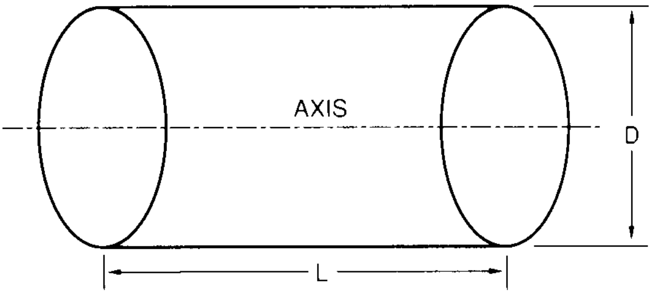
Inertia is the measure of resistance to changes in linear or angular velocity. The moment of inertia (WK^2) is the product of weight (W; lbs) and the radius of gyration squared (K^2; ft^2). The radius of gyration is a measure of how the mass of an object is distributed about the axis of rotation. Most applications are concerned mainly with rotation and most bodies are cylindrical in shape and rotate about their principal axis.

For these cases, the moment of inertia can be calculated according to the formulas in the following sections.

Solid Cylindrical Body

$$WK^2 = 0.000681 \cdot e \cdot L \cdot D^4$$

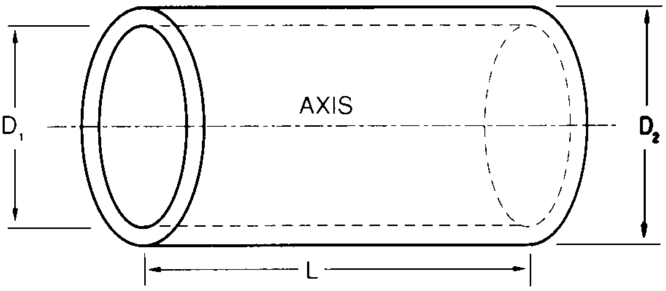
- e = density (lb/in^3)
- D = diameter (inches)
- L = length (inches)



Hollow Cylindrical Body

$$WK^2 = 0.000681 \cdot e \cdot L \cdot (D_2^4 - D_1^4)$$

- e = density (lb/in^3)
- D_1 = inside diameter (inches)
- D_2 = outside diameter (inches)
- L = length (inches)



Complex Bodies

To determine the inertia of a complex rotating body, you must analyze each composite element of the body.

Equivalent Inertia

Mechanical system components moving at different speeds with a direct proportional relationship to motor speed can be converted to an equivalent inertia (WK^2_E) applied to the motor shaft when the load is driven through a gear box or belt drive.

Rotational Motion

$$WK^2_E = WK^2_M \left(\frac{rpm_0}{rpm_1}\right)^2$$

- WK^2_E = equivalent inertia (lb-ft^2)
- WK^2_M = inertia of moving component (lb-ft^2)
- rpm_0 = speed of moving component (rev/min)
- rpm_1 = speed of the driving motor (rev/min)

Linear Motion

Mechanical system components moving linearly can also be converted to an equivalent inertia (WK^2_E) applied to the motor shaft:

$$WK^2_E = \frac{W \cdot V^2}{39.5 \cdot rpm_1}$$

- WK^2_E = equivalent inertia (lb-ft^2)
- W = weight of load (lb)
- V = linear velocity of moving parts (ft/min)
- rpm_1 = speed of the driving motor (rev/min)

Before applying an AFC, there are several items that must be determined:

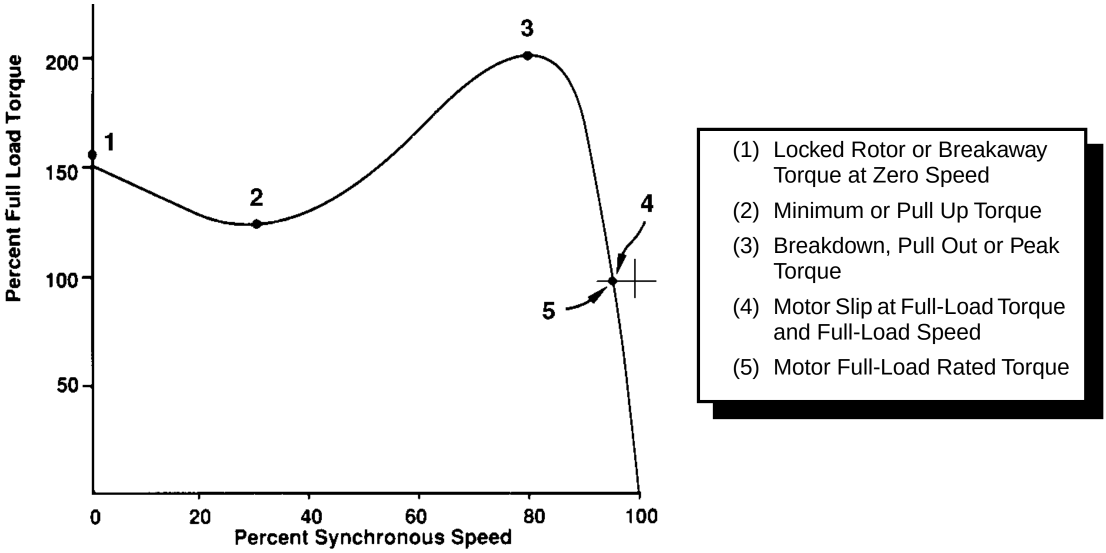
- Maximum Load Horsepower and Maximum Speed for the application (refer to formulas on page 12)
- AC Motor Design (page 17)
- Motor Rated Full-Load Current and Horsepower (page 22)
- Rated Full-Load Speed (page 22)
- Service Factor (page 23)
- Voltage Rating Type of Enclosure (page 23)
- Insulation Systems and Ambient Temperature Rating (page 24)
- Locked Rotor KVA (page 26)
- Time Rating (page 26)

The motor nameplate data beginning on page 22 is specifically for a NEMA Design B motor. General information for NEMA Design B and other motor designs is summarized in "AC MOTOR DESIGNS" below. To determine the final size of the motor for use with an AFC, refer to the flowchart on page 2.

AC MOTOR DESIGNS (INTEGRAL HPs)

The motor nameplate indicates the NEMA design (A, B, C, D or E). The NEMA design identifies the motor locked rotor torque, peak torque and full-load slip ratings. When applying an AFC, you must know the design in order to assure proper operation.

When selecting a motor, it is important to note the motor characteristics (Figure 5).



(1) Locked Rotor or Breakaway Torque at Zero Speed
(2) Minimum or Pull Up Torque
(3) Breakdown, Pull Out or Peak Torque
(4) Motor Slip at Full-Load Torque and Full-Load Speed
(5) Motor Full-Load Rated Torque

Figure 5: Motor Characteristics

The NEMA Design B motor is the simplest, least expensive and most readily available AC motor. When used with an AFC, the NEMA Design B motor has the capability, in many cases, to achieve essentially the same performance and advantages of NEMA Design A, C, D and E. The performance characteristics for each NEMA design are illustrated in Figure 6.

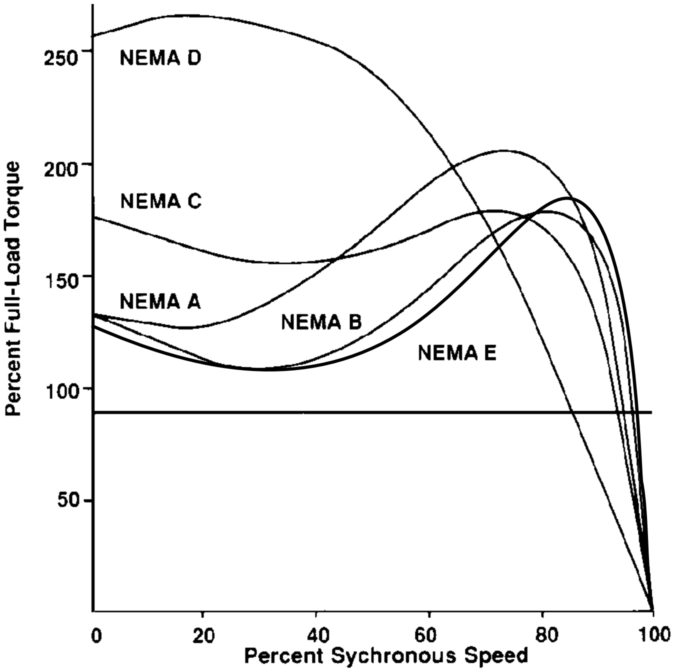


Figure 6: NEMA Design Motor Curves

Although the NEMA Design B motor is the best choice for most general purpose AFC applications, other AC design motors may be applied for retrofit applications or for installations with special performance requirements. For additional information on AC motor operation and performance characteristics, see Product Data C-862A.

When any AC motor listed below is applied with an AFC, consult the AFC manufacturer to ensure proper performance:

- NEMA C
- NEMA D
- NEMA E
- Wound Rotor
- Synchronous Permanent Magnet
- Synchronous Reluctance
- Two Speed
- Inverter Duty

NEMA Design A

NEMA Design A motors have high starting current, normal starting torque, relatively high breakdown torque (200 to 300%) with low slip (3 to 5%).

NEMA Design B

NEMA Design B motors are the most common in the industry. Compared to the other designs, they are typified by normal starting current, normal starting torque, normal breakdown torque, with low slip (2 to 3%).

For induction motors, NEMA has standardized on various values of peak torque and locked rotor torque at full voltage and line frequency. Torque ratings for NEMA Design B motors are listed in Table 6 and 7. This information helps you select a properly sized AFC to retrofit an existing full voltage installation. The NEMA standards are only minimum values and most motor manufacturers' torque ratings exceed these values. Similar ratings are standardized for designs other than NEMA Design B motors also, but are not listed here.

Table 6: Locked Rotor Torque in Percent of Full-load Torque
(1993 NEMA Standards MG 1-12.38.2)

hp	Locked Rotor Torque (%)							
		Synchronous Speed						
	at 60 Hz	3600 rpm	1800 rpm	1200 rpm	900 rpm	720 rpm	600 rpm	514 rpm
	at 50 Hz	3000 rpm	1500 rpm	1000 rpm	750 rpm	—	—	—
0.5		—	—	—	140	140	115	110
0.75		—	—	175	135	135	115	110
1		—	275	170	135	135	115	110
1.5		175	250	165	130	130	115	110
2		170	235	160	130	125	115	110
3		160	215	155	130	125	115	110
5		150	185	150	130	125	115	110
7.5		140	175	150	125	120	115	110
10		135	165	150	125	120	115	110
15		130	160	140	125	120	115	110
20		130	150	135	125	120	115	110
25		130	150	135	125	120	115	110
30		130	150	135	125	120	115	110
40		125	140	135	125	120	115	110
50		120	140	135	125	120	115	110
60		120	140	135	125	120	115	110
75		105	140	135	125	120	115	110
100		105	125	125	125	120	115	110
125		100	110	125	120	115	115	110
150		100	110	120	120	115	115	—
200		100	100	120	120	115	—	—
250		70	80	100	100	—	—	—
300		70	80	100	—	—	—	—
350		70	80	100	—	—	—	—
400		70	80	—	—	—	—	—
450		70	80	—	—	—	—	—

Table 7: Breakdown Torque in Percent of Full-load Torque
(1993 NEMA Standards MG 1-12.39.1)

hp	Breakdown Torque (%)							
		Synchronous Speed						
	@ 60 Hz	3600 rpm	1800 rpm	1200 rpm	900 rpm	720 rpm	600 rpm	514 rpm
	@ 50 Hz	3000 rpm	1500 rpm	1000 rpm	750 rpm	—	—	—
0.5		—	—	—	225	200	200	200
0.75		—	—	275	220	200	200	200
1		—	300	265	215	200	200	200
1.5		250	280	250	210	200	200	200
2		240	270	240	210	200	200	200
3		230	250	230	205	200	200	200
5		215	225	215	205	200	200	200
7.5		200	215	205	200	200	200	200
10 to 125		200	200	200	200	200	200	200
150		200	200	200	200	200	200	—
200		200	200	200	200	200	—	—
250		175	175	175	175	—	—	—
300 and 350		175	175	175	—	—	—	—
400 to 500		175	175	—	—	—	—	—

NEMA Design C

NEMA Design C motors have high starting torque, low starting current, relatively constant acceleration torque, with normal slip (3 to 5%). These motors are typically used in conveyor applications. Many NEMA C motors are unsuitable for AFC operation because of their double cage construction, which causes heating from excessive harmonic currents.

When you are using an AFC with a NEMA Design C motor (primarily for a retrofit), check the load breakaway torque requirement to ensure the AFC is sized sufficiently. The advantages of the NEMA Design C motor for conveyor application cease to exist when an AFC is used with a NEMA Design B motor. Relatively high starting and constant accelerating torque with minimum running slip can be achieved with a NEMA Design B motor and properly applied AFC.

NEMA Design D

NEMA Design D motors have very high starting torque (approximately 300%), low starting current, high breakdown torque, with high slip (5 to 13%). These motors have a low efficiency and are typically used on machines where high slip is necessary for impact loads (such as punch presses), or where high breakaway torque is required (such as hoists).

Speed regulation (especially at low speeds) is very poor when an AFC is used with a NEMA Design D motor. This is due to the high slip characteristics. Also, NEMA Design D motors have a higher peak and breakaway torque capability than equivalent horsepower NEMA Design B motors. Always check the load breakaway torque and acceleration torque requirements to determine if the AFC should be oversized. Consult the AFC manufacturer when applying a NEMA Design D motor with an AFC.

NEMA Design E

NEMA Design E motors are similar to Design B, but have a higher efficiency, high starting currents and lower full-load running currents. Torque characteristics are similar to IEC metric motors of similar power parameters.

Inverter Duty

Inverter duty motors are Design B motors with the added capability of operating constant torque loads over a 100:1 speed range. Inverter duty motors are typically used on machines where low speed and full-load torque are required.

Wound Rotor Motor

Wound rotor motors are typically used for variable speed with controllers, such as secondary resistors, primary voltage or slip recovery. The motor speed-torque characteristics can be customized by the type of controller. In comparison, the speed torque characteristics of other induction motors are fixed by the rotor design, but can be modified, within limits, with an AFC.

When an AFC is used with a wound rotor motor (primarily for a retrofit), the rotor circuit is usually shorted phase-to-phase at the slip rings. However, most of the advantages of the wound rotor motor cease to exist when an AFC is used with a NEMA Design B motor. Normally, a wound rotor motor has a higher peak torque and breakaway torque capability than an equivalent horsepower NEMA Design B motor. Consequently, the load breakaway torque and acceleration torque requirements must be checked to determine if the AFC must be oversized. Consult the AFC manufacturer when applying a wound rotor motor with an AFC.

Synchronous Permanent Magnet Motor

Verify the motor full-load current when applying an AFC with a synchronous permanent magnet motor. Usually full-load current and inrush current are similar to a NEMA Design B motor. Consult the AFC manufacturer when applying a synchronous motor.

Synchronous Reluctance Motor

Always verify the motor full-load current when applying a synchronous reluctance motor with an AFC, because the full-load current is not attainable from table values. Normally, this current is considerably higher than an equivalent horsepower NEMA Design B motor – typically 25% higher. Also, the inrush current may be 10 to 12 times greater than the full-load current. Because these motors do not have separate field windings, separate field control is not required and zero speed deviation can be achieved at reduced speeds. Consult the AFC manufacturer when applying a synchronous motor.

2-Speed Motor

The 2-speed motor is typically used when limited speed control is required for two fixed-speed conditions.There are two designs for 2-speed motors.

- *Two separate stator windings in the motor:* Each winding is designed with the appropriate number of poles for the designated speed. One winding is usually designated for 100% speed (high speed winding) and the other for 50% speed (low speed winding). Two 3-pole contactors are normally used for the connections.
- *Winding connections in the stator form consequent poles in the motor:* Produces a high speed connection and a low speed connection, 50% of maximum speed. One 2-pole contactor and two 3-pole contactors are normally required.

When an AFC is used with a 2-speed motor (primarily for a retrofit), all performance requirements (speed range, breakaway torque, acceleration, deceleration, etc.) for the load must be clearly defined (refer to the flowchart on page ii). To meet the application requirements, you must have the complete motor nameplate information to determine how to size the AFC and connect it to the 2-speed motor. For some types of loads, such as pumps or fans, an AFC applied to the high speed connection may provide adequate control. Always consult the AFC manufacturer when applying 2-speed motors.

MOTOR FULL-LOAD CURRENT AND HORSEPOWER

To properly apply an AFC, you must know the motor nameplate rated full-load current at rated speed. Unfortunately, this data is often obtained from tables, and is occasionally inaccurate. Always refer to the motor nameplate or consult the motor manufacturer for the ratings for the specific motor being considered. For additional information, refer to “AFC CURRENT RATING” on page 61.

The overall rating of the AFC is based on the motor current rating and the horsepower rating. The current rating for a given horsepower motor may vary, depending on the voltage and speed rating. Low speed motors, such as 12-pole at 540 rpm, tend to have higher rated currents than high speed motors, such as 4-pole at 1750 rpm.

MOTOR FULL-LOAD SPEED (Rated Speed, Base Speed)

Misinformation of motor full-load current often occurs for motors with speed ratings below 1800 rpm. Motors with 6 or more poles have a higher full-load current than 2-pole and 4-pole motors.

Motor full-load speed is the speed at which the motor will operate with rated torque conditions at rated line voltage and frequency. You must know the full-load speed when designing an installation, but it is not essential when applying an AFC. The motor full-load speed must meet the speed requirements for the load. This information, and the torque requirements for the load, determines the motor horsepower rating.

The motor full-load is typically between 87 and 98% of synchronous speed, depending upon the NEMA design. NEMA Design B motors are usually rated at 97% of synchronous speed. Table 8 lists synchronous speeds versus number of poles.

$$\text{Synchronous Speed} = \frac{120 \cdot f}{P}$$

- f = frequency
- P= number of poles

Table 8: Synchronous Speed

No. of Poles	Speed (rpm)		
	50 Hz	60 Hz	120 Hz [1]
2	3000	3600	7200
4	1500	1800	3600
6	1000	1200	2400
8	750	900	1800
10	600	720	1440
12	500	600	1200
14	428	514	1028

[1] Consult motor manufacturer to determine if motor is designed to operate above base speed.

Slip is the variance between synchronous speed and full-load speed. It is expressed as a percentage of the synchronous speed.

$$\%\text{Slip} = \frac{\text{Synchronous Speed} - \text{Full-Load Speed}}{\text{Synchronous Speed}} \cdot 100$$

SERVICE FACTOR

When applying an AFC, you must know the nameplate stamped service factor of the AC motor. The service factor determines the thermal capability of the motor. For more information on thermal capability, see Section 3 on page 27.

Motor service factor is usually 1.0 or 1.15. It indicates the overload capability of the motor without exceeding the maximum temperature recommended for the insulation. When operated at ambient temperature (0 to 40 °C) and at rated voltage and frequency, a 100 hp motor with a 1.15 service factor can sustain a 15% overload (115 hp) continuously and will not exceed the temperature rating of the motor insulation.

VOLTAGE RATING

The motor voltage rating determines the voltage rating of the AFC. Each motor is designed and manufactured for optimum performance at a specific line voltage. These voltages are usually 200 VAC, 230 VAC and 460 VAC. Because of typical line voltage variations, most motors are designed to run properly at ±10% of rated voltage.

Consequences of deviations from nominal utilization voltage are reviewed in “Voltage Variations” on page 54.

ENCLOSURES AND VENTILATION

The type of enclosure and reduced speed requirements influence the motor’s heat dissipation capabilities. The motor nameplate usually identifies the type of enclosure and ventilation system:

- Open type, self-ventilated
- Totally enclosed, fan-cooled (TEFC)
- Totally enclosed, non-ventilated (TENV), and others

Under normal conditions, any type of motor enclosure should be applicable for an AFC, if properly applied for an installation. If forced ventilation is required for reduced speeds or the AFC is installed a hazardous location, special considerations may be required. For more information on special requirements, refer to “MINIMUM SPEED LESS THAN 16%” on page 31.

Open Type, Self-Ventilated Enclosure

When operating at full speed with an open type motor, the rotor fan easily transfers heat losses from the frame to the ambient. However, when operating at reduced speed, the rotor fan turns slower and does not transfer as much heat to the ambient. Consequently, forced ventilation or oversizing may be required, depending on specific load information and the speed range.

Totally Enclosed Enclosures

A totally enclosed motor cannot dissipate its losses as well as an open motor. Consequently, the frame size is usually larger for a given horsepower rating. NEMA standards allow non-ventilated motors to operate at a higher temperature. When motors in hazardous areas are controlled by an AFC, consult the motor manufacturer to ensure that the motor surface temperature will not exceed the safe limits for the installation.

INSULATION SYSTEMS AND AMBIENT TEMPERATURE RATING

This information is not always necessary to apply an AFC, but it can help you determine the thermal capability potential for a motor with an AFC at a specific installation. In some cases, specific requirements may be given for a class of insulation (refer to “MOTOR HEATING” on page 27).

The motor nameplate identifies the class of insulation material used in the motor and its rated ambient temperature. Various types of materials can be used for insulation:

- Class A, rated 105 °C
- Class B, rated 130 °C
- Class F, rated 155 °C
- Class H, rated 180 °C

When the ambient temperature exceeds the rating of the insulation material, the insulation life is decreased by approximately 50% for every ten degrees above the rating. By using higher temperature rated materials, more heat losses in the motor can be tolerated and the horsepower rating of a motor can be increased in a given frame size.

NEMA standards specify a permissible temperature rise above a 40 °C ambient. The temperature rise is determined by the type of insulation in the motor, and other motor design and application considerations. Some motors operate at higher temperatures than others, but should never exceed the temperature rating of the insulation. When applying insulation ratings to open motors, a margin of safety is allowed for a hot spot. Occasionally, motors are applied for ambients higher than the standard 40 °C (50 °C, 55 °C, 65 °C, 90 °C 115 °C, etc.). In these cases, you must derate the motor horsepower rating appropriately.

The 1993 NEMA standards MG 1-12.43 state that the temperature rise above the temperature of the cooling medium, for each part of the motor, shall not exceed the values in Table 9 when tested in accordance with the rating. If the motor service factor is 1.15 or higher, the temperature rise shall not exceed the values in Table 9 when tested at the service factor load.

Table 9: Maximum Temperature (NEMA Standards MG 1-12.43)

Paragraph 1: Windings	**Temperature Rise for Class of Insulation**			
	A	B	F	H
Item a.1: Motors with 1.0 service factor other than those in items a.3, a.4	60 °C	80 °C	105 °C	125 °C
Item a.2: All motors with 1.15 or higher service factor	70 °C	90 °C	115 °C	—
Item a.3: Totally enclosed non-ventilated motors with 1.0 service factor	65 °C	85 °C	110 °C	130 °C
Item a.4: Motors with encapsulated windings and with 1.0 service factor, all enclosures	65 °C	85 °C	110 °C	—

Time rating may be continuous or any short-time rating.

Temperature rise is based on a maximum ambient temperature of 40 °C. The average temperature rise is determined by a change of resistance. The allowed temperature rise measured by thermometer will be lower.

Where a Class F or H insulation system is used, special consideration should be given to bearing temperatures, lubrication, etc. The values in the column for Class H apply to polyphase induction motors only.

LOCKED ROTOR KVA

Locked rotor KVA is rarely a consideration when applying an AFC because of an AFC's ability to limit the starting current while permitting high starting torque at zero speed. However, you must know the locked rotor KVA when more than one motor is connected to an AFC and individual motors are switched on and off while the AFC is running. For more information, refer to "SLAMMING MOTORS" on page 70.

Locked rotor KVA may be a consideration when applying motors in a location where the power distribution system has limitations.The motor nameplate identifies locked rotor KVA with a code letter (A thru V – refer to Table 10), designated by the National Electrical Code Table 430-7(b).

Table 10: Locked Rotor KVA (NEC Table 430-7b)

Letter Designation	KVA per Horsepower [1]	Letter Designation	KVA per Horsepower [1]
A	0-3.15	K	8.0-9.0
B	3.15-3.55	L	9.0-10.0
C	3.55-4.0	M	10.0-11.2
D	4.0-4.5	N	11.2-12.5
E	4.5-5.0	P	12.5-14.0
F	5.0-5.6	R	14.0-16.0
G	5.6-6.3	S	16.0-18.0
H	6.3-7.1	T	18.0-20.0
J	7.1-8.0	U	20.0-22.4
		V	22.4 and up

[1] Measured at full voltage and frequency. Locked KVA per horsepower range includes the lower figure up to, but not including, the higher figure. For example, 3.14 is designated by the letter A and 3.15 by the letter B.

TIME RATING

For most AFC applications, motors should be continuously rated. If the motor is not continuously rated, the time rating implies a special application, and you must consult the AFC manufacturer before applying an AFC.

The motor nameplate identifies a time rating. The time rating can be:

- Continuous duty
- Short time (60 minutes, 30 minutes, 15 minutes, 5 minutes, etc.)

At a specified horsepower, a motor operating continuously generates more total losses and requires a larger frame size, compared to a motor operating intermittently. Short time ratings indicate the motor can carry the nameplate loads for the time specified without exceeding the rated temperature rise. After the short time, the motor must be permitted to cool to room temperature.

To determine whether or not the motor will have heating and/or performance considerations, you must know the speed control range required for the motor with an AFC.

As a general rule, motors must be oversized or derated to approximately 85% loading when operating at full speed with an AFC. This is often achieved by specifying a 1.15 service factor for the motor. This generic guideline is not specific for all motor manufacturers or types of motors; verify sizing and derating with the motor manufacturer.

Additional derating factors may be required for various types of loads and speed ranges. This section describes those factors.

MOTOR HEATING

The nameplate ratings for a motor is determined by the motor's thermal capability. These ratings apply for a pure sinusoidal wave at rated speed, rated voltage and rated frequency. When an AFC is used, the motor speed is reduced (intentionally) and a non-sinusoidal wave is produced in the motor (unintentionally). As a result, more heat is generated in the motor, with less capability to dissipate the heat. The extra heat is caused by harmonic currents from the distorted sine wave, The reduced ability to dissipate the heat is a result of the motor fan operating at a lower speed.

To compensate for the additional heat, nearly all AFC manufacturers agree on the need for some additional thermal capacity in the motor. As a general rule, this can be achieved by derating the motor to approximately 85% load for full-speed operation. Also, a 1.15 service factor can be specified for the motor, but the connected load should not exceed the 1.0 service factor rating of the motor. Also refer to “SERVICE FACTOR” on page 23 for more information.

The thermal capability of motors can differ widely, depending on the manufacturer, design parameters, horsepower, frame size, and type of enclosure. In addition, the type of AFC could be a factor. Generally, a six-step current wave produces more harmonic currents than a PWM current wave, and consequently more heat. Consult the motor manufacturer if you have any questions about motor heating with a specific design AFC. General guidelines for various types of loads and speed ranges are located on pages 28 through 31.

Additional derating (or other alternatives) and various types of motor enclosures must be considered at reduced speeds.

In some cases, it may be desirable to have additional thermal capacity in a motor to increase its reliability, or to provide longer life. In addition to the above derating, specifying a motor with Class F insulation and a Class B insulation temperature rise rating, provides more thermal capability. Specifying only Class F insulation does not ensure additional thermal capacity. Specifying only Class F insulation generally permits the motor manufacturer to offer a smaller frame motor, which normally operates at a higher temperature.

The motor nameplate identifies the class of insulation material used in the motor and its rated ambient temperature. Insulation types are summarized in “INSULATION SYSTEMS AND AMBIENT TEMPERATURE RATING” on page 24.

SPEED RANGE

Base speed is frequently used to describe speed range. Base speed is the nameplate rated full-load speed of the motor at rated voltage and rated frequency. The definition of speed range may vary slightly depending on the type of load, but it is usually described as the ratio of the base speed at 60 Hz (motor nameplate rated speed) to a minimum frequency. Examples with 60 Hz as base speed are listed in Table 11.

Table 11: Speed Range Examples (Base Speed = 60 Hz)

Minimum Frequency	% Motor Nameplate Full-Load Speed	Speed Range
30 Hz	50%	2:1
20 Hz	33.3%	3:1
10 Hz	16.6%	6:1
3 Hz	5%	20:1
0.6 Hz	1%	100:1

You must verify that the speed range specified is actually required by the load and not based on a particular type of control. Refer to the type of load identified in Section 1 and apply the appropriate consideration described in the rest of this section.

MAXIMUM SPEED GREATER THAN BASE SPEED (60 Hz)

Variable Torque Loads

Normally, the AFC maximum speed adjustment should be set to prevent this condition. The maximum speed for a fan or pump is usually selected to meet the required flow when running at the motor nameplate rated speed. This should be confirmed. If the motor speed exceeds the rated full-load speed, with pumps for example, the pump flow will increase, possibly overloading the motor or producing undesirable results in the hydraulic system. An AFC allows the motor speed to increase above its nameplate rating. Therefore, it is important to set the AFC adjustments to limit the maximum speed to the specified rating.

Constant Horsepower Loads

Constant horsepower loads are usually applied at speeds above motor base speed, but occasionally some applications require a speed range below base speed. With a constant horsepower load, the speed range is the ratio of maximum frequency to the minimum speed. Examples with 60 Hz as minimum speed are listed in Table 12.

Table 12: Speed Range Examples (Minimum Speed = 60 Hz)

Maximum Frequency	% Motor Nameplate Full-Load Speed	Speed Range
400 Hz	667%	6.7:1
90 Hz	150%	1.5:1

Motor heating is normally not a consideration for this range. This is because as the torque loading drops off, the motor becomes voltage starved and the motor fan can dissipate additional motor heat. Before applying an AFC, be sure the load is constant horsepower. Consult the motor manufacturer to verify the use of motors in this range.

Some motors and/or loads may not be suited for operation at higher than nameplate motor speed and frequency. For example, you should confirm the motor fan and bearing ratings for operation at higher speeds. Before operating the motor above 60 Hz, consult the motor manufacturer and equipment manufacturer to determine if the specified speeds are acceptable. This precaution is necessary to avoid destruction of the motor and potential personal injury from overspeed.

If the motor and constant horsepower load are suitable for operation above base speed, you must know the maximum speed required to ensure the AFC is capable of producing the necessary frequency.

Constant Torque Loads

Operation above base speed with a constant torque load is an unusual condition. For this condition, although the motor fan turns faster to dissipate the heat, additional heat is generated with increasing frequency above base speed. Consequently, some motor derating is required. Both the AFC manufacturer and motor manufacturer must be consulted first for specific derating information.

Some motors and/or loads may not be suited for operation at higher than nameplate motor speed and frequency. For example, you should confirm the motor fan and bearing ratings for operation at higher speeds. Before operating the motor above 60 Hz, consult the motor manufacturer and equipment manufacturer to determine if the specified speeds are acceptable. This precaution is necessary to avoid destruction of the motor and potential personal injury from overspeed.

Follow the procedures below if the motor and load are suitable for operation above base speed.

- You must properly select and apply the motor/AFC combination to maintain constant V/Hz up to the maximum operating frequency. Failure to maintain constant V/Hz results in voltage-starved operation above 60 Hz and speed-torque performance as shown in the constant horsepower profile in Figure 3 on page 10.
- There are two common methods of achieving constant V/Hz when the desired maximum operating frequency is greater than 60 Hz and less than or equal to 120 Hz: a) using a specially wound motor, or b) using a standard motor and an AFC with a constant torque rating.
    a) *Specially wound motor:* Constant V/Hz can be achieved by using a specially wound motor with a V/Hz ratio that enables the motor rated voltage at maximum operating frequency to equal the AFC rated output voltage at maximum operating frequency. The AFC must be able to select a V/Hz ratio to match that of the motor.

b) *Standard 230/460 V motor and AFC with a constant torque rating:* It is simpler to maintain constant V/Hz by using a standard 230/460 V motor and an AFC with a constant torque rating. The AFC must be connected to a 460 V source and the motor must be connected to operate at 230 V. The AFC must include a means of selecting an output voltage of 230 V at 60 Hz to match the 230 V motor connection. Since the AFC is fed from a 460 V source, output voltage can be increased as frequency increases beyond 60 Hz. If the frequency is allowed to reach 120 Hz, the output voltage is 460 V. The 3.8 V/Hz ratio is maintained, allowing the motor to produce constant torque.

When setting up a motor/AFC for this type operation:

- You must size the AFC for the full-load motor current at 230 V, which is two times the current of the same motor connected for 460 V operation.
- You may need to select the motor so it will not be required to deliver full-load torque. This is because the losses in the motor are higher and the loading on the motor may increase due to the shaft-mounted cooling fan. For these cases, consult the motor manufacturer before implementing the application.

MINIMUM SPEED GREATER THAN 50% BASE SPEED (30 Hz) AND SPEED RANGE LESS THAN 2:1

Generally, no additional derating from 85% should be required for this speed range. A motor with a 1.15 service factor should be applicable, but the connected load should not exceed the 1.0 service factor rating of the motor. Because there are differences in motor thermal capabilities, you should consult the motor manufacturer if you have any questions about motor heating in this speed range.

MINIMUM SPEED BETWEEN 50% AND 16% BASE SPEED AND SPEED RANGE BETWEEN 2:1 AND 6:1

Variable Torque Loads

For typical variable torque loads, there should be no additional derating from 85%. Most pumps and fans do not operate within this range, but there are a few exceptions:

- Some centrifugal fans, or centrifugal pumps with a low discharge head, may operate as low as 30%. This should not present any motor heating considerations.
- Centrifugal pumps with heavy consistency fluids, such as a slurry pumps, might require speeds lower than 50%.

In these cases, you should verify the load has variable torque characteristics. Usually these loads are close to a constant torque at low speeds. The motor should be derated as described in the next paragraph.

Constant Torque, Full-Load

Additional motor derating is required for operation at constant torque, full load when the minimum speed is greater than 50% base speed and the speed range is less than 2:1. Under these conditions, you should observe these general rules:

- Derate the motor proportionally from 85% at 30 Hz to 60% at 10 Hz.
- If a 1.15 service factor motor is used with a 1.0 service factor at full speed, it should be derated proportionally from 100% loading at 30 Hz to 75% loading at 10 Hz. Consult the manufacturer to verify this derating for the particular design motor being used.

MINIMUM SPEED LESS THAN 16% BASE SPEED (10 Hz) AND SPEED RANGE GREATER THAN 6:1

Constant Torque, Full-Load

An AFC with a sine-coded PWM design (such as the OMEGAPAK® and ALTIVAR™ AFCs) should be used to provide smooth operation under constant torque and full-load at speed ranges greater than 6 to 1. Motor cooling is also required to prevent the motor from overheating.

Motor performance may be affected when the motor is operated at speed ranges greater than 6 to 1. Motor torque pulsations, referred to as cogging, usually result in a “jerky” rotation when six-step or current-source AFCs are used. To provide smooth rotation below 10 Hz, you should use a sine-coded PWM design AFC for these applications. OMEGAPAK and ALTIVAR AFCs from Square D have sine-coded PWM designs and can be used below 10 Hz to provide smooth rotation. For more information on characteristics of AFCs, refer to Product Data C-870A, *Inverter Fundamentals*.

Special motor cooling considerations are usually required for very low speed, continuous, constant full-load torque operation. Some methods of motor cooling are:

- Motor-mounted blower
- Separate forced-air cooling
- Properly sized TENV motor
- Special insulation ratings

Consult the motor manufacturer to verify that the cooling option is suitable for the specific installation requirements.

Breakaway torque is the initial torque required to move the load. It determines the starting torque required from the motor and the output current rating of the AFC. It is usually expressed as a percentage of the full-load torque. Depending on the type of load, breakaway torque can be an important application consideration, and if not considered, the AFC could be misapplied. The result could be a motor that cannot start the load. For the motor to develop the necessary starting torque, the AFC must be properly rated and must have an adequate low frequency capability.

For examples of relative breakaway torque requirements for typical applications, see "APPLICATION CHARACTERISTICS OF TYPICAL LOADS" on page 12. Consult the machinery manufacturer if you have a question about the breakaway torque requirements.

Refer to the type of load identified in Section 1 and apply the appropriate considerations described in this Section.

BREAKAWAY TORQUE REQUIRED IS LESS THAN OR EQUAL TO 120% OF FULL-LOAD TORQUE

Breakaway torque is not usually an application consideration when applying any type of AFC. For most variable torque loads, the breakaway torque requirement is less than full-load torque. However, for certain types of loads, such as slurry pumps in dredging operations, there may be occasions when a thick slurry requires a higher than normal breakaway torque to get the pump started. In these cases, it is important for you to determine if the breakaway torque requirement is greater than 120% of full-load torque. If the answer is yes, then the application should be considered for breakaway torque greater than 120% (refer to the next paragraph).

BREAKAWAY TORQUE REQUIRED IS BETWEEN 120% AND 150% OF FULL-LOAD TORQUE

To achieve breakaway torque of 120 to 150% of full-load torque, the motor must have sufficient starting torque capability to satisfy the load breakaway torque requirements. The current rating and characteristics of the AFC determine whether or not the motor can develop sufficient starting torque to move the load.

This condition is not normally a consideration if the motor has sufficient starting torque capability and the AFC short time rating is 150% of full-load current (such as AFCs from Square D and most other sine-coded PWM AFCs). Some AFCs, especially those rated for variable torque applications, may have short time ratings of only 110 to 120% of full-load current.

Six-step and current source AFCs may have to be oversized to permit the motor to start. This depends on the manufacturer, installation, and motor characteristics.

NEMA Standard ICS-3-301 states that a general purpose AFC shall be rated for 150% of its full-load current rating for 1 minute. If an AFC meets this NEMA standard, it is often assumed the 150% current limit rating will permit the motor to develop 150% torque. This is not necessarily true. For an AFC to permit 150% torque with 150% current, the AFC output waveform must not include any significant harmonic content. All of the power switching techniques presently used in AFCs produce harmonic currents. Some harmonic currents produce negative torques in the motor and lessen the torque-per-amp capability of the motor.

Most well-designed, sine-coded, pulse-width modulated AFCs have sufficient waveform quality to allow torque and current to be considered directly proportional between approximately 100% and 150% of full-load torque and current. Breakaway torque considerations are not required for this range when a sine-coded PWM AFC (such as an OMEGAPAK or ALTIVAR AFCs) is used.

At very low speeds, six-step and current source inverters produce a relatively high harmonic content in the output waveform. Consequently, torque and current are not proportional up to 150% of full-load rating. In these cases, the motor may not develop sufficient starting torque. It is usually necessary to increase the current rating of the AFC to permit the motor to develop the required starting torque.

For more information on AFC characteristics, refer to Product Data C-870A, *Inverter Fundamentals*.

BREAKAWAY TORQUE IS GREATER THAN 150% OF FULL-LOAD TORQUE

When the breakaway torque is greater than 150% of full-load torque, a general purpose NEMA-rated AFC with an output current rating equal to the motor full-load current rating will not permit the motor to start the load. This is due to the 150% AFC current limit rating explained above.

In these cases, you must select an AFC with a higher rating than the motor full-load current rating. This permits more than 150% motor starting torque. Selecting an AFC that is normally one size larger may be adequate, but this is not a guaranteed procedure. Other factors to consider include: the type of AFC and the motor starting torque capability. Refer to the previous paragraphs for more information on starting torque limitations with various AFC designs.

As a guideline in determining motor starting torque capabilities, NEMA minimum locked rotor ratings are listed in 6 on page 19. These ratings are based on line voltage and 60 Hz. Note that these percentages are only minimum values. The percentages are relatively larger for smaller size lower speed motors, and are relatively smaller for the larger size, higher speed motors.

For example, a 3 hp 1800 rpm motor may have a 215% locked rotor torque rating, and a 300 hp 1800 rpm motor may have only an 80% locked rotor torque rating.

A fairly common misapplication of an AFC can occur for smaller size motors when the rated locked rotor torque is greater than 150% full-load torque. For example, consider a 3 hp 1800 rpm motor with a 215% locked rotor torque rating. The motor may be selected to start a load that requires its full locked rotor torque capability, 215%. This rating is based on line voltage and line frequency (60 Hz). A normally selected PWM type AFC with an output current rating equal to the motor full-load current rating, permits the motor to develop only 150% full-load torque. Although the motor will start with a full voltage starter, it will not start with an AFC selected for the motor full-load current.

To properly size an AFC with adequate low frequency capability, use the following formula:

$$\boxed{I_{AFC} = \frac{LRT}{I_{ST}} \cdot I_M}$$

- I_{AFC} = AFC continuous output current rating (minimum required)
- LRT = motor locked rotor torque, expressed as a percentage of full-load torque (rating at line voltage, line frequency)
- I_M = motor full-load current
- I_{ST} = short time current rating of the AFC

In this example:

$$\boxed{I_{AFC} = \frac{215}{150} \cdot 4.8 \ \langle 460\text{ V rating}\rangle = 6.87\text{ A}}$$

A properly designed AFC with the proper current rating permits a NEMA design B motor to develop up to near its peak torque rating to start the motor at zero speed. In comparison, a NEMA design B motor locked rotor torque rating at line voltage and frequency is considerably less. The peak (breakdown) torque ratings are listed in Table 6 on page 19 and locked rotor torque ratings are listed in Table 7 on page 20. The ratings given are at line voltage and frequency for various horsepower sizes. These NEMA standards are minimum values – most motors have higher ratings.

As an example, for a NEMA design B motor, the curves in Figure 7 on the next page illustrate possible motor performance characteristics with an AFC.

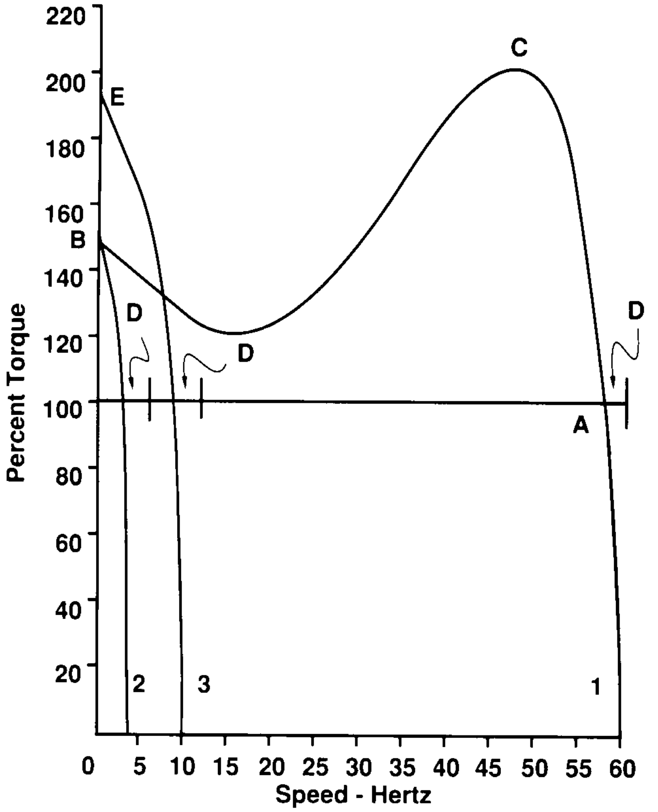


Figure 7: Sample Motor Performance Curves of NEMA Design B Motor

- *Curve 1*: NEMA design B motor characteristics with AFC operating at rated voltage and 60 Hz rated frequency. Motor slip is 3% (1.8 Hz) at point D. Motor starting torque at 0 Hz (point B) is 150% of FLT. Motor rated torque is 100% of FLT at point A. Motor rated peak (breakdown) torque occurs at point C. Motor slip remains constant at reduced speeds and rated load for rated flux.
- *Curve 2:* Motor characteristics with AFC operating at 3 Hz. Motor starting torque at 0 Hz is approximately 150% FLT at point B.
- *Curve 3:* Motor characteristics with AFC operating at 10 Hz. Motor starting torque at 0 Hz (point E) is approximately 195%. This torque can only be achieved if the short time current rating of the AFC allows the motor to draw sufficient current and the output waveform is of sufficiently high quality.

Acceleration torque is the difference in motor torque available from the motor/AFC combination and the torque required to drive the load (which includes the friction and windage losses). The torque required to drive the load may or may not be a function of the speed. For example, with a variable torque load, the acceleration torque decreases as the load increases with speed.

For AFC applications, acceleration torque is a consideration because:

- Insufficient acceleration torque may cause the AFC to trip out.
- Excessive acceleration torque may damage the driven machine.

Acceleration control is not a factor for most pumps and fans. There are a few exceptions, such as large fans with high inertia, or in pumping installations where a sudden large surge in flow or pressure is not tolerable.

When acceleration control is a requirement, you should first consider the AFC adjustments for acceleration time and current limit (when available). In most cases, when acceleration time and inertia are not major factors, these adjustments permit the AFC/ motor combination to meet the installation requirements without oversizing the AFC.

To determine acceleration requirements, you must first understand the relationship between motor acceleration torque, load inertia, and time. These relationships are expressed in the formula:

$$T = \frac{WK^2 \cdot \Delta rpm}{308 \cdot t}$$

- T = torque to accelerate a load (lb-ft at motor)
- WK^2 = inertia of load (lb-ft^2 equivalent at motor)
- Δrpm = change in motor speed (High Speed minus Low Speed)
- t = time (seconds) required to accelerate

Inertia is the measure of a load's resistance to a change in velocity. The moment of inertia (WK^2) is the product of the weight (W) of the load and the square of the radius of gyration (K^2). The larger the inertia and the shorter the acceleration time, the greater the acceleration torque required. If you are unsure about acceleration requirements, you should consider all these parameters when applying an AFC.

The AFC features that influence a motor's acceleration capabilities are:

- Acceleration Time Adjustment (minimum to maximum setting)
- Current Limit Adjustment

The acceleration time adjustment in most AFCs determines how quickly the reference frequency signal ramps from the starting frequency to the operating frequency (60 Hz at base speed) or from a lower frequency to a higher frequency. The actual motor acceleration time may or may not be the same as this setting, depending on the load inertia and the motor acceleration torque.

ACCELERATION TIME

Acceleration time may be important for several reasons, such as:

- To save production time by accelerating a load quickly
- To prevent damage to the load by accelerating a load slowly and gradually
- To meet system requirements

If acceleration time is important for an installation, you should make calculations to determine if the AFC/motor combination can meet the application requirements. It may be necessary to oversize the AFC to meet the specified acceleration time, or to prevent the AFC from tripping out.

In addition to acceleration time required, you must know the inertia of the load equivalent at the motor shaft, the motor rated horsepower and speed, and the percent loading of the motor.

When the acceleration time adjustment is set for a short time, the motor accelerates the load, or tries to accelerate the load, from zero speed to the operating speed in the specified time – if the motor can develop the acceleration torque required for the inertia of the load.

An AFC with 150% current limit setting limits the motor's acceleration torque capability to approximately 150% for sine coded PWM AFCs, and less than this for six-step or current source AFCs. As a result, the acceleration time may be longer than the setting, or the drive may trip out if the acceleration time is longer than 60 seconds. Examples are given in “LOAD INERTIA”.

An AFC without a current limit feature will trip out if the acceleration time setting is too short for the load inertia. In these cases, the acceleration time setting must be increased. Increasing the acceleration time adjustment to its maximum setting usually satisfies most load conditions that require very gradual acceleration to prevent load damage. The shock to a load may also be minimized by reducing the current limit setting and the drive voltage boost adjustment until the load just starts to move.

If the AFC trips out with a high inertia load, a larger size AFC may be required or the acceleration time may be extended. See “LOAD INERTIA”.

LOAD INERTIA

If load inertia is a major factor in an installation, you should make calculations to determine if the AFC/motor combination can meet the application requirements. In addition to the inertia of the load equivalent at the motor shaft, you must know the acceleration time required, motor rated horsepower and speed, and the percent loading of the motor. It may be necessary to oversize the AFC to permit the AFC/motor combination to accelerate the load without tripping the AFC.

If a machine has a large flywheel or appears to possess a large weight that must be put into motion, you must determine the load inertia. This ensures the AFC is sized properly to permit the motor to accelerate the load without tripping.

Load inertia can be furnished by the machinery builder or can be calculated. Refer to “TYPICAL INERTIA FORMULAS” on page 15. To calculate horsepower and torque, see “TYPICAL HORSEPOWER FORMULAS” on page 12.

Examples of time and acceleration torque calculations for a constant torque load are given below using the formula from page 37. Additional calculations are required to determine the acceleration torque for a variable torque load.

Example 1 – Fast Acceleration Requirement

In this example, AFC oversizing is necessary to meet fast acceleration requirement for a motor loaded 100%.

- rpm =1750
- WK^2 = 25 lb-ft^2
- t = Acceleration Time Required for application = 8 seconds
- T_L = Total Load Torque (at motor shaft, assume constant torque load) = 20 lb-ft

Motor Full-load Torque is 20 lb-ft (assume motor is fully loaded)

- T_M = Motor Average Maximum Torque with AFC and 150% current limit

$$= 20 \cdot 1.5 = 30 \text{ lb-ft}$$

- T_{AA} = Average Acceleration Torque Available from motor = $T_M - T_L$

$$= 30 - 20 = 10 \text{ lb-ft}$$

- T_{AR} = Average Acceleration Torque Required to accelerate load in 8 seconds

$$= \frac{WK^2 \cdot \Delta rpm}{308 \cdot t} = \frac{25 \cdot 1750}{308 \cdot 8} = 17.75 \text{ lb-ft}$$

Because T_{AA} from motor is only 10 lb-ft, you must increase the AFC size to permit 17.75 lb-ft average acceleration torque from the motor. This example assumes you have selected a motor with sufficient maximum torque capability to meet the acceleration requirements.

The AFC output current rating increase is:

$$\boxed{\frac{T_{AR} + T_L}{T_{AA} + T_L} = \frac{17.75 + 20}{10 + 20} = \frac{37.75}{30} = 1.25}$$

You must select an AFC with continuous output current equal to 1.25 times motor full-load current.

Example 2 – Accelerating a High Inertia Load

In this example, AFC oversizing is necessary to prevent the AFC from tripping when accelerating a high inertia load with the motor loaded 50%.

- rpm =1750
- $WK^2 = 500$ lb-ft^2
- t = Acceleration Time Required for application = 60 seconds
- T_L = Total Load Torque (at motor shaft, assume constant torque load) = 20 lb-ft

Motor Full-load Torque is 40 lb-ft (assume motor is 50% loaded).

- T_M = Motor Average Maximum Torque with AFC and 150% current limit

$$= 40 \cdot 1.5 = 60 \text{ lb-ft}$$

- T_{AA} = Average Acceleration Torque Available from motor = $T_M - T_L$

$$= 60 - 20 = 40 \text{ lb-ft}$$

- T_{AR} = Average Acceleration Torque Required to accelerate load in 60 seconds

$$= \frac{WK^2 \cdot \Delta rpm}{308 \cdot t} = \frac{500 \cdot 1750}{308 \cdot 60} = 47.3 \text{ lb-ft}$$

Because T_{AA} from motor is only 40 lb-ft, you must increase the AFC size to permit 47.3 lb-ft average acceleration torque from the motor. This example assumes you have selected a motor with sufficient maximum torque capability to meet the acceleration requirements.

The AFC output current rating increase is:

$$\boxed{\frac{T_{AR} + T_L}{T_{AA} + T_L} = \frac{47.3 + 20}{40 + 20} = \frac{67.3}{60} = 1.12}$$

You must select an AFC with continuous output current equal to 1.12 times motor full-load current.

Deceleration torque is the sum of the braking torque available from the motor/AFC combination, and the friction and windage torque losses. Friction and windage help to decelerate the load and add to the motor braking torque. This is in contrast to acceleration, where the AFC/motor combination must provide additional torque for these losses.

For AFC applications, deceleration torque is a consideration because:

- Excessive regenerative energy may cause the AFC to trip out, causing the load to coast to a stop.
- Excessive deceleration torque may damage the driven machine.

Deceleration is not normally a factor for most pump and fans. However, there are some exceptions, such as large fan with high inertia loads, where only limited coasting may be tolerated.

To determine deceleration requirements, it is first necessary to understand the relationship between deceleration torque, load inertia and time. These relationships are expressed in the formula:

$$T = \frac{WK^2 \cdot \Delta rpm}{308 \cdot t}$$

- T = torque to decelerate a load (lb-ft at motor)
- WK^2 = inertia of load (lb-ft^2 equivalent at motor)
- Δrpm = change in motor speed (High Speed minus Low Speed)
- t = time (seconds) required to decelerate

When deceleration control is a requirement, the AFC adjustment for deceleration time should be considered first. In most cases, when deceleration time and inertia are not major factors, this adjustment allows the AFC/motor combination to meet installation requirements without the need for dynamic braking or regenerative braking options.

Inertia is the measure of a load's resistance to a change in velocity. The moment of inertia (WK^2) is the product of the weight (W) of the load and the square of the radius of gyration (K^2). The larger the inertia and the shorter the deceleration time, the greater the braking (deceleration) torque required. If you are unsure about deceleration requirements, you should consider all these parameters when applying an AFC.

The AFC features that influence a motor's braking capabilities are:

- Deceleration Time Adjustment (minimum to maximum setting)
- Dynamic Braking or Regenerative Braking options
- Anti-Regeneration feature

The deceleration time adjustment in most AFCs determines how quickly the reference frequency signal ramps from the operating frequency (60 Hz at base speed) to the starting frequency. The actual motor deceleration time may or may not be the same as this setting, depending on the load inertia and the motor braking torque.

An AFC/motor combination produces limited braking torque because of the capacitance in the DC link and the motor losses. Unless time or inertia are major considerations, this method of deceleration is usually adequate for most installations. For AFCs that have an anti-regeneration feature, the deceleration ramp is automatically extended to maintain operation of the AFC with the inherent braking until the load stops. This inherent braking is only 10 to 15% of motor full-load torque. Without this feature, excessive bus voltage occurs and the AFC will trip and coast to a stop. Some AFCs may include a feature to avoid tripping by coasting to a stop every time.

If AFC tripping or excessive deceleration time occurs, the dynamic braking or regenerative braking option is required. This determines the braking torque available from the motor.

DECELERATION TIME

If deceleration time is important for an installation, you should make calculations to determine the proper application of either dynamic braking or regenerative braking. You must know the specific deceleration time required, the inertia of the load equivalent at the motor shaft, the motor rated horsepower and speed, the percent loading of the motor, and be able to estimate of the mechanical system losses.

Deceleration time may be important to a process for several reasons:

- To save production time by decelerating a load quickly
- For safety, to avoid a long coasting time
- To prevent damage to the load by decelerating a load slowly and gradually
- To meet system requirements

When time is critical, you must use the formula on page 41 to determine the motor braking torque required from either dynamic braking or regeneration. For examples, see “LOAD INERTIA”.

LOAD INERTIA

If load inertia is a major factor in an installation, you should make calculations to determine if the AFC/motor combination can meet the application requirements and whether. If a machine has a large flywheel or possesses a large weight that must have controlled deceleration, you must determine the load inertia. It may be necessary to apply a dynamic braking or regeneration option to permit the motor to decelerate the load without tripping the AFC.

Load inertia can be furnished by the machinery builder or can be calculated. Refer to “TYPICAL INERTIA FORMULAS” on page 15. To calculate horsepower and torque, see “TYPICAL HORSEPOWER FORMULAS” on page 12.

Examples of time and acceleration torque calculations for a constant torque load are given below using the formula from page 41. Additional calculations are required to determine the deceleration torque for a variable torque load.

Example 1 – Fast Deceleration Requirement

This example shows how to calculate the motor braking torque necessary to meet fast deceleration requirement for a motor loaded 100%.

- rpm =1750
- WK^2 = 25 lb-ft^2
- t =Deceleration Time Required for application = 8 seconds
- T_L = Total Load Torque (at motor shaft, assume constant torque load) = 20 lb-ft

Motor Full-load Torque is 20 lb-ft (assume motor is fully loaded).

Assume friction and winding losses are 10%.

- T_F = Retarding Torque from friction, etc.

$$= 20 \cdot 10\% = 2 \text{ lb-ft}$$

- T_D = Deceleration Torque needed to stop the load in 8 seconds

$$= \frac{WK^2 \cdot \Delta rpm}{308 \cdot t} = \frac{25 \cdot 1750}{308 \cdot 8} = 17.75 \text{ lb-ft}$$

- Motor Braking Torque (T_B) = Deceleration Torque (T_D) minus Friction Torque (T_F)

$$T_B = (T_D - T_F) = (17.75 - 2) = 15.75 \text{ lb-ft}$$

Because the motor full-load torque is 20 lb-ft, the motor braking torque is 78% of the full-load torque (15.75 ÷ 20). This determines the design parameters and settings for either a dynamic braking option or regenerative braking option, whichever is used. If the motor braking torque requirement is greater than 100% of motor full-load torque, you should evaluate the duty cycle and AFC ratings to determine if the AFC must be oversized.

Example 2 – Decelerating a High Inertia Load

This example shows how to calculate the motor braking torque required to prevent the AFC from tripping when decelerating a high inertia load.

- rpm =1750
- $WK^2 = 130$ lb-ft^2
- t = Deceleration Time Required for application = 60 seconds
- T_L = Total Load Torque (at motor shaft, assume constant torque load) = 20 lb-ft

Motor Full-Load Torque is 20 lb-ft (assume motor is 100% loaded). Assume friction and winding losses are 10%.

- T_F = Retarding Torque from friction, etc.

$$= 20 \cdot 10\% = 2 \text{ lb-ft}$$

- T_D = Deceleration Torque needed to stop the load in 60 seconds

$$= \frac{WK^2 \cdot \Delta rpm}{308 \cdot t} = \frac{130 \cdot 1750}{308 \cdot 60} = 12.3 \text{ lb-ft}$$

- Motor Braking Torque (T_B) = Deceleration Torque (T_D) minus Friction Torque (T_F)

$$T_B = (T_D - T_F) = (12.3 - 2) = 10.3 \text{ lb-ft}$$

Because the motor full-load torque is 20 lb-ft, the motor braking torque is 51% of the full-load torque (10.3 ÷ 20) for 60 seconds. This represents energy that must be absorbed by the dynamic or regenerative braking method. 100% motor braking torque could be applied and stop the load in less than 60 seconds without tripping the AFC.

MOTOR BRAKING METHODS

There are three major categories of electrical braking for AC induction motors with an AFC:

- Dynamic braking
- Regenerative braking
- DC injection braking

When motor braking is required, the decision to use dynamic braking, regenerative braking or DC injection is based on cost, the magnitude of regeneration energy and specific requirements for the installation.

In most cases, dynamic braking will suffice when coasting is not applicable. However, for fast duty cycles or when a relatively large energy loss is undesirable, regenerative braking is recommended.

Dynamic Braking

Dynamic braking directs the regenerative energy from an AC induction motor into a resistor in the AFC circuits. This condition presents an electrical load, or retarding torque, to the motor, which is acting as a generator. This energy is dissipated in the form of heat. The thermal capacity required for this resistor is determined by the stopping duty cycle for the load and the energy dissipated for each deceleration.

The dynamic braking feature consists of an electronic switch (typically a GTO, transistor or IGBT) placed across the DC bus of the AFC. In series with this solid state switch is a resistor, or resistors, suitably sized to absorb the regenerative energy. Since the regenerative energy from the motor tends to cause a rise in DC bus voltage, dynamic braking circuits are usually set to turn on at a specific voltage, and turn off at some lower voltage. The circuit operates as a chopper, maintaining the DC bus power within its normal limits.

Dynamic braking requires the motor to remain energized to maintain the rotating magnetic field. Dynamic braking cannot operate during periods where power is lost and cannot maintain holding torque when the AFC is stopped. A mechanical brake must be used when the application requires a holding torque at zero speed. Dynamic braking with an AC motor does not provide the same characteristics as with a DC motor. When there is a loss of line power, the DC motor with the proper field and armature circuit connections provides a retarding torque as a function of speed.

Per NEMA standards, the standard dynamic braking feature is designed to absorb six times the stored energy of a motor running at full speed. (Refer to NEMA standard MG1 for standard motor inertias for calculation of dynamic braking requirements.) An AFC with a standard dynamic braking circuit can permit six consecutive stops of a motor from rated speed without overheating the dynamic braking resistor. For small amounts of energy, this dynamic braking option is simpler and less costly than regenerative braking. A heavy duty dynamic braking circuit may be considered when a faster duty cycle is required or to frequently stop a high-inertia load. However, considerable energy loss may result. For these cases, although more costly, a regenerative braking option should be considered.

Regenerative Braking

Regenerative braking directs the regenerative energy from an AC induction motor back into the AC line, thus saving the energy. Current limit adjustments in the regenerative circuits control the level of energy returned to the line, and consequently the braking torque developed by the motor. Use of the regenerative braking option is preferred to the dynamic braking option for applications with a relatively fast duty cycle and when large amounts of energy losses are undesirable.

Like dynamic braking, regenerative braking is not effective during periods of power outages. A mechanical brake must be used with the motor when the application requires a holding torque at zero speed. Regenerative braking cannot maintain a holding torque unless the AFC is capable of operating at zero speed. To achieve this, sophisticated control circuits employing field orientated control (vector control) are required.

DC Injection

DC injection applies DC power to an AC induction motor, which then produces a braking torque. The energy is dissipated in the motor. Because of the motor heating considerations, which already exist with an AFC, this feature has limited use for deceleration from full speed.

Like other means of electrical braking, DC injection braking is not fail safe. Loss of DC power results in loss of braking capability. A mechanical brake should be used with the motor when the application requires holding torque at zero speed.

The environment is an important consideration for a successful AFC installation. The following conditions should be evaluated:

- Ambient temperature
- Altitude
- Humidity
- AFC enclosure design
- Shock and vibration requirements

AMBIENT TEMPERATURE

Typically, solid state power conversion equipment is rated from 0 to 40 °C (32 to 104 °F). Derating is usually required for ambients above 40 °C. Consult the AFC manufacturer for temperature derating.

Ambients below 0 °C typically require space heaters, because derating is not applicable. If the ambient is below 0 °C, the power semiconductors may misoperate.

ALTITUDE

3300 feet (1000 meters) above sea level is the maximum altitude for operation of most solid state power conversion equipment, without derating. This is a result of the thinner air affecting the AFC heat sink cooling ability. Consult the AFC manufacturer for altitude derating of an AFC.

HUMIDITY

Typically, solid state power conversion equipment is rated for 95% humidity, non-condensing. Condensation may occur when the equipment is colder than the surrounding air temperature. Leaving the AFC energized should provide enough heat to minimize condensation, unless the ambient temperature is below 0 °C. Use a properly applied space heater in these cases.

ENCLOSURES

NEMA has established standards for electrical enclosure construction. Verify that the AFC enclosure construction is suitable for the installation environmental conditions. It is important to note that generally Type 1 rated enclosures do not protect devices against conditions such as condensation, icing, corrosion or contamination that may occur within the structure via conduit entry points or unsealed openings.

In applications where the ambient air contains large quantities of particle matter, the use of a fan-cooled AFC is not recommended, because of the possibility of air vents and passages becoming clogged. This type of environment requires the use of totally enclosed non-ventilated (TENV) AFC, ducting of clean air to the AFC, or locating the AFC in a clean area. There may be exceptions to this rule when a fan-cooled AFC is specifically intended for an application.

For this application guide, multimotor applications are defined as the connection or possible connection of more than one motor to a single AFC. Since all motors is connected to the same source, the synchronous speed of the motors is determined by the traditional relationship of frequency and number of poles. The actual operating speed is affected by the loading of individual motors and is within the slip rating of the motor, provided that an overload or overhauling load condition does not exist.

When more than one motor is connected to a single AFC, you must follow the procedures described below. The AFC must be carefully selected to ensure proper operation without nuisance shutdown. In addition, protection of the branch circuit and overload protection of individual motors must be considered to ensure that the installation meets the National Electrical Code and/or any local electrical codes.

SELECTING AN AFC FOR MULTIMOTOR CONTROL

You must comply with following requirements when applying more than one motor with a single AFC:

- AFC selection with output current rating equal to or greater than the sum of all motor full-load current ratings
- Overload protection included for each motor
- Branch circuit fault protection included for each motor
- Disconnect requirement satisfied for each motor
- Output reactor (as required)

Note: AFCs with sensorless flux vector control and flux vector control with sensor may not be suitable for multimotor applications.

Before selecting an AFC, you must determine how many motors are to be operated and the full-load current of each motor. Always select an AFC with an output current rating equal to or greater than the sum of all the full-load current ratings of the motors.

Overload/Overtemperature

When connecting multiple motors to a single AFC, you must ensure that each motor is provided with overload and/or overtemperature protection in accordance with Article 430, Part C of the National Electrical Code, and any applicable local electrical codes. Square D Class 9065 or GV2-M overload devices can provide this protection.

The overload/overtemperature protective means must interrupt current flow to the motor either by causing a shutdown of the AFC or by opening the circuit feeding the protected motor.

Branch Circuit Short-Circuit and Ground Faults

When multiple motors are connected to the output of an AFC, you must ensure that the branch circuit short- circuit and ground-fault protection for each motor are coordinated with upstream protection in accordance with code requirements. To determine protection requirements, consult Article 430, Parts B, D & E of the National Electrical Code, and any applicable local electrical codes.

Square D controls use the fault protection capabilities of the AFC to meet this requirement. In some cases, an installation may require specific coordination requirements with separate protection in each branch circuit to maintain continuation of AFC service.

Disconnecting Means

Requirements for disconnecting each motor must be met. Consult Article 430, Part H of the National Electrical Code, and any applicable local electrical codes. Square D controls use the AFC disconnect to meet these requirements.

Output Reactors

In multi-motor applications, you must determine if output reactors are required to reduce the parasitic capacitance coupling to ground. Consult the AFC manufacturer.

SLAMMING MOTORS WITH AN AFC

Slamming is a term used to describe a condition where a motor at rest is connected to an operating AFC. When slamming motors with an AFC, the AFC must be able to withstand the full voltage inrush current of the motors. You must obtain the full voltage 60 Hz inrush current of all motors that will be switched.

Disconnecting motors while running from a PWM or six-step AFC is usually permitted, but is not permitted with most current source designs.

You must size the AFC output current rating to equal the full-load current of all motors that can potentially operate at one time. In addition, the inrush current of motors that are switched simultaneously must be included. A slamming factor is then applied for the AFC rating to ensure that nuisance tripping will not occur.

When slamming is required, use the following steps to select the AFC:

1. Consult the AFC manufacturer to determine if motors can be disconnected while running. Usually, a PWM or six-step AFC will permit this, but most current source designs will not.

   Motors can be disconnected from OMEGAPAK and ALTIVAR AFCs while they are operating without harming the AFC. However, the motor must not be disconnected from an operating AFC and then reconnected to the AFC unless sufficient time is allowed for the motor open-circuit voltage to decay to less than 10% of the motor nameplate rated voltage. Failure to allow sufficient time before reconnecting a motor can result in nuisance AFC shutdown and/

or damage to the AFC power switching devices. When contactors are used to switch motors while the AFC is operating, the contactor control circuit should include sufficient time delay (typically 0.5 to 1.0 second) to allow motor voltage to decay before permitting reconnection. For installations where motors must be reconnected before the 0.5 second delay, consult the AFC manufacturer for special circuits.

2. Determine the maximum continuous current that the AFC must supply by adding the full-load currents of all motors.
3. Determine the locked rotor current of each motor to be switched. Consult the motor manufacturer for the locked rotor current first, and if not available, use the motor nameplate code. To calculate maximum locked rotor amperes, see “LOCKED ROTOR KVA” on page 26.
4. If only one motor is to be switched at a time, pick the largest switched motor and record the locked rotor amperes from Step 3. If multiple motors are to be switched simultaneously, determine the largest combination of switched motors and add the locked rotor amperes from Step 3.
5. Determine the appropriate AFC slamming factor. This provides a safety margin to insure that the locked rotor current of the reconnected motor(s) will not cause a nuisance instantaneous overcurrent (IOC) trip, or cause the AFC to go into current limit (which would cause a speed reduction of operating motors).
6. Determine the AFC current rating by adding the locked rotor amperes from Step 4 divided by the slamming factor from Step 5 to the full-load amperes of all motors running when the slammed motors are reconnected.

$$FLA_C = \frac{LRA + FLA_R}{SF}$$

- FLA_C = AFC Current Rating
- SF = Slamming Factor
- FLA_R = Full-Load Amperes of Running Motor(s)
- LRA = Locked Rotor Amperes of Switched Motors (from Step 4)

7. Select the larger of the value calculated in Step 6 or the sum of all motor full-load currents from Step 2. This is the minimum continuous output current rating for the AFC.

AC line considerations are an important factor in determining the best type of AFC to use. Regardless of the type of load, you should evaluate AC line considerations before selecting any AFC. It is important to consider line conditions affecting the AFC, and also AFC conditions affecting the line.

Line considerations fall into several categories:

- Branch Circuit Ratings
- Line Voltage Deviations
- Line Harmonic Currents
- Line Power Factor
- Line Available Fault Current
- Isolation Transformers / Line Reactors

BRANCH CIRCUIT RATINGS FOR AN AFC

All branch circuit equipment (transformers, feeder cables, disconnect devices, protective devices, etc.) for an AFC must be rated for the maximum input current rating designated on the AFC nameplate, not the normally used motor full-load current value. This requirement is described in NEC Article 430-2.

AFCs have an input current rating and an output current rating on the nameplate. In a worst case condition, the total RMS input current can be as much as 25% to 30% higher than the output current. The input current could be less, depending on the line input impedance at the AFC installation. This phenomenon is a result of harmonic currents generated by power semiconductors in the AFC. This is described in more detail in "Line Harmonic Currents" on page 56.

Branch circuit equipment ratings are normally based on the motor nameplate information. However, this is not the case when applying an AFC.

Circuit breakers or fused disconnect switches supplied with Square D AFCs are sized for the maximum AFC input current. If you know the available fault current at the installation, you can predict a lower value of input current closer to the output current. With this information, a specific value of additional line reactance could improve the input current value for certain types of AFCs. Consult the AFC manufacturer to determine the additional line reactance.

LINE VOLTAGE DEVIATIONS

Voltage Variations

The AC line voltage must remain within ±10% of the motor rated voltage (typically 460 V, 230 V or 200 V). You should confirm that the AC line voltage remains within this range. Voltage variations greater than this may affect the motor torque performance.

AC motors are rated by NEMA standards to produce 100% output torque within ±10% of the rated voltage applied to the motor's terminals. Although some AFC designs can operate beyond the ±10% rated voltage, motor output torque performance may be reduced under this condition.

If the input voltage is greater than the AFC rated voltage (and the AFC overvoltage trip setting is not exceeded), full rated motor torque can still be maintained. If the input voltage is less than the AFC rated voltage (and the drive undervoltage trip setting is not exceeded), full rated motor torque may or may not be attainable, depending on the AFC design. However, exceeding these tolerances could cause the self-protecting circuits to trip the AFC. Consult the AFC manufacturer when these conditions exist.

Transient Overvoltages – Line Created

Another AC line phenomenon that can affect an AFC performance is AC line voltage transients. Line voltage transients may or may not have an affect on an AFC, depending on the magnitude of the transient and the type of AFC design.

Jogging motors can cause transient overvoltages, particularly when capacitors are energized with a motor. Switching power factor capacitors on a power system is common practice and can cause damaging impulses. Corrective action should be taken at the source to minimize these transients, such as applying capacitor precharge controls. For additional information on voltage transients, refer to Product Data C-882.

- *For AFCs with an SCR front end:* Voltage transients can cause misfiring of the SCRs, possibly resulting in SCR failures, unless protected with semiconductor fuses. Potential failures from transient overvoltages can be minimized with isolation transformers, which attenuate voltage transients. Isolation transformers are not necessary for most PWM (pulse width modulated) AFCs. An improperly applied isolation transformer may worsen a transient problem because of the ringing effect caused by the transformer inductance.
- *For AFCs with a diode front end:* Voltage transients will not cause a misfiring problem. However, the transients can cause an overvoltage condition in the DC link, possibly causing nuisance tripping. The addition of a line reactor option permits an AFC to operate without nuisance tripping, if the transients are not excessive. Consult the AFC manufacturer for this modification.

Transient Voltages (Line Notching) – AFC Created

All types of controllers using power semiconductors (SCR heating controls, DC drives, AC drives, solid state reduced voltage starters, etc.) create voltage notching in an AC line. Depending on the installation, voltage notching created by an AFC using an SCR front end may cause problems in a power system. This can be minimized by using an isolation transformer or additional line reactance. Consult the AFC manufacturer.

The severity of voltage notching is a function of the line input impedance at the installation, and the type of power semiconductor circuit used. Circuits with power semiconductors that are not gated on and off, such as a diode bridges, create only minor voltage notches. These are not a consideration. Circuits with power semiconductors that are gated on and off, such as SCRs, may create substantial voltage notches.

Voltage notches are a result of a very brief line-to-line short circuit when current is commutated from one power semiconductor to another. Notches with an excessive width and depth can cause problems in a power system such as:

- Misoperation of sensitive equipment such as computers, programmable controllers and other adjustable speed drives
- Interference with communications equipment
- Light flickering (severe cases)

For PWM AFCs and AFCs with a diode front end (six-step or current source AFC with a DC chopper and diode front end), line notching is usually insignificant and requires no corrective action.

Line notching could create problems for AFCs with an SCR front end (six-step or current source AFC without a DC chopper). An isolation transformer or line reactors will minimize the effects of this phenomenon on the AC line.

For more information on this subject, refer to Product Data Bulletins C-883 and 8803PD9402.

Voltage Distortion – AFC Created

Line voltage distortion can result in misoperation of electronic equipment connected to a power system. All types of controllers using power semiconductors produce harmonic currents, which cause a non-sinusoidal voltage in the power system. This phenomenon is called voltage distortion and is defined by IEEE Standard 519. Guidelines for maximum distortion factor vary, depending on the power system sensitivity.

The distortion factor is the ratio of the vector sum of all the harmonic voltages to the fundamental voltage. The system sensitivity is determined by the type of installation. For example, conventional contactor type motor control may tolerate a higher distortion factor than sensitive electronic equipment.

The distortion factor created by an AFC is determined by the harmonic currents created by the AFC. If voltage distortion becomes a consideration, minimizing the line harmonic currents will reduce the distortion factor. Refer to “Line Harmonic Currents” below.

LINE HARMONIC CURRENTS – AFC CREATED

Line harmonic currents are a net result of a non-sinusoidal current, which is characteristic of all types of controllers using power semiconductors. Non-sinusoidal currents are composed of a pure sinusoidal component of current (fundamental current) at line frequency, and additional sinusoidal components of current (harmonic currents) at frequencies higher than the line frequency. These harmonic currents do not aid in the transmission of power to a load, but still contribute to the volt-ampere loading by generating losses in the distribution system.

Line harmonic currents are not the same as harmonic currents generated in the power to an AC motor. These two conditions are isolated by virtue of the DC link in an AFC. Motor harmonic currents are discussed on page 27 and page 33.

Line harmonic currents are caused by the diode or SCR bridge in the front end of an AFC, and the magnitude can vary for different types of AFCs. The final magnitude of harmonic currents is determined by the line input impedance at the installation and the type of power semiconductor circuits used in an AFC. Because of these variables, it is difficult to suggest general guidelines to minimize harmonic currents, such as adding line reactance. When this is necessary, consult the AFC manufacturer to determine the feasibility and best method of reducing the input current harmonic content to a lower level. For more detailed information on reducing line harmonic currents, refer to Product Data Bulletin 8803PD9402.

Harmonic currents add to the normal line currents, which is why the input current to an AFC is higher than the output current. This phenomenon may be improved with the addition of line reactance.

Some of the negative effects of line harmonics, if not properly addressed, are:

- Interference with communication equipment
- Overheating of transformers and other branch circuit equipment
- Equipment failure (severe cases)

Problems could be created if you apply power factor correction capacitors to a system where line harmonic currents exist. With certain conditions, harmonic currents can be amplified through resonance with line inductance and power factor capacitors to cause equipment failures. In these cases, the AFC manufacturer can furnish a custom-designed filter network to correct this problem. Normally, with PWM type AFCs, power factor correction capacitors are not applied, and this condition should not exist.

For more detailed information on harmonic currents, refer to Product Data Bulletins C-883 and 8803PD9402.

LINE POWER FACTOR

The total line power factor with an AFC consists of two components:

- Displacement component – the conventional displacement angle between voltage and current as a result of circuit impedance and phase control
- Distortion or harmonic component – a function of input line impedance

Distortion power factor is a result of harmonic currents, and exists with all types of AFCs. This condition cannot be corrected with capacitors, but can be improved by adding line reactance (refer to “BRANCH CIRCUIT RATINGS FOR AN AFC” on page 53).

Since the distortion component of the total power factor is determined by the line input impedance for a specific installation, it is impractical to publish a total line power factor value for AFCs. Most manufacturers publish only the displacement power factor, which is more predictable.

For PWM AFCs and AFCs with a diode front end, the displacement power factor is high (approximately 0.95) and remains constant at all speeds. Power factor correction capacitors are not normally required.

For AFCs with an SCR front end, the displacement power factor is poor at reduced speed. Power factor correction capacitors, if applied, should be carefully analyzed to avoid the harmonic resonance problem described in “LINE HARMONIC CURRENTS”.

For more details on power factor, refer to Product Data C-873A.

LINE AVAILABLE FAULT CURRENT

It is important to know the fault current available from an AC line to determine whether or not the withstand rating of an AFC is adequate for an installation. An AFC withstand rating should be high enough for the power system fault capability. Some AFCs may require additional line reactance. When in doubt, consult the AFC manufacturer.

The withstand rating should be designated on the AFC nameplate. Although many AFCs provide electronic short circuit and ground fault protection, their maximum withstand capability may not be sufficient to be coordinated with upstream protective devices. Typically, 65,000 A available withstand current may be specified for an MCC lineup. For remote installations, available withstand current can be considerably less.

In some cases, additional line reactance may be required if an AFC does not meet the withstand rating required for an installation. An isolation transformer may provide the additional reactance.

ISOLATION TRANSFORMERS

For AFCs with an SCR front end, isolation transformers can help minimize the effects of some voltage transients and line harmonic currents, and improve the AFC withstand capability if it is insufficient for the installation. To avoid misapplication, consult the AFC manufacturer before applying an isolation transformer.

For Square D PWM AFCs, isolation transformers are not normally necessary to minimize the effects of voltage transients and line harmonic currents, or to improve the withstand capability. In some cases, line harmonic currents can be minimized with simple line reactors. In special cases, an isolation transformer may be helpful when a specific voltage transient can be characterized. Consult the AFC manufacturer in these cases.

NEMA has set up guidelines for determining the need for isolation transformers in conjunction with an AFC. The following conditions may warrant an isolation transformer:

- Voltage matching
- Codes
- Nuisance grounding
- Line voltage imbalance
- Input harmonic currents
- Voltage transients
- Excessive available fault current

Voltage Matching

When line voltage is different from the rated AFC input voltage, a step-up or step-down transformer or autotransformer at the AFC input may be used. The voltage transformation may be accomplished by using feeder transformers supplying mixed loads. In the case of larger AFCs, separate dedicated transformers may be supplied for single AFCs or groups of AFCs.

Codes

Local or plant codes may specify electrical isolation, which could include the use of transformers.

Installations Prone to Nuisance Grounding

For certain applications, engineering practice may dictate the use of ungrounded or impedance-grounded branch circuits on controllers and motors. To maintain continuity of service in a nuisance ground environment, an isolation transformer is used to galvanically isolate the AFC branch circuit from the overall distribution system. Continued AFC branch circuit operation is possible with a single nuisance ground. To provide continued protection, clear the nuisance ground at the earliest opportunity.

Line Voltage Imbalance

Unbalanced voltage greater than 2% between phases of the incoming line may cause larger than rated line currents to be drawn from the AC line. An isolation transformer may be used to compensate the voltage imbalance at all rated load conditions.

Reducing AFC Input Harmonic Currents

On certain types of AFCs, the harmonic content of the input line current may be reduced by inserting impedance between the AFC input and the distribution system. Transformers are a convenient device to accomplish this, but the AFC manufacturer should be consulted first.

For more details, refer to “LINE HARMONIC CURRENTS” on page 56.

Reducing Voltage Transients

On certain types of AFCs, voltage transients (drive generated and line generated) may be reduced by inserting impedance between the AFC input and the distribution system. Although the use of isolation transformers, properly applied, may reduce the harmonic currents and line-to-ground overvoltage transients, there may be very little effect on line-to-line voltage transients. In some cases, this additional impedance and the AFC DC link capacitors can make the transient overvoltage condition worse. To minimize voltage transients, consult the AFC manufacturer before applying isolation transformers.

For more details on voltage transients, refer to “Transient Voltages” on page 55.

Reducing Available Fault Current

When the distribution system fault current capacity exceeds the AFC rated withstand capability (indicated on the AFC nameplate), isolation transformers can be used to decrease the system fault capability at the AFC input terminals.

When selecting an AFC, in addition to all the application considerations reviewed in the previous sections, there are several important subjects that must be considered:

- AFC current rating / horsepower rating
- Motor overtemperature/overload protection
- AFC disconnect device
- Isolation contactor
- Bypass control
- Automatic restart
- Automatic speed control

AFC CURRENT RATING

When selecting an AFC, you must initially size the output current rating based on the rated full-load current of the motor and motor horsepower rating. Refer to “MOTOR FULL-LOAD CURRENT AND HORSEPOWER” on page 22 for motor current rating. You may need to oversize the AFC, increasing the initial rating to accommodate the application requirements (such as breakaway torque, acceleration, deceleration, environment or multimotor operation). These should all be reviewed as described in the flowchart steps on page 2.

These application requirements include:

- Breakaway Torque Requirements – Section 4 (page 33)
- Acceleration Requirements – Section 5 (page 37)
- Deceleration Requirements – Section 6 (page 41)
- Environmental Requirements – Section 7 (page 47)
- Multimotor Requirements – Section 8 (page 49)

MOTOR OVERTEMPERATURE/OVERLOAD PROTECTION

For motors controlled with an AFC, most manufacturers recommend the use of a temperature-sensitive switch in the motor, in addition to the current-sensitive overload device. This is essential to protect the motor for overtemperature at low speeds, even though the motor may not be current overloaded. All Square D AFCs have provisions for motor thermal switches. Verify that the AFC includes motor overload protection. For terminal connections, refer to the instruction bulletin supplied with the controller.

Many AFCs are stand-alone controllers and may or may not include motor overload protection. In some cases, these devices may be furnished separately to meet NEC requirements. It is important to check an installation to determine if separate motor overload protection is provided or if space is available for mounting the overload device with the AFC.

AFC DISCONNECT DEVICES

To meet NEC requirements, a disconnect device is required for each motor branch circuit. If a disconnect is not supplied remotely, you should check each AFC to determine if a disconnect device is included or if space is available for one. See drive controller Product Data Bulletin 8800PD950x for Square D disconnect features.

Many AFCs are stand-alone controllers, with the power fed from a switchboard. Since a disconnecting means is usually provided at the switchboard (to meet NEC requirements), it may not be necessary to have an additional disconnecting means at the AFC. If, for safety or convenience, you choose to provide a local disconnecting device at the AFC, verify that the enclosure selected for the AFC can accommodate a disconnecting device.

Disconnecting means can take the form of a circuit breaker or a fusible disconnect switch. Circuit breakers are generally more convenient, and the preferred choice. When the system has high fault current availability that requires current limiting fuses to meet the interrupting capacities, a fusible disconnect switch is required.

ISOLATION CONTACTOR FOR AN AFC

Although not usually required, there are instances when an isolation contactor between the motor and the AFC may be desirable. For example, an isolation contactor may be used to provide total isolation between the AFC and the motor when the AFC is shut down. The normal sequencing for this is to energize the contactor when the AFC starts; the contactor remains closed as long as the AFC is operating. When the AFC receives a stop command, the motor is decelerated with the AFC deceleration ramp. Upon reaching minimum frequency, the AFC shuts off, and the contactor is deenergized. This insures that leakage current from the AFC power switching devices does not reach the motor windings.

BYPASS CONTROL FOR AN AFC

Bypass control is recommended for installations where you must keep the motor in service if the AFC is out of service. It is important to adhere to NEC requirements when using bypass control.

The installation should be compatible for full voltage 60 Hz starting and full speed operation with the bypass control. In addition, the bypass control must meet all applicable application considerations for the AFC.

To provide the most flexible and fully rated bypass control, the basic circuit should consist of:

- Disconnect devices (may be same disconnect as drive controller)
- Short circuit protection
- Motor overload devices
- Isolation contactors for the bypass connection and the AFC connection

Isolation contactors prevent backfeeding line voltage into the AFC output terminals, which could damage the AFC. An alternative to this control scheme is a transfer switch circuit, which should be verified to meet NEC requirements for the current interrupting conditions.

Because bypass control can be manual or automatic, you must ensure that a suitable time delay occurs when the motor is transferred from the AC line back to the controller. This allows the magnetic flux in the motor to decay before being connected to the AFC.

AUTOMATIC RESTART FOR AN AFC

Depending on the installation, automatic restart may be desirable when a momentary or temporary power outage occurs. Many applications, particularly pumps and fans, require that an AFC be able to automatically restart if shutdown occurs due to loss of the supply voltage. The automatic restart function can take several forms, depending on the requirements of the application. Typical methods for automatic restarting are:

- Time delay
- Coasting motor restart
- Synchronous restart

Evaluate the installation to determine which method of restarting is best suited for the type of AFC being used. Not all AFC manufacturers offer all three methods.

Time Delay Automatic Restart

Time delay is the easiest of the three means of automatic restart. A time delay circuit, which drops out during loss of power, is preset to allow sufficient time for the load to coast to a complete stop before the AFC is restarted. Automatic restart occurs if the input signal is calling for operation of the AFC.

Coasting Motor Restart

Coasting motor restart permits an AFC to restart into a coasting motor without damaging the power semiconductors or causing nuisance tripping of the protective circuit. If a power dip occurs in the circuit feeding an AFC equipped with a coasting restart feature, the AFC shuts down and remains deenergized during the power interruption. If the power is restored to normal before the motor coasts to a complete stop, upon reenergization and the presence of a maintained contact calling for AFC operation, the AFC will restart.

A low voltage, low frequency output is applied to the motor terminals. This has an effect similar to the application of DC injection braking, causing the motor to decelerate to a speed that matches the applied frequency. Once positive speed control is regained, the AFC accelerates the motor with the normal acceleration ramp to the required operating speed. Properly designed circuits allow coasting restart to occur, regardless of direction of rotation of the motor. The motor can be windmilling or turbining backwards due to operation of the driven loads.

Synchronous Restart

The most complex of the automatic restart circuits is synchronous restart, which requires the capability to catch a motor on the fly. This method restarts a coasting motor without reducing its speed to near zero. Synchronous restart may not be used in multimotor or three-wire control installations.

To perform a synchronous restart, the AFC must produce an output frequency that matches the equivalent frequency at the motor restart speed. Some AFCs require a speed feedback device to sense the actual motor speed, while others sense the motor EMF.

During periods of power interruption, the AFC shuts off. When power is reapplied, the AFC increases its output frequency up to the frequency that matches the motor operating speed. The motor operating speed is determined by the tachometer feedback signal or motor EMF, depending on the AFC design). While the AFC is matching its output frequency with the motor speed, the AFC output voltage is held very low. This results in little or no motor torque developed to change the motor speed. Once the output frequency is at the proper point, voltage regulator circuits allow the output voltage to return to normal and the motor produces torque at the speed where it was coasting. The output frequency is then allowed to return to the frequency required by the speed command signal input to the AFC.

AUTOMATIC SPEED CONTROL

Many applications for adjustable speed require the AFC to follow some type of process signal to change the motor speed automatically. In these cases, it is first necessary to determine the type of follower signal provided by the process controller. Typically, process control signals are:

- 4-20 mADC
- 0-10 VDC
- 3-15 psi pneumatic

When selecting the proper automatic process follower, you must determine whether an isolated or non-isolated follower circuit is required. Isolation must be provided at either the transmitter or at the AFC; it is not required at both locations. With an isolated follower, the AFC power supply ground point is kept galvanically isolated (usually with an opto-coupler) from the power supply ground point in the process control transmitter. Failure to provide isolation could result in a ground loop, which could pick up excessive electrical noise. This could cause misoperation of the controls.Unless there is a known isolated follower signal from the transmitter, an isolated follower for the AFC is recommended.

After determining the type of automatic process signal and selecting the proper levels, you must determine if both manual and automatic operation are required.

Occasionally, setpoint control is required in addition to an automatic process signal. Setpoint control is an internal AFC function (as opposed to the process signal, which has an external source). Setpoint control provides stability to an AFC operation by maintaining a process setpoint or controlled range with a higher degree of accuracy.

- An example of proportional plus integral setpoint control is when an AFC controls the speed of a pump to maintain a constant pressure in a hydraulic system.
- An example of proportional setpoint control is when an AFC controls the speed of a pump from minimum speed to maximum speed for designated levels in a reservoir.

You may use a process follower stepped signal or a signal from a SY/MAX® programmable logic controller via a serial communication option.

It is not practical to list all of the special considerations that exist for every AFC application. However, some special considerations are common to many applications and are reviewed in this section:

- Motor audible noise
- Electromagnetic interference (EMI)
- Explosion-proof motor/AFC combination
- Pumping applications
- Fan and blower applications
- Slamming motors

MOTOR AUDIBLE NOISE

Motor audible noise occurs primarily for fan or blower applications, and occasionally for pumping installations. For AFCs with fan or blower motors in air-handling systems, motor audible noise is sometimes undesirable. This condition may exist also for some pumping systems. For most other AFC applications, motor audible noise is not a consideration.

Motor audible noise does not exist with six-step or current source AFCs. For installations where the motor may be in close proximity to people, such as offices and hospitals, audible noise may be a serious application consideration.

Audible noise in electrical equipment originates from alternating magnetic fields created when AC power is applied to a coil with an iron core. This phenomenon is frequently observed in transformers. The noise is created by minute vibrations of the iron core laminations. The pitch and loudness of the sound is influenced by the magnitude of the AC power, the physical characteristics of the iron laminations and how well the lamination assembly is constructed.

Motor audible noise is caused by PWM type AFCs with carrier frequencies in the audible range (such as 1 kilohertz). It is a result of the pulse width modulated waveform applied to the motor. This waveform consists of a series of pulses; whereas the six-step AFC wave has only six distinct steps. The rate at which these pulses are applied is usually called the carrier frequency. As the carrier frequency is changed in the audible range during the operation of an AFC, there is a distinct sound from the motor. When high speed power switching devices are used, carrier frequencies above the audible range can be applied, eliminating the motor audible noise.

For PWM designs with carrier frequencies in the audible range, the intensity of the motor noise can be decreased noticeably by reducing the V/Hz ratio to the motor at reduced speeds. This results in less torque capability from the motor, but is not detrimental for variable torque fan or pump loads. Another method is to increase the AFC carrier frequency above the audible range.

A more effective alternative to minimize motor audible noise is to use a motor with windings that have been vacuum impregnated with an epoxy compound.

ELECTROMAGNETIC INTERFERENCE (EMI)

Electromagnetic interference (EMI), occasionally referred to as radio frequency interference (RFI), occurs primarily for some HVAC applications, and occasionally for pumping installations. EMI can be an application consideration, primarily in commercial buildings. In these cases, high frequency emissions generated from the AFC panel or from line conductors connected to the AFC can cause noisy interference or misoperation of adjacent electronic equipment, such as TVs or radios, especially AM receivers. FM receivers are normally not affected. These electromagnetic emissions are a result of the rapid gating on and off characteristics of power switching devices in the AFC.

FCC Rules and Regulations, Volume II, Part 15, Subpart J, Class A, establishes limits for both conducted and radiated emissions at various frequencies. To comply with these regulations, you must limit conducted and radiated emissions, but this does not necessarily prevent problems from occurring in every situation.

Usually, proper routing of AFC conductors in separate conduits away from suspect equipment is sufficient to limit interference from AFCs. Consult the AFC manufacturer for the best wiring practices with his equipment. For recommended installation wiring, refer to the instructional material supplied with the drive controller.

When serious problems exist (such as noisy interference with weak AM stations), input mains filters can be installed to attenuate the conducted EMI. The effectiveness of any filter is highly sensitive to where it is installed, and to the routing of customer-installed cables. Each installation must be analyzed separately when an interference problem occurs.

Fortunately, EMI interference is an exception rather than the rule for most AFC installations, and furnishing expensive filters without due cause serves no useful purpose. The best approach is to use equipment from reliable AFC manufacturers who can assist the user in solving an EMI problem. It is our policy at Square D to assist the user in solving any EMI problem with Square D AFCs.

When this type interference is an application consideration, consult the AFC manufacturer should to determine corrective action necessary for the specific installation conditions.

EXPLOSION-PROOF MOTOR/AFC COMBINATION

The use of an explosion-proof motor with an AFC may be required for a hazardous location. When an explosion-proof motor is used with an AFC, the motor should be UL listed for use with a specific design AFC for a specifically defined hazardous area. Normally, the AFC would be remotely located in a non-hazardous area.

An explosion-proof motor, when applied fully loaded at line voltage and line frequency, operates with its surface temperature at safe levels for a defined hazardous area. When an AFC is used with the motor, additional heat is produced in the motor, thus raising its surface temperature. This subject is reviewed in Section 3.

To apply an explosion-proof motor/AFC combination with a UL listing, the motor must be tested with a specific type AFC to operate within surface temperature values set by UL for a specifically defined hazardous area. Some motor manufacturers have completed these tests with PWM type AFCs for Class I Groups C & D and Class II Groups E & F hazardous areas.

PUMPING APPLICATION CONSIDERATIONS

When using an AFC in a pumping application, you should check special sequencing requirements, reverse turbining, motor audible noise and EMI. Special sequencing arrangements may be required for an AFC to interface with check valves or other pumping system devices.

Starting a pump that is reverse turbining could be an application consideration. In this case, starting without an AFC coasting motor restart capability could be difficult. See “Coasting Motor Restart” on page 63 for information on this feature.

Valve sequencing control can be an important consideration to avoid the serious adverse effects of a stuck discharge valve. For example, an open valve might cause reverse turbining of a pump. This could result in severe torque and current surges, which may damage the pump, motor, AFC and drive shaft. Serious hydraulic problems, such as wet well flooding, could develop. In some cases, the well could be pumped dry.

Square D valve sequencing control with an AFC ensures that discharge valves are opened and closed in the proper sequence when starting and stopping pumps. To protect against a discharge valve stuck open, valve sequencing control permits the motor/ AFC combination to operate at a specified reduced speed that results in only a very slight reverse flow. This helps prevent the potential problems associated with malfunctioning discharge valves. For additional information on the operation of Square D control, see Product Data C-879.

FAN AND BLOWER APPLICATION CONSIDERATIONS

When using an AFC in a fan application, you should check special sequencing requirements, windmilling, frequency avoidance, EMI and motor audible noise. Special sequencing arrangements may be required for an AFC to interface with dampers or inlet vanes for fans.

Starting a fan that is windmilling, forward or reverse, could be an application consideration. In this case, starting without an AFC coasting motor restart capability could be difficult. See “Coasting Motor Restart” on page 63 for information on this feature.

Another consideration for fans is frequency avoidance. This may be required when an air duct or other mechanical component of an air-handling system resonates at the operating frequency of the AFC. Avoiding this frequency in operating the AFC may be necessary to eliminate excessively noisy vibration of the mechanical system.

SLAMMING SINGLE MOTORS WITH AN AFC

In this case, the term slamming describes a condition where a motor at rest is connected to an operating AFC. Application considerations for this are identical to those described in “SLAMMING MOTORS WITH AN AFC” on page 50, except a single motor is used.

OVERHAULING LOADS

An overhauling load exists when the load torque is in the same direction as the motor driving torque. It will start or keep the motor rotating in its same direction when power and any mechanical braking are removed. Overhauling loads require special evaluation for each installation. Consult the AFC manufacturer for proper application.

A load becomes overhauling during deceleration. In this case, inertia keeps the motor rotating in the same direction for a limited time. This type of overhauling condition is reviewed in “LOAD INERTIA” on page 42 and in “MOTOR BRAKING METHODS” on page 44.

A common type of overhauling load is a hoist, when lowering its load to the ground. Certain types of conveyors or transfer cars, operating with a downhill slope, also present an overhauling load.

For these type applications, the motor/AFC combination must develop a retarding torque to control the speed, or decelerate the motor to zero speed. Dynamic braking, regenerative braking or DC injection braking methods can be used to accomplish this. See “MOTOR BRAKING METHODS” for more information.

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