Engineering Bulletin

Starters, Drives, and Electrical Components for CenTraVac™ Chillers

CVHE, CVHF, CVHG
CDHF, CDHG
Introduction

This document explains key electrical concepts and starter product information relating to Trane® water chillers. Topics include voltage classes, motors, motor protection, starter types, variable-frequency drives, wire sizing, power factor correction, and electrical term definitions.

Information in this document changes frequently. To make sure you are viewing the most recent version, be sure to download the latest copy available on e-Library.

**Dimensional data**

Job specific submittals are always the best source of dimensional data. General starter dimensions are shown with the descriptions of each starter type in this document.

**Wiring information**

The best source for additional information is the Installation, Operation, and Maintenance manual shipped with the chiller. Field connection diagrams are also available on the website.

All unit-mounted starters are designed for top-entry line power only. Remote starters are typically designed for top-entry line power and a bottom exit for load wires. The medium-voltage starter submittals show conduit space for alternate wiring options. Additional wiring options may be available.

For your convenience, power wire sizing charts for various voltages and conduit combinations are provided.

**Fuse and circuit breaker sizing**

Proper sizing of fuses and circuit breakers upstream of the starter is the responsibility of the customer or the electrical engineer. Disconnects and circuit breakers are options that can be installed within the Trane® starters. What Trane would install may not necessarily satisfy UL, NEC, or local code requirements for installation of overcurrent devices.

*Important:* Trane, in presenting electrical information and system design and application concepts, assumes no responsibility for the performance or desirability of any resulting system design. Design of the HVAC and related electrical system is the prerogative and responsibility of the engineering professional. Trane has a policy of continuous product and product information improvement and reserves the right to change design and specifications without notice. Consult the chiller submittal for the most up-to-date information as applied to the specific chiller under consideration.

**Trademarks**

Adaptive Frequency, CenTraVac, TOPSS, Tracer AdaptiView, Tracer Summit, Trane, and the Trane logo are trademarks of Trane in the United States and other countries. All trademarks referenced in this document are the trademarks of their respective owners.

Cutler-Hammer is a federally registered trademark of Eaton Corporation.
Table of Contents

Introduction .................................................................................................................. 2

About Starters ................................................................................................................. 5
  What a Starter Does ...................................................................................................... 5

Motor Types and Voltage Classes .................................................................................. 6
  Voltage Classes ............................................................................................................. 6
  Motors ........................................................................................................................... 6

Chiller Selection and Electrical Specification ............................................................... 8
  Standard Components of Trane Starters ....................................................................... 8
  Chiller Selection Report ............................................................................................... 8

Motor Protection .............................................................................................................. 11

Low-Voltage Starter Types ............................................................................................ 15
  Low Voltage—Wye-Delta ............................................................................................. 16
    Wye-Delta Starters ...................................................................................................... 16
  Low Voltage—Solid-State ........................................................................................... 20
    Solid-State Starters .................................................................................................... 20
  Low Voltage—Unit-Mounted Adaptive Frequency Drive ............................................. 23
  Low Voltage—Remote-Mounted Adaptive Frequency Drive ....................................... 26

Medium-Voltage Starter Types (2,300–6,600 Volts) ....................................................... 29
  Medium Voltage—Across-the-Line (2.3–6.6 kV) ......................................................... 30
    Across-the-Line Starter (2,300–6,600 volts) ............................................................... 30
  Medium Voltage—Primary Reactor (2.3–6.6 kV) ......................................................... 33
    Primary Reactor Starter (2,300–6,600 volts) ............................................................... 33
  Medium Voltage—Autotransformer (2.3–6.6 kV) ......................................................... 36
    Autotransformer Starter (2,300–6,600 volts) ............................................................... 36
    Unit-Mounted Starter Top Hat—NEC 2005 Code Requirement ............................ 38
  Medium Voltage—Remote-Mounted Adaptive Frequency Drive ............................... 40
    Chiller Unit Control Features for the AFD ................................................................. 41

Medium-Voltage Starter Types (10,000–13,800 Volts) .................................................. 43
  Medium Voltage—Across-the-Line (10–13.8 kV) ......................................................... 43
    Across-the-Line Starter (10,000–13,800 volts) .......................................................... 43
  Medium Voltage—Primary Reactor (10–13.8 kV) ......................................................... 45
    Primary Reactor Starter (10,000–13,800 volts) .......................................................... 45
  Medium Voltage—Autotransformer (10–13.8 kV) ......................................................... 46
    Autotransformer Starter (10,000–13,800 volts) .......................................................... 46

Electrical System—Ratings ............................................................................................. 48

Electrical System—Design Guidelines ............................................................................ 51
About Starters

What a Starter Does

Electric, centrifugal, water-cooled chillers use relatively large induction motors to drive the compressors. These motors use a control device to connect to and disconnect from the electrical power source. These control devices are referred to as combination controllers or, most commonly, as motor starters. Variable-frequency drives or Adaptive Frequency™ Drives (AFDs) also serve as motor starters, but their capabilities extend beyond starting and stopping the motor.

There are three main functions of the motor starter. The first function is to serve as the link between the chiller’s motor and the electrical distribution system. It is used during the starting and stopping sequence.

Starting an induction motor from standstill causes a large electrical current draw for a few seconds. The extra current is used to develop the required torque to get the compressor motor running at full speed. The initial rush of current decreases as the compressor motor ramps up to full speed, and is commonly referred to as inrush current.

The second function of the starter is to keep the initial current inrush below a specified level. Third, the starter communicates with the unit controller to coordinate motor protection.

Starters can be as simple or as complex as necessary to meet various engineering specifications and/or customer needs. A variable-speed drive can provide starter functions, among other things (see “Low Voltage—Unit-Mounted Adaptive Frequency Drive,” p. 23 and “Medium Voltage—Remote-Mounted Adaptive Frequency Drive,” p. 40). It will be classified as a starter type for the purposes of this document.

Several voltage classes and starter types are available as indicated on the chart below. Each one is described in greater detail in this document.

### Table 1. Trane CenTraVac chiller starter choices

<table>
<thead>
<tr>
<th>Low Voltage (208–600 V)</th>
<th>Medium Voltage (2,300–6,600 V)</th>
<th>Medium Voltage (10–13.8 kV)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Remote-Mounted</td>
<td>Remote-Mounted</td>
<td>Remote-Mounted</td>
</tr>
<tr>
<td>Unit-Mounted</td>
<td>Unit-Mounted</td>
<td>Unit-Mounted</td>
</tr>
<tr>
<td>Wye-Delta</td>
<td>Wye-Delta</td>
<td>Across-the-Line</td>
</tr>
<tr>
<td>Up to 1,700 amps</td>
<td>Up to 1,316 amps</td>
<td>Up to 360 amps isolation switch, power fuses standard</td>
</tr>
<tr>
<td></td>
<td>(Up to 1,120 amps with disconnect/circuit breaker option)</td>
<td></td>
</tr>
<tr>
<td>Solid-State</td>
<td>Solid-State</td>
<td>Primary Reactor</td>
</tr>
<tr>
<td>Up to 1,472 amps</td>
<td>Up to 1,472 amps</td>
<td>Up to 205 amps isolation switch, power fuses standard</td>
</tr>
<tr>
<td>(Up to 1,120 amps with disconnect/circuit breaker option)</td>
<td>(Up to 1,120 amps with disconnect/circuit breaker option)</td>
<td></td>
</tr>
<tr>
<td>Adaptive Frequency Drive</td>
<td>Adaptive Frequency Drive</td>
<td>Autotransformer</td>
</tr>
<tr>
<td>460/480/575/600 V</td>
<td>Up to 1,210 amps</td>
<td>Up to 205 amps isolation switch, power fuses standard</td>
</tr>
<tr>
<td>Up to 1,360 amps (460/480 V)</td>
<td>Circuit breaker standard 460–480 V</td>
<td></td>
</tr>
<tr>
<td>1,120 amps (575/600 V)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Adaptive Frequency Drive</td>
<td>Up to 250 amps isolation switch, power fuses standard</td>
<td></td>
</tr>
</tbody>
</table>

CTV-PRB004-EN  5
Motor Types and Voltage Classes

Voltage Classes

There are two primary voltage classes typically used in the water-cooled chiller industry: low and medium. For centrifugal chillers this is generally restricted to three-phase power only.

Low voltage ranges from 208 to 600 volts. Starters and frequency drives in this voltage range include sizes up to 1,700 amps.

Medium voltage has two main voltage groups. One ranging from 2,300 to 6,600 volts and the other ranging from 10,000 to 13,800 volts. Starters in this class have sizes up to 360 amps and 94 amps respectively.

For a given power (kW), the higher the voltage the lower the amperage. The voltage is typically established prior to creating the job plans and specifications.

Motors

A centrifugal motor is a relatively simple motor. Specifically, it is referred to as a three-phase, squirrel-cage, 3,600-rpm, alternating-current induction motor with two-pole construction.

The squirrel-cage motor consists of a fixed frame, or stator, carrying the stator windings and a rotating member called the rotor. Figure 1 shows a cutaway of a typical low-voltage motor. The rotor is built by rigidly mounting steel laminations to the motor shaft. The motor winding consists of aluminum bars that are die-cast into slots in the rotor. The aluminum bars are connected at each end by a continuous ring. This skeleton of rotor bars with end rings looks like a squirrel cage and gives the motor its name.

In a three-phase motor, three windings on the stator connect to a motor terminal board, and ultimately to the power grid via the starter. When the polyphase alternating current flows through the stator winding it produces a rotating magnetic field. The resulting magnetic forces exerted on the rotor bars cause the rotor to spin in the direction of the stator field. The motor accelerates until a speed is reached corresponding to the slip necessary to overcome windage and friction losses. This speed is referred to as the no-load speed.

Low-voltage motors typically have six motor terminals to electrically connect the motor in a wye (star) or delta configuration. Most low-voltage motors are random-wound motors, but larger amperage higher horsepower motors are form wound for better heat dissipation. Connecting links can be used to convert the six motor electrical connections to three connections.

Medium-voltage motors (2,300–6,600 V) have three motor terminals. Figure 2 shows a typical medium-voltage motor minus the rotor shaft. You can visually compare most low- and medium-voltage motors. Medium-voltage motors are always form wound and you can see that the insulation is thicker and the windings are more evenly spaced.
Medium-voltage motors (10–13.8 kV) have the same design and construction attributes as other medium-voltage motors with some externally visible differences. Ceramic insulators and larger spacing of the motor terminals are commonly found on typical 10–13. kV medium-voltage motors. Internally, these motors are form wound and structurally similar to other medium-voltage motors. The ceramic insulators combined with the larger spacing between the motor terminals help prevent electrical arcing.

Higher voltage motors and starters are being used in large chiller plants where incoming line power makes 10–13.8 kV accessible. In some cases, higher voltage chillers allow for the elimination of electrical components with their associated space requirements and energy losses. In particular, chiller installations with on-site or dedicated power generation, such as district cooling, higher education, hospitals, industrials, and airports have opportunities for electrical distribution system simplification and energy savings.

Benefits of 10,000–13,800 volts include:
- No need for step-down transformer
- No transformer losses
- Higher uncorrected power factor
- Reduced electrical design and labor
- Reduced mechanical room space

**Note:** Motors and starters at 10,000–13,800 volts typically cost more, and the motor efficiency is lower than 2,300–6,600-volt motors.

Motors are available in specific power sizes, which are rated in kilowatts or horsepower. The TOPSS™ computer software selection program selects the proper motor to meet the specific cooling duty of the application.
Chiller Selection and Electrical Specification

Standard Components of Trane Starters

- A 4 kVA control-power transformer (CPT) supports all of the chiller auxiliary power needs—3 kVA control-power transformer supplied with AFDS.
- Primary and secondary current transformers (CTs) support the overload and momentary power loss protection functions of the unit controller. This allows amps per phase and percent amps to be displayed at the unit controller.
- Potential transformers (PTs) support motor protection functions such as under/overvoltage within the unit controller. This allows voltage per phase, kilowatts, and power factor to be displayed at the unit controller.
- Grounding provisions are standard.
- A terminal block for line power connection is standard. Load-side lugs are standard for remote starters. The lug sizes and configuration are shown on the submittal drawing. The Trane® AFD has a circuit breaker as standard. Medium-voltage starters have provisions for a bolted connection.

Chiller Selection Report

The following terms are found on a typical TOPSS product report. Review the example selection output report shown in Figure 3, p. 10.

Electrical information

Usually the primary RLA and kW of the chiller are used as nameplate values. Occasionally, an engineer may decide to specify slightly higher RLA and kW as the nameplate value to provide extra capability for the chiller. This is possible, provided the nameplate kW does not exceed the rating of the motor and the RLA does not exceed the amp rating of the starter and any supplied circuit breaker or disconnect.

A. Motor size (kW). The motor size is listed on the program report based on its output kW. The output kW is the motor’s full, rated power capacity. There is an amperage draw associated with the motor size called full-load amps (FLA). FLA is the amperage the motor would draw if it were loaded to its full rated capacity, i.e. the motor size. The FLA is not available from the chiller selection program, but it can be obtained from motor data sheets upon request.

B. Primary power (kW). The primary power is the power the chiller uses at its design cooling capacity. The primary power will always be less than or equal to the motor size.

C. Motor locked-rotor amps (LRA). There is a specific locked-rotor amperage value associated with each specific motor. This is the current draw that would occur if the rotor shaft were instantaneously held stationary within a running motor. LRA is typically six to eight times the motor full-load amps (FLA). LRA is also used commonly in discussing different starter types and the inrush amperages associated with the motor start. For example, a wye-delta starter will typically draw approximately 33 percent of the motor LRA to start. A solid-state starter will draw approximately 45 percent of the motor LRA to start.

D. Primary rated-load amps (RLA). The RLA is also commonly referred to as the selection RLA or unit RLA. This is the amperage that is drawn when the chiller is at full cooling capacity. Nameplate RLA (usually the same as Primary RLA) is the key number used to size the starter, disconnects, circuit breakers, and Adaptive Frequency Drives for a typical cooling-only unit. Nameplate RLA is also the value used to determine the minimum circuit ampacity (MCA) for sizing conductors. Primary RLA is always less than or equal to the motor full-load amps (FLA).

E. Minimum circuit ampacity (MCA). This term appears on the chiller nameplate and is used by the electrical engineer to determine the size and number of conductors needed to bring power to the starter.
MCA = 1.25 \times RLA + \left( \frac{4000}{\text{volts}_{\text{motor}}} \right) 

... with this number rounded up to the next whole number. Said another way, the MCA is 125\% of the motor design RLA plus 100\% of the amperage of other loads (sump heater, oil pump, purge, etc.). The MCA is listed on the chiller selection report. Power cable sizes and conduits are discussed in “Electrical System–Power Wire Sizing,” p. 55.

**F. Maximum overcurrent protection (MOP or MOCP).** The MOP appears on the chiller nameplate. The electrical engineer often wants to know the MOP when the chiller is selected for sizing fuses and upstream circuit breakers. Understand that the MOP is a maximum, *NOT* a recommended fuse size. Improperly sized circuit breakers or fuses can result in nuisance trips during the starting of the chiller or insufficient electrical protection. MOP is also *NOT* used to size incoming power wiring—the MCA is used for this purpose.
**Chiller Selection and Electrical Specification**

**Figure 3. Excerpt from chiller selection report**

### Unit Information

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Model</td>
<td>CVHF</td>
</tr>
<tr>
<td>Compressor size</td>
<td>770</td>
</tr>
<tr>
<td>Motor size</td>
<td>588</td>
</tr>
<tr>
<td>Motor frequency</td>
<td>60 Hz</td>
</tr>
<tr>
<td>Motor voltage</td>
<td>460</td>
</tr>
<tr>
<td>Impeller size</td>
<td>289</td>
</tr>
<tr>
<td>Orifice size</td>
<td>1185</td>
</tr>
<tr>
<td>Evap shell size</td>
<td>080L</td>
</tr>
<tr>
<td>Evap bundle size</td>
<td>800</td>
</tr>
</tbody>
</table>

### Design Information

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cooling capacity</td>
<td>800.0 tons</td>
</tr>
<tr>
<td>Primary power</td>
<td>505.6 kW</td>
</tr>
<tr>
<td>Primary efficiency</td>
<td>0.628 kW/ton</td>
</tr>
<tr>
<td>NPLV</td>
<td>0.406 kW/ton</td>
</tr>
<tr>
<td>Adaptive frequency drive</td>
<td>AFD</td>
</tr>
<tr>
<td>Application type</td>
<td>Standard cooling</td>
</tr>
<tr>
<td>HCFC 123 refrigerant charge</td>
<td>1100 lb</td>
</tr>
<tr>
<td>Shipping weight</td>
<td>29425 lb</td>
</tr>
<tr>
<td>Operating weight</td>
<td>33147 lb</td>
</tr>
<tr>
<td>Sound level</td>
<td>0 dBA</td>
</tr>
<tr>
<td>Green Seal certification</td>
<td>Yes</td>
</tr>
<tr>
<td>Free cooling option</td>
<td>No</td>
</tr>
<tr>
<td>Heat rejected into equip room</td>
<td>8.54 MBh</td>
</tr>
</tbody>
</table>

### Evaporator Information

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Evap leaving temp</td>
<td>40.00 F</td>
</tr>
<tr>
<td>Evap flow rate</td>
<td>1193.9 gpm</td>
</tr>
<tr>
<td>Evap entering temp</td>
<td>56.00 F</td>
</tr>
<tr>
<td>Evap flow/capacity</td>
<td>1.49 gpm/ton</td>
</tr>
<tr>
<td>Evap water box type</td>
<td>non-marine</td>
</tr>
<tr>
<td>Evap pressure drop</td>
<td>14.81 ft H2O</td>
</tr>
<tr>
<td>Evap fouling factor</td>
<td>0.00010 hr-sq ft-deg F/Btu</td>
</tr>
<tr>
<td>Evap fluid type</td>
<td>water</td>
</tr>
<tr>
<td>Evap fluid concentration</td>
<td>N/A</td>
</tr>
<tr>
<td>Evap water box pressure</td>
<td>150 psig evap. water pressure</td>
</tr>
<tr>
<td>Evap min flow rate</td>
<td>480.50 gpm</td>
</tr>
</tbody>
</table>

### Condenser Information

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cond entering temp</td>
<td>85.00 F</td>
</tr>
<tr>
<td>Cond flow rate</td>
<td>1920.0 gpm</td>
</tr>
<tr>
<td>Cond leaving temp</td>
<td>96.84 F</td>
</tr>
<tr>
<td>Cond flow/capacity</td>
<td>2.40 gpm/ton</td>
</tr>
<tr>
<td>Cond water box type</td>
<td>non-marine</td>
</tr>
<tr>
<td>Cond pressure drop</td>
<td>21.29 ft H2O</td>
</tr>
<tr>
<td>Cond fouling factor</td>
<td>0.00025 hr-sq ft-deg F/Btu</td>
</tr>
<tr>
<td>Cond fluid type</td>
<td>water</td>
</tr>
<tr>
<td>Cond fluid concentration</td>
<td>N/A</td>
</tr>
<tr>
<td>Cond water box pressure</td>
<td>150 psig cond. water pressure</td>
</tr>
</tbody>
</table>

### Electrical Information

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Motor LRA</td>
<td>4389 A</td>
</tr>
<tr>
<td>Primary RLA</td>
<td>685.7 A</td>
</tr>
<tr>
<td>Min circuit ampacity</td>
<td>867 A</td>
</tr>
<tr>
<td>Max over current protection</td>
<td>1200 A</td>
</tr>
</tbody>
</table>
Motor Protection

Historically, motor protection was provided in the starter by some type of monitoring system. Starter manufacturers usually provide a full range of optional equipment mounted on the starter. Eaton Cutler-Hammer® offers IQ metering and motor protection products for their starters.

Today, Trane provides most of the key motor protection and metering functions (see Table 2, first column) within the chiller microprocessor control panel as standard. Having the motor control and chiller control in one panel provides better integration and optimization of the two control systems. For example, the chiller controller can unload the chiller when approaching an overload “trip” point, so that the chiller stays online.

Table 2 and Table 3, p. 12 can be used to compare the standard electrical features of the chiller controller with those of other common Eaton Cutler-Hammer® starter-mounted devices. Additional starter-mounted metering and motor protection may not be required and could be considered redundant.

Table 2. Protection and functions by motor packages

<table>
<thead>
<tr>
<th>Protection Functions</th>
<th>Tracer AdaptiView</th>
<th>MP 3000(a)</th>
<th>IQ 210</th>
<th>IQ DP 4130</th>
</tr>
</thead>
<tbody>
<tr>
<td>Communications</td>
<td>Optional</td>
<td>Optional</td>
<td>Optional</td>
<td>Optional</td>
</tr>
<tr>
<td>Ground fault</td>
<td>Optional(c)</td>
<td>Standard</td>
<td>N/A</td>
<td>N/A</td>
</tr>
<tr>
<td>Long acceleration</td>
<td>Standard</td>
<td>Standard</td>
<td>N/A</td>
<td>N/A</td>
</tr>
<tr>
<td>Maximum number of starts</td>
<td>Standard</td>
<td>Standard</td>
<td>N/A</td>
<td>N/A</td>
</tr>
<tr>
<td>Momentary power loss (distribution fault)</td>
<td>Standard</td>
<td>N/A</td>
<td>N/A</td>
<td>N/A</td>
</tr>
<tr>
<td>Motor overload</td>
<td>Standard</td>
<td>Standard</td>
<td>N/A</td>
<td>N/A</td>
</tr>
<tr>
<td>Motor winding temperature</td>
<td>Standard</td>
<td>Optional</td>
<td>N/A</td>
<td>N/A</td>
</tr>
<tr>
<td>Over temperature</td>
<td>Standard</td>
<td>N/A</td>
<td>N/A</td>
<td>Standard</td>
</tr>
<tr>
<td>Overvoltage</td>
<td>Standard(f)</td>
<td>N/A</td>
<td>N/A</td>
<td>Standard</td>
</tr>
<tr>
<td>Phase imbalance</td>
<td>Standard</td>
<td>Standard</td>
<td>N/A</td>
<td>Standard</td>
</tr>
<tr>
<td>Phase loss</td>
<td>Standard</td>
<td>Standard</td>
<td>N/A</td>
<td>Standard</td>
</tr>
<tr>
<td>Phase reversal</td>
<td>Standard</td>
<td>N/A</td>
<td>N/A</td>
<td>Standard</td>
</tr>
<tr>
<td>Run timer</td>
<td>Standard</td>
<td>Standard</td>
<td>N/A</td>
<td>N/A</td>
</tr>
<tr>
<td>Separate alarm levels(g)</td>
<td>Standard</td>
<td>Standard</td>
<td>N/A</td>
<td>N/A</td>
</tr>
<tr>
<td>Surge capacitor/lightning arrester</td>
<td>Optional</td>
<td>N/A</td>
<td>N/A</td>
<td>N/A</td>
</tr>
<tr>
<td>Undervoltage</td>
<td>Standard(f)</td>
<td>N/A</td>
<td>N/A</td>
<td>Standard</td>
</tr>
</tbody>
</table>

(a) The MP 3000 features Intel-I-Trip overload protection, enhanced custom trip curve development, UL 1053 ground fault, and advanced data logging and diagnostics.

(b) PowerNet power management system has replaced IMPACC (Integrated Monitoring Protection and Control Communications system).

(c) For low voltage, a Trane-supplied circuit breaker or non-fused disconnect is also required when ground fault is specified.

(d) The chiller controller monitors the motor temperatures of all three phases with one resistance temperature detector (RTD) per phase.

(e) For this option, add one or two sets (three RTDs per set) of 100-ohm platinum RTDs to the motor. Contact La Crosse Field Sales Support.

(f) Under/over phase-voltage sensors include volts per phase, kW, power factor, and under/overvoltage. A required pick on medium-voltage starters.

(g) Three alarm levels are used: warning only, nonlatching (auto-reset), and latching (manual reset required).
Overload or overcurrent protection shields the motor from small levels of overcurrent ranging from 107 to 140 percent of the primary RLA of the chiller. In contrast, fuses and circuit breakers are used to protect against short-circuit currents which may range to well over 100,000 amps.

Inductive loads, such as a chiller motor, behave differently than resistive loads such as electric heaters. Their current draw is greatest at startup and corresponds to the existing load when running. In other words, a motor operating normally draws rated amps (RLA) at rated load, fewer amps at less-than-rated load and more amps at greater-than-rated load. It is the latter condition that requires overload protection.

Adding an overload protection device prevents the motor from drawing more than its rated amperage for an extended period. Basic overload devices simply open the circuit when current draw reaches the “trip” point. More sophisticated devices attempt to restore normal motor operating conditions by reducing the load, but will disconnect the motor if overloading persists.

As with most overload devices, the chiller controller determines the “trip time” by measuring the magnitude of the overload. It then compares the overload to the programmed RLA “time-to-trip” curve. At startup, the standard overload protection is bypassed for the starter’s acceleration time, or until the motor is up to speed.

(a) The MP 3000 features Intel-I-Trip overload protection, enhanced custom trip curve development, UL 1053 ground fault, and advanced data logging and diagnostics.

(b) Under/over phase-voltage sensors include volts per phase, kW, power factor, and under/overvoltage. A required pick on medium-voltage starters.
Overload situations, left unchecked by protection, can cause excessive motor heat, that can permanently damage the windings and lead to motor failure. The time until motor damage depends mainly on the magnitude of the overcurrent and has an inverse time versus current relationship. The greater the overcurrent, the less time it takes to cause motor damage.

Overcurrent can be the result of motor overload, low line voltage, unbalanced line voltage, blocked load (rotor cannot freely rotate), single phasing, bad connections, broken leads, or other causes. It can occur in any one winding, a set of windings, or in all the motor windings.

The threshold of overcurrent is generally the primary RLA, which may be raised for service factor or lowered due to any derating factor, such as ambient temperature or line-voltage imbalance.

Overload protection is bypassed during a start due to the high currents associated with locked rotor and motor acceleration. Maximum allowed acceleration times per the AdaptiView unit controller are listed in Table 4.

Table 4. Long acceleration protection

<table>
<thead>
<tr>
<th>Starting Method (starter type)</th>
<th>Maximum Setting for the Acceleration Timer (sec)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wye-Delta</td>
<td>27</td>
</tr>
<tr>
<td>Solid-State</td>
<td>27</td>
</tr>
<tr>
<td>Variable-Frequency Drive</td>
<td>12</td>
</tr>
<tr>
<td>Across-the-Line</td>
<td>6</td>
</tr>
<tr>
<td>Primary Reactor</td>
<td>16</td>
</tr>
<tr>
<td>Autotransformer</td>
<td>16</td>
</tr>
</tbody>
</table>

**Motor overheat protection**

The unit controller monitors the motor winding temperatures in each phase and terminates chiller operation when the temperature is excessive. This feature also prevents the chiller from starting if the motor temperature is too high.

**Momentary power loss protection (distribution fault)**

Momentary power losses longer than 2 or 3 line cycles will be detected and cause the chiller to shut down, typically within 6 cycles. The chiller can also shut down due to excessive or rapid voltage sags. Shutting down the chiller prevents power from being reapplied with different motor phasing.
Phase failure/loss protection
The chiller will shut down if any of the three-phases of current feeding the motor drop below 10-percent RLA.

Phase imbalance protection
Based on an average of the three phases of current, the ultimate phase-imbalance trip point is 30 percent. The RLA of the motor can be derated depending on the percent of this imbalance. The phase-imbalance trip point varies based on the motor load.

Phase reversal protection
Detects reverse-phase rotation and shuts the chiller down (backwards rotation).

Under/overvoltage protection
The chiller is shut down with an automatic reset due to excessive line voltage ±10 percent of the design voltage.

Short cycling protection
Prevents excessive wear on the motor and starter due to heating from successive starts. The unit controller uses an algorithm based on a motor heating constant and a background timer (measuring the running time since the last start).

Supplemental motor protection
This is a set of optional motor protection features, offered as an option in addition to the Industrial Package (see “SMP, Supplemental Motor Protection—Medium voltage only (INDP option),” p. 65).
Low-Voltage Starter Types

Table 5 shows the most common low-voltage starter types available and lists their advantages and disadvantages. Typical inrush profiles for these starters are shown in Figure 5, p. 16. It is very uncommon to see a full-voltage starter in a low-voltage application due to the high inrush current; however, it is represented on the chart to provide a frame of reference.

Which starter type is best?

The wye-delta starter has been around a long time and, except for an AFD, it draws the lowest inrush current. Wye-delta starters are electromechanical and service technicians are typically more comfortable with them. The solid-state starter is a relatively newer design compared to the wye-delta, and has a slightly higher inrush current in chiller applications. The solid-state starter inrush can be set lower (the starter takes longer to get the motor up to speed), but it must be above the minimum inrush required to develop the proper starting torque. The solid-state starter is comparable in price to the wye-delta starter and has a smoother inrush curve without any current spikes. The wye-delta’s transition spike is not long enough to set utility demand ratchets or reduce the life of the motor. The starter type chosen ultimately depends on the application.

Table 5. Comparison of low-voltage starter types

<table>
<thead>
<tr>
<th>Starter Type (closed-transition)</th>
<th>Inrush Current % LRA</th>
<th>Percent Rated Torque</th>
<th>How Often Used</th>
<th>Advantages</th>
<th>Disadvantages</th>
<th>Typical Acceleration Time (seconds)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wye-Delta (Star-Delta)</td>
<td>33</td>
<td>33</td>
<td>60%</td>
<td>• Equal reduction of torque and inrush current • Low cost • Can be unit mounted</td>
<td>• Only applicable up to 600 volts • &quot;Spike&quot; at transition</td>
<td>5–12</td>
</tr>
<tr>
<td>Solid-State</td>
<td>~45</td>
<td>33</td>
<td>15%</td>
<td>• Gradual inrush/ramp up • No “spike” at transition • Price comparable to the wye-delta</td>
<td>• Higher level of service expertise than wye-delta • Higher inrush current than wye-delta • Starting harmonics may be an issue</td>
<td>5–12</td>
</tr>
<tr>
<td>Adaptive Frequency Drive (AFD)</td>
<td>&lt;13 (&lt;RLA) varies</td>
<td>25%</td>
<td>25%</td>
<td>• Lowest inrush current • Better chiller efficiency at reduced lift</td>
<td>• Most expensive • Efficiency loss at full load • Harmonics may be an issue</td>
<td>8–30</td>
</tr>
</tbody>
</table>

Trane® Adaptive Frequency Drives provide motor control, but they are much more than just starters. They also control the operating speed of the compressor-motor by regulating output voltage in proportion to output frequency. Varying the speed of the compressor-motor can translate into significant energy savings.

Applications that favor the use of an AFD exhibit increased operating hours at reduced condenser water temperatures and high energy costs. However, it is important to recognize that all variable-speed drives, including the Trane® AFD, require more energy near full-load design conditions, often coinciding with the peak electrical demand of the building. This may result in higher demand charges and diminish the overall energy savings. An analysis of the full-year operation of the chiller plant using an hour-by-hour simulation program that does not use blended kW and kWh energy rates will help determine whether an AFD is appropriate for a specific application and location.

Unit or remote mounted?

Unit-mounted starters can save on installed cost and space, and they can be tested in the factory and shipped on the chiller in a NEMA 1 enclosure. Remote-mounted starters provide more options for multiple starter lineups, and may be chosen in order to implement some of the industrial starter options such as high-fault and NEMA 12/3R.
Low-Voltage Starter Types

Low Voltage—Wye-Delta

Wye-Delta Starters

One of the most common starters in the industry is the wye/star-delta. It is an electromechanical starter initially set up in a "wye" or "star" configuration, then it transitions to a "delta" configuration during the starting sequence. To illustrate a typical starting sequence using a generic (non-Trane) schematic, refer to Figure 6, p. 17 and its "Starting sequence," p. 17.

Figure 5. Comparison of low-voltage starting current

![Graph showing comparison of low-voltage starting current for X-Line, Solid-State, Wye-Delta, and AFD.]
Starting sequence
1. The "start" signal from the CenTraVac controller energizes the pilot relay (PR).
2. The PR contacts close to energize the star contactor (S).
3. The S contacts close to connect the motor in the star configuration.
4. An S interlock closes to energize the start contactor (1M).
5. The 1M contacts close to connect the motor to the line.
6. A time delay relay or current monitoring device initiates transition by energizing the resistor contactor (1A).
7. 1A contacts close to connect the resistors to the line in the star configuration and in parallel with the compressor motor.
8. A 1A interlock now opens to de-energize the S contactor.
9. The S contacts open to connect the resistors and motor windings in series in the delta configuration.
10. An S interlock closes to energize the run contactor (2M).
11. The 2M contacts close to bypass the resistors and connect the compressor motor directly to the line in the delta configuration.

Dimensions
The typical unit-mounted wye-delta starter size is shown in Figure 8, p. 18. Typical remote-mounted one-, two- and three-door starter sizes are shown in Figure 9, p. 18, Figure 10, p. 18, and Figure 11, p. 19. Always consult the submittal drawings for as-built dimensions.
Low-Voltage Starter Types

The one-door remote-mounted starter size is generally used for 155- to 606-amp starters with no disconnect. The two-door size is used for 640- to 1,856-amp starters with no disconnect. The three-door size is used for 1,385- to 1,700-amps when disconnects are included.

Figure 7. Unit-mounted WD

Figure 8. Remote 1-door WD

Figure 9. Remote 2-door WD

Figure 10. Remote 3-door WD
**Standard features**

- Unit or floor mounted
- 115-volt control-power transformer
- Padlock tab for additional locking of the starter door
- Line-side connection terminal block/main lug only
- UL and CUL certified

**Environmental specification**

- Designed, developed, and tested in accordance with UL 508
- NEMA 1A enclosure as standard
- Operation from sea level to 6,000 ft (1,829 m)
- Operating ambient temperature range 32°F to 104°F (0°C to 40°C)
  - Relative humidity, non-condensing 5 percent to 95 percent
- Non-operating ambient temperature range -40°F to 158°F (-40°C to 70°C)
- Voltage utilization range ±10 percent
Low Voltage—Solid-State

Solid-State Starters

The Trane® solid-state starter produces a soft start with a gradual inrush current and no transition spikes. It controls the starting characteristics of a motor by controlling the voltage to the motor. It does so through the use of silicon controlled rectifiers (SCRs), which are solid-state switching devices, and an integral bypass contactor for power control. An SCR will conduct current in one direction only when a control signal (gate signal) is applied. Because solid-state starters use alternating current (AC), two SCRs per phase are connected in parallel, opposing each other so that current may flow in both directions. For three-phase loads, a full six-SCR configuration is used, as shown in Figure 12.

Figure 12. Six-SCR arrangement

Starting sequence

During starting, control of current or acceleration time is achieved by gating the SCRs “on” at different times within the half-cycle. The gate pulses are originally applied late in the half-cycle and then gradually applied sooner in the half-cycle. If the gate pulse is applied late in the cycle, only a small increment of the wave form is passed through, and the output is low. If the gate pulse is applied sooner in the cycle, a greater increment of the wave form is passed through, and the output is increased. By controlling the SCRs’ output voltage, the motor’s acceleration characteristic and current inrush are controlled as illustrated in Figure 13.

Figure 13. Starting sequence wave forms

When the SCRs are fully “phased on,” the integral bypass contactors are energized. The current flow is transferred from the power pole to the contactors. This reduces the energy loss associated with the power pole, and extends contactor life. When the starter is given the stop command, the SCRs are gated “full voltage” and the bypass contactor is de-energized. The current flow is transferred from the contactors back to the power poles. Less than one second later, the SCRs are turned off and the current flow stops.
Features

- Unit- and floor-mounted models are available
- 115 volt control-power transformer
- Starting current is factory set and field adjustable
- Starting torque is factory set and adjustable via a voltage “notch” setting
- Six-SCR power section
- Air-cooled design with bypass contactor eliminates need for a water-cooling circuit, pump, and heat exchanger
- Bypass contactor rated to carry 100% of the full-load motor phase current
- Protection from shorted SCRs and high starter heatsink temperature
- Protection from transient voltage through resistor-capacitor (RC) snubbers across SCRs and metal oxide varistors (MOVs)
- Padlock tab for additional locking of starter door
- Line-side connection terminal block/main lug only
- UL and CUL certified

Dimensions

Typical dimensions for unit- or remote-mounted solid-state starters are shown in Figure 14. Always consult the submittal drawings for as-built dimensions.

Figure 14. Solid-state dimensions
Environmental specification

- Designed, developed, and tested in accordance with UL 508
- NEMA 1A enclosure as standard
- Operation from sea level to 6,000 ft (1,829 m)
- Operating ambient temperature range 32°F to 104°F (0°C to 40°C)
  - Relative humidity, non-condensing 5% to 95%
- Non-operating ambient temperature range -40°F to 158°F (-40°C to 70°C)
- Voltage utilization range ±10%
Low Voltage—Unit-Mounted Adaptive Frequency Drive

The Trane® Adaptive Frequency Drive is a refrigerant-cooled, microprocessor controlled design. The AFD is used in lieu of a constant-speed starter and is currently available for use with 460 or 480 volts only. Adaptive Frequency is a trademarked term for the Trane® variable-speed drive, using proprietary control logic and made to Trane specifications.

About the Trane AFD

The AFD is unit-mounted and ships completely assembled, wired, and tested from the factory. The AFD controller is designed to interface with the chiller controller. It adapts to the operating ranges and specific characteristics of the chiller. The optimum chiller efficiency is created by coordinating the compressor-motor speed with the compressor inlet guide vanes. The chiller controller and the AFD controller work together to maintain the chilled-water setpoint and avoid surge. If surge is detected, the chiller controller’s surge-avoidance logic in the chiller controller makes the proper adjustments to move the operating point away from surge.

How it works

The frequency drive regulates output voltage in proportion to output frequency to maintain ideal motor flux and constant torque-producing capability. Or put simply, a variable-speed drive controls load-side frequency and voltage to adjust the compressor motor speed. The AFD is a voltage-source, pulse-width modulated (PWM) design. It consists of three primary power sections as shown in Figure 16: the active rectifier, the DC bus, and the inverter.

Figure 16. AFD power sections

Rectifier (active). Takes incoming AC power, filters it with an LCL filter (not shown), and then converts it to a fixed DC voltage. The insulated-gate bipolar transistor (IGBT) active rectifier significantly reduces the amount of line-side harmonic levels and the amount of ripple on the DC bus. The active rectifier also has some traditional post-generation filtering capabilities to further smooth out remaining line-side harmonics.

DC bus. Capacitors store the DC power provided by the rectifier until it is needed by the inverter.

Inverter. Converts the DC voltage into a synthesized AC output voltage. This synthesized output controls both the voltage and the frequency. The synthesized output waveform consists of a series of pulses, hence the “pulse” in PWM.

Starting sequence

Trane® AFDs are programmed to start the compressor motor using low frequency and low voltage, thereby minimizing the inrush current. The motor is then brought up to speed by gradually increasing both frequency and voltage at the same time. Thus, current and torque are much lower during startup and motor acceleration than the high current, high torque associated with across-the-line or even reduced-voltage starters; refer to the inrush current vs. time graph (Figure 5, p. 16).
The AFD is rated by output current and is limited to a maximum of 100-percent continuous RLA (rated-load amps) by the Trane® chiller unit controller. A 100-percent output current capability results in 100-percent torque generated by the motor.

Features
The standard design features for the AFD include:

- NEMA 1, ventilated enclosure with a hinged door, tested to a short-circuit rating of 65,000 amps.
- Padlock-able, door-mounted circuit breaker/shunt trip with an AIC rating of 65,000 amps.
- SCR/AIC rating of 100,000 amps available as a design special.
- UL/CUL listed as a package.
- Simple, modular construction.
- 480/60/3 input power ±10 percent, with drive overload capability of 100 percent continuous to 150 percent for five seconds.

Note: For voltages other than 460/480 V, a transformer is currently needed to produce 460/480 V.

- Motor thermal overload protection 102 percent continuous, 108 percent for 60 seconds, 140 percent for 1.5 seconds.
- Minimum efficiency of 97 percent at rated load and 60 hertz.
- Soft-start, controlled acceleration, coast-to-stop.
- Adjustable frequency from 38 to 60 hertz.
- Control circuit voltages physically and electrically isolated from power circuit voltage.
- 150 percent instantaneous torque available for improved surge control.
- Output line-to-line and line-to-ground short-circuit protection.
- Ground fault protection (UL listed).
Environmental specification

- 32°F to 104°F (0°C to 40°C) operating ambient temperature.
- Altitude to 3,300 feet (1,000 m), amperage derate of 1 percent per every 300 feet above 3,300 feet.
- Humidity, 95 percent non-condensing.

Dimensions

Typical dimensions for the unit-mounted Adaptive Frequency Drive are shown in Figure 18 and Figure 19. Always consult the submittal drawings for as-built dimensions.

Motor-AFD mutual protection

The chiller unit-controller capabilities allow the control/configuration interface to, and the retrieval/display of AFD-related data. AFD standard design features controlled through the Tracer AdaptiView™ include:

- Current limited to 100 percent.
- Motor overload protection.
- Motor over-temperature protection.
- Phase loss, phase reversal, and phase imbalance protection.
- Undervoltage and overvoltage protection.
- Output speed reference via IPC3 communication bus from the chiller controller to the AFD.

Digital data display

The following points are digitally displayed at the chiller controller:

- Output speed in hertz
- Output speed in rpm
- Input line voltage
- Input line kW, load-side amps
- Average output current in percent RLA
- Load-side power factor
- AFD transistor temperature
- Fault

Harmonics

Harmonics has become a frequently used term in the power quality arena. Of all the power quality issues encountered today, harmonics is the least understood and most feared; unfortunately, this has resulted in overstating the impact of harmonics.
Low-Voltage Starter Types

Harmonics is not a “thing” but a way to define current or voltage distortion on a power line. Harmonics can be directly linked to nonlinear loading of a power system. Nonlinear loads are created by devices connected to a given power system that draw current from the power source with a waveform that is not a pure sine wave.

All nonlinear loads, including variable-frequency drives, will create current and voltage distortion. Typically harmonics is not an insurmountable issue when applying an AFD on a centrifugal chiller.

**Harmonic attenuation**

Harmonic attenuation is standard on the unit-mounted refrigerant-cooled AFDs and includes:

- Integrated active rectification control of the building AC power assures low line-generated harmonics back to the user’s power grid. This results in less than 5 percent current harmonic distortion (TDD) as measured at the AFD.
- Active input rectifier will regulate to a displacement power factor of 0.98 or better at full load and a value of 0.96 at part load.
- Full motor voltage is applied regardless of the input voltage.

*Note:* TDD is a direct affect of variable-frequency drives and is a larger and more critical value than the amount of total harmonic distortion (THD). As measured at the AFD, the amount of THD will be less than the TDD.

**IEEE 519**

It is important to recognize that IEEE 519 relates to the entire system, not specifically to any one load or product. IEEE 519 establishes requirements at the point of common coupling (PCC) where the building connects to the utility system. The standard contains no specific requirements for the internal electrical loads.

Even though Trane® AFD-equipped chillers will attenuate their own harmonics, other nonlinear loads on the same system could still create harmonic problems. In buildings where harmonics might be a concern, Trane recommends conducting a power-distribution system analysis to determine if there is a need to further attenuate harmonics at the system level.

**Low Voltage—Remote-Mounted Adaptive Frequency Drive**

Depending on the application, Trane also offers a remote free standing Adaptive Frequency Drive (AFD). The remote AFD comes as a complete, free-standing package that includes the necessary controls, control power and programming needed for operation. Each Trane Adaptive frequency drive arrives completely programmed with all chiller control communication logic installed. Input voltage options include 460, 480, 575, and 600 volts. Most of the low-voltage AFDs in the industry are designed to work at 460/480 volts only. In HVAC applications were the voltage is 575/600, a transformer would be need to apply an AFD. With the Trane remote AFD, a transformer would not be needed, thereby eliminating the associated extra design time, space requirements, installation costs and energy losses.

**The design**

The remote AFD design is a voltage-source, pulse-width modulated (PWM) type. It consists of three primary power sections.

**Rectifier.** Constructed of silicon controlled rectifiers (SCR), which convert the incoming utility AC sine wave into DC voltage that will be stored in the DC Bus section.

**DC Bus Section.** A capacitor bank that is used to store energy for use within the inverter section.

**Inverter IGBTs.** Use the pulse width modulation (PWM) method to convert the DC voltage from the capacitor bank into a synthesized output AC voltage that controls both the voltage and frequency applied to the motor.
Features
The standard design features for the AFD include:
- Free standing NEMA 1, ventilated enclosure with a hinged door, tested to a short-circuit rating of 65,000 amps. Enclosure locking provisions are standard.
- Lockable, door-mounted circuit breaker/shunt trip with an AIC rating of 65,000.
- Amps, and enclosure short circuit rating of 65,000 amps standard.
- UL/CUL listed as a package.
- Simple, front access only design.
- 460/480/60/3 input power ±10 percent.
- 575/600/60/3 input power ±10 percent.
- Minimum efficiency of 97 percent at rated load and 60 hertz.
- Displacement power factor at 0.96 at all loads.
- Soft-start, linear acceleration, coast-to-stop.
- Adjustable frequency from 38 to 60 hertz.
- 150 percent instantaneous torque available for improved surge control.
- Output line-to-line and line-to-ground short-circuit protection.
- Ground fault protection (UL listed).

Optional Items
- NEMA 12 enclosure.
- 100,000 amp enclosure short circuit rating (SCR) with 100,000 amp AIC circuit breaker available as a design special.

Environmental specification
- Operating temperature: 32°F to 104°F (0°C to 40°C).
- Storage temperature: -4°F to 149°F (-20°C to 65°C).
Low-Voltage Starter Types

- Humidity: 95 percent non-condensing.
- Maximum elevation: 3280 ft (1000 m) rated output current.
- Derate 4 percent/3280 ft over rated altitudes up to 9840 ft (3000 m).

**Dimensions**

Table 6 provides some basic reference dimensions and weights for the remote AFD. Always refer and use the Trane submittals for actual dimensions.

**Table 6. Remote AFD dimensions**

<table>
<thead>
<tr>
<th>Frame</th>
<th>460 Vac</th>
<th>575 Vac</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Power (hp)</td>
<td>Max. Amps</td>
</tr>
<tr>
<td>E2</td>
<td>450–600</td>
<td>649</td>
</tr>
<tr>
<td></td>
<td>N/A</td>
<td>N/A</td>
</tr>
<tr>
<td>F3</td>
<td>650–750</td>
<td>791</td>
</tr>
<tr>
<td></td>
<td>950–1050</td>
<td>1031</td>
</tr>
<tr>
<td>F4</td>
<td>1150–1350</td>
<td>1360</td>
</tr>
</tbody>
</table>

**Digital data display**

The following points are digitally displayed at the chiller controller:
- Frequency command
- Input line voltage
- Load-side amps

**Harmonics**

The remote AFD is a standard six pulse design. Therefore the harmonic level is ~35 percent total demand distortion TDD as measured at the AFD input. If lower levels of attenuation are required, upstream filtering would be required.
Medium-Voltage Starter Types (2,300–6,600 Volts)

Table 7 shows the most common medium-voltage starter types available and compares inrush current, torque, frequency of use, advantages and disadvantages, and typical acceleration time. The inrush profiles are shown in Figure 21.

Which starter type is best?

One question often asked is: “Which is better, full voltage or reduced voltage?” Because medium-voltage starters by nature use less current than low voltage, and therefore have significantly less current inrush. Across-the-line medium-voltage starters are more commonly used; however, in certain applications reduced voltage will be used to minimize starting strain on the electrical system.

Table 7. Comparison of medium-voltage starters (2,300–6,600 volts)

<table>
<thead>
<tr>
<th>Starter Type (closed-transition)</th>
<th>Inrush Current % LRA</th>
<th>Percent Rated Torque</th>
<th>How Often Used</th>
<th>Advantages</th>
<th>Disadvantages</th>
<th>Typical Acceleration Time (seconds)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Across-the-Line (Full Voltage)</td>
<td>100</td>
<td>100</td>
<td>27%</td>
<td></td>
<td></td>
<td>3–5</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>• Low cost</td>
<td>• Draws highest inrush current at startup</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>• Least complex</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Primary Reactor 65% TAP</td>
<td>65</td>
<td>42</td>
<td>49%</td>
<td></td>
<td>More expensive than Across-the-Line</td>
<td>5–12</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>• Good compromise between first cost and inrush current reduction</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>• Least maintenance</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Autotransformer 65% TAP</td>
<td>45</td>
<td>42</td>
<td>22%</td>
<td></td>
<td>Most expensive</td>
<td>5–12</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>• Almost equal reduction of torque and inrush current</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>• Lowest inrush current</td>
<td></td>
<td></td>
</tr>
<tr>
<td>AFD (&lt;13 (&lt;RLA))</td>
<td>Varies</td>
<td>2%</td>
<td></td>
<td></td>
<td>Very expensive</td>
<td>5–12</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>• Efficiency at part lift</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>• Power factor</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Large and heavy</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Complex</td>
<td></td>
</tr>
</tbody>
</table>

Figure 21. Comparison of medium-voltage starting current

Unit- or remote-mounted?

Unit-mounted medium-voltage starters can save on installed cost and space. They are tested in the factory and are shipped on the chiller. Remote-mounted starters are sometimes bussed together in various configurations as shown in “Multiple Starter Lineups (2,300–6,600 volts),” p. 60. Remote-mounted starters from Trane can have special NEMA options, whereas unit-mounted starters are NEMA 1A. All starters conform to ANSI/NEMA ICS-6 enclosure standards unless otherwise noted.
Other options for remote-mounted starters are available in the Industrial Package (see “Industrial-Grade Starters,” p. 62.)

**NEC 2005 changes for medium-voltage (2,300–6,600 volt) wire**

NEC code for 2005 requires that medium-voltage cable is shielded. This affects the power wire selection and connection provisions to the chiller, and between the chiller and starter when it is remote mounted. When you use shielded cable, you must also use stress cones at the termination points (motor terminal connection, remote starter, or unit-mounted starter connection). Stress cones are composed of electrical shielding wrap and are typically 9–12 inches in length. Stress cones are used to confine the dielectric field and reduce electrical stresses at the termination point. Trane® unit-mounted medium-voltage starters now ship with a field-installed accessory “top hat” that is shown in our as-built submittal drawings. The top hat is enclosed in the starter cabinet during shipment and then reversed for field installation. Motor terminal boxes and remote-mounted starters are designed to accommodate stress cones without an additional enclosure. Refer to the appropriate submittals drawings to verify that the starter has sufficient connection space for your requirements. For more information regarding the top hat, refer to “Unit-Mounted Starter Top Hat—NEC 2005 Code Requirement,” p. 38.

**Medium Voltage—Across-the-Line (2.3–6.6 kV)**

**Across-the-Line Starter (2,300–6,600 volts)**

Figure 22, p. 31 shows a schematic for the most basic starter type; the across-the-line (X-Line) starter, which is also known as a full-voltage starter. To illustrate a typical starting sequence using a generic (non-Trane) schematic, refer to Figure 22, p. 31 and the starting sequence below.

**Starting sequence**

1. A “start” signal from the chiller controller energizes the pilot relay (PR).
2. The PR contacts close to energize the start/run contactor (1M).
3. The 1M contacts close to connect the compressor motor directly to the line.
Medium-Voltage Starter Types (2,300–6,600 Volts)

Standard features

- 4 kVA control-power transformer
- Primary and secondary current transformers (CTs)
- Potential transformers (PTs)
Medium-Voltage Starter Types (2,300–6,600 Volts)

- Grounding provisions
- Bolted line-power connections
- Bolted load-side connections for remote starters
- Standard motor protection

**Environmental specification**
- Designed, developed, and tested in accordance with UL 347
- NEMA 1A enclosure as standard
- Operation from sea level to 6,000 ft (1,829 m)
- Operating ambient temperature range 32°F to 104°F (0°C to 40°C)
  - Relative humidity, non-condensing 5 percent to 95 percent
- Non-operating ambient temperature range -40°F to 158°F (-40°C to 70°C)
- Voltage utilization range ±10 percent

**Dimensions**
Typical dimensions for unit- and remote-mounted across-the-line starters are shown in Figure 23, p. 31 and Figure 24, p. 32. Always consult the submittal drawings for as-built dimensions.

**Figure 24. Remote-mounted XL**
One of the most common starters in the industry is the primary reactor. To illustrate a typical starting sequence using a generic (non-Trane) schematic, refer to Figure 26, p. 34 and the starting sequence below.

**Starting sequence**

1. A “start” signal from the chiller controller energizes the pilot relay (PR).
2. The PR contacts close to energize the start contactor (1M).
3. The 1M contacts close to connect the compressor motor to the line with the motor in series with the reactor.
4. A time delay or current monitoring device initiates transition by energizing the run contactor (2M).
5. The 2M contacts close to bypass the reactor and connect the compressor motor directly to the line.

Figure 26. Simplified primary reactor wiring diagram

Standard features
- 4 kVA control-power transformer
- Primary and secondary current transformers (CTs)
- Potential transformers (PTs)
- Grounding provisions
- Bolted line-power connections
- Bolted load-side connections for remote starters
- Standard motor protection

Environmental specification
- Designed, developed, and tested in accordance with UL 347
- NEMA 1A enclosure as standard
- Operation from sea level to 6,000 ft (1,829 m)
- Operating ambient temperature range 32°F to 104°F (0°C to 40°C)
  - Relative humidity, non-condensing 5% to 95%
- Non-operating ambient temperature range -40°F to 158°F (-40°C to 70°C)
- Voltage utilization range ±10%

Dimensions
Typical dimensions for remote-mounted primary reactor starters are shown in Figure 27, p. 35. Unit-mounted primary reactor starter dimensions are shown in Figure 28, p. 35. Always consult the submittal drawings for as-built dimensions.
Figure 27. Remote-mounted, reduced-voltage starter dimensions

Figure 28. Reduced-voltage, unit-mounted starter dimensions
Medium-Voltage Starter Types (2,300–6,600 Volts)

Another medium-voltage starter type is the autotransformer. To illustrate a typical starting sequence using a generic (non-Trane) schematic, refer to Figure 30, p. 37 and the starting sequence below.

Starting sequence
1. A “start” signal from the chiller controller energizes the pilot relay (PR).
2. The pilot relay contacts close to energize the shorting contactor (S).
3. The S contacts close to complete the autotransformer circuit.
4. An S interlock closes to energize the start contactor (1M).
5. The 1M contacts close to connect the compressor motor to the line with the motor in series with the autotransformer.
6. A time-delay relay or current-monitoring device initiates transition by energizing the transition relay (T).
7. The T contacts open to de-energize the S contactor.
8. The S contacts open to open the autotransformer circuit.
9. The autotransformer is now connected as a series reactor with the motor.
10. Now, a second T interlock and a second S interlock both close to energize the run contactor (2M).
11. The 2M contacts close to bypass the transformer and connect the compressor motor directly to the line.

Figure 30. Simplified autotransformer wiring diagram

Standard features
- 4 kVA control-power transformer
- Primary and secondary current transformers (CTs)
- Potential transformers (PTs)
- Grounding provisions
- Bolted line-power connections
- Bolted load-side connections for remote starters
- Standard motor protection

Environmental specification
- Designed, developed, and tested in accordance with UL 347
- NEMA 1A enclosure as standard
- Operation from sea level to 6,000 ft (1,829 m)
- Operating ambient temperature range 32°F to 104°F (0°C to 40°C)
  - Relative humidity, non-condensing 5% to 95%
- Non-operating ambient temperature range -40°F to 158°F (-40°C to 70°C)
- Voltage utilization range ±10%
Medium-Voltage Starter Types (2,300–6,600 Volts)

Dimensions

Typical dimensions for both unit-mounted and remote-mounted autotransformer starters are the same as the primary reactor starters shown in Figure 27, p. 35 and Figure 28, p. 35. A chiller with a unit-mounted autotransformer starter is pictured in Figure 29, p. 36. Always consult the submittal drawings for as-built dimensions.

Solid state medium voltage starters

If you look at the medium-voltage chiller industry, there are three primary electro-mechanical starter types commonly used: 1) Full Voltage (X-Line), 2) Primary Reactor, and 3) AutoTransformer. Of these, X-Line and Primary Reactor make up a majority of the business. The balance is in AutoTransformer and some solid state. Cost increases as you move from X-Line to AutoTransformer, as does the relative complexity, and size. These starters are considered simple to begin with in comparison to solid state starters; however, we always want to use the simplest design if the performance (inrush level) meets the requirements of the application. This is why the X-Line type is often used at this voltage, because the amps are generally low to begin with based on the voltage class (i.e., 4160 volts). Trane has shipped thousands of chillers and starters with these electromechanical starter types. We know of no better way to offer the highest reliability, lowest inrush, and still meet the 30-year life expectancy.

Over the years solid state starters have been available, however when the pros and cons are evaluated, a traditional electro-mechanical is typically the best choice. Many claim that the solid state is a “soft starter.” What does this really mean? For most, this means a ramped inrush profile with no transients; however, because we are dealing with large induction motors, the ramp-up is quick to enable the required torque. We think you need to look at the inrush magnitude, and when you review the starter types, the primary reactor is very comparable to a solid state. However, the cost of the primary reactor is typically less, it is simpler, more reliable, does not have harmonic aspects to consider, and is easier to service and maintain. In the end, the decision is up to the customer.

Unit-Mounted Starter Top Hat—NEC 2005 Code Requirement

As outlined in “Unit-Mounted Starter Top Hat—NEC 2005 Code Requirement,” p. 38, NEC 2005 code requirements specify the use of shielded cables and stress cones for medium-voltage wiring. For Trane® unit-mounted medium-voltage starters (and “SMP, Supplemental Motor Protection—Medium voltage only (INDP option),” p. 65) a supplementary enclosure, or top hat, is shipped in the starter cabinet in order to fully enclose the incoming wire and stress cones terminated at the starter. The top hat is shipped inverted in the starter cabinet to avoid damage and must be properly configured in the field. The unit-mounted top hat is shown in Figure 31, p. 39.
Figure 31. Top Hat placement for shipment and installation

Sheet Metal “Top Hat” Section
(allows space for shielded cable/stress cones—field provided)

Stowed for Shipment

Installed for Stress Cones
Medium Voltage—Remote-Mounted Adaptive Frequency Drive

The Trane® AFD is a remote-mounted air-cooled, microprocessor based pulse width modulation PWM design. The AFD use a “direct to drive” design that connects the power supply directly to the medium voltage drive without the use of an isolation transformer. The AFD is a current source inverter that uses Symmetrical Gate Commutated Thyristors (SGCTs) power semiconductor switches in both the rectifier and inverter sections. The active front end rectifier and common mode choke blocks any common mode voltages, smooths the DC current, and mitigates the motor neutral to ground voltage. Because there is no negligible common mode voltages and currents, no special compressor bearing provisions are required. The design does not generate dv/dt or reflected wave voltage that can stress the motors. As a result, standard duty medium voltage motors can be used with the AFD.

The AFD includes a line starter contactor and current limiting power fuses and a lockable non-load break isolation switch as standard. The fuses are installed via fuse clips and can be replaced without special tools. An integral common mode choke with iron core eliminates the need for semiconductor fuses which reduce nuisance trips. The AFD ships as a single, free-standing enclosure (with a small exception of small top hat sections), wired, and tested to the job site.

Figure 32. Front view, medium voltage remote-mounted AFD

Remote AFD Design Features

- NEMA 1 ventilated, gasketed enclosure with hinged doors.
- Design access from the front only. The patented PowerCage inverter and rectifier module allows easy access to main power components without the use of special hardware. Power switch components are replaceable without removal of the entire power module.
- Paint—All exterior metal parts are painted with hybrid epoxy powder paint ANSI 49 medium grey. The low voltage section is color coded black for safety.
- The entire package is UL/CUL listed.

Other AFD features include:
- Simple modular design.
- Compact, light weight design.
- Designed for minimum availability of 99.9 percent.
- Typical Mean time between failure is 180,000 hours.
- Minimum predicted life expectancy is 20 years.
- The AFD is rated for the nominal chiller voltage ±10 percent.
- Displacement power factor is 0.96 at all loads.
- Efficiency is 97.7 percent at rated load, 60 Hz.
- Soft-start; linear acceleration; coast to stop.
Medium-Voltage Starter Types (2,300–6,600 Volts)

- All control circuit voltages are physically and electrically isolated from the power circuit voltage.
- 110 percent instantaneous torque available for improved surge control.
- Output line-to-line and line-to-ground short circuit protection.
- Input protection via surge arrestors.
- Kirk key for interlocking the system which prevents unsafe access to doors.
- General AFD protection—The AFD includes a comprehensive set of protection features segmented into the following three categories: 1) Line side level, 2) System level, and 3) Load side level. For more information, refer to the Installation, Operation, and Maintenance manual.
- Near sinusoidal voltage and current waveforms to the motor at all speeds and loads. Output current THD is less than 5 percent.
- The control power monitoring system monitors all power.
- Power switch device diagnostics detect and protect against device short, over or under gate voltage loss, of gating, loss of diagnostic feedback, heat sink temperature feedback as well as overload monitoring and protection.
- The drive system shall provide controlled speed over the range from 38 to 60 Hz.
- The AFD has a “normal duty” rating of 100 percent continuous current with a short time duty rating of 110 percent overload for one minute, once every 10 minutes.

Chiller Unit Control Features for the AFD

The chiller unit control panel capabilities provide for the control/configuration interface to—and the retrieval/display of—AFD-related data. AFD standard design features controlled through Tracer AdaptiView include:
- Current limited to 100 percent at start, no inrush, true soft start
- Motor overload protection
- AFD over temperature protection
- Phase loss, phase reversal, and phase imbalance protection
- Overvoltage and undervoltage protection

Digitally-displayed AFD parameters on the AdaptiView panel: output speed in hertz, output speed in rpm, input line voltage, input line kw, output/load amps, average current in % RLA, load power factor, fault, AFD temperature

In addition, on the AFD enclosure there is a 16-line, 40-character LCD display that can be utilized by operators as needed. It includes a full comprehensive list of AFD performance parameters. refer to the Installation, Operation, and Maintenance manual and the AFD manufacturer’s documentation.

The AFD is designed for top entry line power and top or bottom load power exit. The power cable connections are bolted type. Lugs are not provided. Use copper conductors only for terminal connections. Failure to do so may cause corrosion or overheating, and AFD damage.

Environmental Ratings
- -40°F (-40°C) to 158°F (70°C) storage ambient temperature range.
- 32°F (0°C) to 104°F (40°C) operating ambient temperature range.
- Altitude to 3280 ft (1000 m), amperage derate output current above rated altitude up to 9840 ft (3000 m).
- Humidity, 95 percent non-condensing.

Design Notes
The AFD should be located within 150 ft of the chiller. If this distance must be exceeded due to application requirements, contact your local Trane representative.

The AFD is designed for a maximum operating temperature of 104°F. However, optimal operation and design life will be experienced if the ambient temperatures are kept well below this maximum.
The maximum AFD heat rejection is listed on the AFD submittal drawing in this package. Additional equipment room cooling provisions may be required.

For all remote medium voltage AFDs, note that 4 kVA at 120 volt control power must be provided to the chiller control panel, and this is customer supplied. Refer to the wiring diagrams in this submittal package.

On some larger Frame B AFDs, note that the AFD itself requires a separate 8 kVA at 480 volt power supply. This is in addition to the main power supply voltage.

**Installation Notes**

The AFD ships as a single enclosure, except for some “top hat” enclosures. These top hat sections must be field installed. Refer to the AFD drawings for more information.

It is suggested that the AFD be placed on a housekeeping pad; anchoring the AFD to the ground is not a manufacturer’s requirement. Consult local codes.

Refer to the AFD installation, operation, and maintenance manual, AFDJ-SVU01A-EN (*Installation, Operation, and Maintenance: Remote-Mounted Medium Voltage Air-Cooled Adaptive Frequency Drive with Tracer AdaptiView Control*), or the most recent revision, for more detailed information on AFD installation, operation and maintenance requirements.

**Dimensions**

See the specific submittals for the application. In general, for the the 4160 volt class, the geometry is as follows for the two frame sizes:

**A Frame.** RLA from 61–140 amps nominal at 4160 V
94” wide X 40” deep X 105” high

**B Frame.** RLA from 160–250 amps nominal at 4160 V
182” wide X 40” deep X 105” high

**Digital data display**

The following points are digitally displayed at the chiller controller:

- Output speed in hertz
- Output speed in rpm
- Input line voltage
- Input line kw, load side amps
- Average output current in % RLA
- Load side power factor
- AFD temperature
- Fault

**Harmonics**

- Harmonic currents on the line side—Harmonics are minimized through the use of a common mode choke and active rectifier. The AFD will meet a current harmonic distortion level of 5 percent or less in total demand distortion TDD as measured at the input to the AFD.
Medium-Voltage Starter Types (10,000–13,800 Volts)

Table 7, p. 29, shows the available medium-voltage starter types for 10,000–13,800 volts. These are identical in nature to their 2,300–6,600-volt counterparts in terms of inrush current, starting torque, and their inherent advantages/disadvantages. Enclosure sizes are larger due to incoming line provisions, internal components, and electrical shielding. These starters are available in remote-mounted options only due to electrical restrictions associated with these higher voltages.

Note: UL certification of these starters is not available due to AC voltage ranges exceeding 7,200 volts as specified in UL Standard 347. This includes all chiller starter manufacturers selling 10–13.8 kV refrigeration equipment. Low-voltage sections of the starters are UL rated as applicable.

Which starter type is best?

In terms of starting torque and inrush current, these starters share the same advantages and disadvantages similar to the 2,300–6,600-volt starters. The major difference for 10–13.8 kV starters is the increased floor space required. If PFCCs are required, the dimensions will further increase because the capacitors require their own separate enclosure. All starters are NEMA 1A rated as standard and conform to ANSI/NEMA ICS-6 enclosure standards unless otherwise noted.

Medium Voltage—Across-the-Line (10–13.8 kV)

Across-the-Line Starter (10,000–13,800 volts)

Starting sequence

Refer to the across-the-line starting sequence (“Starting sequence,” p. 30).

Standard features

- 4 kVA control-power transformer
- Primary and secondary current transformers (CTs)
- Potential transformers (PTs)
- Grounding provisions
- Bolted line-power connections
- Bolted load-side connections for remote starters
- Standard motor protection

Dimensions

Typical dimensions for a remote-mounted across-the-line starter are shown in Figure 33, p. 44. PFCCs, if required, are housed in a 36 inch wide auxiliary cabinet (not shown). Always consult the submittal drawings for as-built dimensions.

Environmental specification

- Designed, developed and tested in accordance with IEC 60470, 62271-200
- NEMA 1A enclosure as standard
- Operation from sea level to 6,000 ft (1,829 m)
- Operating ambient temperature range 32°F to 104°F (0°C to 40°C)
  - Relative humidity, non-condensing 5 percent to 95 percent
- Non-operating ambient temperature range -40°F to 158°F (-40°C to 70°C)
- Voltage utilization range ±10 percent
Medium-Voltage Starter Types (10,000–13,800 Volts)

Figure 33. Remote-mounted, across-the-line dimensions

Figure 34. Remote-mounted, 11-kV, across-the-line starter

1. Current-limiting power fuses
2. Isolation switch (provision for one lock)
3. Control-power transformer
4. Vacuum contactors
Medium Voltage—Primary Reactor (10–13.8 kV)

Primary Reactor Starter (10,000–13,800 volts)

Starting sequence
1. Refer to the primary reactor starting sequence (“Starting sequence,” p. 33).

Standard features
- 4 kVA control-power transformer
- Primary and secondary current transformers (CTs)
- Potential transformers (PTs)
- Grounding provisions
- Bolted line-power connections
- Bolted load-side connections for remote starters
- Standard motor protection

Dimensions
Typical dimensions for remote-mounted primary reactor starters are shown in Figure 35, p. 46. PFCCs, if required, are housed in a 36-inch wide auxiliary cabinet (not shown). Always consult the submittal drawings for as-built dimensions.

Environmental specification
- Designed, developed and tested in accordance with IEC 60470, 62271-200
- NEMA 1A enclosure as standard
- Operation from sea level to 6,000 ft (1,829 m)
- Operating ambient temperature range 32°F to 104°F (0°C to 40°C)
  - Relative humidity, non-condensing 5 percent to 95 percent
- Non-operating ambient temperature range -40°F to 158°F (-40°C to 70°C)
- Voltage utilization range ±10 percent
Medium Voltage—Autotransformer (10–13.8 kV)

Autotransformer Starter (10,000–13,800 volts)

Starting sequence
Refer to the autotransformer starting sequence (“Starting sequence,” p. 36).

Standard features
- 4 kVA control-power transformer
- Primary and secondary current transformers (CTs)
- Potential transformers (PTs)
- Grounding provisions
- Bolted line-power connections
- Bolted load-side connections for remote starters
- Standard motor protection

Dimensions
Typical dimensions for remote-mounted autotransformer starters are shown in Figure 36, p. 47. PFCCs, if required, are housed in a 36-inch wide auxiliary cabinet (not shown). Always consult the submittal drawings for as-built dimensions.

Environmental specification
- Designed, developed and tested in accordance with IEC 60470, 62271-200
Medium-Voltage Starter Types (10,000–13,800 Volts)

- NEMA 1A enclosure as standard
- Operation from sea level to 6,000 ft (1,829 m)
- Operating ambient temperature range 32°F to 104°F (0°C to 40°C)
  - Relative humidity, non-condensing 5 percent to 95 percent
- Non-operating ambient temperature range -40°F to 158°F (-40°C to 70°C)
- Voltage utilization range ±10 percent

Figure 36. Remote-mounted, autotransformer dimensions
**Electrical System—Ratings**

“Normal” and “overload” conditions ... “fault current” ... “interrupt” versus “short-circuit” ratings” ... “current-limiting.” Knowing what these terms mean and applying them correctly are fundamental to designing safe, reliable electrical distribution systems. This is especially true in light of more stringent code enforcement and the current design trend to deliver energy savings by selecting low-impedance transformers: How does this influence safety? Lower transformer impedances result in higher short-circuit currents.

Simply choosing a circuit breaker with a high-interrupt rating won’t assure adequate protection under short-circuit conditions. An “ounce of prevention” helps avoid the code official’s “red tag” at the next system startup. The following section reviews the meaning of terms, defines some of the issues related specifically to HVAC motor starter applications, and identifies practical effective solutions.

**Normal operation**

“Normal operation” describes the full-load (or rated) conditions of each system component. For motors, it includes the amps initially drawn at startup, i.e. inrush current, as well as the full- or rated-load amps drawn while running. The magnitude of inrush current for a particular application depends on the motor, voltage, and type of starter used.

Normal operating conditions determine wire and transformer sizing. They are also used in conjunction with “fault conditions” to select overcurrent protection devices such as circuit breakers and fuses. Rating factors are applied, based on the type and number of connected loads, to assure that the devices selected adequately protect the motor as it starts and while it is running.

The size of the interconnecting wires between the transformer and starter reflects the type and rated amperage draw of the load, i.e. the chiller motor. Sizing the wires on this basis assures that they can carry the inrush current at startup without overheating.

**Available Fault Current (AFC)**

Refer to Figure 38, p. 51, for the reference points or label locations of each rating. AFC is the calculated potential short-circuit current at a point just upstream of the starter. It is calculated by the electrical engineer and is a function of the electrical distribution system—including the transformers.

Imagine a wrench inadvertently left in a starter after servicing. Touching two power phases, it completes the circuit between them when the panel is energized. This results in a potentially dangerous situation, or “fault condition,” caused by the low-impedance phase-to-phase or phase-to-ground connection ... a “short circuit”

Fault current, also called “short-circuit current” (I_{sc}), describes the amount of current flow during a short. It passes through all components in the affected circuit. Fault current is generally very large and, therefore, hazardous. Only the combined impedance of the object responsible for the short, the wiring, and the transformer limits the fault current.

One objective of electrical distribution system design is to minimize the effect of a fault, i.e. its extent and duration, on the uninterrupted part of the system. Coordinating the sizes of circuit breakers and fuses assures that these devices isolate only the affected circuits. Put simply, it prevents a short at one location from shutting down power to the entire building.

Calculating the magnitude of short-circuit current is a prerequisite to selecting the appropriate breakers and fuses. If the distance between the transformer and starter is short, the calculation can be simplified by ignoring the impedance of the interconnecting wiring...a simplification that errs on the side of safety. One can also assume that the source of the fault has zero impedance, i.e. a “bolted” short. Given these assumptions, only the transformer impedance remains. (Impedance upstream of the transformer is usually negligible.)

Suppose a 1,500-kVA, 480-volt transformer has impedance of 5.75 percent. With this value, use the equation below to determine how much fault current a short circuit will produce. The resulting I_{sc} shows that a short would force the wiring to carry more than 30,000 amps when it was designed to handle only 400 amps!
Short-circuit current is often two orders of magnitude greater than normal operating current. Unless a circuit breaker or fuse successfully interrupts the fault, this enormous amperage rapidly heats components to very high temperatures that destroy insulation, melt metal, start fires ... even cause an explosion if arcing occurs or components disintegrate. The inherent likelihood of severe equipment and property damage, as well as the risk of personal injury or death, underscores the importance of sufficient electrical-distribution system protection.

Ampere-Interrupt Current (AIC)
Determined under standard conditions, the “interrupt rating” specifies the maximum amount of current a protective device can cut off safely ... i.e. without harm to personnel or resulting damage to equipment, the premises or the device itself. For example, a circuit breaker that trips “safely” successfully interrupts the fault, can be reset, and will function properly afterward.

A common misconception is, “An overcurrent protection device with a comparatively high-interrupt rating limits current to other components.” Not so, not unless it is also a true current-limiting device. Even though the device successfully breaks the circuit, all components in the circuit will be exposed to the full magnitude of fault current (as well as the severe thermal and magnetic stresses that accompany it) for the small amount time it takes the device to respond.

Short-Circuit Rating (SCR)
Sometimes referred to as the short-circuit withstand rating (SCWR), the short-circuit rating is probably the most critical rating for short-circuit protection that the electrical engineer must obtain from the starter supplier. The entire assembled starter enclosure has an SCR.

The short-circuit rating is the maximum fault current that the starter withstood during testing by Underwriters Laboratories, Inc. UL 508 defines the short-circuit test methods and parameters for HVAC equipment, and therefore the SCR is mainly a low-voltage issue. Essentially, the test simulates an actual fault current in the starter enclosure, e.g. 50,000 amps. If the doors blow open or if the starter emits debris, the enclosure fails the test. For those that pass, it is “acceptable,” and even probable, that the internal components will be damaged beyond repair. Given the destructiveness and expense of this test, it is not surprising that most manufacturers prefer not to pursue higher-than-normal short-circuit ratings for their equipment unless there is a documented need.

Recall that when a fault occurs, all components in the circuit experience the brunt of the short circuit until it is interrupted. Therefore, it is important to assure that all components “at risk” can withstand a fault condition without causing personal injury or damaging the surroundings. The National Electric Code (NEC) states this requirement in Section 110.10, “Circuit Impedance and Other Characteristics”:

The overcurrent protective devices, the total impedance, the component short-circuit [withstand] ratings, and other characteristics of the protected circuit shall be selected and coordinated to permit the used circuit protective devices to clear a fault without extensive damage to the circuit’s electrical components. This fault is assumed to be either between two or more of the circuit conductors, or between any circuit conductor and the grounding conductor or enclosing metal raceway. Listed products applied in accordance with their listing shall be considered to meet the requirements of this section.

Commentary in the 1996 National Electrical Code™ Handbook further explains Section 110.10:
Overcurrent protective devices (such as fuses and circuit breakers) should be selected to ensure that the short-circuit withstand rating of the system components will not be exceeded should a short circuit or high-level ground fault occur.
System components include wire, bus structures, switching, protection and disconnect devices, distribution equipment, etc., all of which have limited short-circuit ratings and would be damaged or destroyed if these short-circuit ratings are exceeded. Merely providing overcurrent protective devices with sufficient interrupting ratings will not ensure adequate short-circuit protection for the system components. When the available short-circuit current exceeds the withstand rating of an electrical component, the overcurrent protective device must limit the let-through energy to within the rating of that electrical component.

To comply with this section of NEC without additional current-limiting devices, most chiller-motor configurations will require a short-circuit rating well above UL’s standard ratings.

**Let-Through Current (LTC)**

This is the fault current that passes through the circuit breaker before the circuit breaker trip element has time to respond, typically equal to or less than the available fault current and lasting three-quarter of an electrical cycle.

**Current limiting**

All components and wiring in an electrical distribution system offer some degree of resistance. Under normal conditions, the heat produced when current flows against this resistance readily dissipates to the surroundings; however, the enormous current generated during a short circuit produces damaging heat at a much faster rate than can be safely dissipated. Interrupt the current and you stop adding heat to the system. As Figure 37 suggests, time is a critical determinant of the amount of heat (energy) added. An electrical short that lasts three cycles, for example, adds six times the energy of an electrical short lasting just one-half cycle. It is in this sense that all circuit breakers and fuses “limit” current.

Figure 37 also shows the effect of a current-limiting device. To be truly current limiting, the interrupting device must open the circuit within one-quarter cycle (1/240 second), i.e. before the fault current peaks.

**Figure 37. Illustration of short-circuit current**
Electrical System—Design Guidelines

There are three functions that electrical engineers must address when designing electrical systems that include chiller motors and the associated starters:

1. Means of disconnect
2. Means for short circuit interruption
3. Making sure that the starter enclosure has an adequate short-circuit rating for the available fault current (low voltage) or properly sized fuses (medium voltage)

Disconnect Means

Low-voltage disconnect

Low-voltage starters from Trane do not have a disconnect means as standard. The standard line power connection is a terminal block (i.e., main lug only) connection. An optional non-fused disconnect switch, in a molded case as shown in Figure 39, can be installed. These non-fused disconnect switches typically have locking provisions to allow the switch to be locked open; often with up to three different padlocks.

Figure 39. Non-fused disconnect

A non-fused disconnect switch is used when servicing the chiller to protect someone from personal injury, and it can also be used as a load-break switch in an emergency. Since the disconnect switch
is a non-fused device, current limiting protection must be installed upstream of the chiller by others.

**Medium-voltage disconnect**

All medium-voltage starters have an isolation switch as standard. This switch is a non-load-break switch that is not designed to be opened under load, i.e. while the chiller is operating. All medium-voltage starters have a mechanical interlock to prevent opening the isolation switch while the main contactor is closed and the compressor is running.

In order to open the medium-voltage compartment door, the compressor must be turned off before the isolation switch can be opened. Then the isolation switch stabs can be separated from the medium-voltage bus. Baffles slide over the stab slots and the medium-voltage bus is completely isolated behind shielding panels. Now the medium-voltage compartment door can be opened safely. After servicing, the medium-voltage compartment door must be secured before the isolation switch can be closed.

![Figure 40. Isolation switch](image1)

If there is a requirement to be able to open the circuit while under load, a load-break disconnect switch may be furnished as a special option on medium-voltage starters. The load-break switch is mounted in an additional section of the starter-cabinet assembly. See Figures Figure 40 and Figure 41 for a comparison of the two options. A switch spring is loaded, or “charged,” as the handle is moved. When spring pressure is sufficient, a device releases the switch mechanism. The spring loading provides a rapid, positive opening and closing of the contacts.

**Note:** Medium-voltage circuit breakers are not available through Trane.
Short-Circuit Interruption

**Low-voltage short circuit interruption**

When a circuit breaker is specified, it serves both as the short-circuit interrupt protector and the disconnect switch. Unlike the non-fused disconnect, a circuit breaker does have an interrupting rating. Because a circuit breaker is constructed to safely interrupt the high level of current caused by a short circuit (fault current), it may be opened safely at any time. A low-voltage starter door may be opened only if the circuit breaker is in the “off” or open position.

Circuit breakers of various interrupt ratings are offered as options. The interrupting capacity of a circuit breaker must also be considered. An analysis of an installation is usually done by the electrical engineer to calculate the maximum available fault current (AFC) that could be delivered if a short circuit occurred.

When a low-voltage starter is ordered with a circuit breaker, the starter manufacturer furnishes a standard circuit breaker sized at approximately 125 percent of compressor RLA or larger. The trip current of a circuit breaker is adjustable so that it will not trip during starting and acceleration, but will trip instantaneously (typically within 1 cycle) if a short circuit occurs.

**Short-Circuit Rating (SCR)**

The disconnect means and the short-circuit protection discussed above are either supplied and installed by the customer upstream of the starter or they can be supplied as options with the Trane® starter. However, the starter’s SCR must be communicated to the electrical engineer early in the project to ensure that the starter short-circuit rating will meet the requirements. If the SCR is not high enough, the electrical engineer will have to look for solutions upstream of the starter.

Each low-voltage Trane® starter or frequency drive has a short-circuit rating, based on the size of the starter as well as the type of disconnect or circuit breaker included. See the appropriate submittal drawings for the starter short-circuit rating.

*Note:* Don’t confuse short-circuit rating (SCR) with silicone controlled rectifier (SCR)—utilized in solid-state starters and AFDs.

**Medium-voltage short circuit interruption**

All medium-voltage starters contain current-limiting fuses for short circuit protection. The current-limiting fuses and isolation switch, which is furnished as standard, fulfill the request for a fused disconnect. If you need more detail on the fuses for a particular starter contact CenTraVac Field Sales Support.

It turns out that the starter short-circuit rating is not an issue with medium-voltage starters. Because Trane® medium-voltage starters meet UL 347, current-limiting power fuses are required and provided as standard, and the starter short-circuit rating no longer applies. Medium-voltage starters from Trane have an interrupt rating based on the standard current-limiting fuses. At 4,160 volts, the NEMA E2 fused-interrupt rating is 50,000 amperes or 400 MVA.

**Medium voltage fuse coordination suggestions**

Proper sizing of fuses and circuit breakers upstream of the starter is the responsibility of the customer or the electrical engineer.

**Power Circuit Requirements**

**Starter Applications**

When applying a starter to a chiller motor on a specified power circuit, the power circuit has to meet minimum criteria to allow for a successful chiller start without an immediate shutdown or safety trip. This applies to utility power, local or smaller-scale facility power, and backup or peak-shaving generator power.

The following are some considerations for motor starter power quality requirements:
- Size of the power circuit
When evaluating a power system for a chiller-compressor motor with a specified starter type, calculations must be done in order to size or “correct” the power circuit properly in order to successfully start the motor and keep the motor-starter combination online during operation. Table 9 and Table 10, p. 54 show specific starter characteristics and minimum power requirements.

Table 9. Sizing requirements

<table>
<thead>
<tr>
<th>Starter Type</th>
<th>Voltage Range</th>
<th>Inrush Current % LRA</th>
<th>Maximum Acceleration Time (sec)</th>
<th>Percent Rated Torque</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wye-Delta</td>
<td>208–600 V</td>
<td>33</td>
<td>27</td>
<td>33</td>
</tr>
<tr>
<td>Solid-State</td>
<td>208–600 V</td>
<td>~45</td>
<td>27</td>
<td>33</td>
</tr>
<tr>
<td>X-Line</td>
<td>2.3–13.8 kV</td>
<td>100</td>
<td>6</td>
<td>100</td>
</tr>
<tr>
<td>Primary Reactor</td>
<td>2.3–13.8 kV</td>
<td>65</td>
<td>16</td>
<td>42</td>
</tr>
<tr>
<td>Autotransformer</td>
<td>2.3–13.8 kV</td>
<td>45</td>
<td>16</td>
<td>42</td>
</tr>
<tr>
<td>AFD</td>
<td>460–600 V</td>
<td>&lt;13</td>
<td>12</td>
<td>Varies</td>
</tr>
</tbody>
</table>

Table 10. Motor starter operational voltage range—during a start

<table>
<thead>
<tr>
<th>Starter Size</th>
<th>Starter Description</th>
<th>Maximum Line-to-Line RMS Voltage Sag</th>
<th>Maximum Line-to-Line RMS Voltage Swell</th>
</tr>
</thead>
<tbody>
<tr>
<td>155–606 amps</td>
<td>Unit- and Remote-Mounted Wye-Delta</td>
<td>25%</td>
<td>15%</td>
</tr>
<tr>
<td>607–1,316 amps</td>
<td>Unit-Mounted Wye-Delta</td>
<td>25%</td>
<td>15%</td>
</tr>
<tr>
<td>607–1,856 amps</td>
<td>Remote-Mounted Wye-Delta</td>
<td>20%</td>
<td>15%</td>
</tr>
<tr>
<td>185–1,472 amps</td>
<td>Unit- and Remote-Mounted Solid-State</td>
<td>25%</td>
<td>15%</td>
</tr>
<tr>
<td>180–960 amps</td>
<td>Remote-Mounted, High-Fault Solid-State</td>
<td>25%</td>
<td>15%</td>
</tr>
<tr>
<td>961–1,600 amps</td>
<td>Remote-Mounted, High-Fault Wye-Delta</td>
<td>25%</td>
<td>15%</td>
</tr>
<tr>
<td>155–1530 amps</td>
<td>Unit- and Remote-Mounted Low Voltage AFD (460–600 V)</td>
<td>25%</td>
<td>10%</td>
</tr>
<tr>
<td>94, 187, 205/288 amps (205 reduced voltage, 288 full voltage)</td>
<td>Unit-Mounted Medium Voltage (2.3–6.6 kV)</td>
<td>25% (20% w/additional protection)</td>
<td>15%</td>
</tr>
<tr>
<td>94, 187, 360 amps</td>
<td>Remote-Mounted Medium Voltage (2.3–6.6 kV)</td>
<td>25% (20% w/additional protection)</td>
<td>15%</td>
</tr>
<tr>
<td>94 amps</td>
<td>Remote-Mounted Medium Voltage (10–13.8 kV)</td>
<td>25% (20% w/additional protection)</td>
<td>15%</td>
</tr>
<tr>
<td>61–250 amps @ 4,160 V</td>
<td>Remote Medium-Voltage AFD</td>
<td>25%</td>
<td>10%</td>
</tr>
</tbody>
</table>

Note: The maximum allowable under/overvoltage during normal operation is ±10 percent.
Electrical System–Power Wire Sizing

This section provides guidance for the sizing of electrical power leads to the starter, and the leads from the starter to the compressor motor for Trane® CenTraVac water chillers. This guide is not a design manual and does not supersede local code requirements or National Electric Code (NEC) recommendations. Wire size and count should be coordinated with the starter selection so the starter can be ordered with the proper terminal lugs. The starter is shipped with standard lugs as shown on the as-built submittals. Alternate lugs are often available and can be purchased locally. Standard lugs accept a wide range of wire sizes but not all possible combinations.

General rules

- When more than one lead per phase is used, the leads must be of the same size and length so that they share the load equally.
- When two or more conduits are used, each phase must be equally represented in each conduit to avoid overheating.

Specific to the starter supply leads

Line-side wiring to the starter must be copper. A discussion of why aluminum should not be used can be found in the glossary (“Aluminum conductors,” p. 72).

Supply leads to all starters must be in multiples of three.

Supply leads listed in the following tables are only applicable to the inside-the-delta solid-state starter designs offered for CenTraVac chillers shipped since June 1999.

Specific to the motor leads

All wiring to the CenTRAVac motor must be copper.

Power leads to motors used with across-the-line, autotransformer, or primary reactor starters must be in multiples of three.

Power leads to motors used with star-delta or inside-the-delta solid-state starters must be in multiples of six.

Flexible conduit is required for motor leads on remote starters for the last three feet.

Sizing conductors

Wire size is typically determined using the National Electric Code. Various factors are involved in selecting the proper wire. These include amperage draw of the load, type of load, voltage, temperature rating of the wire, and number of conductors within a conduit. In addition, the wires connecting the motor to the starter may need to be sized differently than the wires that connect the starter to the distribution system.

To simplify the wire selection for CenTraVac chillers, the above factors have all been incorporated into the following tables. These table ampacities were derived from conductor ampacity as listed in the 2002 National Electric Code (Tables 310-16 and 310-73). The user simply enters the appropriate table, knowing the RLA of the chiller and the table provides the minimum wire size for several conduit combinations. All safety factors and derating factors are already considered.

A word of caution: Wire is typically sized based on rated-load amperage (RLA) as defined in the terminology section and stamped on the nameplate of the unit. In some rare cases, electrical inspectors demand that the wire be sized based on full-load amperage (FLA) of the motor. Sizing the wiring to RLA is sufficient because the current overload protection on the chiller limits the amperage draw to the RLA during operation. However, if the local jurisdiction requires sizing based on FLA, it is often simpler and less expensive to size to the FLA than to obtain a variance.

Good circuit design will involve checking the voltage drop of the distribution circuit. The NEC does not require this step, but does suggest that 3% voltage drop on a branch circuit feeder and 5% overall will provide “reasonable efficiency of operation.”
Example
Assume a 460-volt chiller drawing 300 RLA with a remote-mounted wye-delta starter. If 75°C conductors are used, the supply leads to the starter and the motor leads from the starter could be:

Supply leads to starter (Table 11, p. 57)
- 1 conduit containing three 500 MCM conductors
- 1 conduit containing six 250 MCM conductors
- 2 conduits containing three 3/0 conductors each, and so on

Motor leads from starter (Table 12, p. 57)
- 1 conduit containing six 300 MCM conductors
- 2 conduits containing three 4/0 conductors each
- 2 conduits containing six 1/0 conductors each, and so on

The following wire sizing tables (Table 11, p. 57 through Table 16, p. 59) may be used for selecting conductor and conduit combinations that will support the ampere draw requirements of CenTraVac chillers. Wire sizes are given in units of AWG (American wire gauge) and MCM (thousands of circular mils, or KCmil).
**Electrical System—Power Wire Sizing**

**Note:** Use Table 11 to size supply leads for all starters and motor leads for remote-mounted Across-the-Line, Primary Reactor, Autotransformer, and Adaptive Frequency Drives.

### Table 11. 0 to 2,000 volts, 75°C conductor temperature rating, 2002 NEC Table 310-16

<table>
<thead>
<tr>
<th>Wire Size 75°C Copper</th>
<th>Maximum Rated-Load Amps (Nameplate)</th>
<th>1 Conduit 3 Wires</th>
<th>1 Conduit 6 Wires</th>
<th>2 Conduits 3 Wires Ea.</th>
<th>2 Conduits 6 Wires Ea.</th>
<th>2 Conduits 3 Wires Ea. 6 Wires Ea.</th>
<th>3 Conduits 3 Wires Ea.</th>
<th>3 Conduits 6 Wires Ea.</th>
<th>4 Conduits 3 Wires Ea.</th>
<th>4 Conduits 6 Wires Ea.</th>
<th>5 Conduits 3 Wires Ea.</th>
<th>5 Conduits 6 Wires Ea.</th>
<th>6 Conduits 3 Wires Ea.</th>
<th>6 Conduits 6 Wires Ea.</th>
</tr>
</thead>
<tbody>
<tr>
<td>8</td>
<td>40</td>
<td>52</td>
<td>68</td>
<td>80</td>
<td>92</td>
<td>104</td>
<td>120</td>
<td></td>
<td>140</td>
<td>160</td>
<td>184</td>
<td>204</td>
<td>228</td>
<td>248</td>
</tr>
<tr>
<td>6</td>
<td>192</td>
<td>240</td>
<td>360</td>
<td>480</td>
<td>512</td>
<td>600</td>
<td>720</td>
<td></td>
<td>840</td>
<td>960</td>
<td>1104</td>
<td>1224</td>
<td>1368</td>
<td>1488</td>
</tr>
<tr>
<td>4</td>
<td>360</td>
<td>360</td>
<td>512</td>
<td>640</td>
<td>736</td>
<td>920</td>
<td>1104</td>
<td></td>
<td>1240</td>
<td>1340</td>
<td>1520</td>
<td>1824</td>
<td>1608</td>
<td>1824</td>
</tr>
<tr>
<td>3</td>
<td>512</td>
<td>512</td>
<td>640</td>
<td>800</td>
<td>1020</td>
<td>1240</td>
<td>1488</td>
<td></td>
<td>1608</td>
<td>1824</td>
<td>2016</td>
<td>2424</td>
<td>2424</td>
<td>2424</td>
</tr>
<tr>
<td>2</td>
<td>512</td>
<td>512</td>
<td>640</td>
<td>800</td>
<td>1020</td>
<td>1240</td>
<td>1488</td>
<td></td>
<td>1608</td>
<td>1824</td>
<td>2016</td>
<td>2424</td>
<td>2424</td>
<td>2424</td>
</tr>
<tr>
<td>1</td>
<td>512</td>
<td>512</td>
<td>640</td>
<td>800</td>
<td>1020</td>
<td>1240</td>
<td>1488</td>
<td></td>
<td>1608</td>
<td>1824</td>
<td>2016</td>
<td>2424</td>
<td>2424</td>
<td>2424</td>
</tr>
<tr>
<td>0</td>
<td>512</td>
<td>512</td>
<td>640</td>
<td>800</td>
<td>1020</td>
<td>1240</td>
<td>1488</td>
<td></td>
<td>1608</td>
<td>1824</td>
<td>2016</td>
<td>2424</td>
<td>2424</td>
<td>2424</td>
</tr>
<tr>
<td>00</td>
<td>512</td>
<td>512</td>
<td>640</td>
<td>800</td>
<td>1020</td>
<td>1240</td>
<td>1488</td>
<td></td>
<td>1608</td>
<td>1824</td>
<td>2016</td>
<td>2424</td>
<td>2424</td>
<td>2424</td>
</tr>
<tr>
<td>000</td>
<td>512</td>
<td>512</td>
<td>640</td>
<td>800</td>
<td>1020</td>
<td>1240</td>
<td>1488</td>
<td></td>
<td>1608</td>
<td>1824</td>
<td>2016</td>
<td>2424</td>
<td>2424</td>
<td>2424</td>
</tr>
<tr>
<td>0000</td>
<td>512</td>
<td>512</td>
<td>640</td>
<td>800</td>
<td>1020</td>
<td>1240</td>
<td>1488</td>
<td></td>
<td>1608</td>
<td>1824</td>
<td>2016</td>
<td>2424</td>
<td>2424</td>
<td>2424</td>
</tr>
<tr>
<td>250</td>
<td>512</td>
<td>512</td>
<td>640</td>
<td>800</td>
<td>1020</td>
<td>1240</td>
<td>1488</td>
<td></td>
<td>1608</td>
<td>1824</td>
<td>2016</td>
<td>2424</td>
<td>2424</td>
<td>2424</td>
</tr>
<tr>
<td>300</td>
<td>512</td>
<td>512</td>
<td>640</td>
<td>800</td>
<td>1020</td>
<td>1240</td>
<td>1488</td>
<td></td>
<td>1608</td>
<td>1824</td>
<td>2016</td>
<td>2424</td>
<td>2424</td>
<td>2424</td>
</tr>
<tr>
<td>350</td>
<td>512</td>
<td>512</td>
<td>640</td>
<td>800</td>
<td>1020</td>
<td>1240</td>
<td>1488</td>
<td></td>
<td>1608</td>
<td>1824</td>
<td>2016</td>
<td>2424</td>
<td>2424</td>
<td>2424</td>
</tr>
<tr>
<td>400</td>
<td>512</td>
<td>512</td>
<td>640</td>
<td>800</td>
<td>1020</td>
<td>1240</td>
<td>1488</td>
<td></td>
<td>1608</td>
<td>1824</td>
<td>2016</td>
<td>2424</td>
<td>2424</td>
<td>2424</td>
</tr>
<tr>
<td>500</td>
<td>512</td>
<td>512</td>
<td>640</td>
<td>800</td>
<td>1020</td>
<td>1240</td>
<td>1488</td>
<td></td>
<td>1608</td>
<td>1824</td>
<td>2016</td>
<td>2424</td>
<td>2424</td>
<td>2424</td>
</tr>
<tr>
<td>600</td>
<td>512</td>
<td>512</td>
<td>640</td>
<td>800</td>
<td>1020</td>
<td>1240</td>
<td>1488</td>
<td></td>
<td>1608</td>
<td>1824</td>
<td>2016</td>
<td>2424</td>
<td>2424</td>
<td>2424</td>
</tr>
</tbody>
</table>

**Note:** Use Table 12 to size motor leads from remote-mounted Wye-Delta and Solid-State starters (inside-the-delta designs only).

### Table 12. 0 to 2,000 volts, 75°C conductor temperature rating, 2002 NEC Table 310-16

<table>
<thead>
<tr>
<th>Wire Size 75°C Copper</th>
<th>Maximum Rated-Load Amps (Nameplate)</th>
<th>1 Conduit 6 Wires</th>
<th>2 Conduits 3 Wires Ea.</th>
<th>2 Conduits 6 Wires Ea.</th>
<th>2 Conduits 3 Wires Ea. 6 Wires Ea.</th>
<th>3 Conduits 3 Wires Ea.</th>
<th>3 Conduits 6 Wires Ea.</th>
<th>4 Conduits 3 Wires Ea.</th>
<th>4 Conduits 6 Wires Ea.</th>
<th>5 Conduits 3 Wires Ea.</th>
<th>5 Conduits 6 Wires Ea.</th>
<th>6 Conduits 3 Wires Ea.</th>
<th>6 Conduits 6 Wires Ea.</th>
</tr>
</thead>
<tbody>
<tr>
<td>8</td>
<td>55</td>
<td>69</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>72</td>
<td>90</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>94</td>
<td>117</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>100</td>
<td>138</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>127</td>
<td>159</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>143</td>
<td>179</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>0</td>
<td>166</td>
<td>207</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>00</td>
<td>193</td>
<td>242</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>000</td>
<td>221</td>
<td>276</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>0000</td>
<td>254</td>
<td>318</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>250</td>
<td>282</td>
<td>352</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>300</td>
<td>315</td>
<td>394</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>350</td>
<td>343</td>
<td>429</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>400</td>
<td>370</td>
<td>463</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>500</td>
<td>420</td>
<td>525</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>600</td>
<td>465</td>
<td>581</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Note:** Conductors to the starter and motor that are connected in parallel (electrically joined at both ends to form a single conductor) must be size #0 or larger (NEC 310-4). Each phase must be equally represented in each conduit.
**Electrical System–Power Wire Sizing**

**Note:** Use Table 13 to size supply leads for all starters and motor leads for remote-mounted Across-the-Line, Primary Reactor, Autotransformer, and Adaptive Frequency Drives.

Table 13. 0 to 2,000 volts, 90°C conductor temperature rating, 2002 NEC Table 310-16

<table>
<thead>
<tr>
<th>Wire Size 90°C Copper</th>
<th>Maximum Rated-Load Amps (Nameplate) 1 Conduit 1 Conduit 2 Conduits 3 Conduits 2 Conduits 4 Conduits 5 Conduits 6 Conduits 3 Wires 3 Wires Ea. 3 Wires Ea. 6 Wires Ea. 6 Wires Ea. 6 Wires Ea. 6 Wires Ea.</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>8</td>
<td>44</td>
<td>—</td>
</tr>
<tr>
<td>6</td>
<td>60</td>
<td>—</td>
</tr>
<tr>
<td>4</td>
<td>76</td>
<td>—</td>
</tr>
<tr>
<td>3</td>
<td>88</td>
<td>—</td>
</tr>
<tr>
<td>2</td>
<td>104</td>
<td>—</td>
</tr>
<tr>
<td>1</td>
<td>120</td>
<td>—</td>
</tr>
<tr>
<td>0</td>
<td>136</td>
<td>217</td>
</tr>
<tr>
<td>00</td>
<td>156</td>
<td>249</td>
</tr>
<tr>
<td>000</td>
<td>180</td>
<td>288</td>
</tr>
<tr>
<td>0000</td>
<td>208</td>
<td>332</td>
</tr>
<tr>
<td>250</td>
<td>232</td>
<td>371</td>
</tr>
<tr>
<td>300</td>
<td>256</td>
<td>409</td>
</tr>
<tr>
<td>350</td>
<td>280</td>
<td>448</td>
</tr>
<tr>
<td>400</td>
<td>304</td>
<td>486</td>
</tr>
<tr>
<td>500</td>
<td>344</td>
<td>550</td>
</tr>
<tr>
<td>600</td>
<td>380</td>
<td>608</td>
</tr>
</tbody>
</table>

**Note:** Use Table 14 to size motor leads from remote-mounted Wye-Delta and Solid-State starters (inside-the-delta designs only).

Table 14. 0 to 2,000 volts, 90°C conductor temperature rating, 2002 NEC Table 310-16

<table>
<thead>
<tr>
<th>Wire Size 90°C Copper</th>
<th>Maximum Rated-Load Amps (Nameplate) 1 Conduit 2 Conduits 2 Conduits 4 Conduits 3 Conduits 6 Conduits 6 Wires Ea. 6 Wires Ea. 3 Wires Ea.</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>8</td>
<td>60</td>
<td>—</td>
</tr>
<tr>
<td>6</td>
<td>82</td>
<td>75</td>
</tr>
<tr>
<td>4</td>
<td>104</td>
<td>131</td>
</tr>
<tr>
<td>3</td>
<td>121</td>
<td>151</td>
</tr>
<tr>
<td>2</td>
<td>143</td>
<td>179</td>
</tr>
<tr>
<td>1</td>
<td>165</td>
<td>206</td>
</tr>
<tr>
<td>0</td>
<td>187</td>
<td>234</td>
</tr>
<tr>
<td>00</td>
<td>215</td>
<td>268</td>
</tr>
<tr>
<td>000</td>
<td>248</td>
<td>310</td>
</tr>
<tr>
<td>0000</td>
<td>286</td>
<td>358</td>
</tr>
<tr>
<td>250</td>
<td>320</td>
<td>400</td>
</tr>
<tr>
<td>300</td>
<td>353</td>
<td>441</td>
</tr>
<tr>
<td>350</td>
<td>386</td>
<td>482</td>
</tr>
<tr>
<td>400</td>
<td>419</td>
<td>524</td>
</tr>
<tr>
<td>500</td>
<td>474</td>
<td>593</td>
</tr>
<tr>
<td>600</td>
<td>524</td>
<td>655</td>
</tr>
</tbody>
</table>

**Note:** Conduits to the starter and motor that are connected in parallel (electrically joined at both ends to form a single conductor) must be size #0 or larger (NEC 310-4). Each phase must be equally represented in each conduit.
Electrical System–Power Wire Sizing

**Note:** Use Table 15 to size line-side wiring to the starter and load-side wiring between the starter and the motor.

**Table 15.** 2,001 to 5,000 volts, 90°C conductor temperature rating, 2002 NEC Table 310-73

<table>
<thead>
<tr>
<th>Wire Size 90°C Copper</th>
<th>Maximum Rated-Load Amps (Nameplate)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1 Conduit 3 Wires</td>
</tr>
<tr>
<td>8</td>
<td>44</td>
</tr>
<tr>
<td>6</td>
<td>60</td>
</tr>
<tr>
<td>4</td>
<td>77</td>
</tr>
<tr>
<td>2</td>
<td>104</td>
</tr>
<tr>
<td>1</td>
<td>124</td>
</tr>
<tr>
<td>0</td>
<td>144</td>
</tr>
<tr>
<td>00</td>
<td>164</td>
</tr>
<tr>
<td>000</td>
<td>192</td>
</tr>
<tr>
<td>0000</td>
<td>224</td>
</tr>
<tr>
<td>250</td>
<td>252</td>
</tr>
<tr>
<td>350</td>
<td>308</td>
</tr>
<tr>
<td>500</td>
<td>380</td>
</tr>
</tbody>
</table>

**Note:** Use Table 16 to size line-side wiring to the starter and load-side wiring between the starter and the motor.

**Table 16.** 5,001 to 6,600 volts, 90°C conductor temperature rating, 2002 NEC Table 310-73

<table>
<thead>
<tr>
<th>Wire Size 90°C Copper</th>
<th>Maximum Rated-Load Amps (Nameplate)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1 Conduit 3 Wires</td>
</tr>
<tr>
<td>6</td>
<td>66</td>
</tr>
<tr>
<td>4</td>
<td>88</td>
</tr>
<tr>
<td>2</td>
<td>120</td>
</tr>
<tr>
<td>1</td>
<td>136</td>
</tr>
<tr>
<td>0</td>
<td>156</td>
</tr>
<tr>
<td>00</td>
<td>180</td>
</tr>
<tr>
<td>000</td>
<td>208</td>
</tr>
<tr>
<td>0000</td>
<td>236</td>
</tr>
<tr>
<td>250</td>
<td>264</td>
</tr>
<tr>
<td>350</td>
<td>316</td>
</tr>
<tr>
<td>500</td>
<td>384</td>
</tr>
</tbody>
</table>

**Note:** Conductors to the starter and motor that are connected in parallel (electrically joined at both ends to form a single conductor) must be size #0 or larger (NEC 310-4). Each phase must be equally represented in each conduit.
Starter Options

Starter Options
Customers often look for methods to reduce the installed cost and space requirements associated with electrical equipment. In addition, they may have specific electrical distribution requirements and the starters must have the flexibility to address these needs.

Configured options
There are many starter options available for low- and medium-voltage starters. These include, but are not limited to:
- Power factor correction capacitors (208 through 4,160 volts, 60 Hz)
- Digital meters
- Surge protection/lightning arrestors
- Ground fault protection
- Industrial package

These options are directly selectable in the order configuration system. The next section will explain several of them in greater detail.

Design specials
There are also many design-special starter options that can be offered by contacting CenTraVac Field Sales Support. These include but are not limited to:
- Power factor correction capacitors (all 50 Hz, and 60 Hz from 4,800 to 6,600 volts)
- NEMA 12, NEMA 3R, or NEMA 4 enclosures, remote starters only
- Wattmeter
- Watt-hour meter, add for demand register and pulse initiator
- Watt transducer
- Current transducer
- Voltage transducer
- MP 3000 motor protection package
- Communications cards for meters/motor protection packages
- IQ Analyzer motor protection/metering package
- Emergency stop button
- Extra control relays
- Main bus sections including ground bus (typically for medium voltage)
- Load-break switch (medium voltage only), formerly referred to as an ADM (AMPGARD Disconnect) switch

Multiple Starter Lineups (2,300–6,600 volts)

Side-by-side starters
Several design special options are available with remote-mounted medium-voltage starters. These reduce the installed cost and space requirements associated with the electrical equipment or to comply with special electrical distribution requirements.

Figure 42, p. 61 shows two across-the-line starters “bussed” together. This option has a single line power feed for the starter “line-up.” Additional starters can be added to the lineup as long as each starter has the top-mounted main bus section. Each starter has its own load wires that will run out to the chillers.
Bottom-entry line power

Figure 43, p. 62 shows the same concept as above; however, it uses what is called an auxiliary section that allows the customer to bring wires in from the bottom to power the main bus.
Multiple starter lineups for 10–13.8 kV starters
Side-by-side starter lineups are available for 10–13.8 kV starters. Contact CenTraVac Field Sales Support for dimensions and availability.

Industrial-Grade Starters
High-fault starters can be selected independently of the INDP option.

High-fault, remote, solid-state starters (IHRS)
- NEMA 12 ≤ 960 amps
- Flanged disconnect
- 100,000 amps short-circuit rating
- SAE HS-1738
- Up to 600 volts

High-fault, remote, wye-delta starters (HRWD)
- NEMA 1A, 961 to 1,600 amps
- Non-flanged disconnect
- 100,000 amps short-circuit rating
- Up to 480 volts

Medium-voltage remote starters (2,300–6,600 volts)
- Across-the-line, primary reactor, and autotransformer
- NEMA 12 option
- SAE HS-1738 option
- Flanged disconnect
### Industrial Package (INDP)

Applications that require the utmost reliability and rugged construction may prompt the selection of the Industrial Package (INDP). INDP-equipped CenTraVac chillers are constructed to NEMA 4 guidelines and feature completely enclosed wiring in seal-tight conduits and junction boxes. The INDP control panel also includes some additional installation features and layout improvements. The purge is also upgraded to NEMA 4 construction. The entire chiller is silicone-friendly—all silicone is encapsulated and non-volatile so it does not affect any industrial and/or chemical processes.

**Figure 44. CenTraVac with Industrial Package (AdaptiView unit controller)**

*Note: Unit shown with optional, unit-mounted control power transformer (below motor terminal box).*

These and other features listed in the following section allow the CenTraVac to meet or exceed the rigorous criteria of the Society of Automotive Engineers “Standard for Electrical Equipment for
Starter Options

Automotive Industrial Machinery, 2002 Edition™ (SAE HS-1738). HS-1738 provides requirements and recommendations relating to the electrical equipment of machines so as to promote:

- safety of persons and property
- consistency of control response
- ease of maintenance

**Industrial Purge**

- NEMA 4 construction
  - Seal-tight conduits
  - Sealed motor terminal box
  - Totally Enclosed Fan Cooled (TEFC) pumpout motor

**Industrial Control Panel**

- NEMA 4 construction
  - accessory port circuit breaker
  - screw-type terminal block connections
  - welded seam construction

**Industrial Chiller Enhancements**

- SAE HS-1738
- Warning markings
- Phenolic (permanent) labels on control devices
- Silicone-friendly to industrial processes—all utilized silicone is encapsulated and non-volatile
- Polycarbonate junction boxes listed NEMA 4X
Enhanced Protection (EPRO)

The INDP package includes the EPRO package, which includes sensors and transducers that enable the following chiller protection features:

**Enhanced condenser-limit control.** Factory-installed condenser-pressure transducer with interconnecting piping and wiring provides enhanced high-pressure cutout avoidance by energizing a relay to initiate head relief.

*Note: This protection is in addition to the standard high refrigerant-pressure safety contact.*

**Compressor-discharge refrigerant temperature protection.** Factory-installed sensor and safety cutout on high compressor-discharge temperature allows Tracer AdaptiView to monitor compressor discharge temperature and display the temperature at the chiller controller and at Tracer Summit™.

**Bearing oil temperatures.** Factory-installed sensors allow high-temperature safety cutouts to monitor the leaving bearing oil temperatures and display the temperatures at the chiller controller and at Tracer Summit.

The high bearing-temperature cutout is fixed at 180°F (82.2°C). If either bearing temperature violates the cutout, a latching (manual reset) diagnostic is generated.

INDP Options

In addition to the above standard elements, customers who purchase the Industrial Package have additional options. These options can be applied to remote-mounted medium-voltage starters, both from Trane and from other starter manufacturers.

**CPTR, Control-Power Transformer (INDP option).** 4 kVA control-power transformer mounted on the chiller (480 to 115 volts)
- Flanged disconnect
- Fused primary and secondary power
- Secondary fuse status indicator (blown or not-blown)
- UL 508 Type 12 construction
- Unit mounted and factory wired

**SMP, Supplemental Motor Protection—Medium voltage only (INDP option).** A separate enclosure mounted to the motor includes:
- Surge capacitors
- Lightning arrestors
- Zero-sequence ground fault

Other features:
- UL 347 tested Type 12 construction
- Field-accessible terminal block for trouble-shooting via panel
• Unit-mounted and factory-wired

When the SMP option is selected, the medium voltage starter must be remote.

*Note:* Additional "top hat" provisions may need to be field-supplied to allow for shielded cable with stress cones (field-provided).

**DMP, Differential Motor Protection (selectable with the SMP option).** DMP replaces the zero-sequence ground fault protection. Instead, it uses a flux-summation, self-compensating differential protection scheme for a quicker and more precise removal of line power during a fault (see “Differential motor protection,” p. 74).

*Note:* DMP is available only for 1062 kW and larger motor sizes up to 5,000 volts.

**Figure 45. Supplemental motor protection enclosure with DMP option**

1. Lightning arrestors
2. Surge capacitors
3. SEPAM module (*Square D Electrical Protection and Metering*)

**Implications of INDP and SMP option on customer-supplied starters (SBO).** Most of the accommodations that would need to be met by the customer who wishes to use a non-Trane starter are provided with the INDP package and the SMP option.

*Note:* Trane-supplied starters already include these items.

The supplemental motor-protection enclosure will include:
- Primary, single-stage current transformer in lieu of primary and secondary CTs

The oversized control panel will include:
- Second-stage PTs, 115 to 30 volts, for medium-voltage applications only
- Three-pole disconnect
- Industrial terminal block for field control and control-power connections
The customer is still responsible for providing primary potential transformers for medium voltage.

**Criteria for the INDP option.** The industrial package may be selected for CenTraVac chillers that meet the following criteria:

- Single compressor (no Duplex)
- 60 Hz only
- 080, 142, 210, and 250 shells in all short, long, and extended combinations
- Motor frame sizes 440E, 5000, 5800, and 5800L, which correspond to approximate chiller capacities from 450 to 2,000 tons
- NEMA 1 unit-mounted starters can be accommodated. Contact CenTraVac Field Sales Support for details.

*Note:* Placing a unit-mounted starter on an INDP equipped chiller negates the chiller’s NEMA 4 rating and changes it back to a standard NEMA 1 rating.

**Industrial paint.** Trane offers a two component, catalyzed, executive beige high-solids epoxy coating paint system to meet or exceed the performance of the US Department of Defense (USDOD) military specification MIL-PRF-22750F. This paint has a volatile organic compound (VOC) content less than 2.8 lb/gal (335.6 g/L). It offers protection and resistance to fluids, adhesives, solvents, heat, and weather. We recommend that it be used with the “Industrial Package (INDP),” p. 63; it is priced separately.

**Starters by Other Manufacturers (SBO)**

Occasionally a customer chooses to reuse an existing starter or purchase a starter directly from a starter manufacturer. While this can be accommodated, it requires careful coordination between the Trane sales representative and the owner, engineer, and starter manufacturer because generic or existing starters are not compatible with the Trane® chiller control panel.

Non-Trane starters must be modified with the proper components and control wiring before they are connected to a Trane® chiller. Existing starters should be modified by the owner’s representative; new starters should modified by the starter manufacturer. Trane assumes no responsibility for the design, construction, compatibility, installation, startup, long-term support, and will not maintain records or drawings for the resulting starter.

Trane provides a Starter by Others specification, which provides the information required for others to build a starter that is compatible with Trane® centrifugal compressor motors and controls. When a non-Trane-provided starter is used, it must be modified to conform to the appropriate Trane Starter by Others specification. SBO specifications are revised on a regular basis, so it is important to obtain the correct version before building or modifying a starter by others.

It is also important to include the cost of conversion when determining the total cost of a non-Trane starter; therefore, the owner should be provided with the appropriate SBO specification before the decision is made to reuse or purchase a non-Trane starter. Components required for conversion include but are not limited to:

- 4 kVA control-power transformer (1)
- Primary current transformers (3)
- Secondary current transformers (3)
- Primary potential transformer (1) for medium-voltage starters
- Secondary potential transformers (3) for medium-voltage starters
- Other optional starter equipment, e.g. power factor correction capacitors, as required by the specification

The Trane® chiller control panel integrates the chiller, motor, and starter into a single control and protection system. Therefore, non-Trane starters do not require an additional motor-starter protection package. If a non-Trane starter includes a protection package, the protection package must be disabled or the sensitivity of all the starter trip levels must be readjusted so that the Trane® control panel acts as the primary protection for both the chiller and the starter.
Chillers used with non-Trane starters must ship with a special control panel to accommodate the non-Trane starter. It is the responsibility of the Trane sales representative to select the “Starter by Others (SBO)” option when pricing the chiller and to assure that the non-Trane starter is built according to the proper “Starter by Others” specification.

**Note:** The industrial package (INDP) can simplify the procedure for using a non-Trane starter; see “Implications of INDP and SMP option on customer-supplied starters (SBO),” p. 66.

In summary, when a customer wants to buy a starter from a manufacturer other than Eaton Cutler-Hammer®, the procedure is as follows:

1. Price the appropriate customer-supplied starter.
2. Provide a copy of the “Starter by Others” (SBO) specification S6516-0513 from CenTraVac Field Sales Support to the customer/starter manufacturer. This specification lists the allowable starter types.
3. Inform the customer that Trane assumes no responsibility for the design, construction, compatibility, installation, startup, long-term support, and will not maintain records or drawings for the resulting starter.

**Power Factor and CenTraVac Chiller Motors**

CenTraVac squirrel-cage induction motors normally have an uncorrected full-load power factor of 88 to 92 percent. The power factor decreases slowly as the motor’s torque output drops from full load to approximately 50 percent, and then falls more rapidly at lower loads. If the full-load power factor is corrected to 95 percent, the entire curve shifts upward and the corrected power factor remains at a high value (Figure 46, p. 69). The current (amps) for a motor with a corrected power factor is lower than the current for a motor with an uncorrected power factor.

In some cases, a power factor greater than 95 percent is specified for “all load ratios above 40 percent” or at a particular operating point. Multiple-capacitor arrangements with an elaborate switching mechanism can provide this level of correction without overcorrecting by “cycling” various capacitor combinations on and off as motor loading dictates; however, this arrangement is complex and its cost may be prohibitive.

Typically, specifications stipulate a corrected power factor of 95 percent at full load. This results in an economical application that balances the first cost of the capacitors with the benefits of a higher power factor.

Several equations are helpful:

\[
\text{ApparentPower (kVA)} = \frac{\text{ActualPower (kW)}}{\text{PowerFactor}}
\]

\[
\text{ApparentPower (kVA)} = \frac{\text{Volts} \times \text{Amps} \times \sqrt{3}}{1000}
\]

\[
\text{ActualPower (kW)} = \frac{\text{Volts} \times \text{Amps} \times \sqrt{3} \times \text{PF}}{1000}
\]
PFCC Placement and Sizing. PFCCs may be installed at various locations in the power supply network. Utility companies install capacitor banks on their distribution feeders and substation buses. These capacitors correct for the utility's reactive loads and for other large reactive loads, such as those found in business or industrial areas.

When utility customers correct for the reactive loads in their facilities, they usually install PFCCs at the facility’s electrical service entrance or at the individual loads within the facility. Connecting the PFCCs at the service entrance corrects reactive loads throughout the facility. This strategy can be advantageous if the facility contains a large number of small reactive loads—but it can also be costly. Successful implementation requires expensive hardware to monitor the power factor as loads are added to and removed from the distribution system, then switch capacitors on- and offline accordingly. To avoid this expense, PFCCs are most commonly installed near each piece of switchgear that supplies a reactive load.

Engineering Toolbox. Trane has a program called Engineering Toolbox, available online or through Trane Desktop Manager, that can be used to calculate the kilovolt-amperes reactive (kVAR) of correction needed. Toolbox can calculate kVAR using information from the motor data sheets without adjustments at 60 and 50 Hz. Contact your Trane sales representative for more information.

PFCC Application Guidelines. Three “rules” govern the application of capacitors dedicated to a specific reactive load and its switchgear:

- **Rule 1**—Simultaneously disconnect capacitors and load from line power
- **Rule 2**—Size motor overload protection to account for capacitor-supplied current
- **Rule 3**—Accurately size PFCCs that remain connected to the motor when it is offline

These guidelines are explained on the following pages.

**Rule 1**—Simultaneously disconnect capacitors and load from line power.

If the capacitors are not switched offline when the load is disconnected, they continue to add capacitance to the electrical distribution system. A “leading” power factor—too much capacitance may eventually develop. This overcorrection causes poor voltage regulation, i.e., voltage is high when the circuit is unloaded, then drops as loads are added.

**Rule 2**—Size motor overload protection to account for capacitor-supplied current.

Overloads are typically set to measure the total current drawn by the motor. When PFCCs are used, they become another source for a part of that current. If the current they provide is not “seen” by the overload protectors, potentially damaging amperage can reach the motor. The simplest way to ensure that the overloads “see” all current supplied to the motor is to position the PFCCs upstream of the overloads as shown in Figure 47.
Starter Options

Figure 47. PFCCs installed downstream of starter contactor, upstream of overloads

If the capacitor connection points are downstream of the overload devices, route the PFCC leads through the overloads as shown in Figure 48, p. 70. This assures that the overloads register both line- and capacitor-supplied current.

Figure 48. PFCC wires routed through overload protectors

Rule 3—Accurately size PFCCs that remain connected to the motor when it is offline.

Connecting PFCCs to the load side of the motor-starter contactor is commonly used as a simple, low-cost way to comply with “Rule 1.” However, the motor may be damaged if the PFCCs are too large. As a “rule of thumb,” the maximum corrected power factor is 95 percent for a CenTraVac chiller motor operating at full load.

Failure to comply with this rule can cause significant damage due to voltage regeneration. The manufacturers of CenTraVac chiller motors place maximum limits on both the corrected power factor and the capacitor size. PFCCs that remain connected to the motor when it is offline must not exceed the motor manufacturer’s maximum limit.
Line-side PFCC placement. Figure 49, depicts an arrangement that provides an alternative to installing capacitors downstream of the motor-starter contactor. While this configuration can be used with any type of starter, it is mandatory for all solid-state starters. Notice that the PFCCs are connected to the line side of the main contactor (or other switching device) via a separately controlled contactor. This separate contactor is governed by a pilot relay (PR) at/in the motor-starter contactor or silicon controlled rectifiers (SCRs, solid-state starter applications) to switch the capacitors on- and offline with the load.

By connecting the PFCCs through a separate contactor they do not remain connected to the motor or the line when the motor is disconnected. This configuration prevents voltage-feedback problems and can be used for cases where correction beyond 95 percent is desirable. Correction beyond the manufacturer’s maximum limit should not be done without consulting the manufacturer regarding the application.

If the PFCC connections are downstream of the overloads, the capacitor leads must be routed through the overloads as Figure 49, p. 71 illustrates. Notice that the capacitors are not connected to the motor when it is disconnected from the line. This prevents the “motor-generated voltage buildup” described in “Rule 3”, p. 70.
Glossary

A

**Acceleration time**
The time it takes a motor to reach full design speed from the moment power is applied. Typical CenTraVac motor acceleration times associated with various starter types are listed in Table 5, p. 15 (low voltage) and Table 7, p. 29 (medium voltage).

**Advanced motor protection system**
Standard motor protection provided by the CenTraVac microprocessor-based control panel. By monitoring current and voltage in each of the three motor power phases, the panel provides protection throughout the motor starting and running modes from the adverse effects of phase imbalance, phase failure, phase reversal, overvoltage, undervoltage, and electrical distribution fault (momentary power loss). Sensing any of these faults, the panel trips-out the motor instantaneously and provides a diagnostic display. The chiller controller also protects "adaptively" for overcurrent. By reducing the load, it may be able to avoid a shutting down the chiller once it reaches the current limit.

Automatic restart is provided after restoration of power when the stoppage is caused by distribution fault or extended power loss.

**Air break**
Contacts exposed to open air that rely on an air gap to keep an electrical circuit open. Air break contactors are an obsolete technology that has been replaced by vacuum break contactors. See "Vacuum break," p. 80.

**Aluminum conductors**
Trane requires that power wiring to the motor use copper conductors. Aluminum conductors are not suitable for the following reasons:

- UL requirements
- Galvanic corrosion
- Higher probability of connection failure
- Terminal block design

*Galvanic corrosion* occurs when air and moisture are present at an aluminum-copper connection. The resulting electrolysis process causes the loss of aluminum at the interface of the dissimilar metals.

Another reason to use copper conductors is the *decreased probability of connection failure*. Aluminum connections require greater care at initial installation as well as periodic maintenance and inspection because of oxidation, torque requirements, cold flow, and thermal expansion coefficients.

Greater care in connecting aluminum wire is required since an *aluminum oxide film* must be removed or penetrated before a reliable aluminum joint can be made. This oxide film insulates the aluminum and increases joint resistance.

*Torque requirements* are critical when aluminum connections are made. It is difficult to ensure that these requirements will be met at the time of installation.

*Cold flow* or "creep" results because aluminum has a lower modulus of elasticity than copper and tends to creep away from a stressed area when under pressure. The resulting loosened connection can increase joint resistance and lead to failure of the connection. Periodic maintenance and inspection is required to assure good connections.

Aluminum and copper have different *thermal expansion coefficients*. Aluminum expands 36 percent more than copper under thermal cycling. When the terminals and connections are subjected to a large temperature change, a gap may open between the aluminum cable and the copper lug. This, combined with cold flow, can result in a very high resistance joint and lead to failure of the connection.

The final reason to use copper conductors is *terminal block design*. Because aluminum electrical conductivity is about 60 percent that of copper, larger aluminum cables are required to conduct the same amount of current. These larger cable sizes may not fit terminals designed for copper. It is also possible that the block itself may not be suitable for use with aluminum wire as determined by the block manufacturer.

**Amps, motor full-load amps (FLA)**
FLA is the amperage the motor would draw if it was loaded to its full rated capacity, i.e. motor size kW. The FLA is not available from the selection program; however, it can be obtained from CenTraVac Field Sales Support.

**Amps, motor locked-rotor amps (LRA)**
Once a motor has been selected, there is a specific locked rotor amperage value associated with the specific motor. This is the current draw that would occur if a motor was running, and then the rotor shaft was instantaneously held stationary. LRA is typically 6–8 times that of the motor full-load amps (FLA). LRA is also used commonly in discussing different starter types and the amperages associated with the start.
Amps, primary rated-load amps (RLA)
Commonly referred to as the selection RLA or the unit RLA. This is the amperage that is drawn when the chiller is at full cooling capacity in terms of cooling tons (kW). RLA is listed on the nameplate, and it is the key number used to size the starter, disconnects, circuit breakers, and Adaptive Frequency Drives (AFD) for a typical chiller. It is also the value used to determine the minimum circuit ampacity (MCA) for sizing conductors. Primary RLA is always less than or equal to the motor full-load amps (FLA).

Anti-recycle protection
A control method that limits the number of compressor starts within a given time period. Prior to 2000, the CenTraVac was limited to one start every 30 minutes (30 minutes from start-to-start).

Today, a more flexible protection system called restart inhibit is utilized. Typically several rapid restarts are allowed before a time limit is set. The time limit, if enforced due to several rapid restarts, is dependent on motor winding temperature, unit size, and an adjustable delay time constant.

This protection is a standard feature of the CenTraVac control panel.

Available fault current (AFC)
Electrical engineers usually calculate and design to a potential short-circuit current that originally comes from the utility power system. They call this term the available fault current because they take the potential fault current and then evaluate it via computer programs to determine an available fault current just upstream of the chiller starter or frequency drive. The starter short-circuit rating should be greater than or equal to the available fault current to safely contain starter components should a short-circuit occur.

B
Bus
A bar of conductive material—usually copper—used to carry large electrical currents to supply multiple circuits or components. A bus is typically used to connect several medium-voltage starters together and thereby require only a single power connection for incoming line power.

C
California code
Available on CenTraVac chillers with low-voltage starters (UL as standard) with disconnects or circuit breakers. Low-voltage starters with terminal blocks require a special configuration which is available as a standard option in the order system. On medium voltage, the standard UL certification satisfies California Code requirements.

Circuit breaker
A device that protects a circuit by opening its contacts when a current responsive element senses overcurrent or short-circuit current. A circuit breaker protects electrical components from further damage if any one component within that system experiences a short circuit. Circuit breakers are used on low-voltage starters only. The overload function is not used; overload is accomplished by the chiller controller. Circuit breakers are sized based on the primary RLA from the nameplate, the required AIC of the breaker, and the required SCR of the starter enclosure.

Contactor
A multi-pole relay whose contacts are rated to carry line current. The contactor connects and disconnects a motor to and from line power. The coil of a contactor may be operated by line voltage, control voltage, or through a rectifier (DC voltage).

Control-power transformer (CPT)
A device that reduces incoming line voltage to control voltage (i.e., 480 V to 120 V). The control-power transformer is usually located in the starter. A 4 kVA transformer is provided as standard in CenTraVac starters—3 kVA transformer provided with AFDs. The INDP option provides an option to mount the CPT separately on the side of the chiller. This transformer takes care of the chiller’s auxiliary power needs such as the purge, oil pump, heater, etc.

Corona
A visible pale glow surrounding an insulated conductor typically carrying over 2000 volts. Ozone odor is present and the air around the wire becomes ionized. An increase in voltage may cause the corona effect of adjacent wires to increase until spark-over occurs. See “Stress cone (stress relief cone),” p. 79.

Current-limiting fuse
A current-limiting fuse is a fuse that recognizes the rate of current increase and will melt its element and open the circuit in less than one-quarter of an electrical cycle in the event of a short circuit. Thus, the total short-circuit current available never passes through the current-limiting fuse. CenTraVac medium-voltage starters contain three current-limiting fuses as standard.
Glossary

Current transformer
A device that produces a reduced current signal that is proportional to the primary current. A current transformer may resemble a square or round doughnut. Each motor lead passes through the center of a current transformer and a reduced proportional current signal is obtained at the current transformer leads. There is no direct electrical connection between the motor lead and the current transformer. The voltage in the output circuit of a current transformer will be whatever voltage is necessary to drive the output current through the load with the voltage limited only by the line power or saturation level of the current transformer; therefore, the secondary of a current transformer must never see an open circuit.

D

Differential motor protection
Means of detecting current leakage in a motor from winding-to-winding or from winding-to-ground. Differential motor protection requires a six lead motor. Three current transformers, one for each motor phase, monitor the current in and out of each of the motor windings. If, due to leakage or some fault within the motor, the current in and the current out are not identical in each winding, a current will be induced in the secondary of one or more of the current transformers. This induced current will energize a differential relay which will open a contactor and de-energize the motor.

Differential protection is available as part of the industrial package's supplemental motor protection option. Differential protection is not applicable to Trane's standard, low-voltage wye-delta starters.

Differential relay
Current sensitive relay that has three coils, each connected to one of the current transformers used for differential protection. Energizing any one of the three coils will operate the relay. A differential relay is furnished with the differential protection option.

Disconnect
A device for manually isolating an electrical circuit.

Distribution fault
Transient power losses longer than 2 or 3 cycles will be detected and cause the chiller to shut down, typically within 6 cycles. The chiller can also shut down due to excessive or rapid voltage sags. Shutting down the chiller prevents the motor having power reapplied with different phasing. Utility power outages are not considered distribution faults—Trane refers to this type of fault as a momentary power loss (MPL).

E

Enclosure
The sheet metal structure and access door that surrounds the starter. The standard enclosure is NEMA Type 1A, which means general purpose indoor with a gasketed access door. Other enclosure classifications to meet requirements of different environments are available as special options. See “NEMA 1A,” p. 77.

F

Full-load amps (FLA)
See “Amps, motor full-load amps (FLA),” p. 72.

Fuse
A device that protects a circuit by fusing (melting) open its current-responsive element due to an overcurrent or short-circuit current. A fuse protects electrical components from further damage if any one component within that system experiences a short circuit.

Fuse - dual element
A dual element fuse is a single cartridge fuse having two different current-responsive elements in series. A dual element fuse is required to carry 500 percent of its current rating for a minimum of 10 seconds. One of the current-responsive elements will have inverse time characteristics while the other element will handle larger currents without intentional time delay. Since most CenTraVacs draw inrush currents in excess of this rated minimum ampacity during acceleration, all low-voltage CenTraVacs with fuse protection must use dual element fuses.

Fuse rating
NEC code allows a maximum fuse rating that is 175 percent of the RLA. To prevent blowing fuses during motor acceleration this maximum value is allowed to increase up to 225 percent of the RLA. CenTraVac dual element fuses are sized at 150–195 percent of the chiller RLA.

G

Ground fault
A leakage of line current to ground. Ground faults are typically caused by the breakdown or cracking of wire insulation.
Ground fault protection—low voltage

Low voltage ground fault protection consists of a ground fault sensor, a ground fault relay, and a disconnect device (circuit breaker or non-fused disconnect switch) equipped with a shunt trip device.

The ground fault sensor is a specially rated current transformer and must be applied only with a ground fault relay. Ground fault sensors cannot be used with any other equipment.

The ground fault relay is designed to work with a ground fault sensor. The current level required to activate the ground fault relay is adjustable. The response speed (time delay) is also adjustable to avoid nuisance trips. All ground fault relays require a manual reset. The time-current tripping curve of a ground fault relay is nearly instantaneous when the current setting and time delay have been exceeded. The contacts of the ground fault relay energize a shunt trip device to open the circuit and isolate the ground.

The shunt trip device is a circuit breaker with a shunt trip coil. Such a circuit breaker can either be opened manually, opened by its current sensing element (short circuit), or opened by energizing its shunt trip coil. A circuit breaker is used to open the circuit because it is capable of successfully interrupting fault current; the current to ground may be catastrophic.

The minimum setting of the ground fault protection system should be 20 percent of the disconnect rating with a 10-cycle time delay.

Ground fault protection—medium voltage

Medium voltage ground fault protection consists of a ground fault sensor and ground fault relay. The ground fault relay interrupts control power to the main contactors causing them to open. All medium-voltage starters are equipped with current-limiting fuses. In the event of a catastrophic ground, the current-limiting fuses would react much faster than the ground fault protection relay; therefore, the fuses would perform the act of interrupting the circuit and isolating the ground.

The minimum setting of the ground fault protection system should be 20 percent of the disconnect rating with a 10-cycle time delay.

Grounding

Electrical refrigeration components such as motors and control panels must be grounded for the protection of maintenance and service personnel.

Equipment ground connection bolts are provided in the control panel, the motor junction box, and in the starter of all CenTraVacs. On those CenTraVacs where the control panel is isolated, grounding straps are installed to ground the control panel to the chiller frame. Thus, all pieces of a CenTraVac are provided with an individual equipment ground.

It is the responsibility of the installing contractor to ground the CenTraVac equipment to an earth ground per NEC and local codes.

“Gutless” circuit breaker

See “Non-fused disconnect”, p. 77.

Inrush current

The current drawn by a motor during acceleration. Inrush current for various types of starters (in percent of LRA) is given in Figure 5, p. 16 (low voltage) and Figure 21, p. 29 (medium voltage).

Interlock, electrical

Auxiliary contacts on a contactor, typically used in control voltage circuits, to monitor the position of the contactor. These auxiliary contacts may be normally open, normally closed, or convertible.

Interlock, mechanical

Bars, levers, or catches that physically prevent operation of a device under certain circumstances. (i.e. a CenTraVac starter door may not be opened if a circuit breaker is closed)

Interrupting capacity

The rated maximum current that a device can successfully interrupt without damage to itself. This applies to a circuit breaker or a fuse only. It is not proper to refer to a starter as having an interrupting capacity. Starters have an overall short-circuit rating. See “Short-circuit rating (SCR)”, p. 78.

Ionization

Insulated conductors carrying over 2000 volts are subject to ionization. Ionization results in the formation of gas pockets between the insulation layers. These gas pockets form areas of unequal stress that may lead to premature breakdown of the insulation. See “Stress cone (stress relief cone)”, p. 79.

IQ 310

This is a starter mounted meter that digitally displays many parameters. It is a starter option, however most functions are displayed as standard on the unit controller.
See the comparison tables (Table 2, p. 11 and Table 3, p. 12).

IQ 4130
This is a starter mounted meter that digitally displays many parameters. It is a starter option, however most functions are displayed as standard on the unit controller. See the comparison tables (Table 2, p. 11 and Table 3, p. 12).

Isolation switch
A device used to connect and disconnect a load to and from line power for servicing. Isolation switches are non-load break and cannot be opened under load. Trane® medium-voltage starters have a mechanical interlock that prevents the isolation switch from being opened while the chiller is running. This is a standard item on Trane® medium-voltage starters.

Kirk key
A locking arrangement between a remote disconnect switch and a starter that is designed to prevent closing the remote switch and powering the starter that is being serviced.

A single key is used and it is held captive in the disconnect switch. The disconnect switch must be opened and then locked open. The kirk key may then be removed and used to unlock the starter. The key remains captive in the starter until the starter door is closed and locked. The key may then be removed and used to unlock the disconnect switch. The switch may then be closed.

Lightning arrester
A device that protects electrical equipment from high voltage spikes by providing a high resistance path (an air gap) to ground—essentially an air gap small enough to allow a spark-over to occur for voltages much larger than the chiller’s operating voltage. The device provides protection by consistently conducting to ground when the magnitude of the voltage exceeds a predetermined value.

Although lightning arresters may be used alone, they are used usually in conjunction with surge protection capacitors.

The function of a lightning arrester is to limit the magnitude of a voltage spike. The function of a surge capacitor is to limit the rate of rise of a voltage spike. See “Surge capacitor,” p. 79.

Lightning arresters are a starter option.

Load-break switch (LBS)
A manual switch that has an interrupting rating and can be used to safely interrupt a live circuit. It is sometimes called an ADM switch. This term is typically used with medium-voltage starters when customers want Trane to provide a load-break switch. The standard isolation switch that comes with medium-voltage starters is non-load break. The load-break switch is a design special. The switch is housed within a 90” high, 36” wide, and 30” deep enclosure. A circuit breaker or non-fused disconnect on low-voltage starters can be used as a load-break switch.

Locked-rotor amps (LRA)
See “Amps, motor locked-rotor amps (LRA),” p. 72.

Lug
A device used to mechanically connect a conductor (wire) to a piece of electrical equipment. Lugs are furnished by the starter vendor. The number of wires per phase and range of wire sizes that the lugs will accept are listed in the starter submittals. The range of wire sizes indicates the maximum size wire that will fit into the lug hole and the minimum wire size that the screw can securely clamp in place. Optional lugs that accommodate different number of wires per phase and size are generally available for every starter. These can be purchased through a local vendor if required.

Note: Wire sizes “pulled” by contractor that are different from the lug sizes shown on the starter submittal will impact the lug sizes needed. In this case, the correct lug sizes must be obtained locally.

Maximum overcurrent protection (MOP)
The maximum overcurrent protection (MOP, or sometimes abbreviated as MOPC) appears on the chiller nameplate. The electrical engineer often wants to know the MOP when selections are being made. It is used to assist in the sizing of fuses and circuit breakers. MOP is an output of the TOPSS selection program. Also see the discussion on fuse and circuit breaker sizing (“Electrical System—Ratings,” p. 48 and “Electrical System—Design Guidelines,” p. 51). Use of improperly sized circuit breakers can result in nuisance trips during the starting of the chiller. For CenTraVac chillers the MOP is NOT the value used to size incoming wire (see MCA).

Minimum circuit ampacity (MCA)
This term appears on the chiller nameplate and is used by electrical engineers to determine the size and number of
conductors bringing power to the starter. The formula for MCA is 1.25 x (Primary RLA) + (4000/motor voltage), rounded up to the next whole number. The formula is 125% of the motor design RLA plus 100% of the amperage of other loads (control-power transformer, oil pump motor, and purge etc.) MCA is an output of the TOPSS selection program. Table 11, p. 57 through Table 16, p. 59 show power wire sizing based on the MCA.

**Molded case switch**
See “Non-fused disconnect,” p. 77.

**Momentary power loss (MPL)**
See “Distribution fault”, p. 74.

**Motor FLA**
See “Amps, motor full-load amps (FLA),” p. 72.

**Motor LRA**
See “Amps, motor locked-rotor amps (LRA),” p. 72.

**Motor size in kilowatts (kW)**
The motor size is listed on the program output in kW. This is the motor’s full, rated capacity. There is an amperage draw associated with power draw at full capacity called full-load amps (FLA). FLA is the amperage the motor would draw if it is loaded to its full rated capacity i.e. motor size kW. The FLA is not available from the TOPSS selection program, however can be obtained from CenTraVac Field Sales Support.

Usually the selection RLA and kW are used as the nameplate RLA and kW. Occasionally, an engineer may decide to specify slightly higher RLA as the nameplate data to provide “extra” capability for the chiller. The higher kW and RLA cannot exceed the motor size (kW), the starter size (RLA), or the disconnect/circuit breaker size (RLA).

**N**

**NEMA 1**
Enclosures are intended for indoor use primarily to provide a degree of protection against limited amounts of falling dirt.

**NEMA 1A**
Identical to NEMA 1 with the addition of a rubber gasket that seals the access door.

**NEMA 12**
Enclosures are intended for indoor use primarily to provide a degree of protection against circulating dust, falling dirt, and dripping non-corrosive liquids.

**NEMA 3R**
Enclosures are intended for outdoor use primarily to provide a degree of protection against rain, sleet, and damage from external ice formation.

**NEMA 4**
Enclosures are intended for indoor or outdoor use primarily to provide a degree of protection against windblown dust and rain, splashing water, hose-directed water, and damage from external ice formation.

**NEMA 4X**
Enclosures are intended for indoor or outdoor use primarily to provide a degree of protection against corrosion, windblown dust and rain, splashing water, hose-directed water, and damage from external ice formation.

**Non-fused disconnect**
A circuit breaker without a thermal or magnetic overcurrent element. It is used solely as a manual disconnect means. This is also called a “gutless” circuit breaker or molded case switch.

**O**

**Overload protection**
A scheme or device that monitors motor current and interrupts control power to the main contactor(s), disconnecting the motor from the line, if motor current exceeds preset limits of current and time. Motor current may be monitored directly or through current transformers.

**Overload relay**
A device that senses current flow to a motor. The relay can be set to trip at a certain value. If the motor attempts to draw current in excess of this value, the relay will trip, de-energizing the contactor coil, disconnecting the motor from the line.

**P**

**Phase failure**
An opening in one of the three main power leads caused by a blown fuse or broken conductor. This results in only one phase being delivered to the load. Thus, phase failure is the same as single phasing. Phase failure protection is standard on CenTraVac chillers with microprocessor-based chiller control panels and was available as a starter option on older CenTraVacs.
**Glossary**

**Phase imbalance**
An imbalance in the current level or voltage level among the three phases. Phase imbalance can cause motor overheating.

**Phase reversal**
A change in the desired electrical phase relationship. Phase reversal causes motors to rotate in the wrong direction.

**Phase failure/phase reversal relay**
A device that monitors the phase relationship and opens a contact to stop the compressor motor in the event of phase failure, phase reversal or phase imbalance.

The advanced motor protection provided by the chiller controller performs the functions of a phase failure/phase reversal relay.

**Pilot relay**
A term describing the fact that all CenTraVac starters start and stop the compressor by means of a relay that responds to commands from the CenTraVac control panel. Push-to-start push-buttons or any other forms of manual starting of the compressor are not allowed. The CenTraVac safeties in the control panel must not be bypassed.

**Power factor**
The ratio of real power (watts) to apparent power (volt-amperes). Induction motors, such as CenTraVac compressor motors, require some energy for magnetizing that does no actual work and is not registered on a wattmeter.

**Power factor correction capacitor (PFCC)**
May be used to improve the power factor of a CenTraVac by furnishing some of the wattless magnetizing energy required by the motor.

Power factor correction capacitors are a starter option. They are mounted in or on the starter and are typically wired to the load side of the compressor contactor. Since the capacitors are wired in parallel with the motor, the maximum capacitor size is determined by the motor.

The capacitors furnished as a starter option will correct the compressor motor to approximately 93.5 to 95.5 percent power factor at full load.

**Power wiring**
Refer to Table 11, p. 57 through Table 16, p. 59 for wire sizing for line and load wire associated with CenTraVac starters.

**Primary power**
The performance number called primary power is the kW usage at chillers full cooling capacity. The primary power will always be less than the motor size. See “Motor size in kilowatts (kW),” p. 77.

**Primary RLA**
See “Amps, primary rated-load amps (RLA),” p. 73.

**Rated-load amps or running-load amps (RLA)**
See “Amps, primary rated-load amps (RLA),” p. 73.

**Relay**
An electrically-operated device whose contacts switch electrical circuits. A relay is always used as a switching device within a control circuit.

**Resistance temperature detector (RTD)**
A device whose electrical resistance varies with its temperature. RTDs may be used to monitor motor winding temperature.

Every CenTraVac motor has three 75-ohm nickel-iron RTDs buried within its stator windings. These RTDs are connected to the CenTraVac control panel. There, a device monitors the resistance (hence, the temperature) of the RTDs and will stop the compressor if the motor winding temperature exceeds a preset level. These are dedicated RTDs and cannot be used for any additional functions.

If motor winding RTDs are required for any other function, the RTDs required must be described and ordered as a design special. Then, a specially built motor will be provided.

**Short circuit**
An unintentional direct electrical connection from phase-to-phase or from phase to ground resulting in low resistance and very high current flow. Short circuits can result in destruction of conductors and components. Short circuits are caused by the breakdown of insulation, poor wiring, or a conductive piece of metal that accidentally comes in contact with multiple phases or between a phase and ground (i.e. tools and service equipment). See “Available fault current (AFC),” p. 73.

**Short-circuit rating (SCR)**
When a short circuit occurs, there is a period of time that the short-circuit current passes to the shorted circuit before the protection device (circuit breaker or fuse) can
open. This time can be as long as 0.020 seconds (1 cycle). The short-circuit rating of a starter is the maximum short-circuit current that it can pass safely. Components within the starter may be destroyed, but the starter cabinet will safely contain any sparks or flying debris. UL listed starters have a listed short-circuit rating.

**Short-circuit withstand rating (SCWR)**
See “Short-circuit rating (SCR),” p. 78.

**Shunt trip**
A tripping coil added to a circuit breaker or non-fused disconnect to provide a means of tripping the circuit breaker with an external signal. See “Ground fault protection–low voltage,” p. 75.

**Silicone controlled rectifier (SCR)**
A solid state signal controlled, one-way power switching device commonly used in solid-state starters and variable-frequency drives.

**Single phase (single phasing)**
See “Phase failure,” p. 77.

**Solid-state starter**
A starter that starts and accelerates a motor at a preset acceleration rate and current limit. A solid state starter performs this function by modulating the current/voltage wave form delivered to the motor with silicon controlled rectifiers (SCRs). For more information on this starter type, refer to CTV-SLB017-EN (Solid-State Starters for Trane Chillers).

**Starter**
A device consisting of both a contactor and an overload protection system or device whose purpose is to start and stop a motor and protect the motor from overcurrent. Variable-frequency drives are also classified as starters.

**Stress cone (stress relief cone)**
Cables carrying above 2000 volts must have a metallic shield unless the cable is specifically listed or approved for non-shielded use. Shielding is necessary because of the danger of corona or ionization. The purpose of shielding a cable is to confine its dielectric field to the inside of the cable or conductor insulation. The shielding must be grounded at one end.

Stress cones are used to reduce and control longitudinal and radial electrical stresses at the cable end to values within safe working limits for the material used to make-up the termination. An oversized junction box at the motor may be required to accommodate stress cones.

**Surge capacitor**
A device that protects electrical equipment from high voltage spikes by absorbing the peak energy of the spike and then releasing it into the tail of the spike.

Although surge capacitors may be used alone, they are usually used in conjunction with lightning arresters. See “Lightning arrester,” p. 76.

Surge capacitors are a starter option.

**Switchgear**
A switchgear type starter is an across-the-line low-voltage starter that uses a circuit breaker to connect and disconnect the compressor motor to and from the line. Usually a separate power source (i.e., 125 Vdc from a battery bank) is used to open and close the circuit breaker on demand.

Switchgear starters should be used with caution. Some switchgear starters contain a relay that will trip the circuit breaker if auxiliary power is lost. Others do not contain this auxiliary power monitoring relay. It may then be impossible to automatically disconnect the compressor motor from the line in case of a compressor, chiller or starter fault, if auxiliary power is lost while the compressor is running.

**Top hat**
A supplementary sheet-metal enclosure provided with unit-mounted medium-voltage starters and SMP cabinets to help accommodate the space requirements of stress cones.

**Transducer**
A device that converts a control signal from one form to another. For example, conversion of a 0–20 psig pneumatic control signal to a 4–20 milliampere electrical control signal.

**Transition**
Transition is the action taken by a starter when changing from one configuration to another, such as changing (transitioning) from the wye/star configuration to the delta configuration.

**Open transition** … a term indicating that the motor is disconnected from the line, transition is performed and then the motor is reconnected to the line.

**Closed transition** … a term indicating that the motor remains connected to the line during transition.
Glossary

All CenTraVac starters are closed transition. All SBO starters must be closed transition. Open transition starters cause stresses in the motor windings that shorten motor life.

Inrush current is nearly constant during acceleration and then drops quickly to less than RLA when the motor reaches full speed. Starters using the Trane® microprocessor controller monitor motor current continuously and initiate transition when the motor current drops below 85 percent of RLA.

Trip unit
Device that opens the operating mechanism within the circuit breaker in the event of a prolonged overload or short-circuit current. To accomplish this, an internal electronic rating plug is provided, which tells the trip unit when to open the mechanism. Rating plugs are factory set within specific ranges to meet motor performance requirements and are field-adjustable.

U
Unit controller
The microprocessor controller mounted on the chiller. Also referred to as the control panel.

Vacuum break
Contacts that are encapsulated in an evacuated, ceramic bottle. Since the contacts operate in a vacuum, arcs are quickly extinguished because there are no ionized gases present to support conduction. The claimed advantages are no contact maintenance, long contact life and safety, since there is no exposed arcing. All medium-voltage starters used by Trane have vacuum break contactors.

Vacuum break contactors are used typically only on medium-voltage starters.

V
Voltage
The following voltages apply to CenTraVacs:

<table>
<thead>
<tr>
<th>Voltage</th>
<th>Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>Control Voltage</td>
<td>120 Vac</td>
</tr>
<tr>
<td>Low Voltage</td>
<td>208–600 Vac</td>
</tr>
<tr>
<td>Medium Voltage</td>
<td>601–13,800 Vac</td>
</tr>
</tbody>
</table>

The electrical power industry refers to 2,000 through 69,000 volts as medium voltage.

Voltage monitoring relays, overvoltage relay
A relay and an adjustable line voltage monitor that will stop the chiller if the line voltage exceeds a preset value. This overvoltage monitoring system is a lock-out type that requires manual reset at the starter.

The chiller controller provides under/overvoltage protection as standard.

Voltage monitoring relays, undervoltage relay
A nonadjustable relay that is powered directly by line voltage. If line voltage drops below 55 percent nominal voltage, the undervoltage relay will stop the chiller. This relay requires a manual reset at the starter.

The chiller controller provides under/overvoltage protection as standard.

Voltage monitoring relays, adjustable undervoltage relay
A relay and an adjustable line voltage monitor that will stop a chiller if line voltage drops below a preset value. This undervoltage monitoring system is a lock-out system that requires manual reset at the starter.

The chiller controller provides under/overvoltage protection as standard.

W
Wattmeter
A device that displays instantaneous power (watts) in the form of a dial meter or a digital display. When a wattmeter is ordered for a starter, the wattmeter option includes all necessary transformers.

Watt-hour demand register
An option on a watt-hour meter that indicates the total power used per time period (i.e., 15 minutes). The value displayed is proportional to the electrical energy used in the unit’s time period. The watt-hour demand value will only increase when the power demand in a new time period exceeds the power demand in any previous time period; thus, the demand register indicates the largest power demand in any time period. The demand register may be manually reset to zero to monitor a new series of time periods.

Watt-hour meter
A device that measures and registers the cumulative amount of electrical energy used in terms of watt-hours (or kilowatt-hours). This is a standard feature on the unit control panel.
When a watt-hour meter is ordered for a starter, this option includes all necessary transformers.

**Watt-hour meter pulse initiator**
A device that generates pulses (contact closures) proportional to a definite energy value (watt-hours per pulse). Output contacts of pulse initiators are normally connected to pulse-operated demand recorders or used to feed energy consumption information to computers and load controllers.

When ordering pulse initiators, the type of pulses and the pulse rate the end devices will accept must be indicated.

**Withstand rating**
See “Short-circuit rating (SCR)”, p. 78.