Reduced Voltage Starting of Low Voltage, Three-Phase Squirrel-Cage Induction Motors  
Technical Overview  
Class 8600

INTRODUCTION

This product data bulletin reviews the most commonly used methods of reduced voltage starting of three-phase AC squirrel-cage motors. They include primary resistor, autotransformer, part winding, wye-delta and solid state. This document explains the function, characteristics and benefits associated with each type of reduced voltage starter.

Why have reduced voltage starting?

1. To reduce the starting current draw of the motor.
2. To reduce the starting torque provided by the motor.

Whenever a squirrel-cage induction motor is started, the electrical system experiences a current surge and the mechanical system experiences a torque surge. With line voltage applied to the motor, the current can be anywhere from four to ten times the motor full-load current. The magnitude of the torque (turning force) that the driven equipment will see could be in excess of 200% of the motor full-load torque. These current and torque surges can be reduced substantially by reducing the voltage supplied to the motor during starting.

CURRENT REDUCTION

At the moment of energization, the current drawn by a squirrel-cage induction motor is a function of its locked rotor impedance. Typically, this current can be anywhere from four to ten times the current that the motor will draw when it is up to speed and fully loaded. Inrush, or locked rotor current, can cause many objectionable effects on the electrical distribution system.

One of the most noticeable effects of full voltage starting is the dimming or flickering of lights while the motor is starting. This is especially true in rural areas or in other areas where the electrical distribution grid is of insufficient capacity, or insufficiently regulated to start a large motor without excessive line voltage drops.

Since starting current is determined by the impedance of the motor while starting, reduction of the stator voltage will reduce the starting current requirement. If the starting voltage is reduced to 50% of its nominal value, the starting current will also be reduced by the same percentage, in accordance with Ohm's Law: \( I=\frac{E}{Z} \), where \( I \) is the starting current, \( E \) is the voltage applied to the motor and \( Z \) is the locked-rotor impedance of the motor. Since \( Z \) is essentially a fixed value at the instant of starting, any change in voltage will directly affect the starting current.

Figure 1 on page 2 shows the starting current of a squirrel-cage induction motor plotted against speed. The starting current, which has been shown as six times the full load value, remains fairly constant until the motor has reached approximately 50% speed. If the starting voltage were reduced, the entire curve would shift downward by the ratio of the applied voltage to the rated voltage.
TORQUE REDUCTION

Reduced voltage starting minimizes the shock on the driven machine by reducing the starting torque of the motor. This is important since suddenly applied high torque may cause belts to slip, or may damage gears or couplings. Also, material being processed, or conveyed, may be damaged by the suddenly applied high torque.

By reducing the starting voltage at the motor terminals, starting torque is decreased. The starting torque at standstill, of a squirrel-cage induction motor, is approximately proportional to the square of the applied voltage. This is shown in the equation $T = KV^2$, where $T$ is the torque at standstill, $K$ is a constant determined by the particular motor and $V$ is the voltage applied to the stator windings.

From the equation, if the voltage is reduced by 50%, the starting torque at standstill will only be 25% of its normal full voltage value. Figure 2 illustrates the speed versus torque curve for a typical NEMA design B motor. The speed torque curve is given for both a full voltage start and a 70% voltage start.

Figure 1    Line Current Versus Motor Speed

Figure 2    Motor Speed Versus Torque
Note that there are load limitations imposed on reduced voltage starting. The difference between the motor and the load speed-torque curves is torque that is available to accelerate the load. The smaller the torque difference, the slower the acceleration. The motor torque curve must always be greater than the load torque curve at all speeds to maintain positive acceleration.

Reduced voltage starting is generally not recommended for motors with large starting torque requirements.

One of the more common forms of reduced voltage starting employs a resistor in series with each of the motor windings during acceleration. Because of the additional resistance in the circuit, the current drawn by the motor is reduced. There is a voltage drop in the resistor, which reduces the voltage across the motor terminals and produces less starting torque. As the motor accelerates, the current through the resistor decreases to reduce the voltage drop and to increase the voltage across the motor terminals. The result is smooth acceleration with gradually increasing torque and voltage.

The resistors are generally selected so 70% of the nominal line voltage will be applied at the motor terminals the instant of starting. Figure 3 shows the current versus speed curve for a motor started with a primary resistor starter. Notice that the transition to full voltage occurs at approximately 85% of full load speed.

![Figure 3: Line Current Versus Motor Speed — Primary Resistor Starter](image)

Primary resistor starters provide closed transition starting, in which the motor is never disconnected from the line, from the moment it is first connected until the motor is operating at full line voltage. This feature minimizes current transients during transition and may be important in systems sensitive to voltage changes. Note, at the time the resistor is shorted, the current could be greater than the initial value of starting current. The current rise is incremental to the starting current, not a sudden transient increase from zero as in certain other systems.

While primary resistor starters do consume power during starting, with that power being dissipated as heat, the motor starts at a much higher power factor than other starting methods.

Operating Sequence

Refer to Figure 4 on page 4 for the schematic diagram of a primary resistor starter.

1. Operation of the START button energizes the timing relay (TR). An instantaneous contact of TR closes to energize contactor M. Closing of contacts M connects the motor to the line, with a resistor (RES) in each line to the motor. The voltage drop across this resistor reduces the voltage across terminals T1, T2, and T3, thus providing a reduced voltage start.
2. After a time delay, the time delay contacts of TR close to energize contactor A. When contacts A close, the resistor is shorted out, thus transferring the motor from reduced voltage to line (full) voltage operation.

![Diagram of Primary Resistor Starter]

**Figure 4  Primary Resistor Starter**

The National Electrical Manufacturer’s Association (NEMA) specifies that the standard primary resistor starter with automatic acceleration should be suitable for one 5 second start each 80 seconds for an hour (NEMA 116 duty). For longer starting times, or a more severe duty cycle, starters with NEMA 156 resistors are available, providing resistors suitable for one 15 second start each 60 seconds for an hour. Resistors for other duty cycles can be provided on special order.

**Usage**

Primary resistor starters are widely used because they cost less in the smaller horsepower ratings than autotransformer starters. For the large horsepower ratings, where primary resistor and autotransformer starters are priced the same, the autotransformer starter is more popular. This probably occurs because of the large amounts of power used (and the necessity of dissipating the heat generated) in primary resistors, and because autotransformer starters provide more torque per ampere of line current than any other type of reduced voltage starter for squirrel-cage motors. This last effect becomes increasingly important as the motor horsepower ratings increase. One of the main advantages of the primary resistor starter is smooth acceleration.

**Cataloging and Ratings**

Primary resistor starters are available as non-reversing and reversing. They are listed in the Square D digest under Class 8647. Primary resistor starters are available in NEMA size 1 through NEMA size 7 for ratings as large as 600 hp at 460 or 575 V, or 300 hp at 230 V.

**AUTOTRANSFORMER STARTER**

**General**

An autotransformer type starter uses an autotransformer between the motor and the supply line to reduce the motor starting voltage. Taps are provided on the autotransformer to permit the user to start the motor at 50%, 65% or 80% of line voltage. The transformer action reduces current as well as voltage so motor current will also be reduced to 50%, 65%, or 80% of the normal starting current.

With autotransformer starting, the line current is always less than the motor current during starting by an amount equal to the transformation ratio. For example, when a motor is started on the 65% taps, motor current is 65% of line voltage starting values, while the line current is only 65% of 65% (42%) of line voltage starting values. The difference between line and motor current is due to the transformer in the circuit.
Lower line current is the reason the autotransformer starter is a popular type of reduced-voltage starter. Since the motor starting current is greater than the line current with an autotransformer starter, the starter produces more torque-per-ampere of line current than any other type of reduced-voltage starter.

Most motors can be started at 65% of line voltage. If the torque that the motor supplies to the driven equipment is not sufficient on the 65% voltage tap, a higher torque on the 80% tap is available. Similarly, if too much torque is applied to the load with 65% voltage, or if the voltage dip associated with 65% starting is too high, the 50% tap is available. This versatility also makes the autotransformer starter popular. Figure 5 shows the typical schematic diagram for a two coil autotransformer starter. The circuit for a three coil autotransformer starter is similar except that an additional transformer winding is inserted in the L2 leg. There are no significant disadvantages to using a two coil autotransformer design since the starting currents are approximately balanced in each phase.

**Operating Sequence**

Refer to Figure 5 for the schematic diagram of an autotransformer starter.

1. Initial pressing of the start button energizes the timing relay (TR). An instantaneous normally-open contact on TR closes around the start button to provide a normal three-wire control scheme. An additional normally-open instantaneous contact on TR closes, energizing contactor 1S. The 1S contactor connects the autotransformer to line 2. An interlock on the 1S contactor closes to pick up contactor 2S. This connects the autotransformer primary windings to line 1 and line 3. The motor is now connected to the line through the autotransformer taps and accelerates at reduced voltage.

2. After a preset time delay, the timing contacts on the TR timing relay change state, causing contactor 1S to open. Contactor 2S remains closed through its own holding circuit interlock. Once the 1S contact has opened, the motor remains energized and is momentarily connected to the lines through the windings of the autotransformer with the transformer acting as a reactor.

![Figure 5: Autotransformer Starter — Common Control](image-url)
3. As soon as contactor 1S drops out, contactor RUN (R) picks up to connect the motor to the line at full voltage. The 2S coil does not drop out until the RUN starter has been energized. The normally-closed run interlock, in series with the 2S coil, is a late-break type. This ensures that contactor 2S remains energized until after the RUN starter has picked up and sealed in.

By energizing the RUN starter before the 2S contactor is dropped out, the motor is assured to have closed-circuit transition starting. At no time during the starting cycle is the motor disconnected from line power.

4. After the RUN starter shorts out the autotransformer windings, contactor 2S opens. Figure 6 shows the line current as a percent of full load versus motor speed as a percent of synchronous speed. It shows a typical autotransformer type starter starting a NEMA design B motor when the autotransformer is connected on the 65% tap. Line current on the 80% taps would be somewhat higher, line current on the 50% taps would be lower.

![Figure 6: Line Current versus Motor Speed — Autotransformer Starter](image)

The starting method, utilizing two starting contactors and one running contactor ensures closed transition starting, thereby minimizing torque and current transients during transition. If the motor were to be disconnected from the line (open transition) even for a brief period, it would act momentarily as a generator. A large transient could result if the motor is rapidly reconnected to the line. The power fed back into the line by the motor probably would not be in phase with line voltage and current. The transient associated with open-circuit transition starting could be sufficient to cause nuisance tripping of breakers. In addition, there would be a torque surge associated with the motor rapidly accelerating to get in step with the line power. The rapid torque surge may cause additional stress on the motor and the driven load.

**Starting Duty Cycle**

The normal medium duty starting cycle per NEMA standards, for autotransformers rated 200 hp or less, is one 15 second “ON” period every four minutes for an hour, or 15 starts per hour. For starters rated above 200 hp, the starting duty cycle is one 30 second “ON” period each minute for three times total. This can be repeated after a two hour and one hour rest, respectively. Most standard motors have a much lower starting capability than the autotransformers.

These starting duty cycles represent the length of time the autotransformer can be connected in the circuit. The length of time the autotransformer is connected can be longer than either 15 seconds or 30 seconds provided a longer period of time is allowed for the autotransformer to cool. For example if a 100 hp motor requires the autotransformer to be connected in the circuit for 25 seconds, there will be no problem in starting the motor, provided a sufficient time, such as 20 minutes, is provided between starts to allow the autotransformer to cool.
Care must be taken not to exceed the temperature ratings of the autotransformer and power wire insulation systems and assure that the thermal overload protection does not trip. Consult the equipment manufacturer when deviating from standard duty cycles.

Usage

The autotransformer starter is the most popular of the electromechanical reduced voltage starters. Its popularity is attributed to the fact that it can reduce the inrush current in the distribution system to the lowest level of all the different electromechanical types of starters. In addition, the taps on the autotransformer permit adjustment of voltage and motor torque. It is ideally suited for starting most industrial loads.

Cataloging and Ratings

Autotransformer type starters are available as non-reversing and reversing. They are listed in the Square D digest under Class 8606. These starters are available in NEMA Size 2 through NEMA Size 7, for ratings as large as 600 hp at 460 or 575 volts, or 300 hp at 230 volts.

PART WINDING STARTER

General

Part winding motors are squirrel-cage motors having two identical stator windings which are intended to be operated in parallel. By bringing out leads to each winding, the motor manufacturer enables the windings to be paralleled external to the motor.

A part winding starter has two main contactors, one to control each winding of the part winding motor. By energizing these contactors in sequence, first one winding is energized, and a short time later the second winding is energized and connected in parallel. Since the motor is started with a single winding energized, the name of the starting method is derived. This is a closed transition starter since line power is never removed from the motor when transferring from the start to run modes.

Most, but not all, dual-voltage motors have windings that can be isolated and may be suitable for part winding starting. The windings are paralleled and the dual-voltage motor is operated at its lower voltage rating by a part winding starter. The starting torque of a wye-connected motor starter with one half of its windings energized is approximately one-half the torque with both windings energized.

Part winding starting of a motor does not necessarily reduce the maximum starting current, but instead causes incremental starting. Either of the two motor windings does not have the thermal capacity to operate alone for more than a few seconds. Typically, this time is 2 seconds or less. Because of the short time the motor is operated with one winding, the motor current does not decrease significantly before the second winding is energized. Therefore, unless the motor has accelerated to practically full speed on the one winding, the total current draw may approach that of line voltage starting. This can be seen in Figure 7.

Figure 7  Line Current Versus Time — Part Winding Starter
Note that the current is broken up into two parts, or increments, while the motor is accelerating. When the second contactor closes, the second winding current is additive to the current being drawn by the start winding. With one-half of the motor windings energized in a wye-wye connected motor, the starting current is two-thirds (65%) of what it would have been if both windings are energized at the same time. Starting torque is approximately 48% of "both winding" value.

**Operating Sequence**

Refer to Figure 8 for a schematic diagram of a part winding starter.

1. Depressing the start button energizes the timing relay (TR). A pair of instantaneous normally-open contacts on this timing relay close; one around the start push button and one that energizes contactor S, connecting one set of the motor windings to the line. The motor will start with reduced current draw and torque.

2. After a time delay, the normally-open timed-closed contact of TR closes to energize the RUN starter. This connects the second set of windings in parallel with the first winding. The motor is now completely connected to the line.

![Schematic Diagram](image)

**Figure 8** Part Winding Starter — 3-Pole / 3-Pole

Note that two starters are used in Figure 8. Per NEC 430-3 each winding must be provided with its own short circuit, overload, and ground fault protective device, since each winding carries only one-half of the motor full load current.

Smaller NEMA sizes of part winding starters use a 4-pole starting contactor and a 2-pole running contactor instead of 3-pole / 3-pole versions shown in Figure 8. If starter S is a four-pole device, two-thirds of the motor windings in a wye-connected motor could be energized for a higher torque output on start up. A four-pole starter would also allow part winding starting of a dual-voltage delta-connected motor on its lower voltage rating.

**Usage**

Part winding motors (and starters) are well suited to centrifugal loads of low inertia, or on any general load which is started infrequently. Although in the strict sense it does not reduce the voltage, it does reduce the current draw associated with reduced voltage starting. Not all utilities allow this type of starting because the current may be higher on starting than that associated with other forms of reduced voltage starting. In addition, this starter can be applied only to a special motor or a dual voltage motor that can be started on the lower voltage setting. The part winding starter is popular because it is one of the least expensive of the reduced voltage types.
Part winding starters are listed as Class 8640 in the Square D digest. The listing is for non-reversing service, although reversing versions are available. These starters are available in NEMA size 1PW through size 7PW for motors as large as 900 hp at 460 - 575 V, or 450 hp at 230 V.

The wye-delta starter is used only with motors that are suitable for wye-delta starting. As with the part winding starter, full voltage is applied to the motor terminals while starting. The effects of reduced voltage starting are brought about by changing the way that the windings are connected to the line.

The wye-delta motor has the windings connected in a delta (Δ) configuration when operating the motor at its nominal voltage. For starting, the windings are first connected in the wye configuration, resembling the letter Y and then reconnected in a delta configuration as the motor comes up to speed. By connecting the motor in wye, the line voltage is applied across two of the windings, resulting in 58% \((1 - \sqrt{3})\) of the line voltage across each winding.

It is this reduced voltage across the motor windings, while connected in wye, that reduces the current and starting torque during motor acceleration. The motor must be reconnected in the delta configuration once the motor has almost reached full-load speed. When a wye-delta motor is started in the wye configuration, both the starting current and torque are only one-third of the values that would be obtained by starting the motor in delta. There are no external resistors or transformers to reduce the voltage to the motor terminals. The length of time that the motor can be connected in the wye configuration is strictly limited by the motor characteristics. Figure 9 shows line current versus speed during open transition starting for the wye-delta motor.

![Line Current Versus Motor Speed — Wye-Delta Starter](image)

Wye-Delta starters are available in either open or closed transition. Open transition consists of two contactors, mechanically interlocked, plus a magnetic starter and a timing relay. Closed transition has an additional contactor and a 3-phase resistor bank. Closed transition starting is advantageous in some applications because it eliminates the transient current (and torque) which occurs when switching from a wye to delta connection.

At the point where the transfer to a delta connection is made during open transition, line current first decreases to zero and then suddenly increases to a higher value. This is because the motor is momentarily disconnected from the power source. Closed transition starting differs in that there is no drop-off to zero current during the transfer from wye to delta.

In Europe, wye-delta motors are used as dual voltage motors. When they are used in this way, the wye connection has a voltage rating equal to 1.732, or \(\sqrt{3}\), times the voltage rating when connected in delta. Therefore, if the motor is connected in wye and used on the lower voltage rating, the effect is the motor operating at 1/1.732 or 58% of nominal rating. Typical voltages used are 220 V for the delta connection and 380 V for the wye connection.
Operating Sequence

Refer to Figure 10 for a schematic diagram of a Wye-Delta open transition starter.

1. Depressing the start button energizes the TR timer coil. A normally-open TR instantaneous holding circuit contact closes around the start push button. Another instantaneous normally-open contact on TR energizes the shorting contactor S, which connects together motor terminals T4, T5 and T6. These connections form the center of the wye configuration. After the wye has been formed, contactor 1M picks up by means of a normally-open S interlock in series with its coil. Once 1M has picked up, motor terminals T1, T2 and T3 (which are the ends of the wye) are connected to the line. The motor is now connected in wye and begins to accelerate with 58% of line voltage across the motor windings.

2. After a time delay, the normally-closed timed-open contact of TR opens, de-energizing contactor S. When the S contactor is opened momentarily there is no current flowing in the motor windings (open transition). Once S has dropped out, the normally-closed interlock contact in series with the 2M contactor closes, energizing 2M.

3. When 2M is energized the motor is connected in delta. To ensure that the 2M contactor does not energize when the S contactor is energized (causing a line-to-line short), they are both electrically and mechanically interlocked per NEMA standards.

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**Figure 10  Wye-Delta Reduced Voltage Starter — Open Transition**

<table>
<thead>
<tr>
<th>OPERATION</th>
<th>CONTROLLER</th>
<th>CONTACTOR</th>
</tr>
</thead>
<tbody>
<tr>
<td>START (WYE)</td>
<td>X</td>
<td>S 1M 2M</td>
</tr>
<tr>
<td>TRANSITION</td>
<td>X</td>
<td>S 2M</td>
</tr>
<tr>
<td>RUN (DELTA)</td>
<td>X</td>
<td>S 2M</td>
</tr>
</tbody>
</table>

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Refer to Figure 11 for a schematic diagram of a Wye-Delta **closed transition** starter.

Adding resistors to the power circuit as shown in Figure 11 provide closed-circuit transition starting. In order to accomplish this, a contactor and resistor bank are required. Since this resistor bank is only required to provide power to the motor during transition, the length of time that they will be connected is extremely short. The resistors must be sized for a particular ohmic value, but only as intermittent duty.

![Wye-Delta Reduced Voltage Starter - Closed Transition](image)

**Figure 11**  Wye-Delta Reduced Voltage Starter - Closed Transition

![Motor Connections](image)

**Figure 12**  Motor Connections — Wye-Delta Starter

Figure 12 shows the connections when the motor is connected in wye, during transition, and when it is connected in delta. For a short period of time, the resistors are in series with each one of the motor windings. Then, just as in the primary resistor starter, when the 2M contactor closes, the resistors are effectively taken out of the circuit.
Usage

The most common use for a wye-delta motor is for a centrifugal load of either high or low inertia, such as centrifuges, fans, and hermetic centrifugal chillers for large central air conditioning units. Since all of the windings are used, and since there are no limiting devices such as resistors or autotransformers, they are widely used on long accelerating loads of high inertia. If the motor and load take longer than two minutes to accelerate, it is possible the next larger size starter may be required due to heating effects on the starting contacts.

Cataloging and Ratings

Wye-Delta starters, both open and closed transition, are listed under Class 8630 in the Square D digest. Listings are for non-reversing operation, although reversing can be provided. These starters are available in NEMA Sizes 1-YD through 7-YD. Maximum ratings are 1000 hp at 460-575 V, or 500 hp at 230 V.

SOLID STATE REDUCED VOLTAGE STARTER

General

Power semiconductors have been around for many years, but until recently they were too expensive to use in starting standard three-phase induction motors. The lowering of production costs of semiconductors have made them more desirable for use in areas previously dominated by electromechanical starter designs. Also, the rising costs of petroleum based products, steel, semi-precious and precious metals used in electromechanical devices have made solid state devices more price competitive. Additionally, the need to more closely control a motor and its load necessitate the use of solid state power controls or solid state reduced voltage starting.

A solid state reduced voltage starter introduces solid state power semiconductors between the power source and motor during the starting of a motor, just like a primary impedance type starter. The different types of power semiconductors used are transistors, triacs and SCRs. Transistors usually have limited use due to low current and voltage capacity and the cost of these devices. Future designs may make available a high power, low cost transistor. Triacs are also limited to low power applications for the same reasons as the transistor. This leaves only SCRs for high power use. Diodes can be used with SCRs but can introduce a DC component into an AC power circuit which would damage an AC motor. Refer to Figure 13.

![Diagram of SCRs and Diodes](image)

**Figure 13** Using SCRs

The six SCRs, two per phase in a back-to-back or reverse parallel configuration, control the power to the motor. The power to the motor is reduced by “phasing back” or not completely turning on the SCRs when starting. The SCRs will only allow a portion of the three-phase sinusoidal wave to be supplied to the motor on starting, reducing the effective power to the motor. The motor will receive enough power to start rotation and accelerate to full load speed as the SCRs conduct more of the power. When the power to the motor has stabilized, the SCRs may be turned on fully. The “phasing back” of the SCRs allows the current to be limited to reduce inrush current and torque. The current limit will limit the motor current to a preset level at all times during start and run conditions. However, the current should not be reduced beyond the level which allows the motor to accelerate. Since this current level varies as a function of the motor design and load, the current limit setting is generally field adjusted to achieve acceptable acceleration. Refer to Figure 14.
Figure 14  

Current Limit — Solid State Reduced Voltage Starter

This “phasing back” of the SCRs allows the smooth acceleration and deceleration that is characteristic of a solid state reduced voltage starter. Refer to Figure 15. The voltage ramp allows the applied motor voltage to increase from 0% to 100% over an adjustable period of time. This provides acceleration from zero to full speed, but does not require a motor mounted tachometer. The motor current is limited to the current limit setting. In some applications requiring a linear speed versus time acceleration characteristic, a motor mounted tachometer is used to sense speed. The “phase back” of the SCRs is then controlled by the starter electronics to achieve the desired speed versus time profile. Deceleration provides a soft stop by allowing the applied motor voltage to decrease from 50% to 0% over an adjustable period of time. A soft stop helps prevent high friction loads from coming to a sudden stop. This is not to be confused with DC braking, which is basically the opposite of a soft stop.

Figure 15  

Acceleration and Deceleration — Solid State Reduced Voltage Starter

Solid state reduced voltage starters have many special features. They can include solid state overload protection, current limit, phase loss sensing, phase sequence sensing, underload detection and DC braking, in addition to different starting methods that provide closer coordination between the motor and the starter.

Refer to Figure 16 for a schematic diagram of a solid state reduced voltage starter.

1. Depressing the start button energizes the SR2 relay coil. A normally-open SR2 holding circuit contact closes around the start push button. Another normally-open SR2 contact energizes the solid state control M.

2. The solid state M contacts close and energize the motor. The power to the motor is limited for the period of time and to the extent the current limit and voltage acceleration were initially set.

Figure 16  

Solid State Reduced Voltage Starter
3. Once the time for the initial current limit and/or voltage acceleration settings are complete, the motor will receive full power. The motor continues to run at full power unless the energy saving circuit is active and motor load fluctuates.

After the motor is up to speed, the semiconductors may be bypassed (shorted) with an electromechanical contactor as shown in Figure 17. This decreases the amount of heat given off by the semiconductors since they are used only in the start up of the motor.

![Diagram](image)

**Figure 17** Solid State Reduced Voltage Starter with a Shorting Contactor

An up-to-speed contact is included that closes once the solid state starter has completed its start sequence. This contact energizes the CR2 coil. A normally-open CR2 contact closes energizing coil A. The electromechanical contactor A is wired in parallel with the solid state M control. The solid state device is not isolated from the circuit. The current will take the path of least resistance, which is through the A contactor.

**Usage**

The ability of the solid state reduced voltage starter to accelerate the motor load very smoothly makes it ideal for use on most standard applications. It can be used on applications such as conveyors, fans, blowers and pump motors. Most high inertia loads may require special consideration, but can be started with a solid state reduced voltage starter. These types of loads, such as hammer mills and punch presses, require extremely high starting torque.

It should be noted that harmonics on start up can cause line noise or transients in the distribution system. Because of this, applications should be reviewed to assure that both the motor and other equipment on the system can operate with these line disturbances without problems.

**Cataloging and Rating**

Solid state reduced voltage starters are listed under Class 8660 in the Square D digest. Note that there are two different types:

1. **Alpha-Pak**: Available from 5 hp through 100 hp at 460 V and 3 hp through 40 hp at 230 V.
2. **Solid State Reduced Voltage Starter**: Available from 125 hp through 600 hp at 480-575 V and 50 hp through 300 hp at 230 V.
SUMMARY

COMPARISON OF STARTING METHODS

PRIMARY RESISTOR STARTERS

A. Advantages —
   1. Closed transition starting — motor not disconnected from line during acceleration.
   2. Smooth acceleration — terminal voltage increases with speed. As the motor accelerates, the voltage drop across the starting resistor decreases.
   3. Standard motors are used — no need for a special motor.

B. Disadvantages —
   1. Voltage reduction is obtained through a power loss in the resistors. When starting is frequent or prolonged, the power loss may be significant and the heat may be difficult to dissipate.
   2. The percent of line voltage start, and the starting torque is difficult to adjust on the primary resistor starter.

Primary resistor starters are well suited where a modest torque reduction is required with a modest reduction in line current. They provide very smooth acceleration of standard motors, for a modest price.

AUTOTRANSFORMER STARTERS

A. Advantages —
   1. Produces the maximum torque per ampere of line current — no other starting method for squirrel-cage motors produces more.
   2. Maximum reduction of inrush current — more than any other.
   3. Taps on autotransformer permit starting voltage to be changed — enables starting current or starting torque to be adjusted to meet local conditions.
   4. Standard motors are used — no need for a special motor.

B. Disadvantages —
   1. More expensive than other starters in smaller horsepower ratings.

Autotransformer starters are the first choice where maximum starting torque or minimum starting current is a consideration. When starting is frequent or acceleration is long, these starters rate very high. Taps permit adjustment of starting current or torque.

PART WINDING STARTERS

A. Advantages —
   1. Least expensive of types — cost per horsepower is less than other reduced voltage methods.
   2. In most cases a 230/460 V dual voltage motor can be used for part winding starting on 230 V.
   3. Closed transition starting — the motor is not disconnected from line during acceleration.
   4. No heat producing or current changing devices such as resistors, transformers, or SCR's used — contributing to controller simplicity and reduced maintenance.

B. Disadvantages —
   1. Special motors are used — not all motors suitable for part winding starting on lower voltage.
2. Motor will not accelerate load to near full speed — most part winding motors have a severe torque dip at approximately half speed, which prevents acceleration on the half winding beyond half speed.

3. Motors started part winding have little thermal capacity on the half winding — transfer to full voltage must be made within 3-4 seconds to prevent possible overheating of the starting winding.

When starter cost is a prime consideration, the part winding should be considered. When two-step incremental starting, without regard to the total line current draw, is a big factor, part winding starting may be a good choice.

**WYE-DELTA STARTERS**

A. **Advantages** —
   1. Produces high torque per ampere of line current — equals value available with autotransformer.
   2. Inexpensive — for most horsepower ratings is less expensive than primary resistor or autotransformer starters.
   3. No heat producing or current changing device used — contributes to controller simplicity and reduced maintenance.

B. **Disadvantages** —
   1. A special motor is required.
   2. Starting torque is fixed at 1/3 of delta connected (full voltage) starting torque.
   3. Inherently open transition starting, although starters which provide closed transition starting are available at extra cost.

Wye-Delta starting is advantageous where the required starting torque is low and where the line current drawn must be at a minimum. A typical application is a centrifugal compressor, on which compression is delayed (by a valve) until line voltage connection of the motor has been completed.

**SOLID STATE STARTERS**

A. **Advantages** —
   1. Provides smoothest acceleration.
   2. Adjustability of current and torque while starting.
   3. Closer control of the motor and its load.

B. **Disadvantages** —
   1. Heat given off by the SCR's when they are conducting — can be avoided after starting by using a shorting contactor.
   2. Harmonics may be a consideration during the time the SCR’s are not in full conduction.

Of all the reduced voltage starter types, the solid state provides the smoothest acceleration for a squirrel-cage induction motor. It is also the most flexible of the different types of reduced voltage. Because of the microprocessor capability, many special features are available as well as the ability to more closely control a motor and its load. One of the limitations is for high inertia loads (long acceleration time); higher amperage SCRs and a special overload may be necessary. Technology in solid state is constantly changing and as the cost of solid state equipment decreases, its popularity will increase.