PF SOFTSTARTER

Application Techniques

Features of the PF Softstarter and how they apply to different industrial applications and settings

Important User Information

Because of the variety of uses for the products described in this publication, those responsible for the application and use of this control equipment must satisfy themselves that all necessary steps have been taken to assure that each application and use meets all performance and safety requirements, including any applicable laws, regulations, codes and standards.

The illustrations, charts, sample programs and layout examples shown in this guide are intended solely for purposes of example. Since there are many variables and requirements associated with any particular installation, Sprecher and Schuh does not assume responsibility or liability (to include intellectual property liability) for actual use based upon the examples shown in this publication.

Rockwell Automation publication SGI-1.1, *Safety Guidelines for the Application, Installation and Maintenance of Solid-State Control* (available from your local Sprecher + Schuh office), describes some important differences between solid-state equipment and electromechanical devices that should be taken into consideration when applying products such as those described in this publication.

Throughout this manual we use notes to make you aware of safety considerations:

Attention	Identifies information about practices or circumstances that can lead to personal injury or death, property damage or economic loss

Attention statements help you to:
- identify a hazard
- avoid a hazard
- recognize the consequences

Important	Identifies information that is critical for successful application and understanding of the product.

Overview

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Overview

Introduction

The Sprecher + Schuh Softstarter Controller lines offer a broad range of products for starting or stopping AC induction motors from ½ Hp to 1000 Hp. The innovative features, compact design, and available enclosed controllers meet world-wide industry requirements for controlling motors. Whether you need to control a single motor or an integrated automation system, our range of controllers meet your required needs.

This document discusses the PF Softstarter. Some of the key features are listed below.

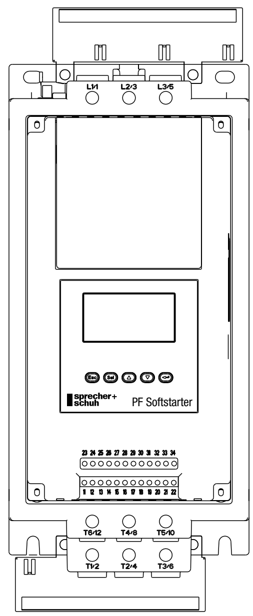
PF Softstarter Features

- Soft Start — with Selectable Kickstart
- Current Limit Start — with Selectable Kickstart
- Dual Ramp — with Selectable Kickstart
- Full Voltage
- Linear Speed Acceleration — with Selectable Kickstart
- Preset Slow Speed
- Soft Stop
- Pump Control — with Selectable Kickstart
- SMB™ Smart Motor Braking
- Accu-Stop™
- Slow Speed with Braking
- Built in Bypass
- Inside the Delta
- Electronic Motor Overload Protection
- Stall and Jam Detection
- Ground Fault Protection
- Thermistor Input (PTC)
- Metering
- Fault Indication
- Parameter Programming
- Communication Capabilities

Description

When the PN Softstarter was first introduced in 1995, its modular design, digital setup, and microprocessor control set the standard for soft starters. The PN controller has been in a class by itself, providing unmatched performance with innovative starting and stopping options. Now, the next generation PF Softstarter controller achieves a higher level of sophistication with greatly enhanced protection, expanded diagnostics, ability to log the motor's operation (A, kW, and power factor), and flexibility to communicate with various network protocols. The PF Softstarter can also be wired in a standard wiring configuration, or inside-the-delta. This allows the product to operate wye-delta motors with a much smaller device than before.

Figure 1 - PF Softstarter Controller



The PF Softstarter controller is a compact, modular, multi-functional solid-state controller used in both starting three-phase squirrel-cage induction motors or wye-delta motors and controlling resistive loads. The PF Softstarter contains, as standard, a built-in SCR bypass and a built-in overload. The PF Softstarter product line includes current ratings 5 to 480 A, 200 to 600V, 50/60Hz. This covers squirrel-cage induction motor applications up to 400 Hp (wye-delta motors up to 650 Hp). The PF Softstarter controller meets applicable standards and requirements.

While the PF Softstarter controller incorporates many new features into its design, it remains easy to set up and operate. You can make use of as few or as many of the features as your application requires.

Modes of Operation

The following modes of operation are standard within a single controller:

Standard

- Soft Start with Selectable Kickstart
- Current Limit with Selectable Kickstart
- Dual Ramp Start with Selectable Kickstart
- Full Voltage Start
- Preset Slow Speed
- Linear Speed Acceleration with Selectable Kickstart
- Soft Stop

Pump Option

- Pump Control with Selectable Kickstart

Braking Option

- Smart Motor Braking
- Accu-Stop
- Slow Speed with Braking

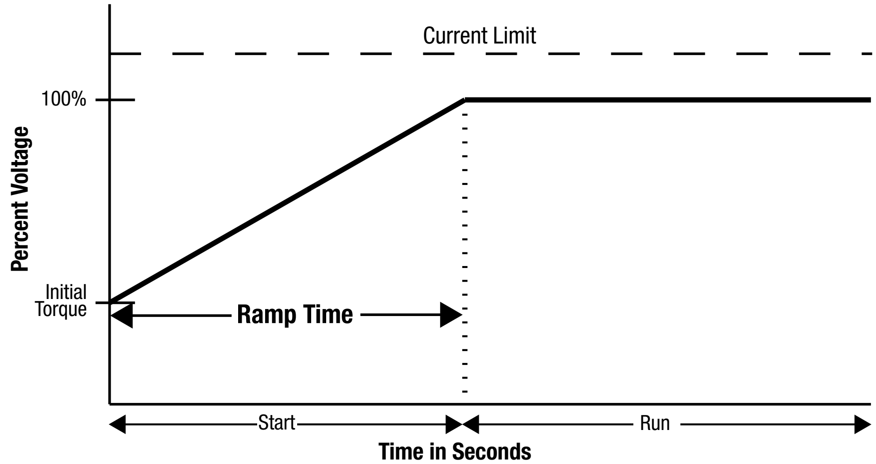
Standard

Soft Start with Selectable Kickstart

This method covers the most general applications. The motor is given an initial torque setting, which is user adjustable from 0 to 90% of locked rotor torque. From the initial torque level, the output voltage to the motor is steplessly increased during the acceleration ramp time, which is user adjustable from 0 to 30 seconds. If, during the voltage ramp operation, the PF Softstarter controller senses that the motor has reached an up-to-speed condition, the output voltage will automatically switch to full voltage, and transition over the SCR Bypass contactors.

The kickstart feature provides a boost at startup to break away loads that may require a pulse of high torque to get started. It is intended to provide a current pulse, user adjustable 0-90% locked rotor torque for a selected period of time from 0.0 to 2.0 seconds.

Figure 2 - Soft Start



Following are the parameters that are specifically used to provide and adjust the voltage ramp supplied to the motor.

Table 1 - Soft Start Parameters

Parameter	Adjustment
PF Option	Standard, Braking, Pump
Starting Mode	Soft Start
Ramp Time	0…30 s
Initial Torque	0…90% LRT
Kickstart Time	0.0…2.0 s
Kickstart Level	0…90% LRT
Option 2 Input	Disable
Stop Mode	Disable
Stop Time	0 s

Figure 3 - Soft Start Sequence of Operation

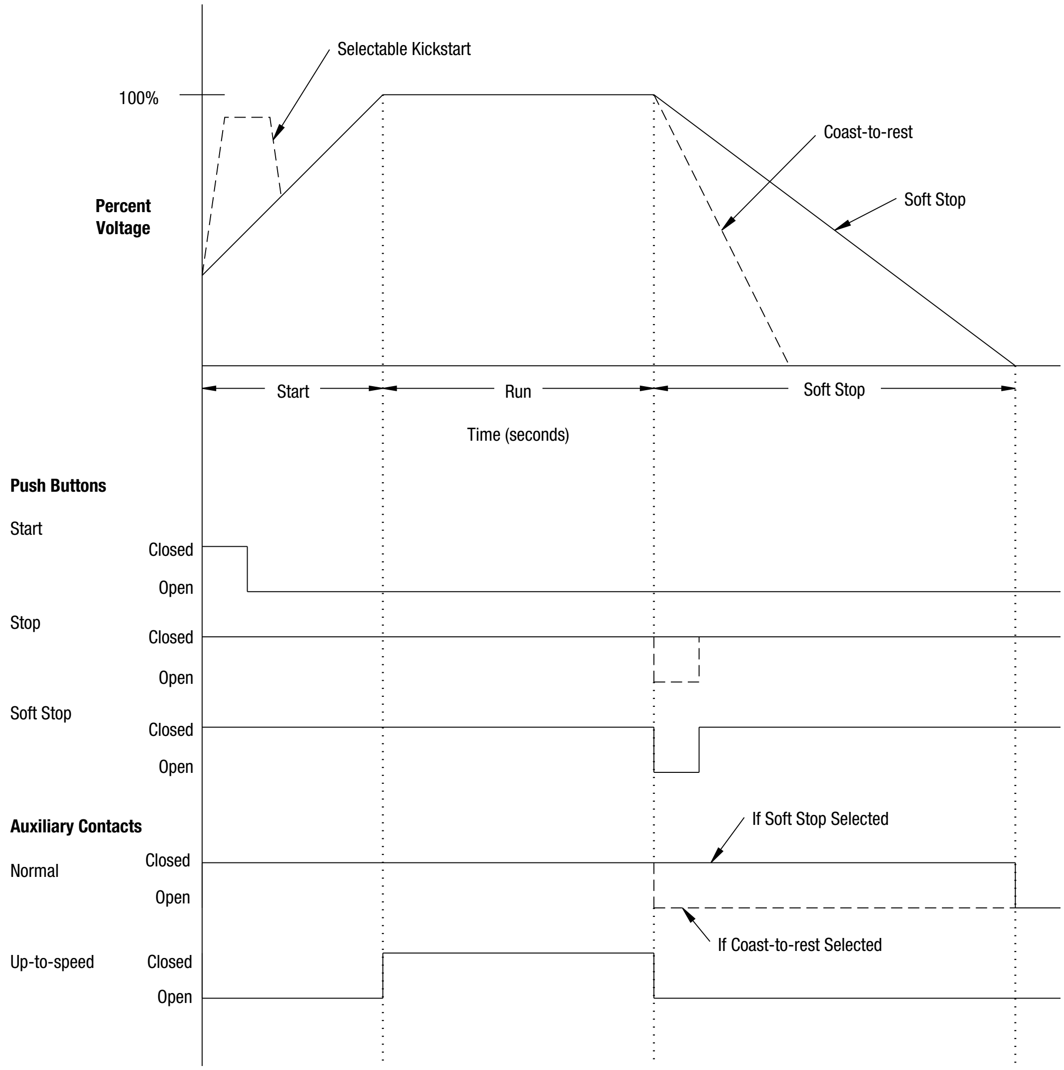
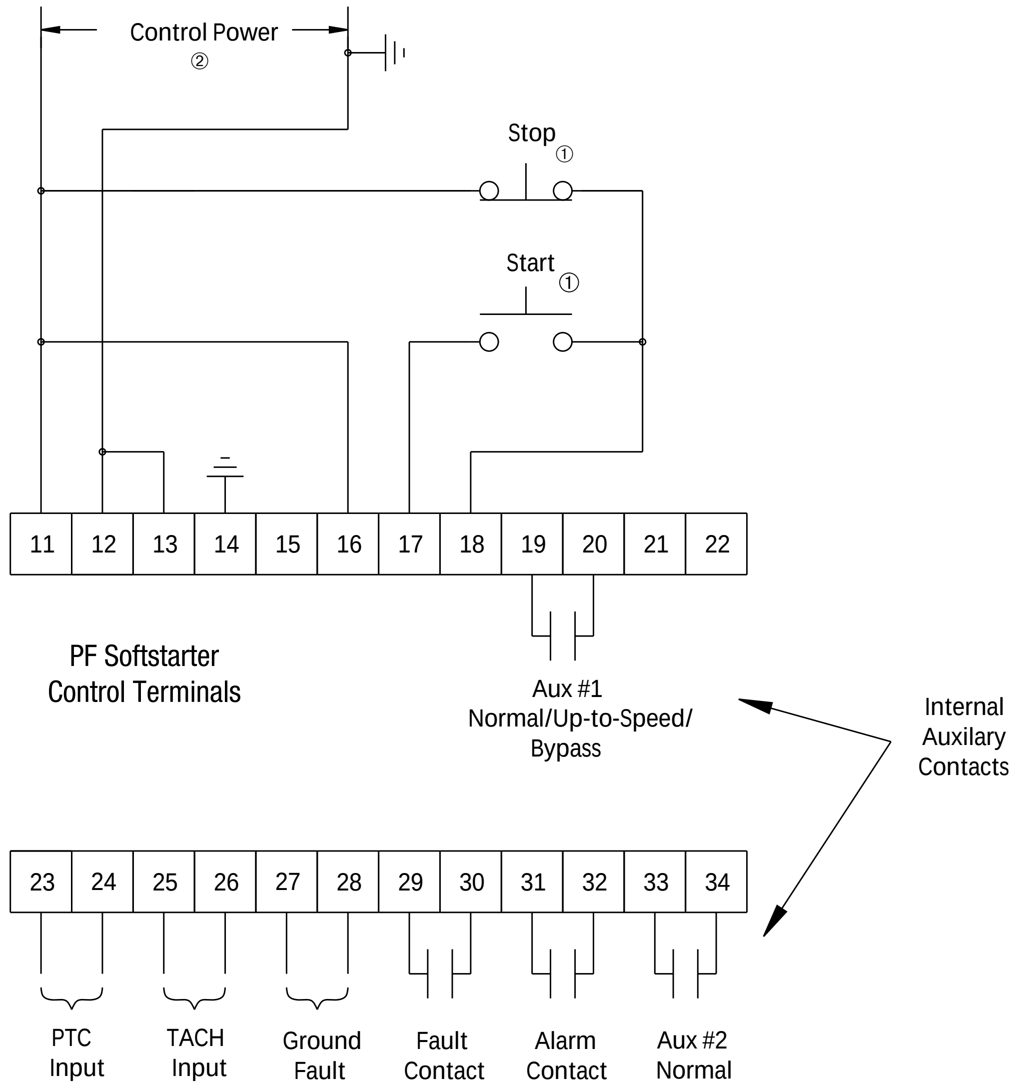


Figure 4 - Soft Start Wiring Diagram



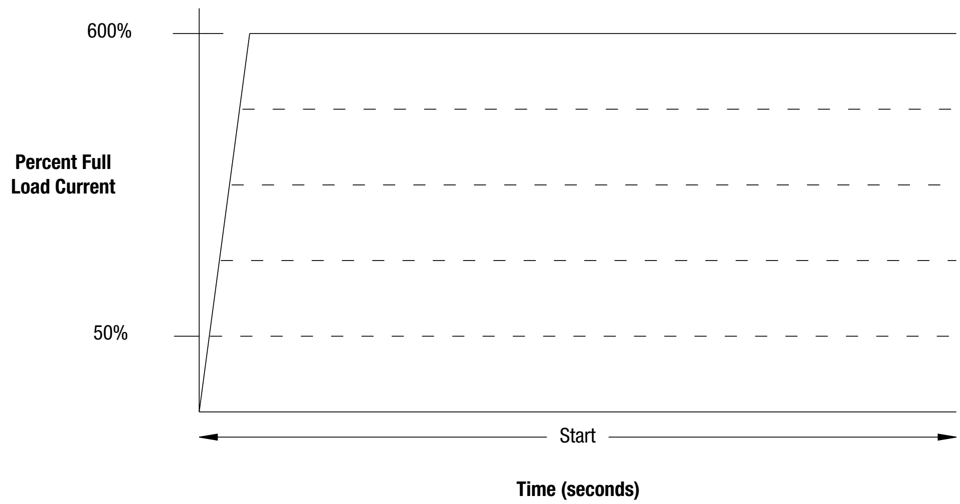
① Customer Supplied
② Refer to the controller nameplate to verify the rating of the control power input rating

Current Limit Start with Selectable Kickstart

This method provides a current limit start and is used when it is necessary to limit the maximum starting current. The starting current is user adjustable from 50 to 600% of full load amperes. The current limit ramp time is user adjustable from 0 to 30 seconds.

The kickstart feature provides a boost at startup to break away loads that may require a pulse of high torque to get started. It is intended to provide a current pulse, user adjustable 0-90% locked rotor torque for a selected period of time from 0.0 to 2.0 seconds.

Figure 5 - Current Limit Start



To apply a current limit output to the motor, the following parameters are provided for user adjustment.

Table 2 - Current Limit Start Parameters

Parameter	Adjustments
PF Option	Standard, Braking, Pump
Starting Mode	Current Limit
Ramp Time	0…30 s
Current Limit Level	50…600% FLC
Kickstart Time	0.0…2.0 s
Kickstart Level	0…90% LRT
Option 2 Input	Disable
Stop Mode	Disable
Stop Time	0 s

Figure 6 - Current Limit Sequence of Operation

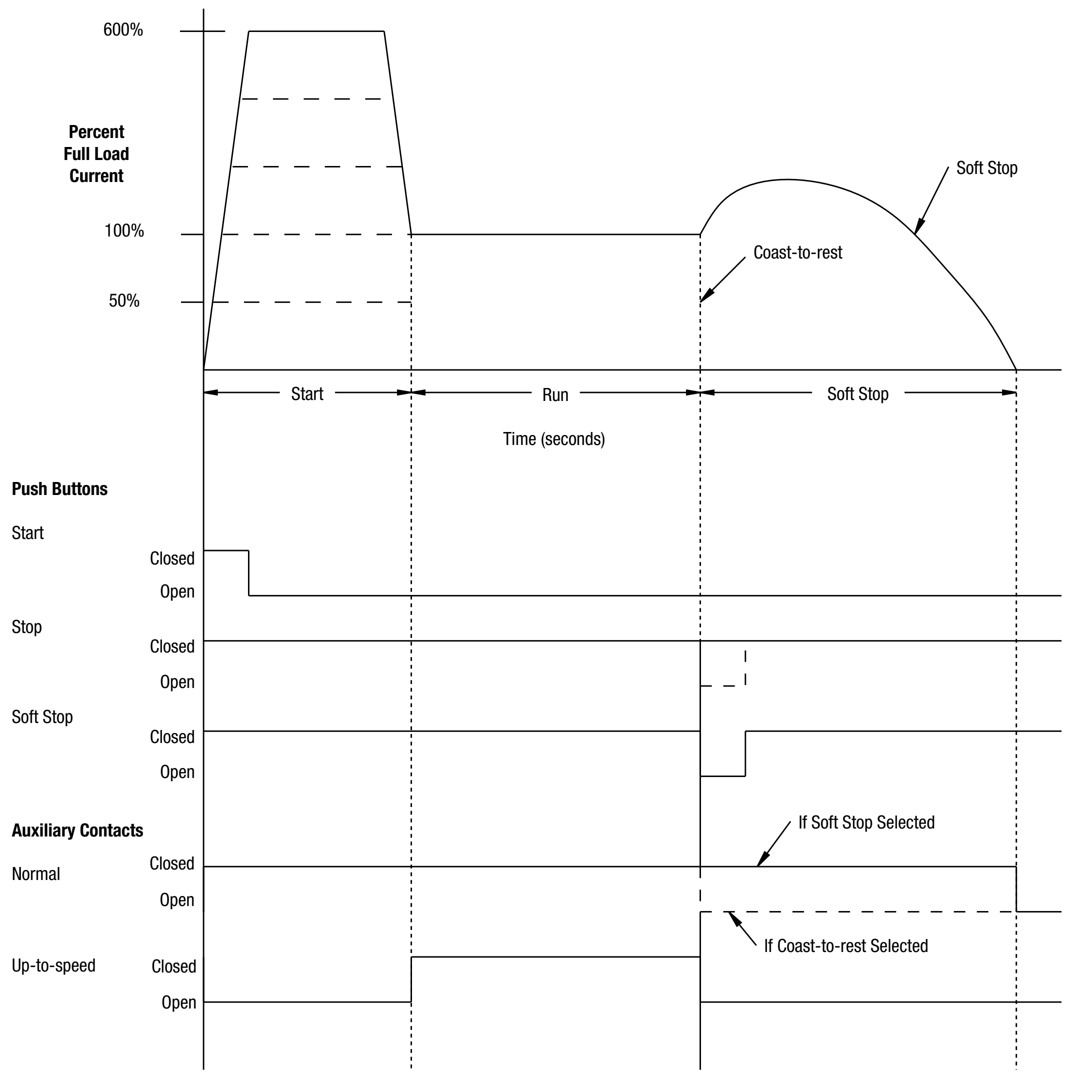
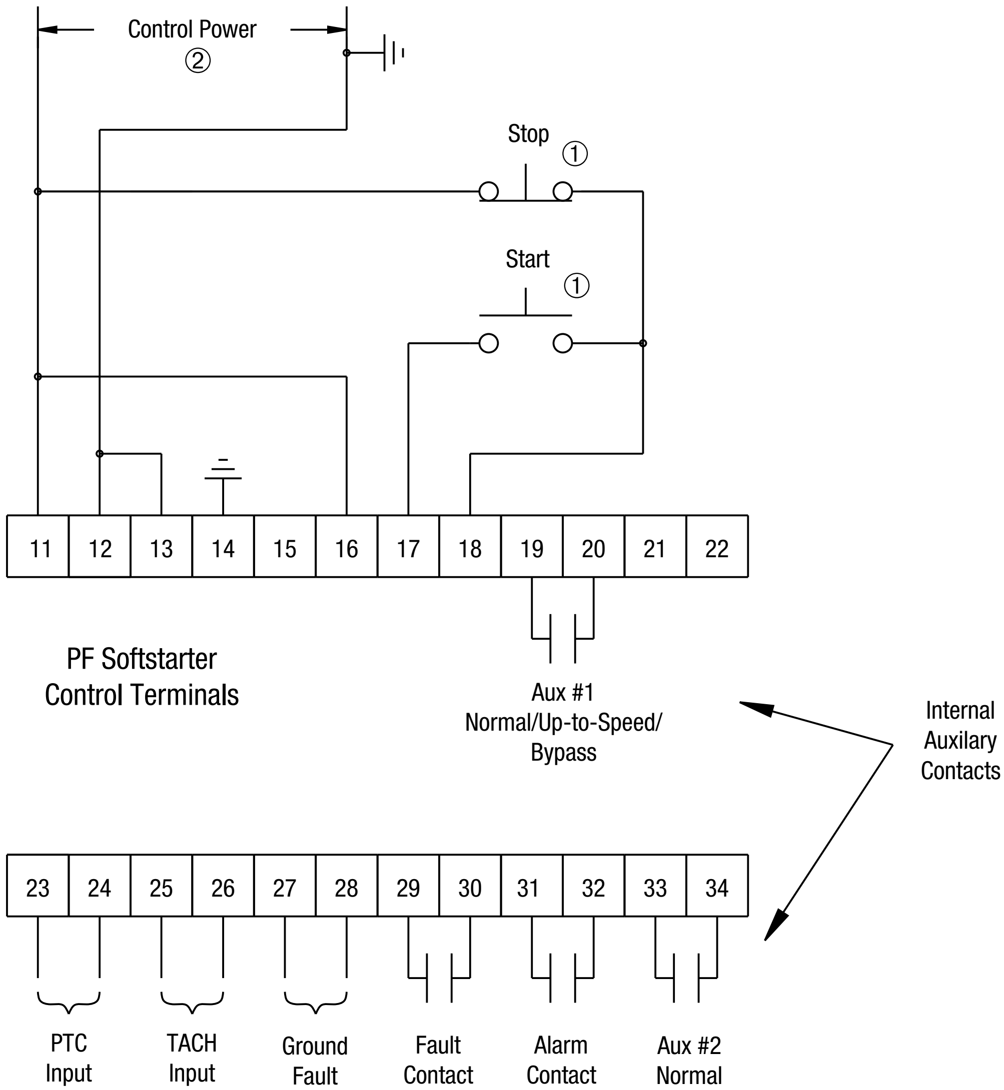


Figure 7 - Current Limit Wiring Diagram



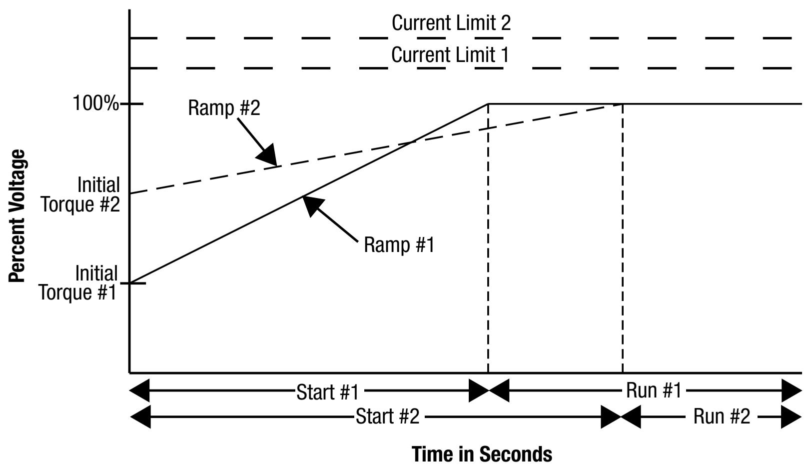
① Customer supplied.
② Refer to the controller nameplate to verify the rating of the control power input rating.

Dual Ramp Start with Selectable Kickstart

This starting method is useful on applications with varying loads, starting torque, and start time requirements. Dual Ramp Start offers the user the ability to select between two separate Start profiles with separately adjustable ramp times and initial torque settings.

The kickstart feature provides a boost at startup to break away loads that may require a pulse of high torque to get started. It is intended to provide a current pulse, user adjustable 0…90% locked rotor torque for a selected period of time from 0.0 to 2.0 seconds.

Figure 8 - Dual Ramp Start



To obtain Dual Ramp Start control, the following parameters are available when you select Dual Ramp in the Option 2 Input parameter.

Table 3 - Dual Ramp Start Parameters

Parameter	Adjustments
PF Option	Standard
Starting Mode	Full Voltage, Current Limit, Soft Start, Linear Speed
Ramp Time	0…30 s
Initial Torque	0…90% LRT
Current Limit Level	50…600% FLC
Torque Limit	0…100% LRT
Kickstart Time	0.0…2.0 s
Kickstart Level	0…90% LRT
Option 2 Input	Dual Ramp
Starting Mode 2	Full Voltage, Current Limit, Soft Start, Linear Speed
Start Time 2	0…30 s
Initial Torque 2	0…90% LRT
Current Limit Level 2	50…600% FLC
Torque Limit 2	0…100% LRT
Kickstart Time 2	0.0…2.0 s
Kickstart Level 2	0…90% LRT
Stop Mode	Disable
Stop Time	0 s

Figure 9 - Dual Ramp Start Sequence of Operation

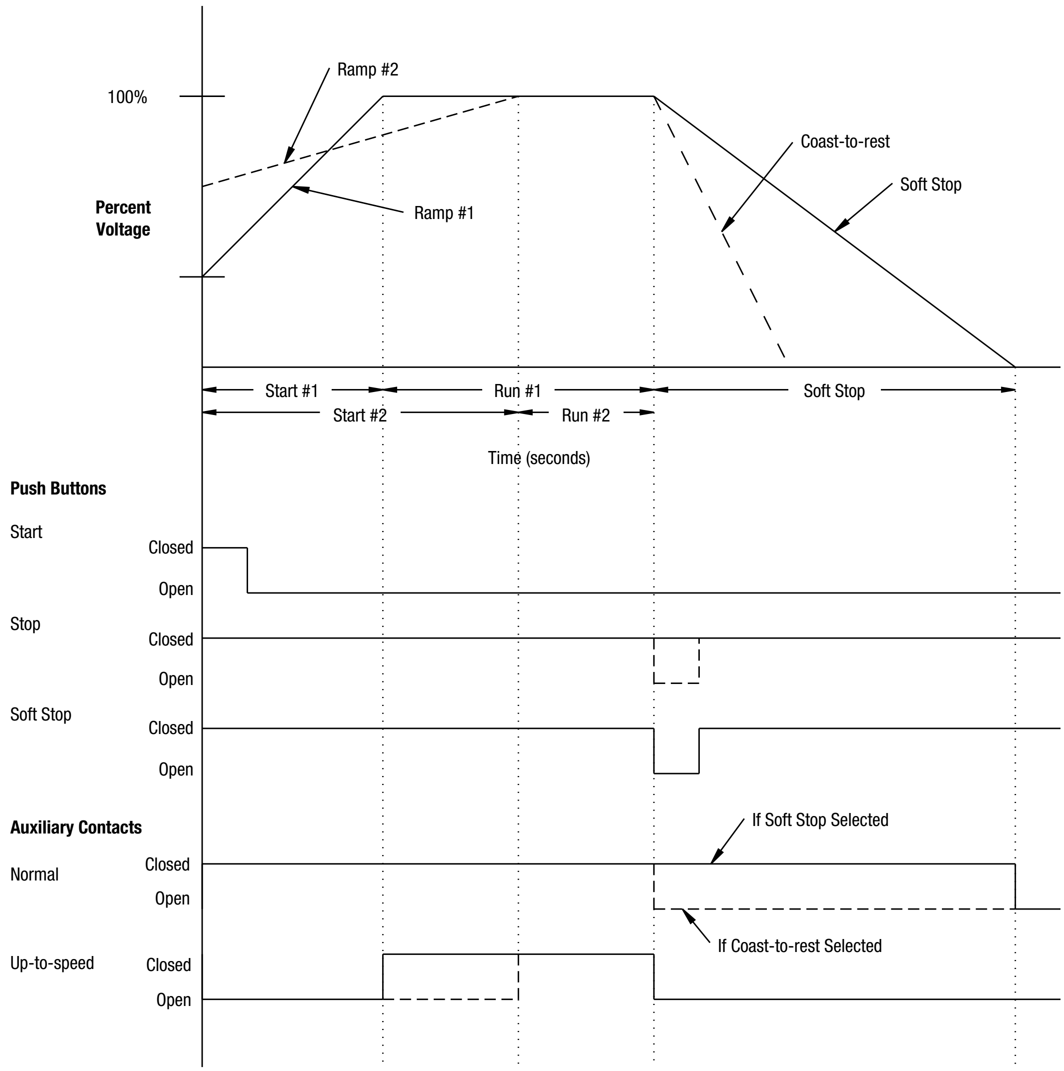
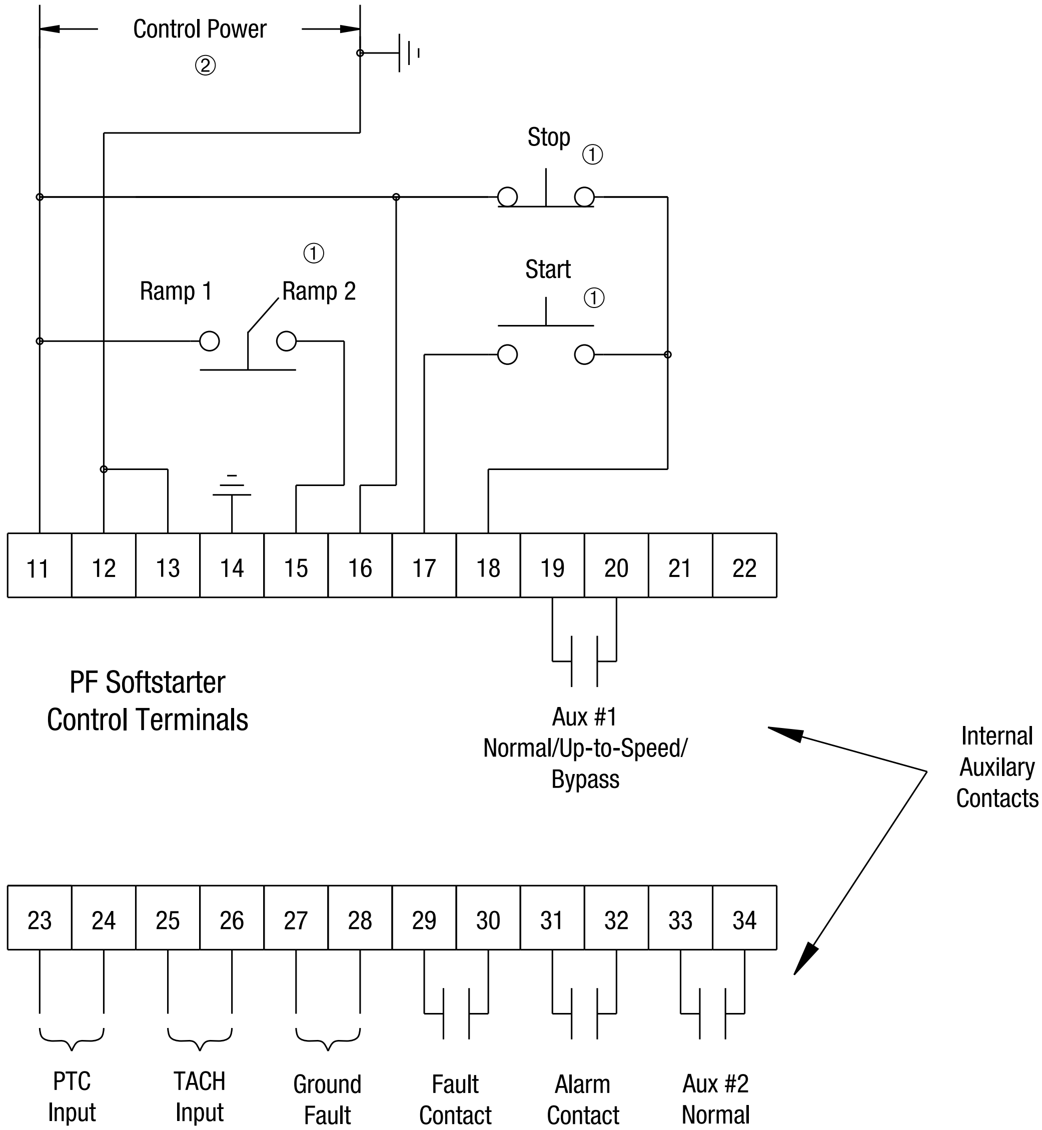


Figure 10 - Dual Ramp Start Wiring Diagram



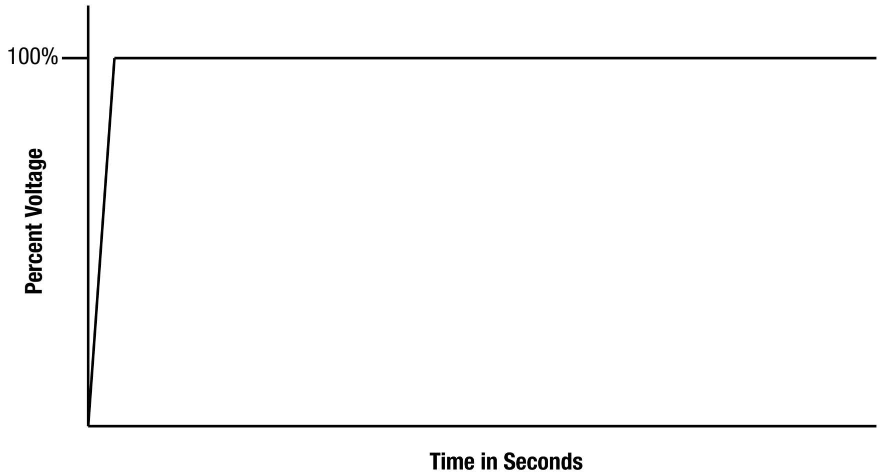
① Customer supplied.
② Refer to the controller nameplate to verify the rating of the control power input rating.

Full Voltage Start

This method is used in applications requiring across-the-line starting. The PF Softstarter controller performs like a solid-state contactor. Full inrush current and locked rotor torque are realized.

The PF Softstarter may be programmed to provide full voltage start in which the output voltage to the motor reaches full voltage in ¼ second.

Figure 11 - Full Voltage Start



The basic parameter setup for Full Voltage Start follows:

Table 4 - Full Voltage Start Parameters

Parameter	Adjustments
PF Option	Standard, Braking, Pump
Starting Mode	Full Voltage
Stop Mode	Disable
Stop Time	0 s

Figure 12 - Full Voltage Start Sequence of Operation

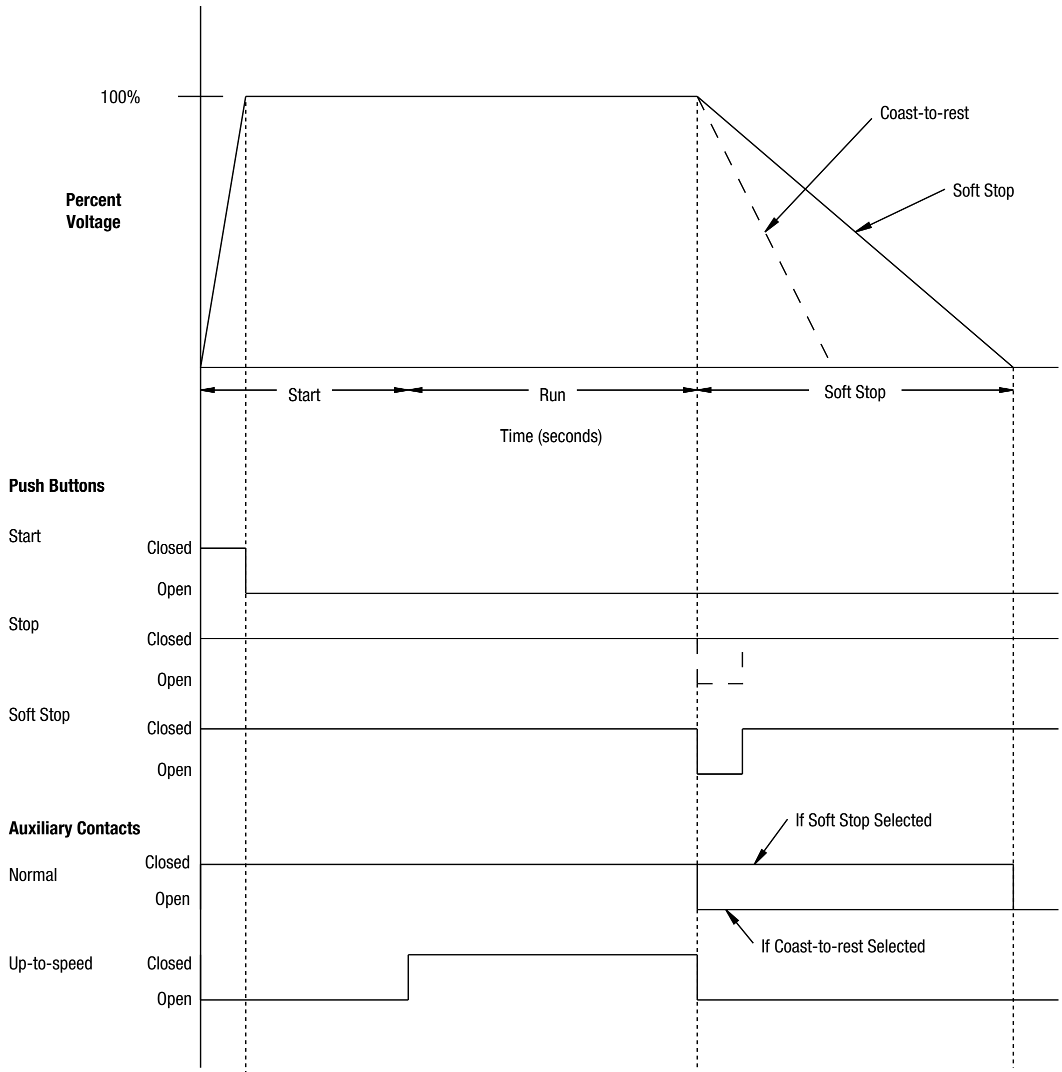
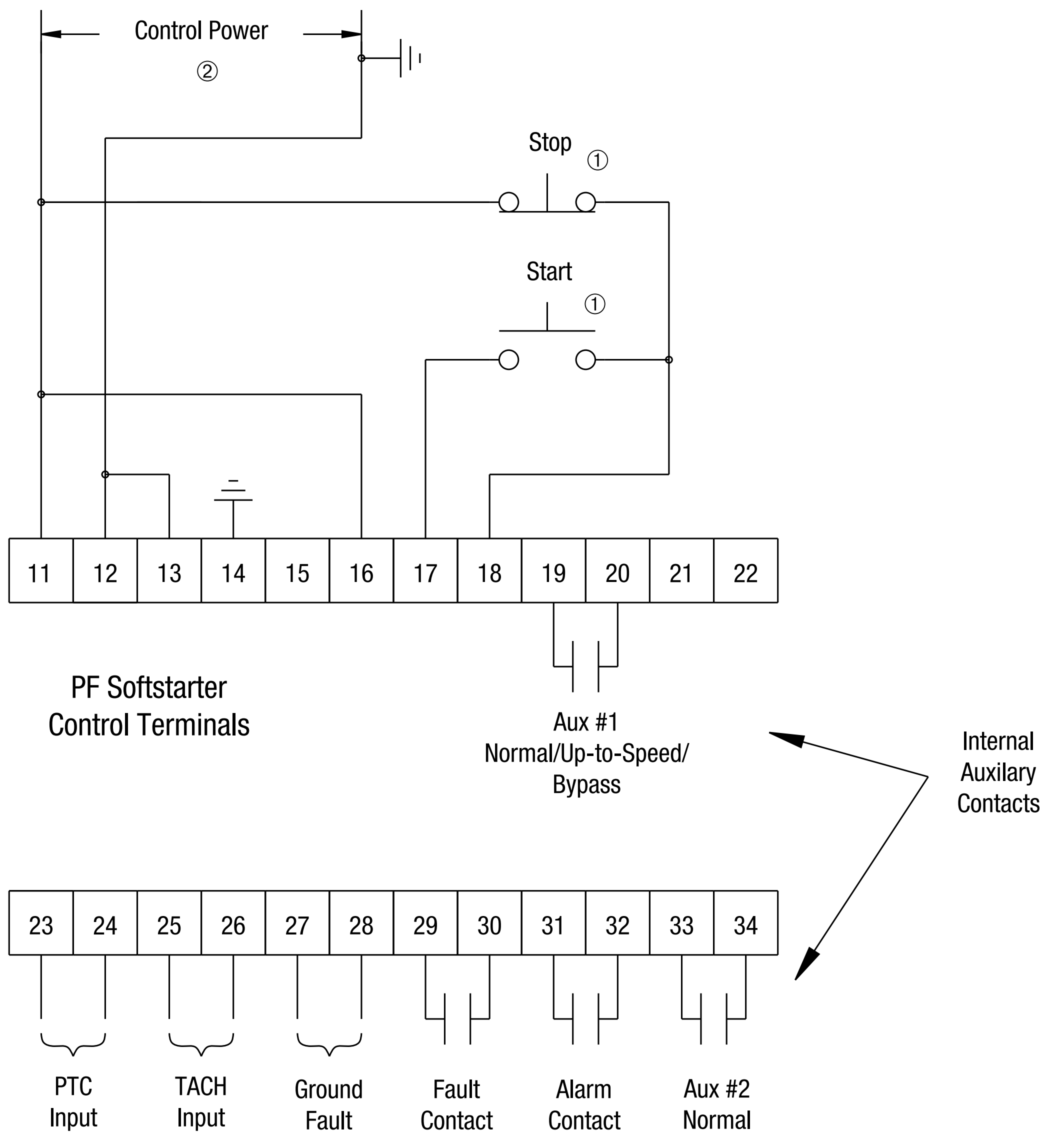


Figure 13 - Full Voltage Start Wiring Diagram

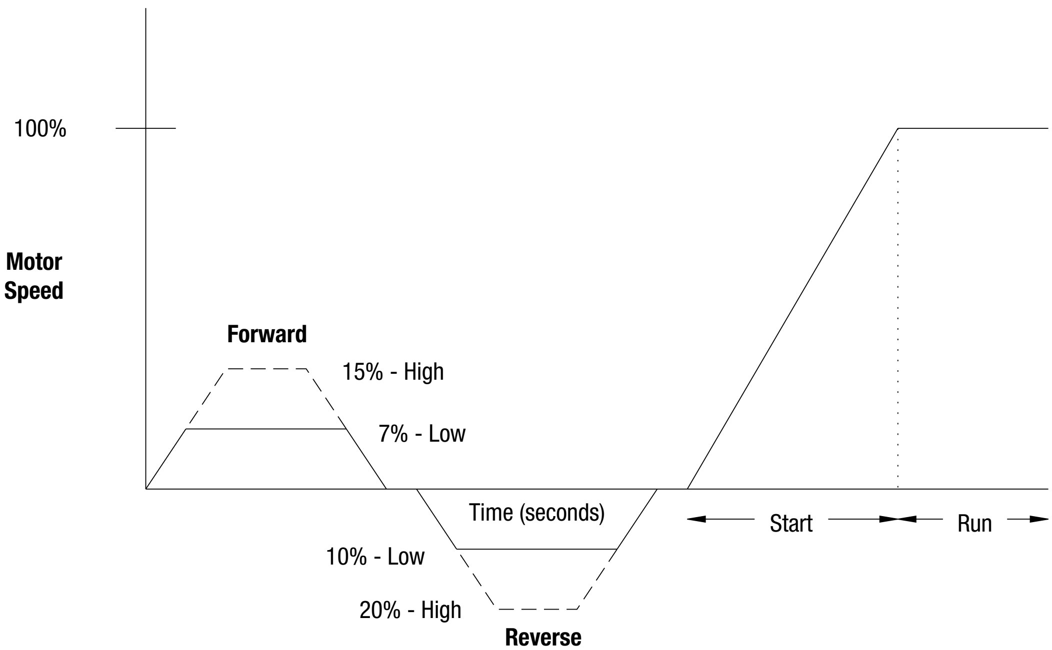


① Customer supplied.
② Refer to the controller nameplate to verify the rating of the control power input rating.

Preset Slow Speed

This method can be used on applications that require a slow speed for positioning material. The Preset Slow Speed can be set for either Low, 7% of base speed, or High, 15% of base speed. Reversing is also possible through programming. Speeds provided during reverse operation are Low, 10% of base speed, or High, 20% of base speed.

Figure 14 - Preset Slow Speed



The basic parameter setup for Soft Start selection with Preset Slow Speed Option follows:

Table 5 - Preset Slow Speed Parameters

Parameter	Adjustments
PF Option	Standard, Braking
Starting Mode	Full Voltage, Current Limit, Soft Start, Linear Speed
Ramp Time	0…30 s
Initial Torque	0…90% LRT
Current Limit Level	50…600% FLC
Torque Limit	0…100% LRT
Kickstart Time	0.0…2.0 s
Kickstart Level	0…90% LRT
Option 2 Input	Preset SS
Stop Mode	Disable
Stop Time	0 s
Slow Speed Sel	SS Low, SS High
Slow Speed Dir	SS Forward, SS Reverse
Slow Accel Cur	0…450% FLC
Slow Running Cur	0…450% FLC

Figure 15 - Preset Slow Speed Sequence of Operation

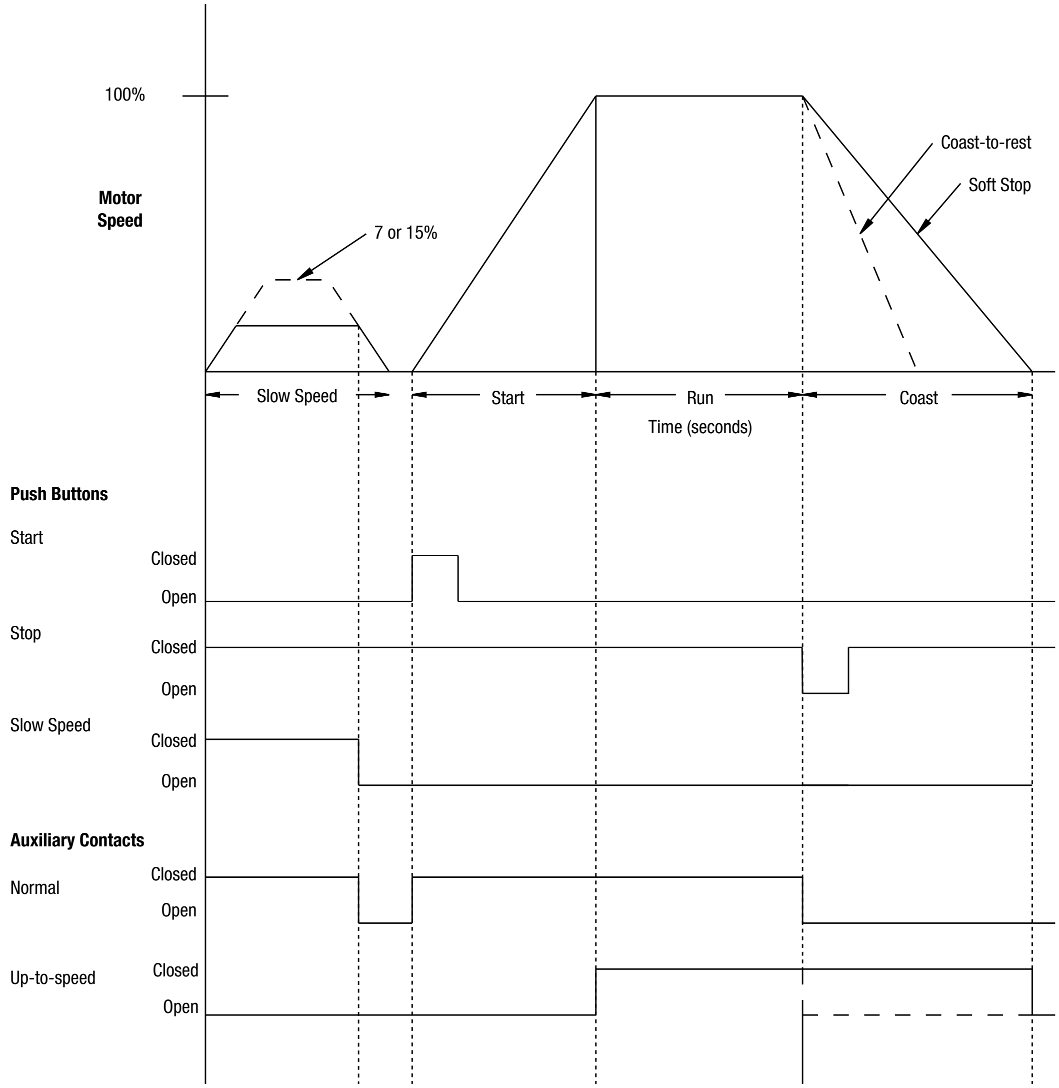
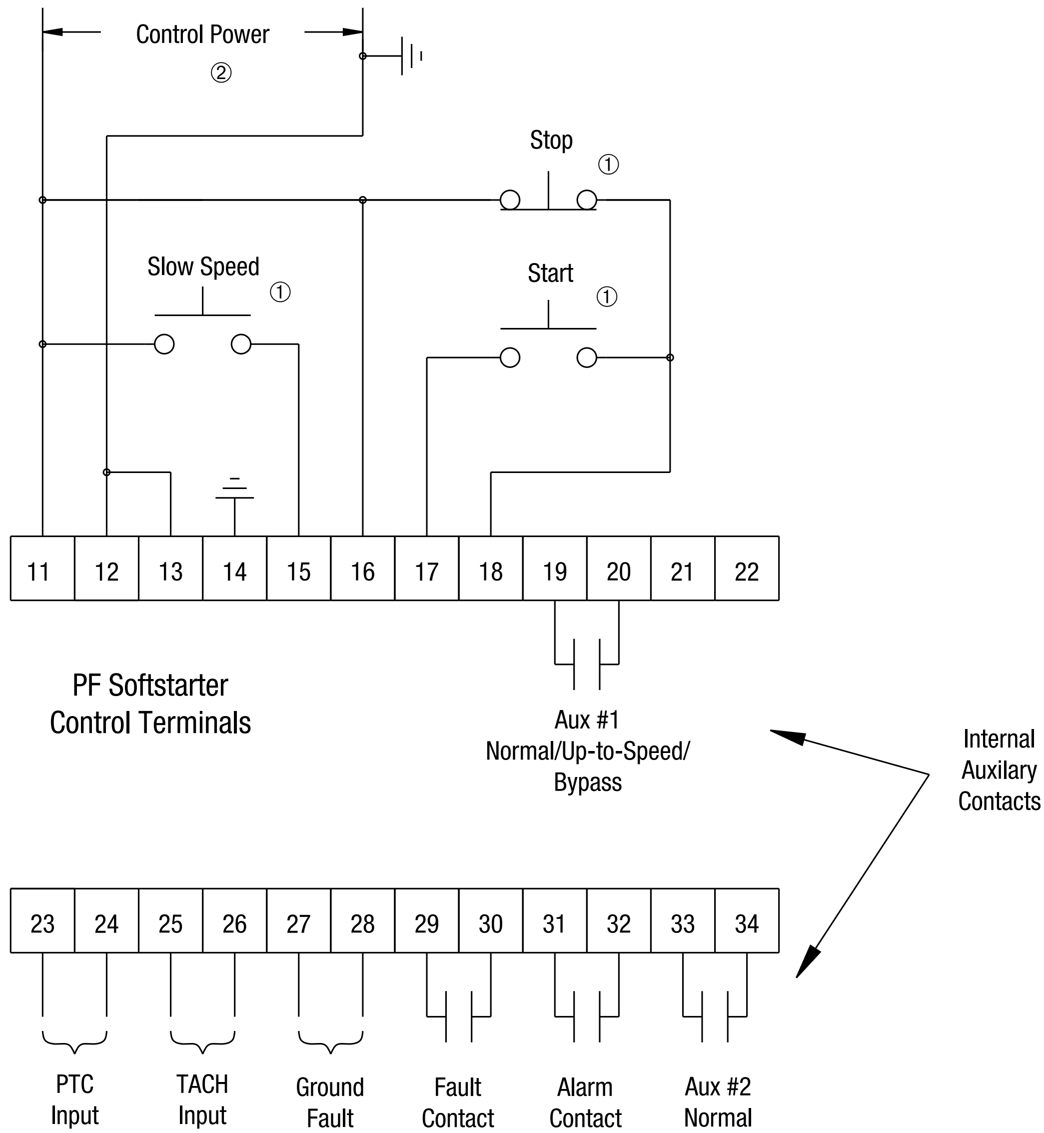


Figure 16 - Preset Slow Speed Wiring Diagram



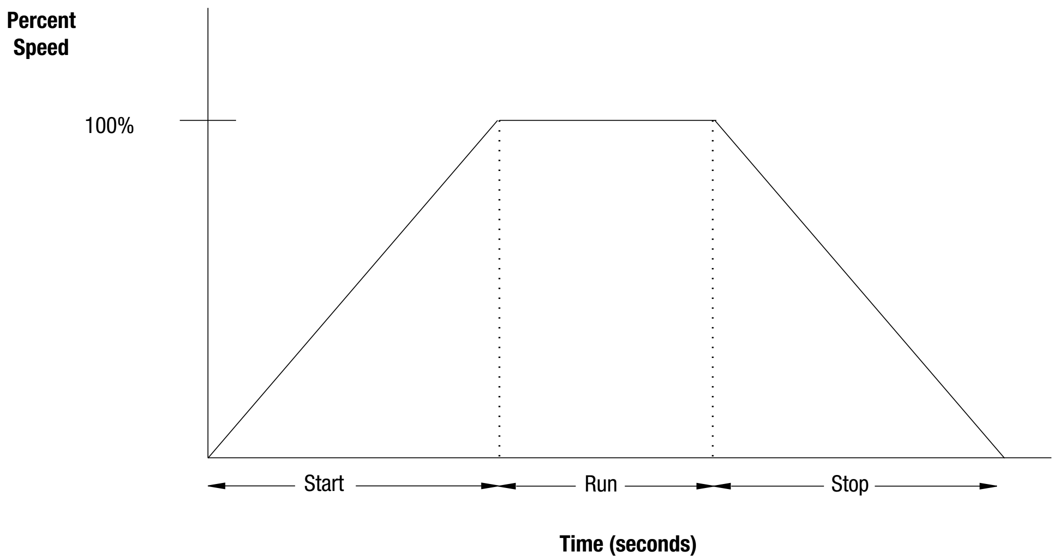
① Customer supplied.
② Refer to the controller nameplate to verify the rating of the control power input rating.

Linear Speed Acceleration with Selectable Kickstart

This method starts the motor following a linear speed ramp. The ramp time defines the time the motor will ramp from zero speed to full speed. This ramp time is user adjustable from 0…30 seconds. Linear Speed requires a tachometer input (0…5V DC, 4.5 V = 100% speed). The current limit is active during the starting ramp.

The kickstart feature provides a boost at startup to break away loads that may require a pulse of high torque to get started. It is intended to provide a current pulse, user adjustable 0…90% locked rotor torque for a selected period of time, 0.0…2.0 seconds. Note that speed ramp begins once the kickstart is completed.

Figure 17 - Linear Speed Acceleration



The basic parameter set for Linear Speed follows:

Table 6 - Linear Speed Acceleration Parameters

Parameter	Adjustments
PF Option	Standard
Starting Mode	Linear Speed
Ramp Time	0.0…30.0 s
Current Limit Level	0…600% FLC (Full Load Current)
Kickstart Time	0.0…2.0 s
Kickstart Level	0…90% LRT
Option 2	Disable
Stop Mode	Linear Speed
Stop time	0.0…120.0 s

Figure 18 - Linear Speed Acceleration Sequence of Operation

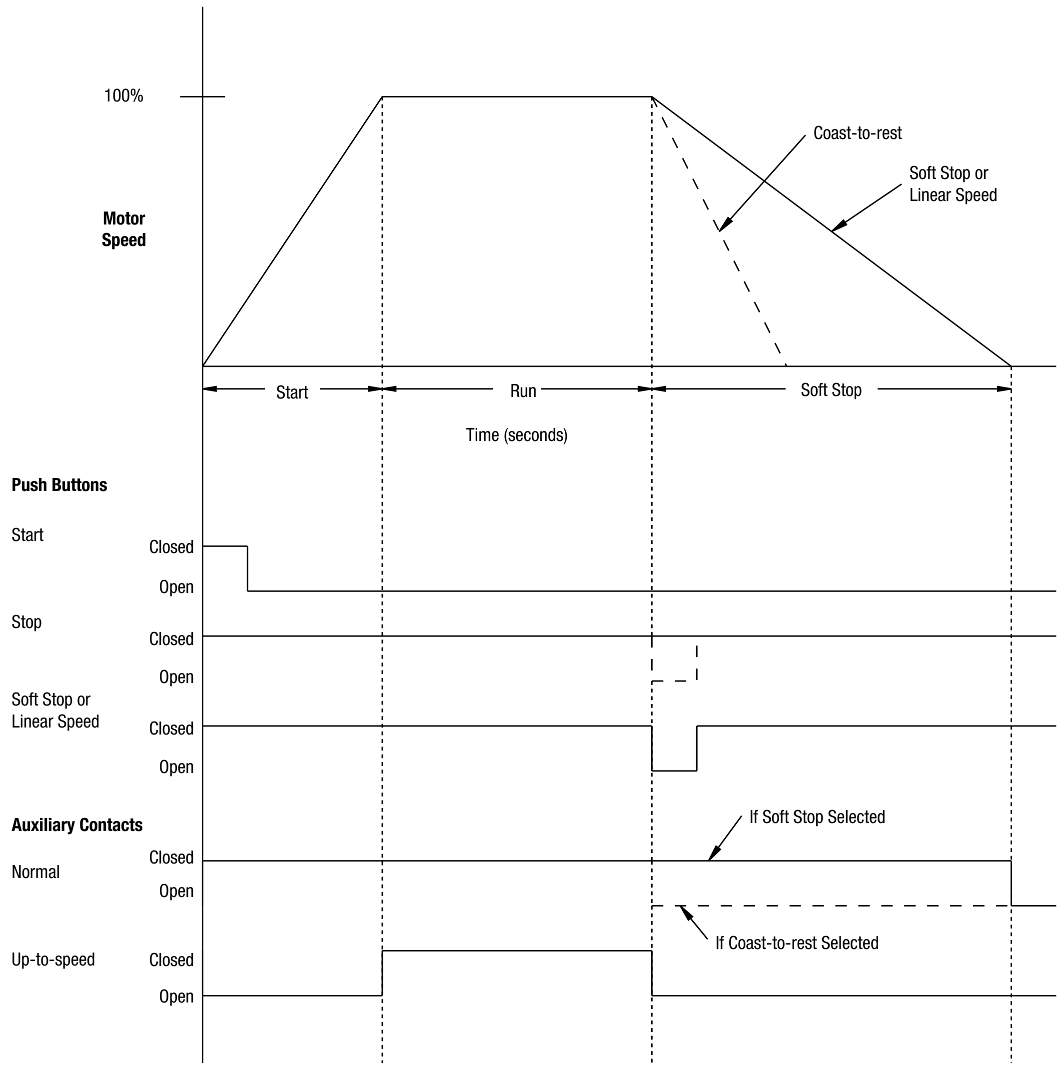
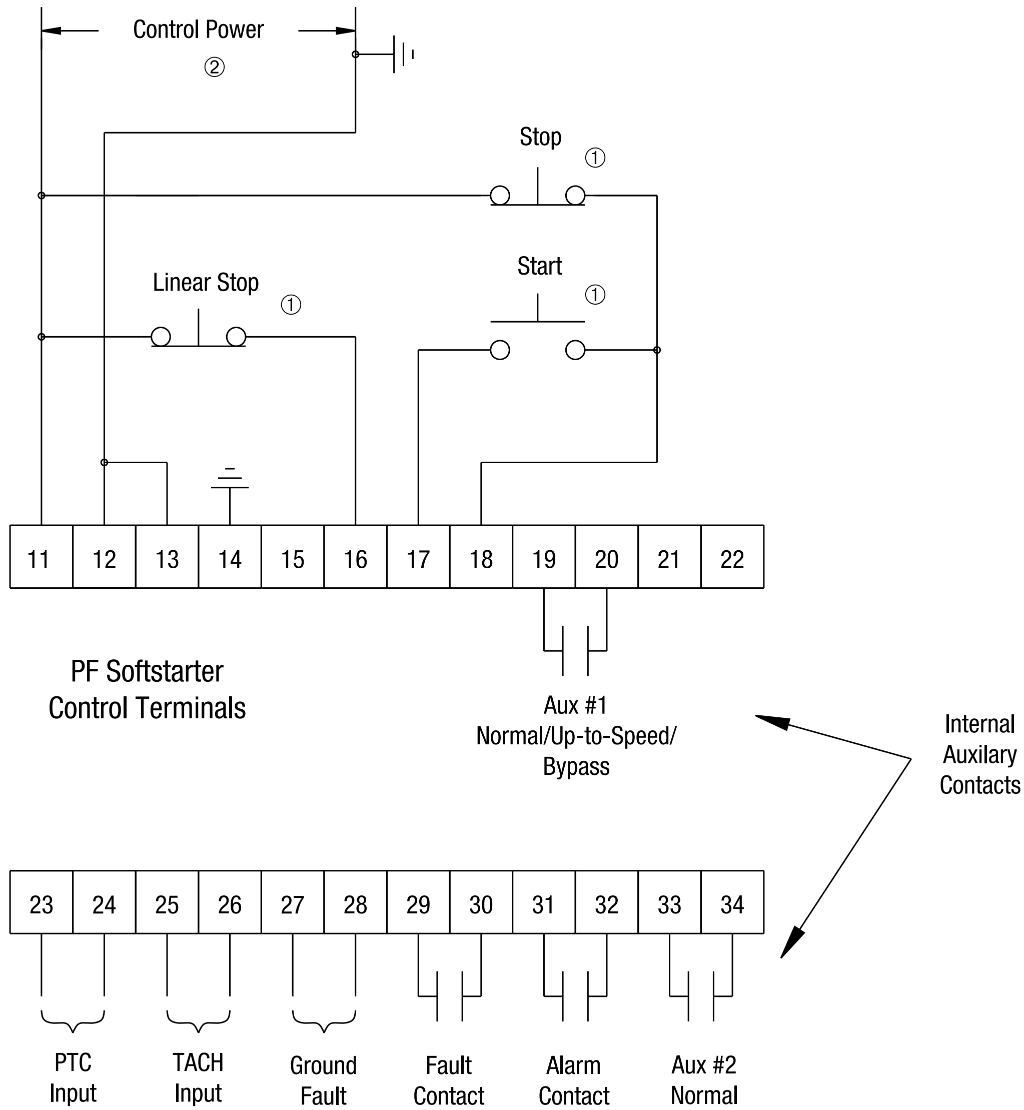


Figure 19 - Linear Speed Acceleration Wiring Diagram

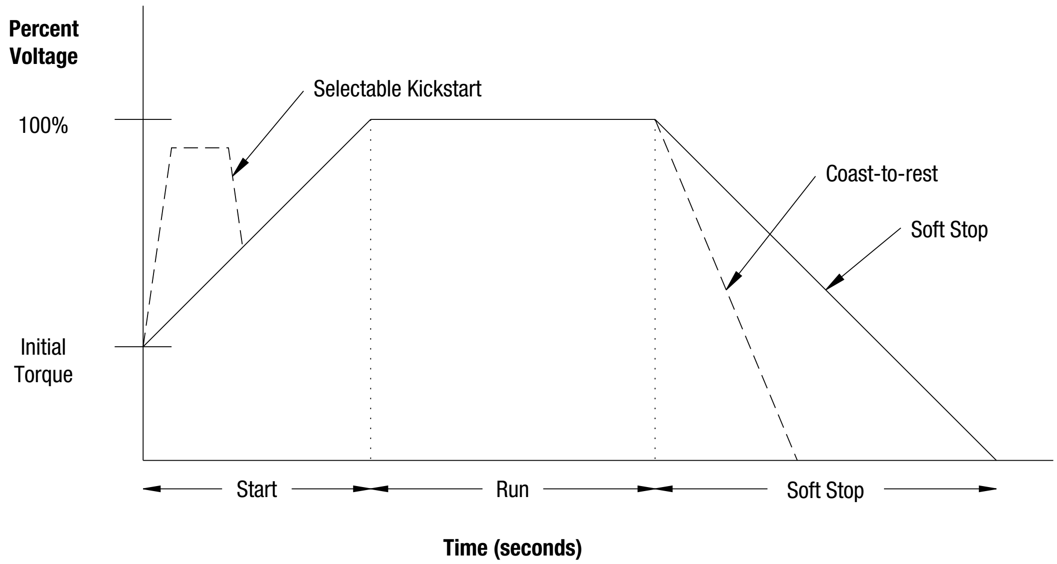


① Customer supplied.
② Refer to the controller nameplate to verify the rating of the control power input rating.

Soft Stop

The Soft Stop option can be used in applications requiring an extended coast-to-rest. The voltage ramp down time is user adjustable from 0…120 seconds. The Soft Stop time is adjusted independently from the start time. The load will stop when the voltage drops to a point where the load torque is greater than the motor torque.

Figure 20 - Soft Stop



The basic parameter setup for Soft Stop follows:

Table 7 - Soft Stop Parameters

Parameter	Adjustments
PF Option	Standard, Braking, Pump
Stop Mode	Soft Stop
Stop Time	0…120 seconds

Figure 21 - Soft Stop Sequence of Operation

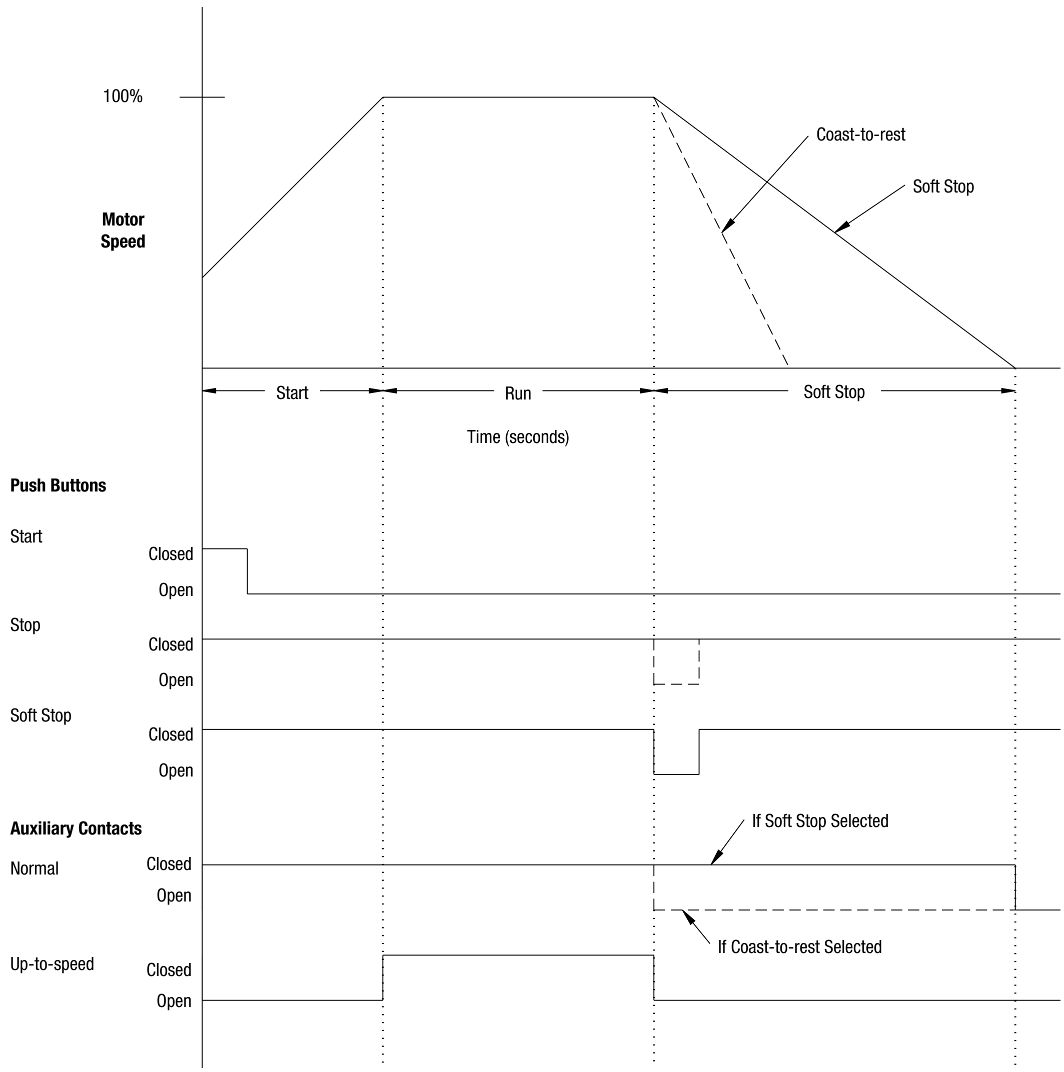
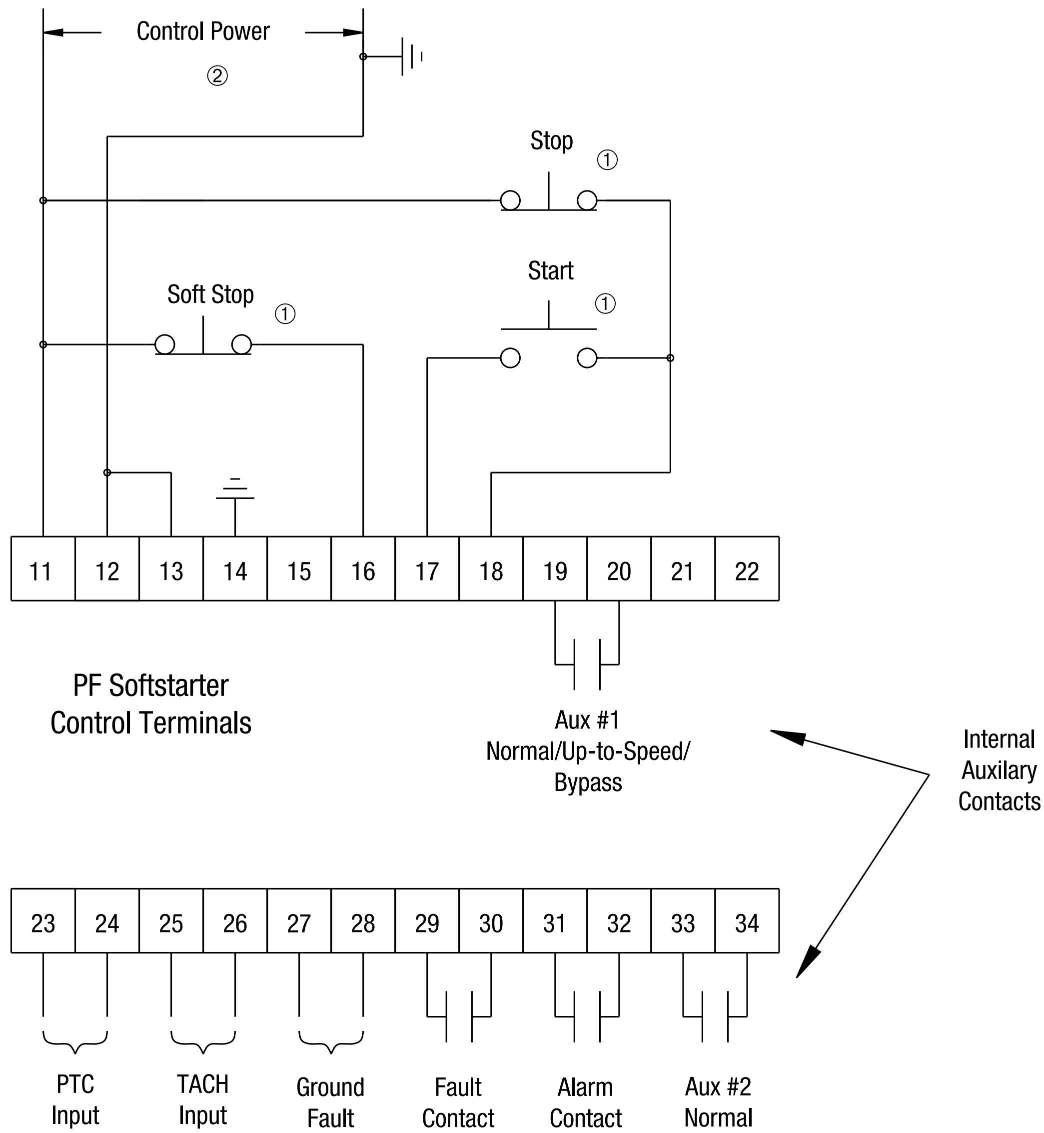


Figure 22 - Soft Stop Wiring Diagram



① Customer supplied.
② Refer to the controller nameplate to verify the rating of the control power input rating.

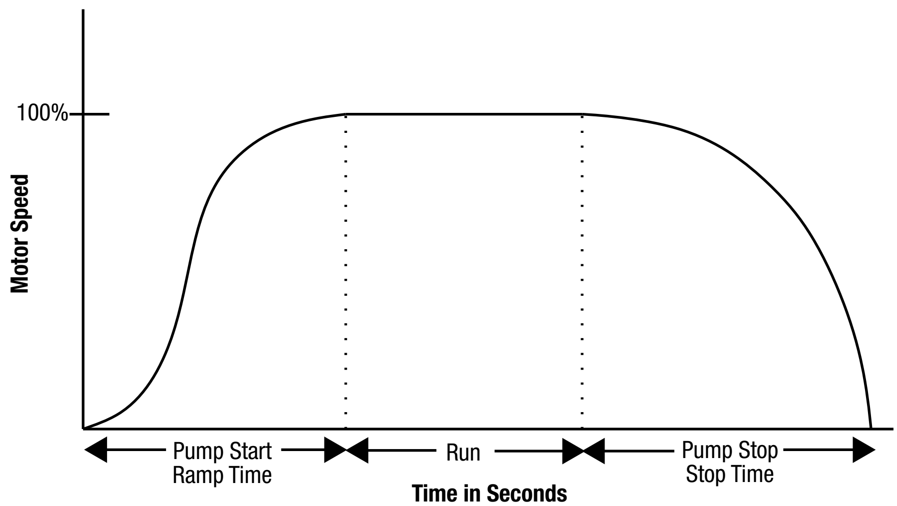
Pump Control

Pump Control Option with Selectable Kickstart

The PF Softstarter controller's unique interactive Pump Control is designed to reduce fluid surges in pumping systems. It provides closed loop acceleration and deceleration control of centrifugal pump motors without the need for feedback devices.

The kickstart feature provides a boost at startup to break away loads that may require a pulse of high torque to get started. It is intended to provide a current pulse with user adjustable locked rotor torque from 0-90% and kickstart time from 0.0 to 2.0 seconds.

Figure 23 - Pump Control Option with Selectable Kickstart



The basic parameter setup for Pump Control follows:

Table 8 - Pump Control Option Parameters

Parameter	Adjustments
PF Option	Pump
Starting Mode	Pump Start
Start Time	0…30 s
Initial Torque	0…90% LRT
Kickstart Time	0.0…2.0 s
Kickstart Level	0…90% LRT
Stop Time	0…120 s
Anti-Backspin Timer	0…999 s

Figure 24 - Pump Control Option Sequence of Operation

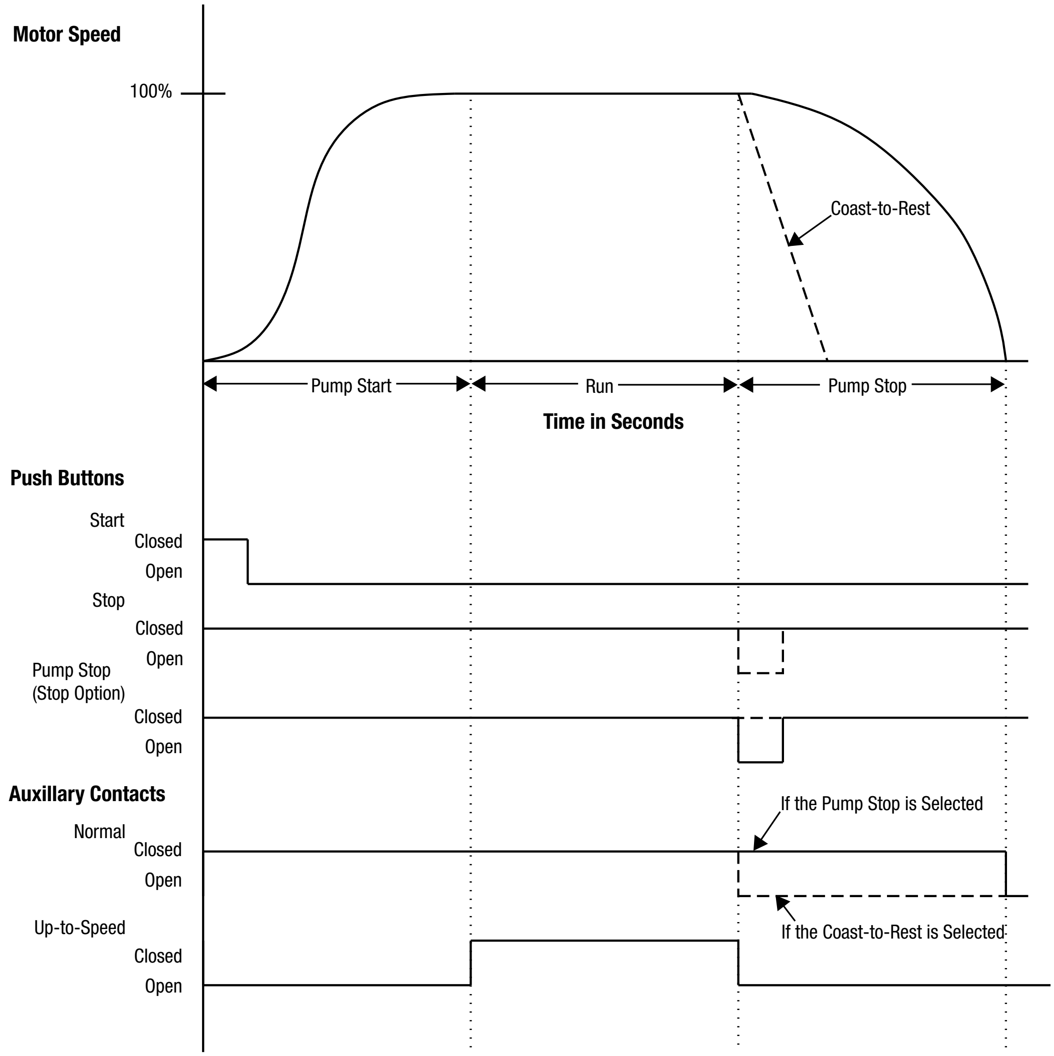
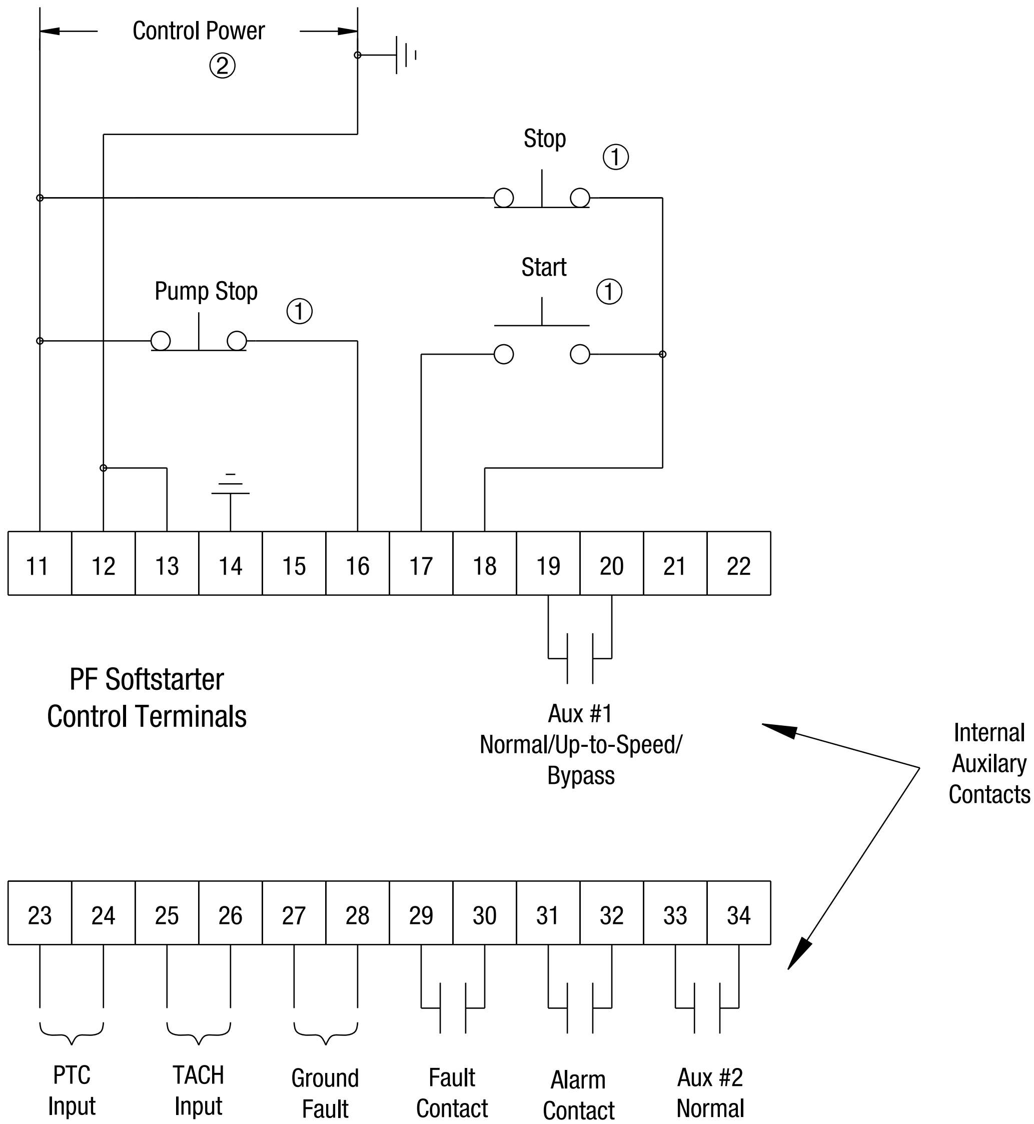


Figure 25 - Pump Control Option Wiring Diagram



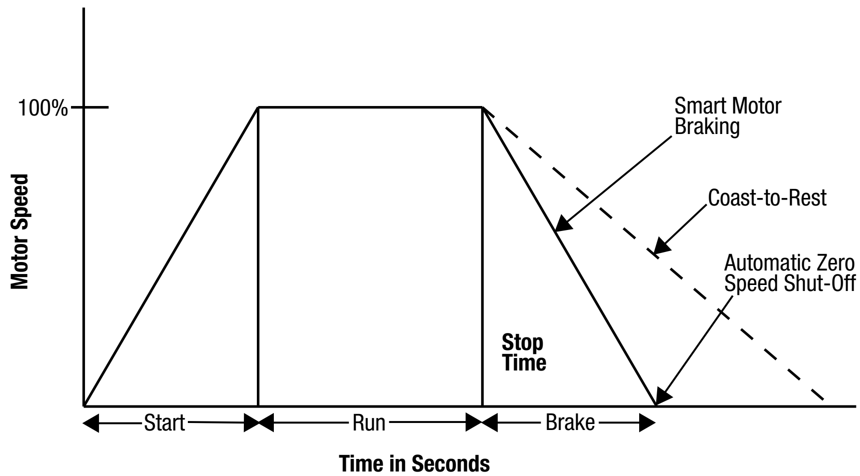
① Customer supplied.
② Refer to the controller nameplate to verify the rating of the control power input rating.

Braking Control

SMB Smart Motor Braking Option

The SMB Smart Motor Braking option provides motor braking for applications, which require the motor to stop quickly. It is a microprocessor based braking system, which applies braking current to a motor. The strength of the braking current is adjustable from 0…400% of full load current.

Figure 26 - Smart Motor Braking



The basic parameter setup for Smart Motor Braking follows:

Table 9 - Smart Motor Braking Parameters

Parameter	Adjustments
PF Option	Braking
Stop Mode	SMB
Braking Current	0…400% FLC

Figure 27 - Smart Motor Braking Sequence of Operation

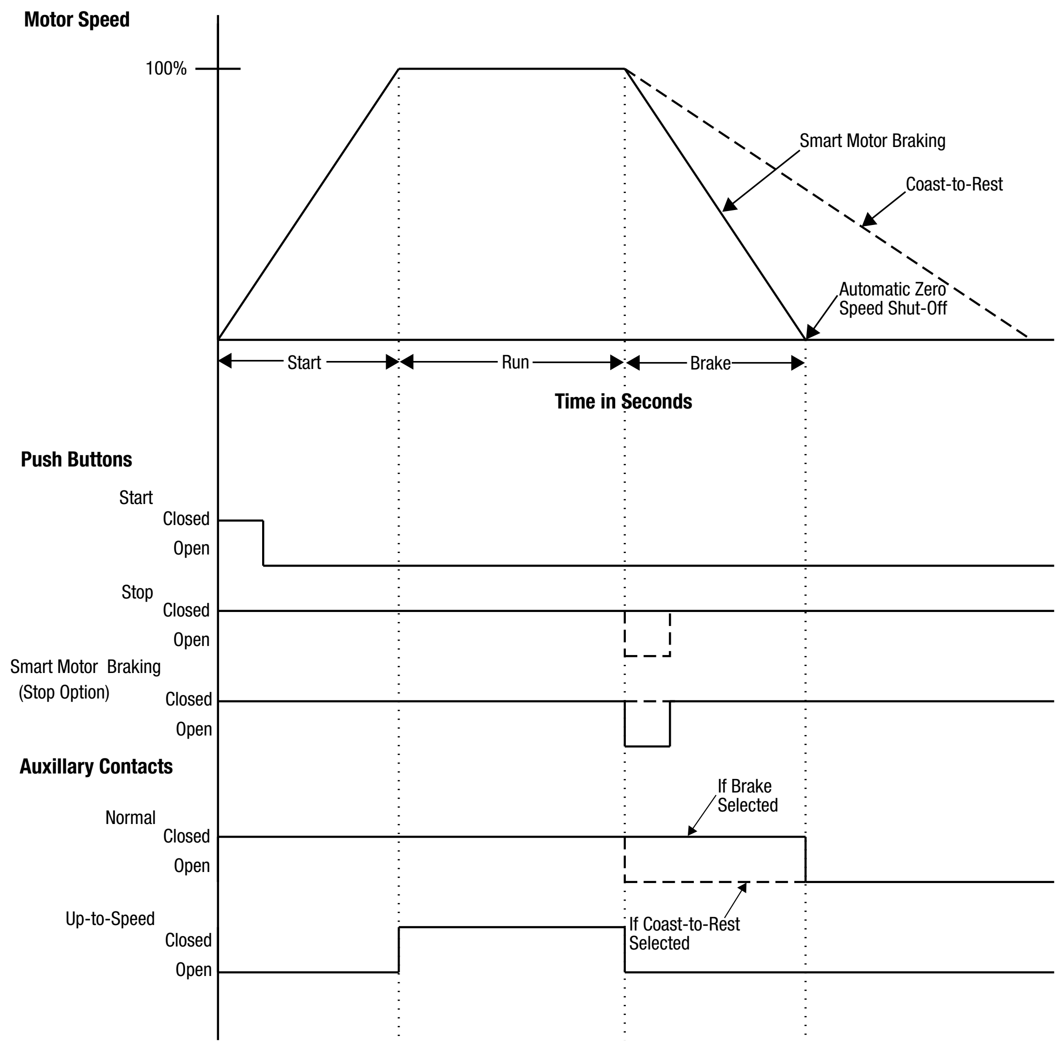
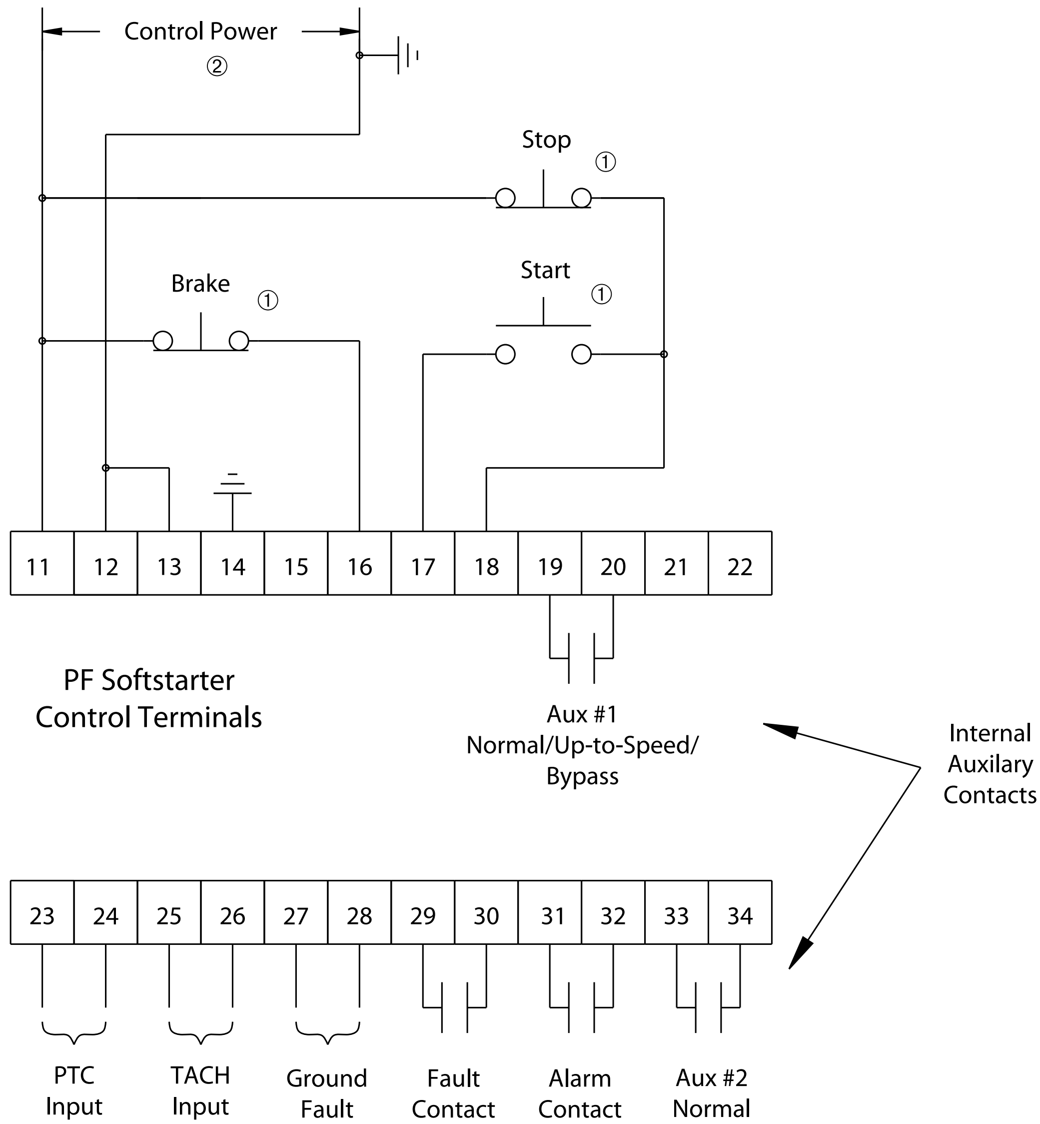


Figure 28 - Smart Motor Braking Wiring Diagram

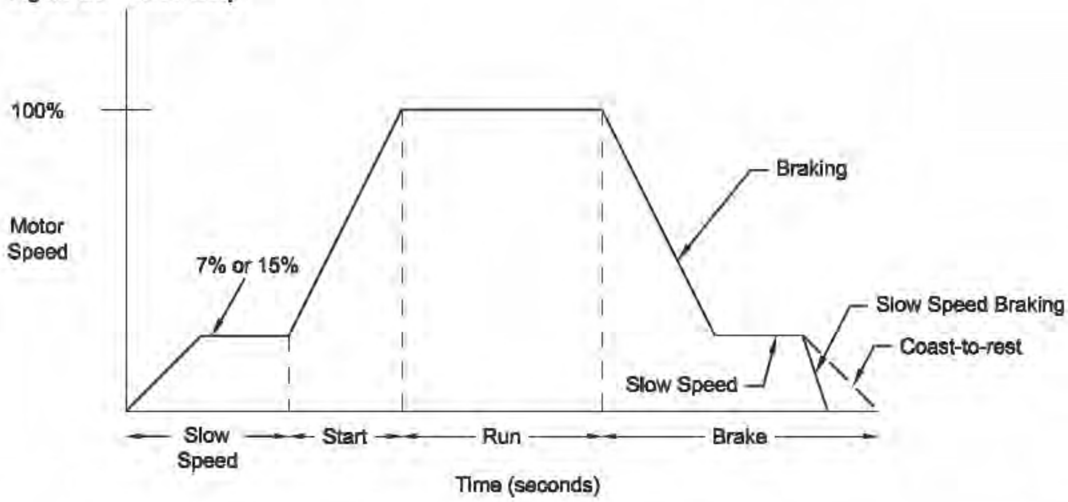


① Customer supplied.
② Refer to the controller nameplate to verify the rating of the control power input rating.

Accu-Stop

The Accu-Stop option provides rapid braking to a slow speed, and then braking to stop, facilitating cost-effective general positioning control.

Figure 29 - Accu-Stop



The basic parameter setup for Accu-Stop follows:

Table 10 - Accu-Stop Parameters

Parameter	Adjustments
PF Option	Braking
Stop Mode	Accu Stop
Slow Speed Sel	SS Low, SS High
Slow Accel Cur	0…450% FLC
Slow Running Cur	0…450% FLC
Braking Current	0…400% FLC
Stopping Current	0…400% FLC

Figure 30 - Accu-Stop Sequence of Operation

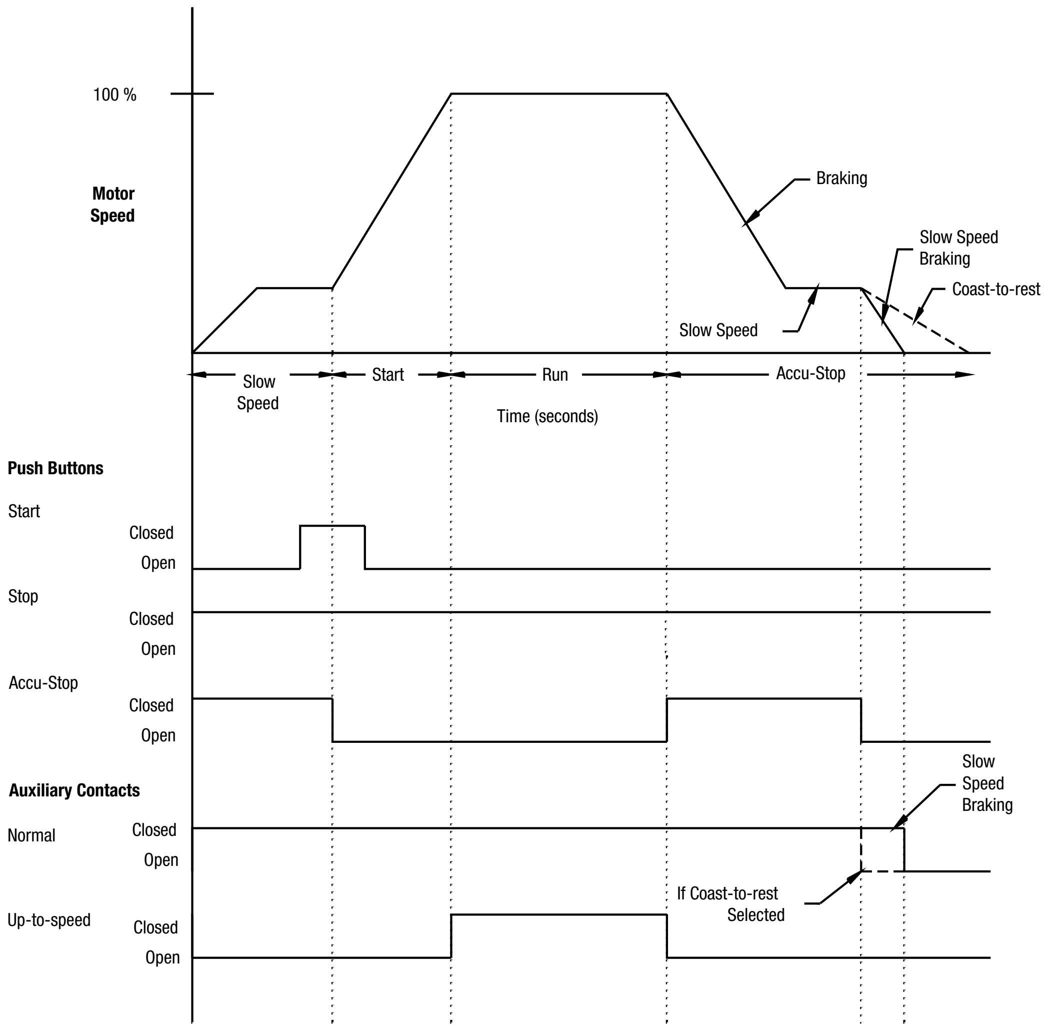
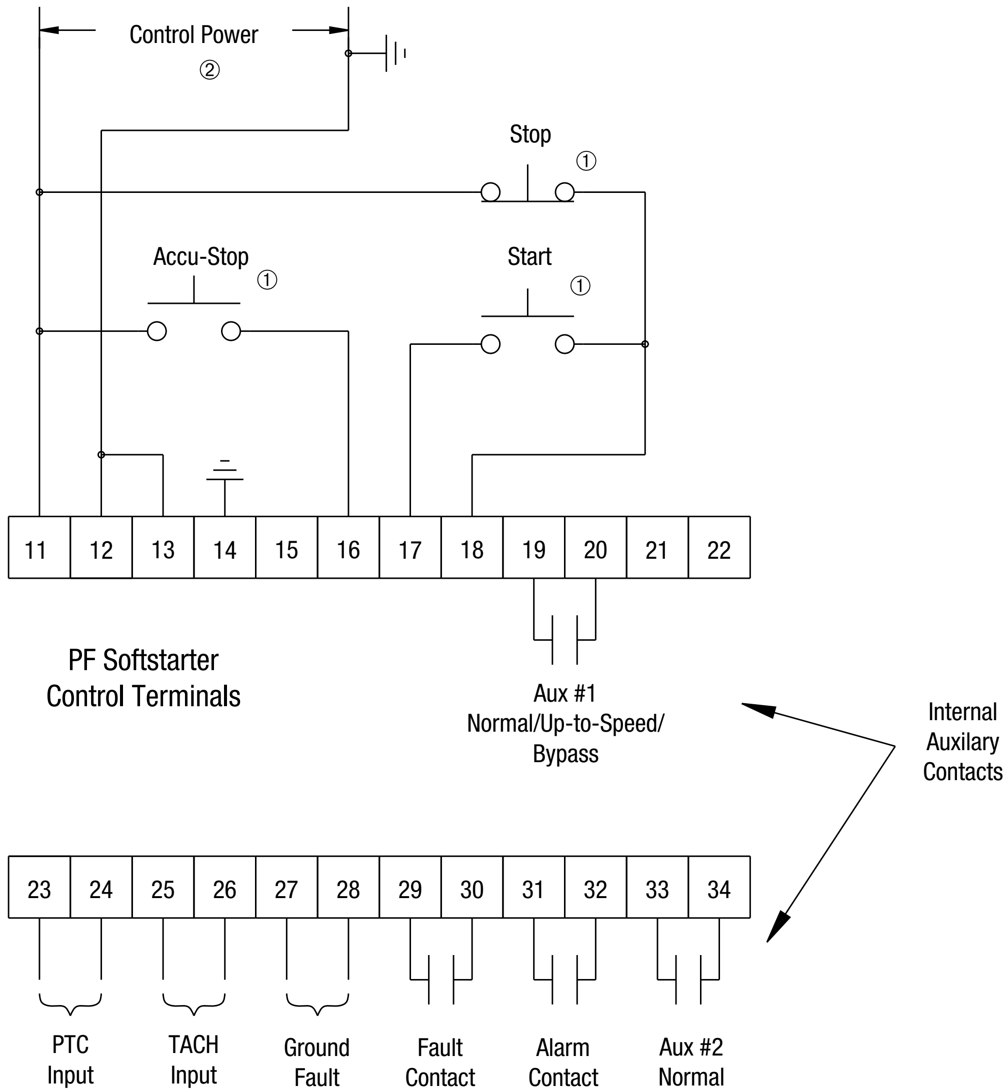


Figure 31 - Accu-Stop Wiring Diagram

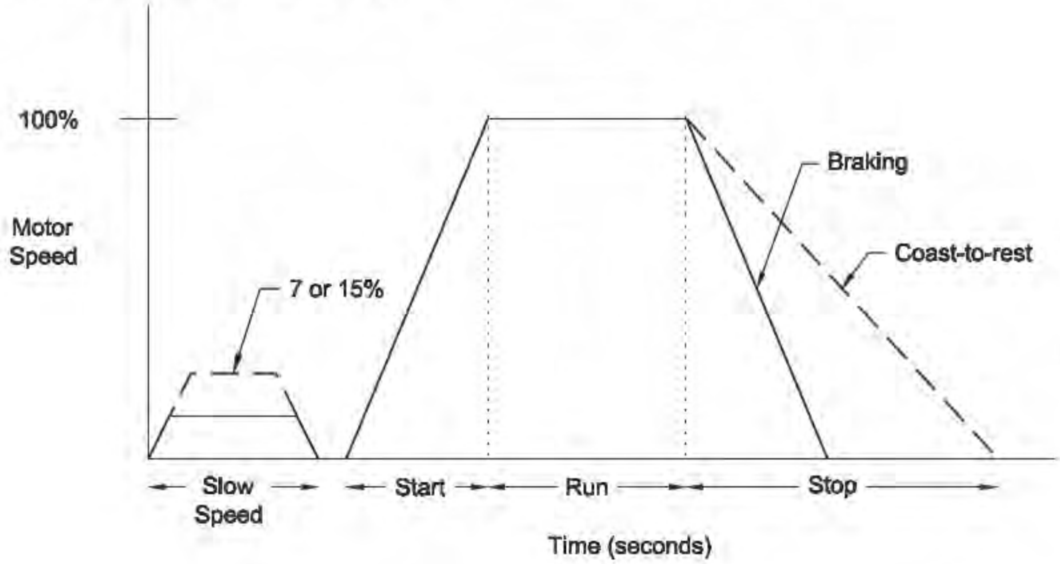


① Customer supplied.
② Refer to the controller nameplate to verify the rating of the control power input rating.

Slow Speed with Braking

The Slow Speed with Braking option combines the benefits of the SMB Smart Motor Braking and Preset Slow Speed options for applications that require slow setup speeds and braking to a stop.

Figure 32 - Slow Speed with Braking



The basic parameter setup for Slow Speed with Braking follows:

Figure 33 - Slow Speed with Braking Parameters

Parameter	Adjustments
PF Option	Braking
Option 2 Input	Preset SS
Slow Speed Sel	SS Low, SS High
Slow Speed Dir	SS Forward, SS Reverse
Slow Accel Cur	0…450% FLC
Slow Running Cur	0…450% FLC
Stop Mode	SMB
Braking Current	0…400% FLC

Figure 34 - Slow Speed with Braking Sequence of Operation

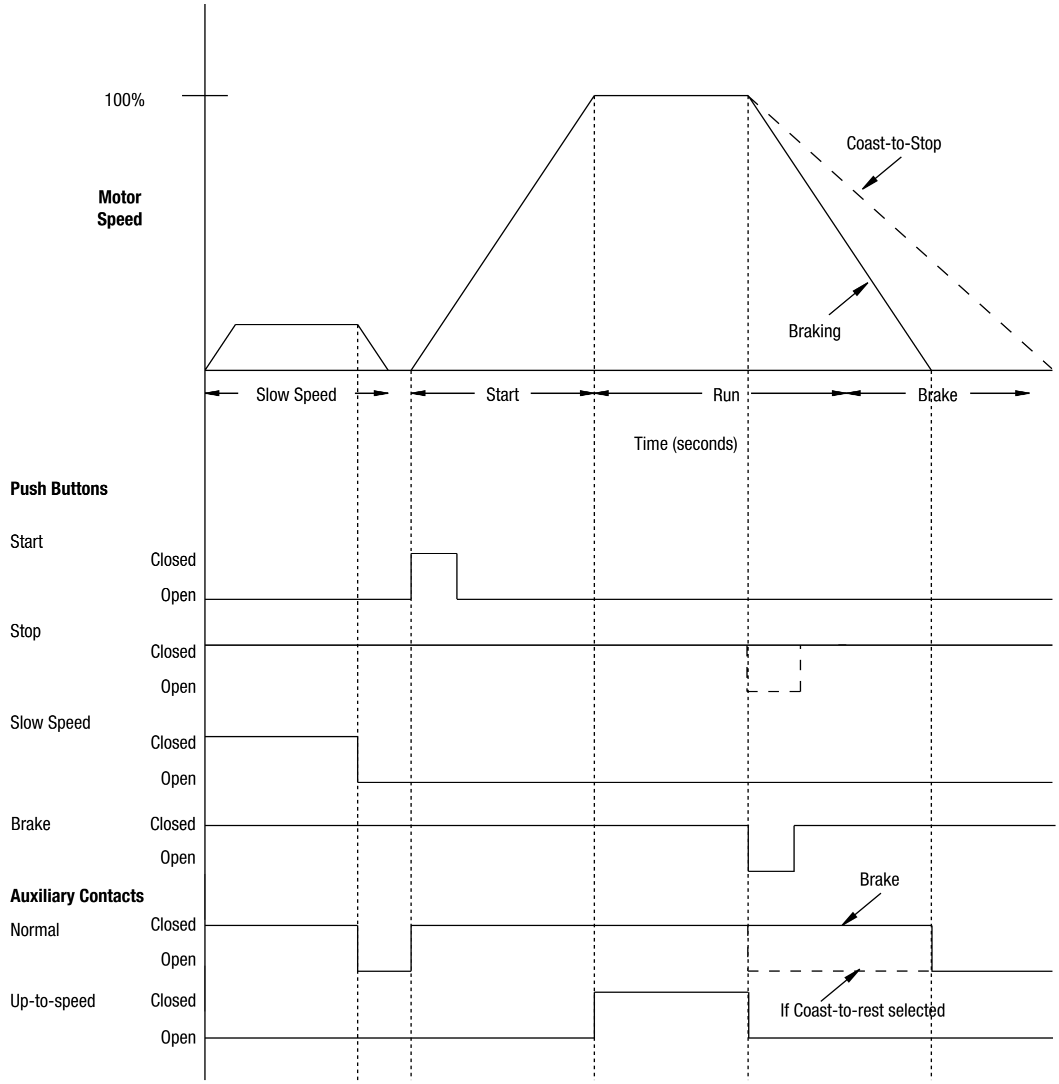
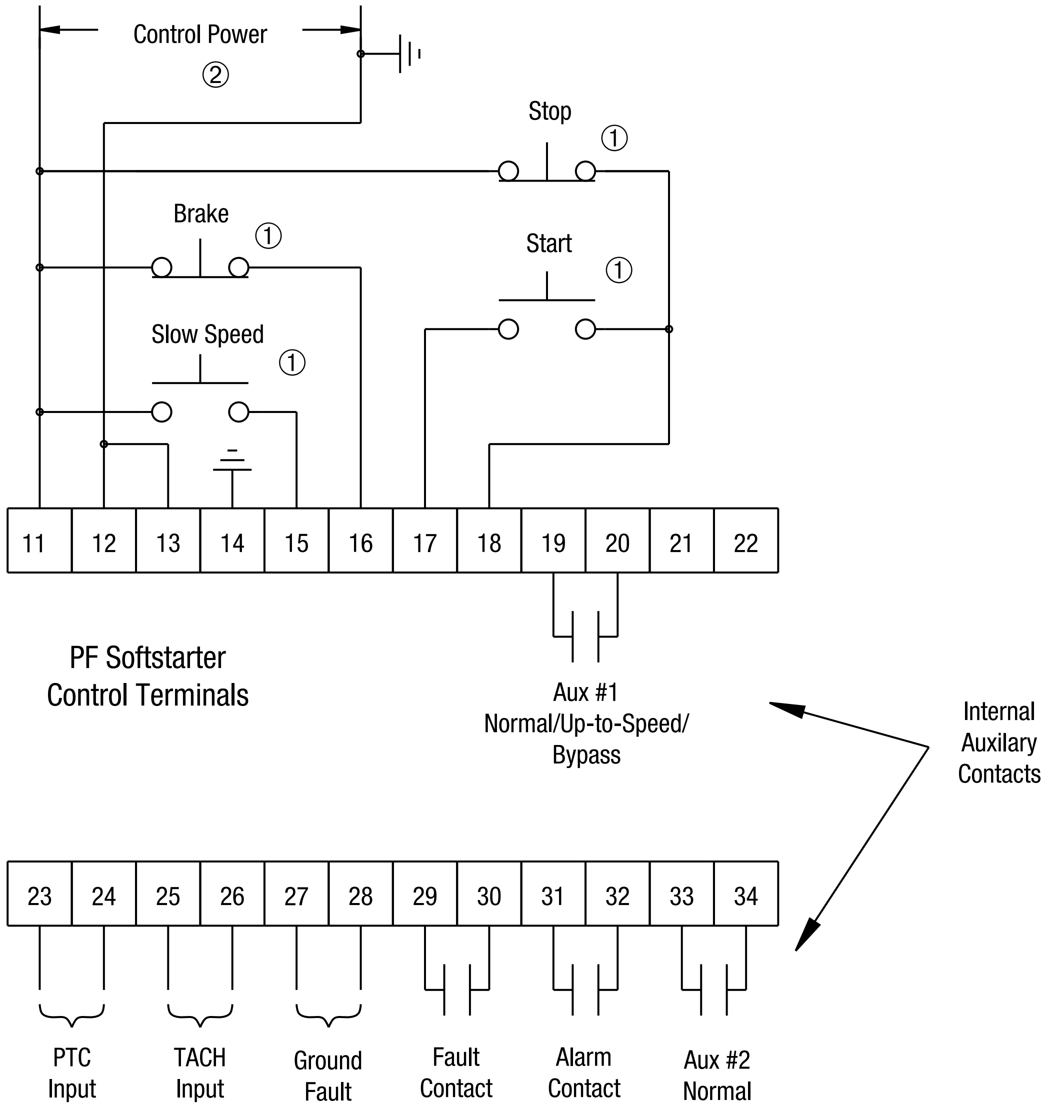


Figure 35 - Slow Speed with Braking Wiring Diagram



① Customer supplied.
② Refer to the controller nameplate to verify the rating of the control power input rating.

Features

SCR Bypass

The PF Softstarter has a built-in bypass contactor that is automatically pulled in when the motor reaches full speed. An external bypass contactor may be used. When an external bypass contactor is enabled (by setting the parameter "Aux1 Config" to "Bypass") the internal bypass contactor will not be used, and a separate overload is required.

Standard or Wye-Delta Wiring

The PF Softstarter can operate either a standard squirrel-cage induction motor or a wye-delta motor. The user must program the selected configuration into the unit using the "Motor Connection" parameter. The wye-delta motor is connected in an inside-the-delta wiring configuration, and the Motor Connection is set to Delta.

LCD Display

A graphical backlit LCD display provides parameter definition with straightforward text so that controller setup may be accomplished without a reference manual. Parameters are arranged in an organized three-level menu structure for ease of programming and fast access to parameters.

The displayed language can also be changed to meet global customer needs.

Parameter Programming

Programming of parameters is accomplished through a five-button keypad on the front of the PF Softstarter controller. The five buttons include up and down arrows, an Enter button, a Select button, and an Escape button. The user needs only to enter the correct sequence of keystrokes for programming the PF Softstarter controller.

Figure 36 - LCD Display with Keypad

Electronic Overload

The PF Softstarter controller meets applicable requirements as a motor overload protective device. Overload protection is accomplished electronically through current sensors and an I2t algorithm.

The overload trip class is selectable for OFF, 10, 15, 20, or 30 protection. The trip current is set by entering the motor's full load current rating and the service factor.

Thermal memory is included to model motor operating and cooling temperatures. Ambient insensitivity is inherent in the electronic design of the overload.

Stall Protection and Jam Detection

Motors can experience locked rotor currents and develop maximum torque in the event of a stall (during start) or a jam (after full speed is reached). These conditions can result in winding insulation breakdown or mechanical damage to the connected load.

The PF Softstarter controller provides both stall and jam detection for enhanced motor and system protection. Stall protection allows the user to program a maximum stall time of up to 10 seconds. Jam detection allows the user to determine the jam level as a percentage of the motor's full load current rating, and a trip delay time of up to 99 seconds.

The stall trip delay time is in addition to the programmed start time.

Figure 37 - Stall Protection Sequence of Operation

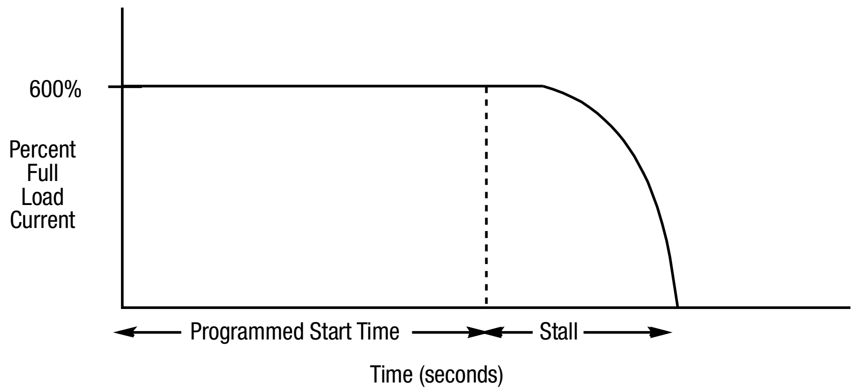
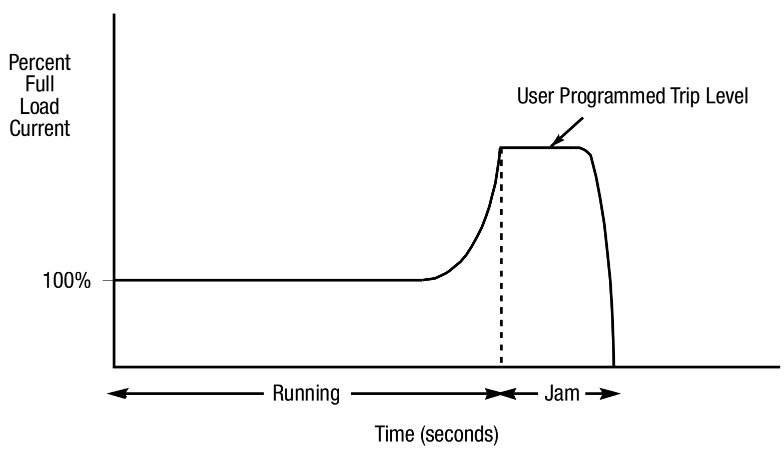


Figure 38 - Jam Detection Sequence of Operation



Ground Fault Protection

The PF Softstarter Controller can sense ground faults before they become "short circuits." Ground faults generally start at low levels (amps), but can rapidly increase to hundreds or thousands of amperes. This feature is not intended as a ground fault circuit-interrupter for personnel protection. The Ground Fault protection settings are user-adjustable. A separate Cat. No. 825-CBCT core balance current transformer is required for setup of this feature.

Thermistor Input

The PF Softstarter controller offers enhanced motor protection with additional circuitry to monitor motor stator-embedded positive temperature coefficient (PTC) thermistors. The PTC acts as a thermally sensitive resistor. It exhibits a large sudden increase in resistance at its activation temperature rating. Excessive motor heating can still occur without the motor being overloaded. Such over-heating can result from blocked motor ventilation or high ambient temperatures, and the PTC will help identify this. The thermistor input settings are user adjustable. See the User Manual for more details.

Metering

The PF Softstarter controller contains several power monitoring parameters as standard. These parameters include:

- Three-phase current
- Three-phase voltage
- Power in kW
- Power usage in kWH
- Power factor
- Elapsed time
- Motor thermal capacity usage

Fault Indication

The PF Softstarter controller monitors both the pre-start and running modes. If the controller senses a fault, the PF Softstarter controller shuts down the motor and displays the appropriate fault condition in the LCD display. The controller monitors the following conditions:

- Line Loss
- Shorted SCR
- Open SCR Gate
- Thermistor (PTC)
- Overtemperature (Power Pole, SCR, Motor)
- Bypass Failure
- No Load
- Overvoltage
- Undervoltage
- Overload
- Underload
- Jam
- Stall
- Phase Reversal
- Phase Unbalance
- Current Unbalance
- Voltage Unbalance
- Loss of Communication
- Power Loss
- Excessive Starts/Hour
- Ground Fault
- Motor Lead Loss
- Line Fault
- Communication Fault

Any fault condition will cause the auxiliary contacts to change state and the hold-in circuit to release.

Parameter Programming

Communication Capabilities

A serial interface port is furnished as standard with the PF Softstarter controller. This communication port allows connection to a Bulletin 20 Human Interface Module.

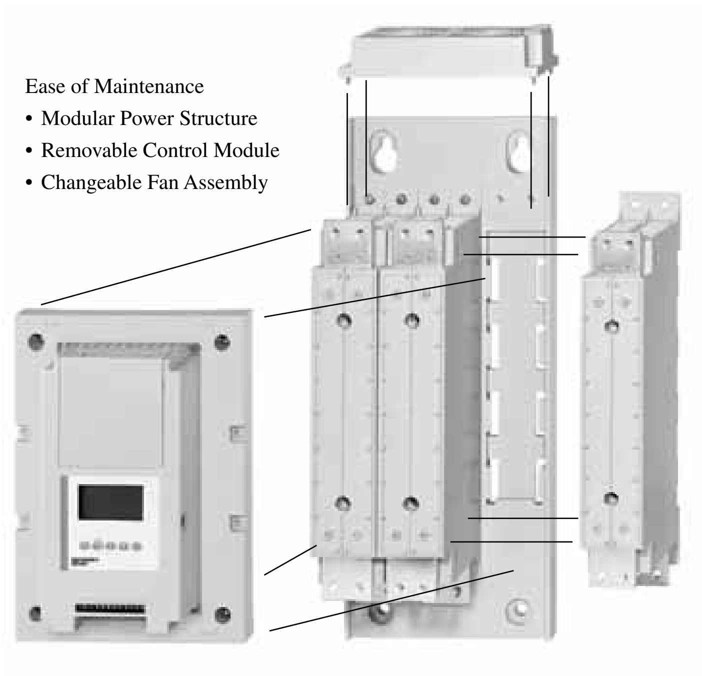
Auxiliary Contacts

Four hard contacts are provided as standard with the PF Softstarter controller. The first contact is programmable for Normal/Up-to-speed/Bypass. The second, third and fourth contact are configured to N.O/N.C.

Modular Design

The PF Softstarter controller packaging is designed for industrial environments. The modularity of control and power modules feature plug-in functionality. There are no gate wires to remove and no soldering is required. Common control modules reduce inventory requirements.

Figure 39 - Exploded View



Control Terminal Description

The PF Softstarter controller contains 24 control terminals on the front of the controller. These control terminals are described below. See Figure 40

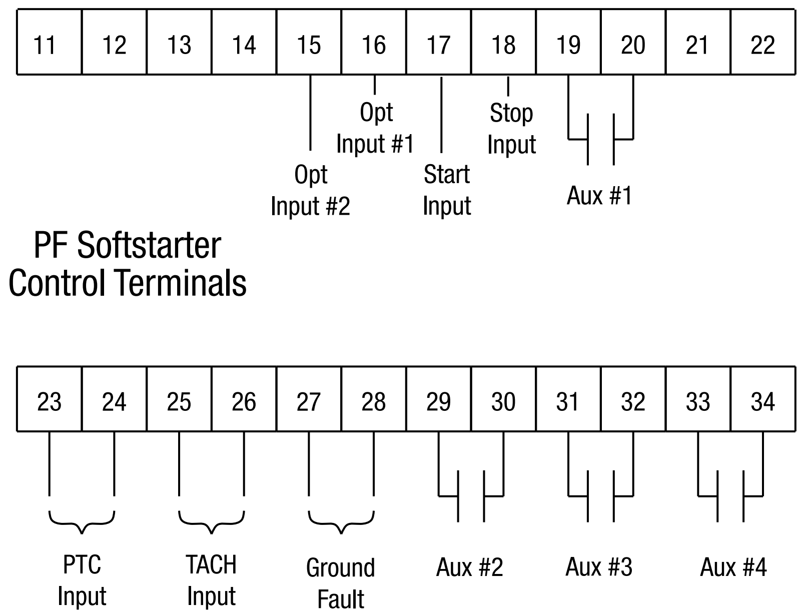
Table 11 - Control Terminal Designation

Terminal Number	Description
11	Control Power Input
12	Control Power Common
13	Controller Enable Input ①
14	Ground
15	Option Input #2 ①
16	Option Input #1 ①
17	Start Input ①
18	Stop Input ①
19	N.O. Aux. Contact #1 (Normal/Up-to-Speed/External Bypass) ②
20	N.O. Aux. Contact #1 (Normal/Up-to-Speed/External Bypass) ②
21	Not Used
22	Not Used
23	PTC Input ①
24	PTC Input ①
25	Tach Input
26	Tach Input
27	Ground Fault Transformer Input ①
28	Ground Fault Transformer Input ①
29	Fault Contact (N.O./N.C.)
30	Fault Contact (N.O./N.C.)
31	Alarm Contact (N.O./N.C.)
32	Alarm Contact (N.O./N.C.)
33	Aux Contact #2 Normal (N.O./N.C.)
34	Aux Contact #2 Normal (N.O./N.C.)

① Do not connect any additional loads to these terminals. These “parasitic” loads may cause problems with operation, which may result in false starting and stopping.

② External Bypass operates an external contactor and overload once the meter reaches full speed. The PF Softstarter overload functionality is disabled when the external bypass is activated. Proper sizing of the contactor and overload is required.

Figure 40 - PF Softstarter Controller Control Terminals



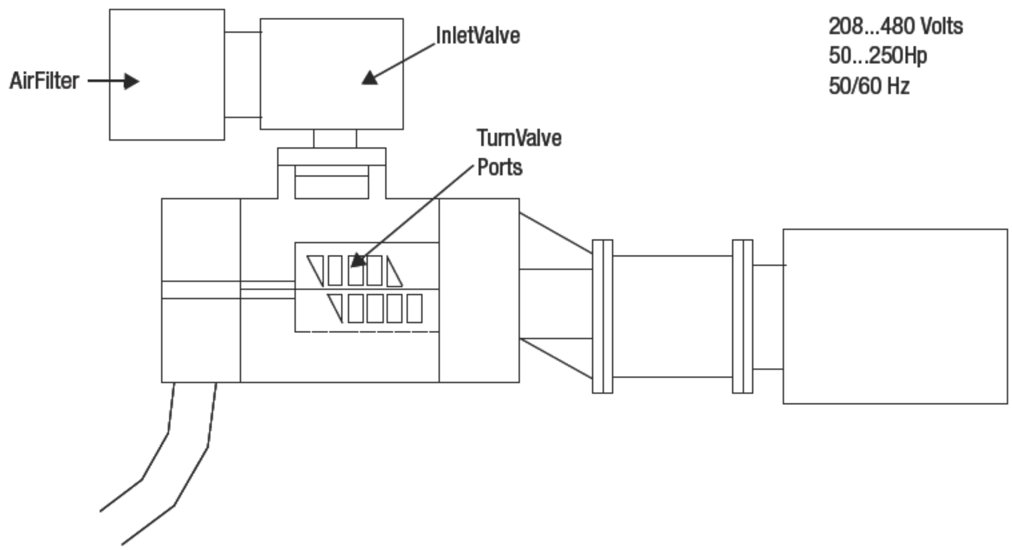
Application Profiles

Overview

In this chapter, a few of the many possible applications for the PF Softstarter controller are described. The basis for selecting a particular control method is also detailed. Illustrations are included to help identify the application. Motor ratings are specified, but the ratings may vary in other typical applications.

For example, a tumbler drum is described as requiring the Soft Start feature. The application is examined further to determine how the PF Softstarter controller options can be used to improve the tumbler drum performance and productivity.

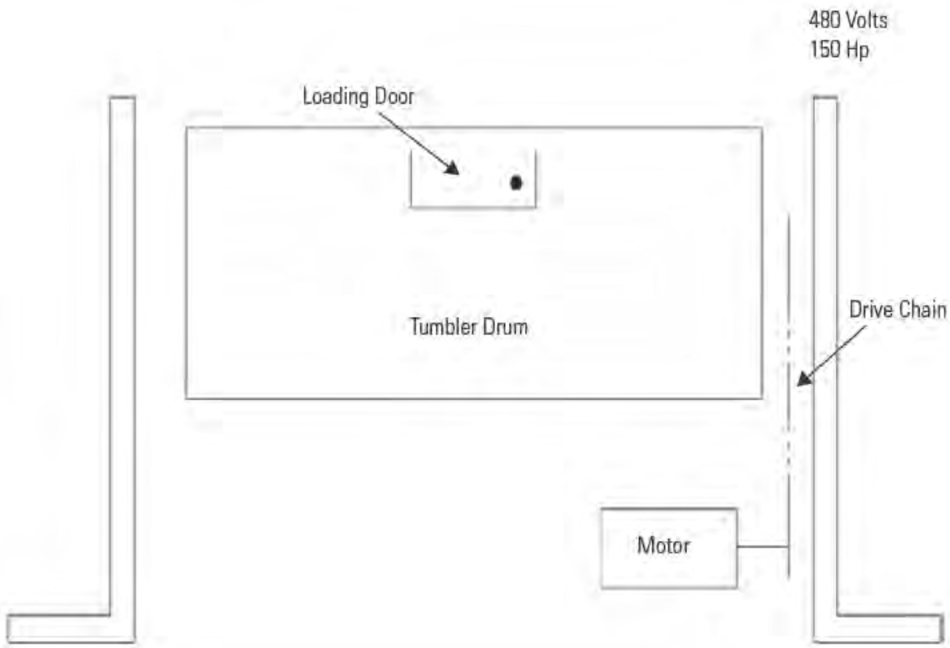
Figure 41 - Compressor with Soft Start



Problem: A compressor OEM shipped its equipment into overseas markets, where wye-delta motors are common. There were many different voltage and frequency requirements to meet because of the compressor's final destination. Due to power company requirements and mechanical stress on the compressor, a reduced voltage starter was required. This made ordering and stocking spare parts difficult.

Solution: The PF Softstarter controller was installed and wired to a wye-delta motor. The unit was set for an 18-second Soft Start, which reduced the voltage to the motor during starting and met the power company requirements. By reducing the voltage, the starting torque was also reduced, minimizing the shock to the compressor. Panel space was saved because the PF Softstarter controller has a built-in overload and SCR bypass feature.

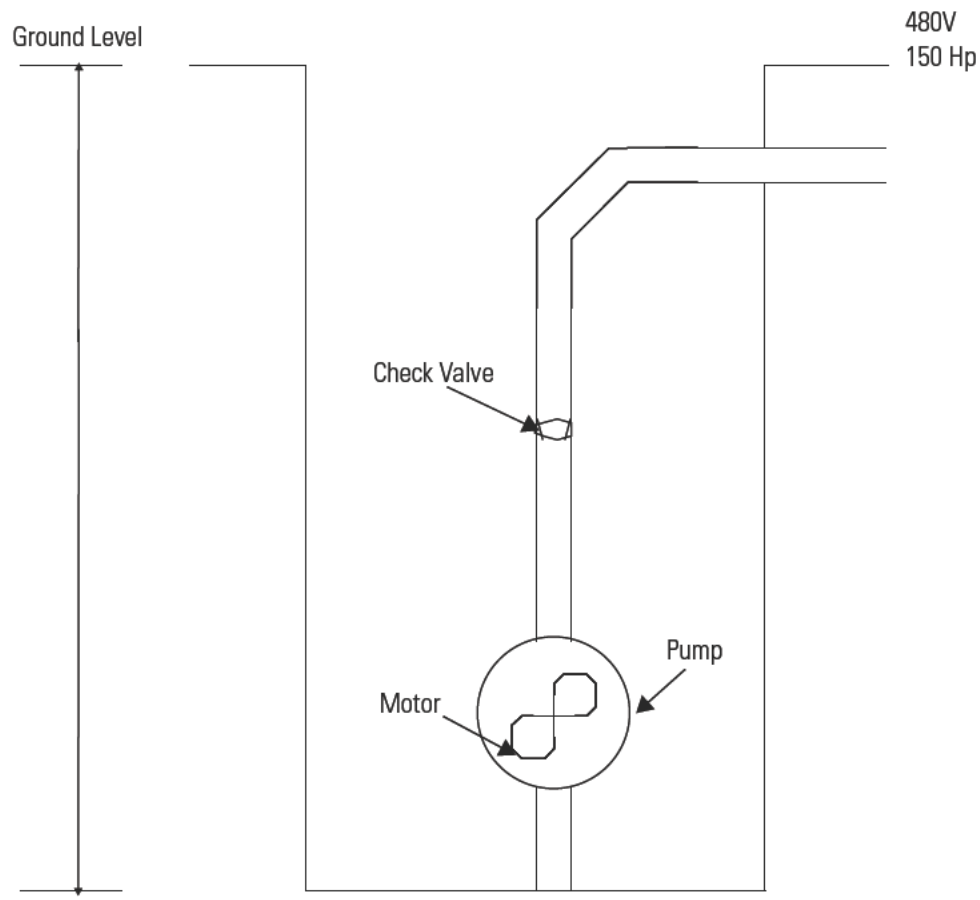
Figure 42 - Tumbler with Soft Start and Accu-Stop



Problem: A tumbler drum used in the de-burring process was breaking the drive chain because of the uncontrolled acceleration from the across-the-line starter. To increase production on the drum, the coasting time on stop had to be reduced. Previous solutions were a separate soft start package plus a motor brake, which required additional panel space and power wiring. A small enclosure size and simplified power wiring were needed to reduce the cost of the controls. Because a PLC was controlling several other processes in the facility, communication capabilities were desired.

Solution: The PF Softstarter controller with the braking option configured as Accu-Stop was installed on the process. The Soft Start provided a smooth acceleration of the drive chain, which reduced downtime. The controlled acceleration made positioning for loading/unloading easier. The drum was positioned for loading using the Preset Slow Speed. For unloading, the drum was rotated at Preset Slow Speed and then accurately stopped. This increased the productivity of the loading/unloading cycle. Further, the Accu-Stop option did not require additional panel space or wiring. The PF Softstarter controller's built-in overload eliminated the need to mount an external overload relay in the enclosure. The built-in SCR Bypass eliminated the need for an external bypass contact in the enclosure. Both features saved further panel space. The communication feature of the PF Softstarter controller allowed remote starting and stopping of the process from a PLC.

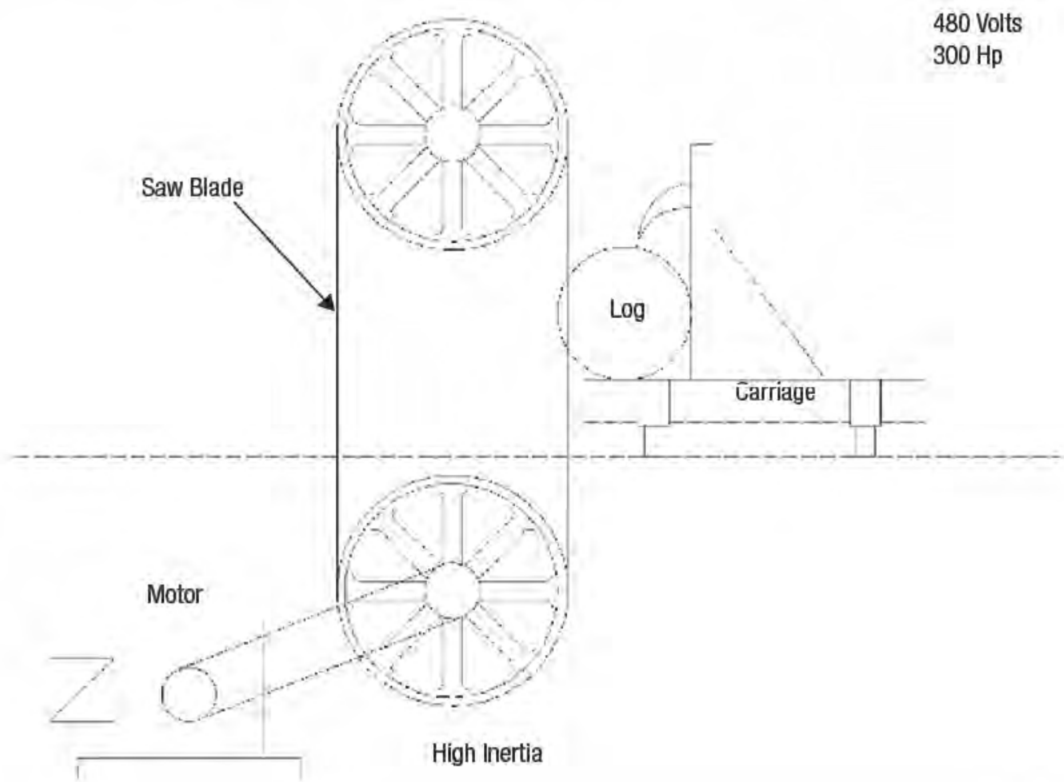
Figure 43 - Pump with Soft Start



Problem: A municipal water company was experiencing problems with pump impellers being damaged. The damage occurred during frequent motor starting while the load below the check valve was draining from the system. A timing relay was installed to prevent restart underload, but need to be adjusted frequently.The pumping station motor was over 100 feet below ground, making repair costly. For maintenance scheduling purposes, an elapsed time meter measuring motor running time had to be installed in the enclosure.

Solution: The PF Softstarter controller with Pump control was installed, providing a controlled acceleration of the motor. By decreasing the torque during start up, the shock to the impeller was reduced. The PF Softstarter Anti-backspin timer feature was implemented to prevent the motor from starting while turning in a reverse direction. Panel space was saved by employing the built-in elapsed time meter. The PF Softstarter controller's line diagnostics detected the pre-start and running single-phase condition and shut off the motor, protecting against motor damage.

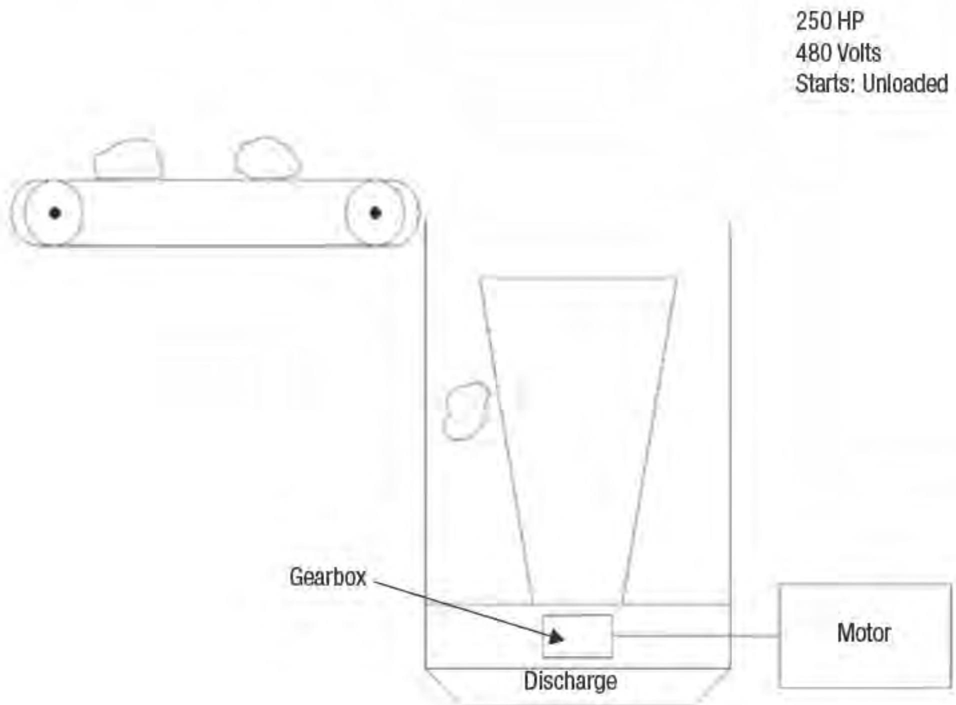
Figure 44 - Bandsaw with Soft Start and Slow Speed with Braking



Problem: Because of the remote location of the facility and power distribution limitations, a reduced voltage starter was needed on a bandsaw application. When the saw blade became dull, the current drawn by the motor increased. Therefore, an ammeter was required. The saw was turned off only during shift changes or routinely to change the saw blade. This application required 25 minutes to coast to stop, and braking devices were unacceptable due to their high complexity and panel space requirements. After a blade was replaced, it was dangerous to bring the saw up to full speed because of alignment problems. Metering the application for jam conditions was a necessity. In addition, single phasing of the motor was a problem because of distribution limitations.

Solution: The PF Softstarter controller was installed to provide a reduced voltage start. This minimized the starting torque shock to the system. With the braking option configured as Slow Speed with Braking, it provided a preset slow speed, allowing the saw blade tracking to be inspected before the motor was brought to full speed. The current monitoring and jam detection features of the PF Softstarter controller were implemented, saving valuable panel space and the cost of purchasing dedicated monitoring devices. The controller's built-in programmable overload protection was used. The PF Softstarter controller's diagnostic capabilities would detect single phasing and shut the motor off accordingly. Starting and stopping control was furnished in a single modular unit, providing ease of installation.

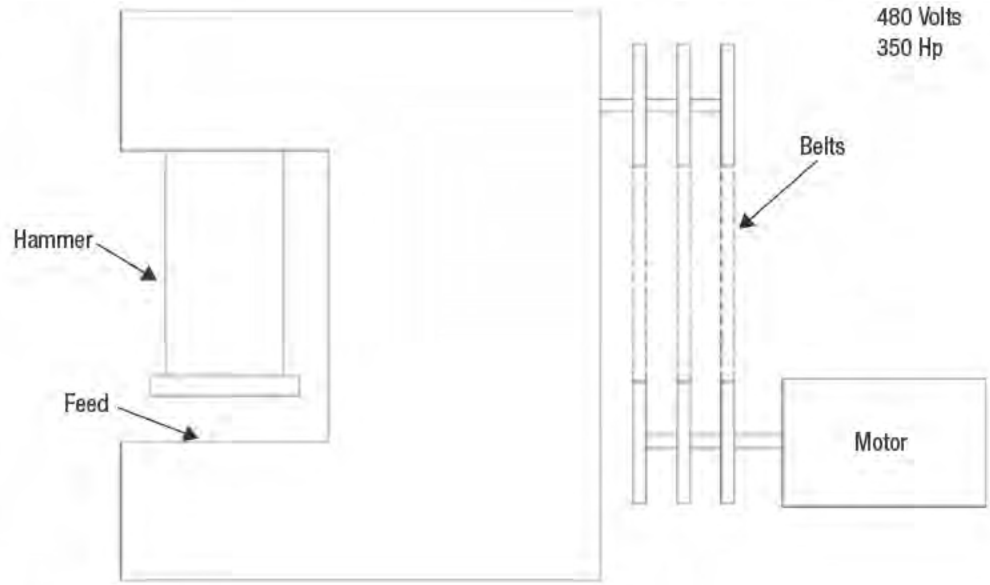
Figure 45 - Rock Crusher with Soft Start



Problem: Because of the remote location of a rock quarry, the power company required a reduced voltage start on all motors over 150 Hp. The starting current on these large motors strained the capacity of the power system, causing severe voltage dips. When the rock crusher became overloaded, the current draw by the Wye-Delta motor increased. Therefore, current monitoring capabilities within the soft starter were required. Because the conveyor feeding the rock crusher was controlled by a PLC, communications between the soft starter and a PLC was necessary. When the rock crusher ran, occasionally a stall or jam would occur.

Solution: The PF Softstarter controller was installed, meeting the power company requirements. The motor was wired inside-the-delta, which saves valuable panel space. The metering capabilities of the PF Softstarter controller allowed the current drawn by the motor to be monitored. With the built-in communications capabilities, the motor current was communicated to the PLC. When the motor current reached a specified limit, the conveyor feeding the rock crusher could be slowed. By slowing the conveyor, a jam condition in the rock crusher was avoided. The stall and jam detection capabilities of the PF Softstarter controller would shut off the motor when a stall or jam condition occurred.

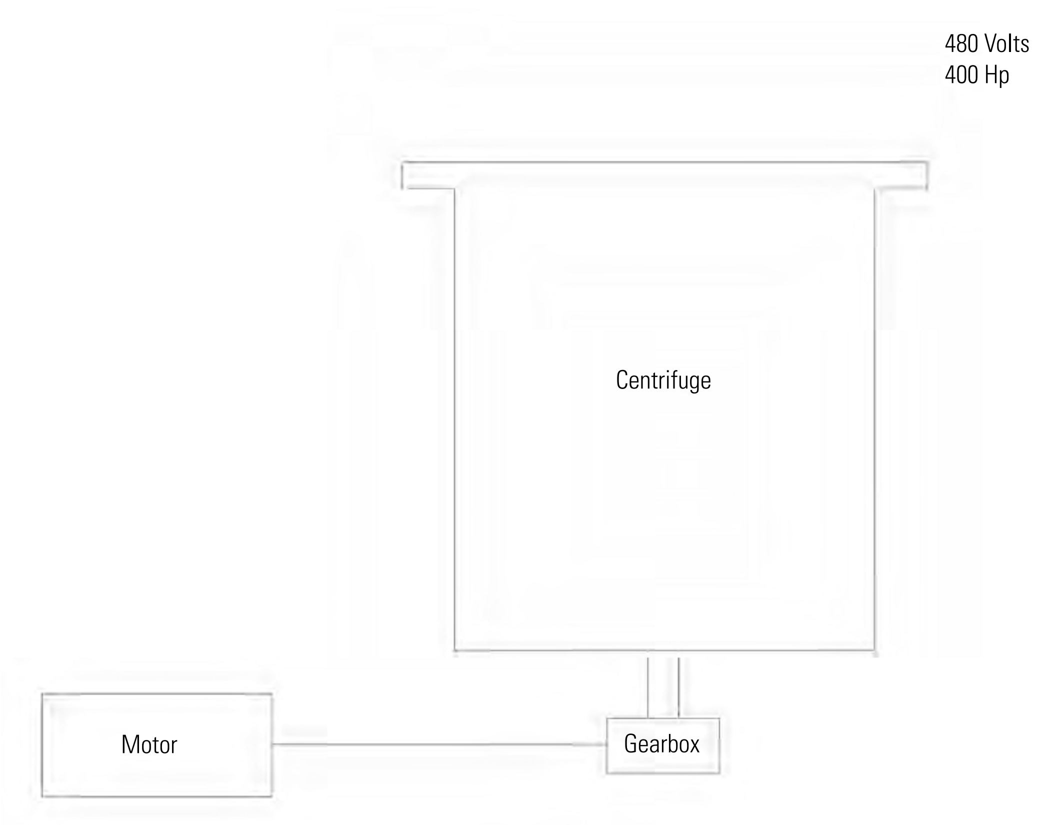
Figure 46 - Hammermill with Current Limit Start and SMB Smart Motor Braking



Problem: A hammermill required a reduced voltage start because of power company restrictions. A stopping time less than the present 5 minute coast-to-rest was desired. To save panel space, the customer wanted to incorporate both starting and stopping control in the same device.

Solution: The PF Softstarter controller with the braking option configured as SMB Smart Motor Braking was installed. A 23-second, 450% current limit acceleration was programmed, meeting the power company requirements and reducing the mechanical stress on the belts during start-up. The braking function was accomplished without additional power wiring, panel space, or contactors. Zero speed was detected without additional sensors or timers. The current limit start, braking, and overload protection were accomplished within the same modular package.

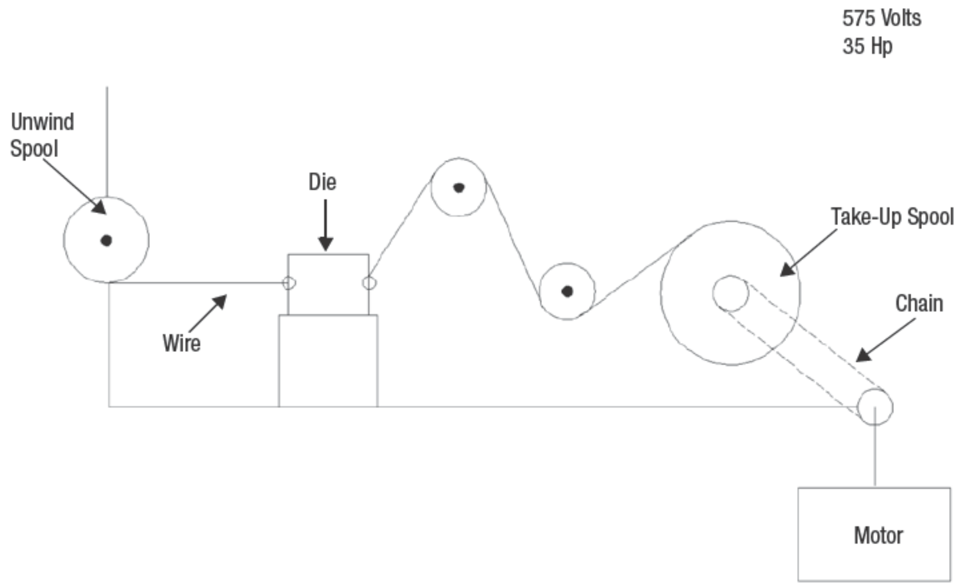
Figure 47 - Centrifuge with Current Limit Start and SMB Smart Motor Braking



Problem: A centrifuge required a reduced voltage start because of power company restrictions. The high torque during starting was causing damage to the gearbox. A shorter stopping time than the present 15 minute coast-to rest was desired. The long stop time caused delays in the production process. A Wye-Delta starter with a mechanical brake was currently in use. A zero-speed switch was used to release the brake. The mechanical brake required frequent maintenance and replacement, which was costly and time consuming. Both the mechanical brake and zero-speed switches were worn out and required replacement.

Solution: The PF Softstarter controller with the braking option configured as SMB Smart Motor Braking was installed and wired inside-the-delta to the wye-delta motor. The controller was set for a 28-second, 340% current limit start, meeting the power company requirements and reducing the starting torque stress to the gearbox. SMB Smart Motor Braking allowed the centrifuge to stop in approximately 1 minute. The PF Softstarter controller with SMB Smart Motor Braking did not require additional mounting space or panel wiring. The controller was mounted in a panel that was considerably smaller than the previous controller. Additionally, the controller did not require frequent maintenance and could sense zero speed without a feedback device.

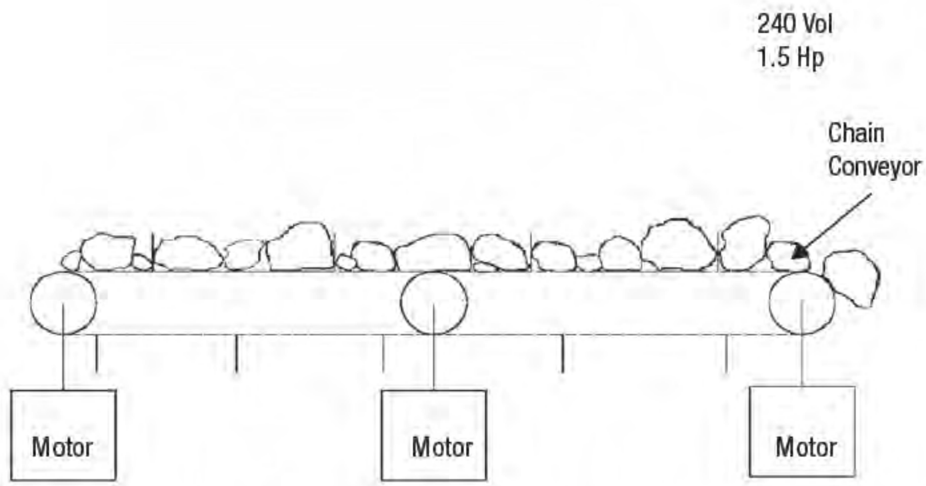
Figure 48 - Wire Draw Steel Mill Machine with Soft Start



Problem: An across-the-line starter was used on a wire draw machine to pull wire. This rapid cycling application caused mechanical wear on both the chain and the electromechanical starter. Other soft starts had been experimented with, but not enough torque was developed to pull the wire through the die.

Solution: The PF Softstarter controller was installed to accelerate the motor smoothly. The kickstart feature was adjusted to provide enough torque to pull the wire through the die. After the initial kickstart, the controller went back to the soft start acceleration mode, reducing the amount of starting torque on the chain and helping to lower maintenance inspection and repair time. The controller was set for a 9-second ramp time.

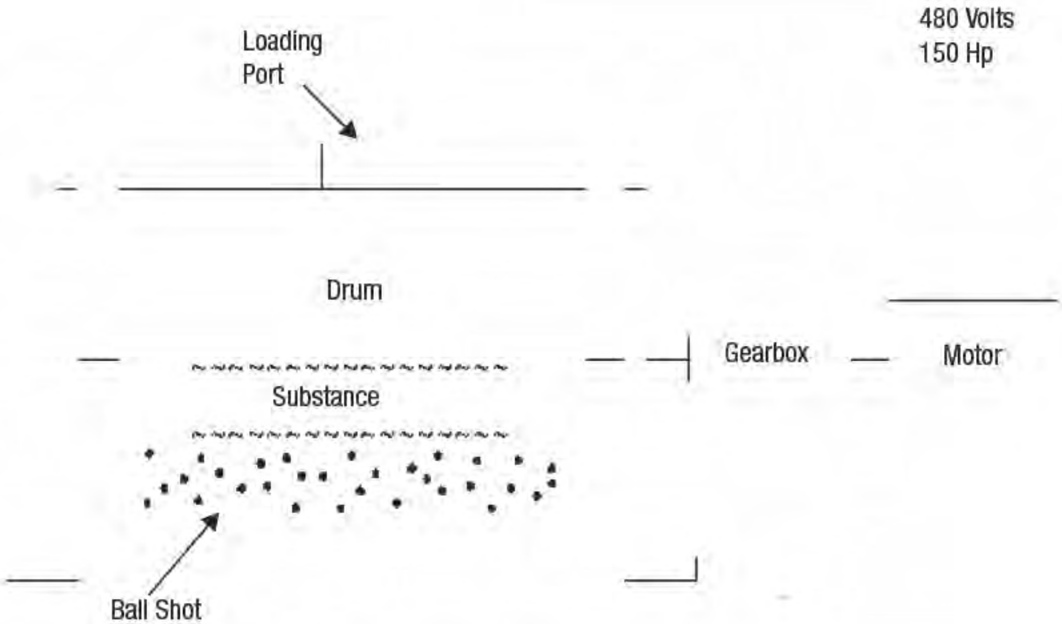
Figure 49 - Overload conveyor with Linear Speed and Tack Feedback



Problem: A overload gravel conveyor had three motors to drive the conveying system. Across-the-line starts caused damage to the conveyor and spilled gravel on the conveyor. Occasionally, the conveyor would stop fully loaded. An across-the-line start would then be needed to provide enough torque to accelerate the load.

Solution: The conveyor OEM installed a single PF Softstarter controller with linear speed and tach feedback to provide a smooth acceleration to all three motors, reducing the starting torque of the motors and the mechanical shock to the conveyor and load. In addition, the controller could be configured to simulate a full voltage start, allowing the conveyor to accelerate when fully loaded. The OEM liked the PF Softstarter controller because of its ability to control three motors as if they were a single motor, eliminating the need for multiple soft starters.

Figure 50 - Ball Mill with Current Limit Start



Problem: An across-the-line starter was used to start the motor in a ball mill application. The uncontrolled start was causing damage to the gearbox, resulting in maintenance downtime, as well as the potential for the loss of the product (paint) being mixed. Line failures were a frequent problem. The application required prestart and running protection, as well as an elapsed time meter to monitor the process time. Communication capability was desired, and panel space was limited.

Solution: The PF Softstarter controller was installed. It was programmed for a 26-second current limit start, thereby reducing the starting torque and the damage to the gearbox. The metering feature of the PF Softstarter controller contained an elapsed time meter, which could monitor the process time of the ball mill. The communications capabilities of the controller allowed the process time to be communicated to the PLC, which could remotely stop the ball mill. The line diagnostics required in the application are standard in the PF Softstarter controller, and the built-in overload protection and SCR Bypass saved panel space.

Special Application Considerations

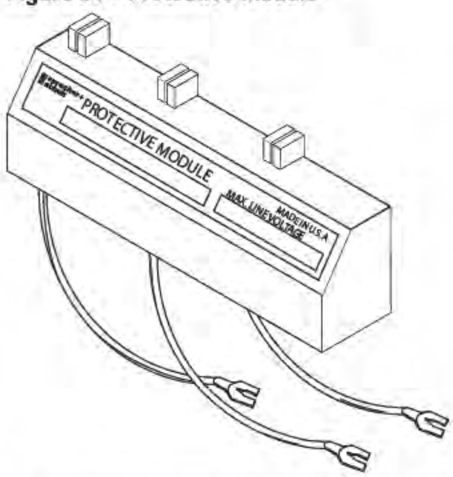
PF Softstarters in Drive Applications

The PF Softstarter controller can be installed in starting and stopping control applications. A variable frequency drive must be installed when speed variation is required during run.

Use of Protective Modules

A protective module (see Figure 51) containing metal oxide varistors (MOVs) can be installed to protect the power components from electrical transients and/or electrical noise. The protective modules clip transients generated on the lines and prevent such surges from damaging the SCRs.

Figure 51 - Protective Module



There are two general situations that may occur which would indicate the need for using the protective modules.

1. Transient spikes may occur on the lines feeding the PF Softstarter controller (or feeding the load from the PF Softstarter controller). Spikes are created on the line when devices are attached with current-carrying inductances that are open-circuited. The energy stored in the magnetic field is released when the contacts open the circuit. Examples of these are lightly loaded motors, transformers, solenoids, and electromechanical brakes. Lightning can also cause spikes.
2. The second situation arises when the PF Softstarter controller is installed on a system that has fast-rising wavefronts present, although not necessarily high peak voltages. Lightning strikes can cause this type of response. Additionally, if the PF Softstarter controller is on the same bus as other SCR devices, (AC/DC drives, induction heating equipment, or welding equipment) the firing of the SCRs in those devices can cause noise.

Motor Overload Protection

When coordinated with the proper short-circuit protection, overload protection is intended to protect the motor, motor controller, and power wiring against overheating caused by excessive overcurrent. The PF Softstarter controller meets applicable requirements as motor overload protective device.

The PF Softstarter controller incorporates, as standard, electronic motor overload protection. This overload protection is accomplished electronically with circuits and an I^2t algorithm.

The controller's overload protection is programmable, providing the user with flexibility. The overload trip class can be selected for class OFF, 10, 15, 20, or 30 protection. The trip current can be programmed to the motor full load current rating.

Thermal memory is included to model motor operating and cooling temperatures. Ambient insensitivity is inherent in the electronic design of the overload.

Stall Protection and Jam Detection

Motors can experience locked rotor currents and develop high torque levels in the event of a stall or a jam. These conditions can result in winding insulation breakdown or mechanical damage to the connected load.

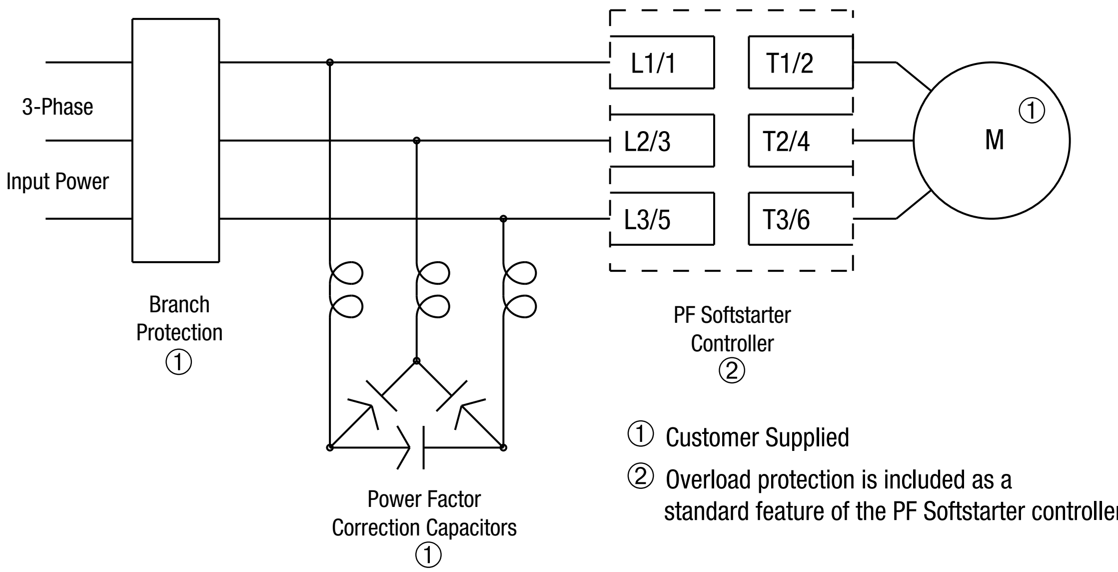
The PF Softstarter controller provides both stall and jam detection for enhanced motor and system protection. Stall protection allows the user to program a maximum stall protection delay time from 0 to 10 seconds. The stall protection delay time is in addition to the programmed start time and begins only after the start time has timed out.

Jam detection allows the user to determine the motor jam detection level as a percentage of the motor's full load current rating. To prevent nuisance tripping, a jam detection delay time, from 0…99 seconds, can be programmed. This allows the user to select the time delay required before the PF Softstarter controller will trip on a motor jam condition. The motor current must remain above the jam detection level during the delay time. Jam detection is active only after the motor has reached full speed.

Power Factor Capacitors

The controller may be installed on a system with power factor correction capacitors. These capacitors must be installed on the line side to prevent damage to the SCRs in the PF Softstarter controller (See Figure 52).

Figure 52 - Power Factor Capacitors



High values of inrush current and oscillating voltages are common when capacitors are switched. Therefore, additional impedance should be connected in series with the capacitor bank to limit the inrush current and dampen oscillations. The preferred practice is to insert air-core inductors as shown in Figure 53.

The inductors can be simply constructed:

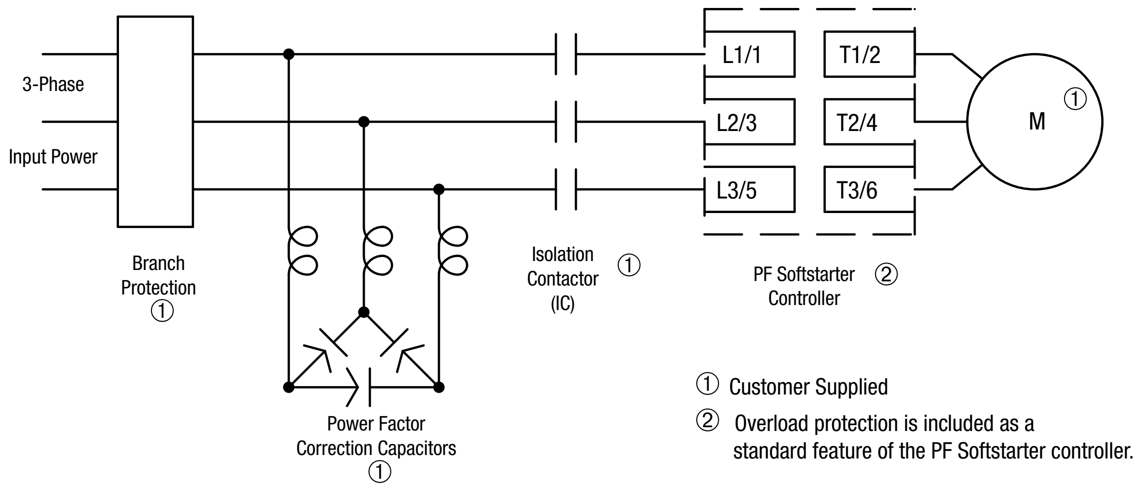
- for volts greater than or equal to 460V: use a six-inch diameter coil with eight loops
- for volts less than 460V: use a six-inch diameter coil with six loops

The wire should be sized to carry the steady-state current that will flow through the capacitor bank during normal operations.

The coils should be mounted on insulated supports away from metal parts. This will minimize the possibility of producing heating effects. Do not mount the coils to be stacked directly on top of each other. This will increase the chances of cancelling the effectiveness of the inductors.

If an isolation contactor is used, it is preferable that the power factor capacitors be installed ahead of the isolation contactor if at all possible (see Figure 53). In some installations, this may not be physically possible and the capacitor bank will have to be connected to the downstream terminals of the contactor. In this case, the installer must exercise caution and ensure that the air-core inductance is sufficient to prevent oscillating voltages from interfering with the proper performance of the PF Softstarter controller. It may be necessary to add more loops to the coil.

Figure 53 - Power Factor Capacitors with Isolation Contactor

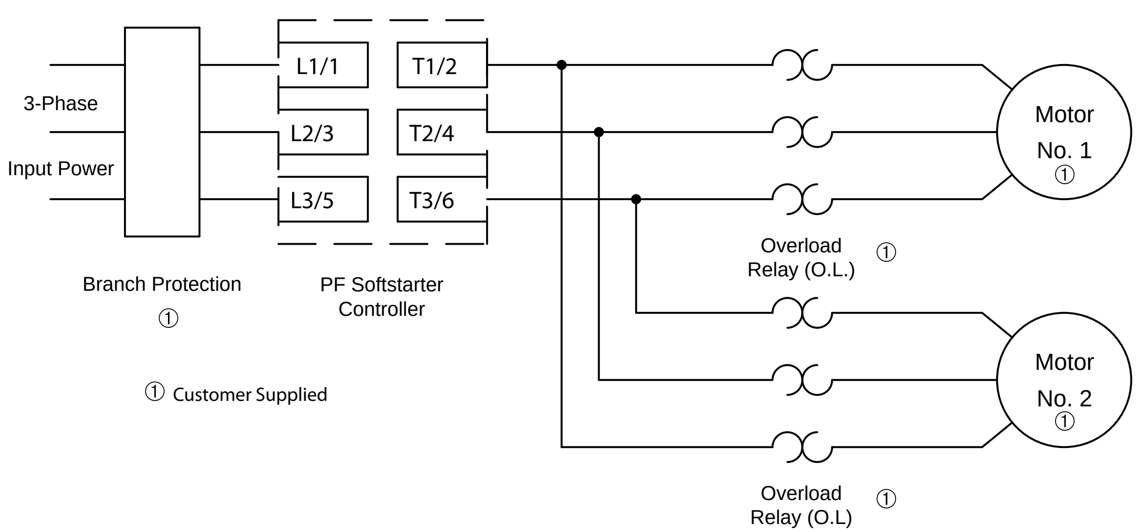


Multi-motor Applications

The PF Softstarter controller will operate with more than one motor connected to it. To size the controller, add the total nameplate amperes of all of the connected loads. The stall and jam features should be turned off. Separate overloads are still required to meet the National Electric Code (NEC) requirements.

Note: The PF Softstarter controller's built-in overload protection cannot be used in multi-motor applications.

Figure 54 - Multi-Motor Application



Special Motors

The PF Softstarter controller may be applied or retrofitted to special motors (wye-delta, part winding, synchronous, and wound rotor) as described below.

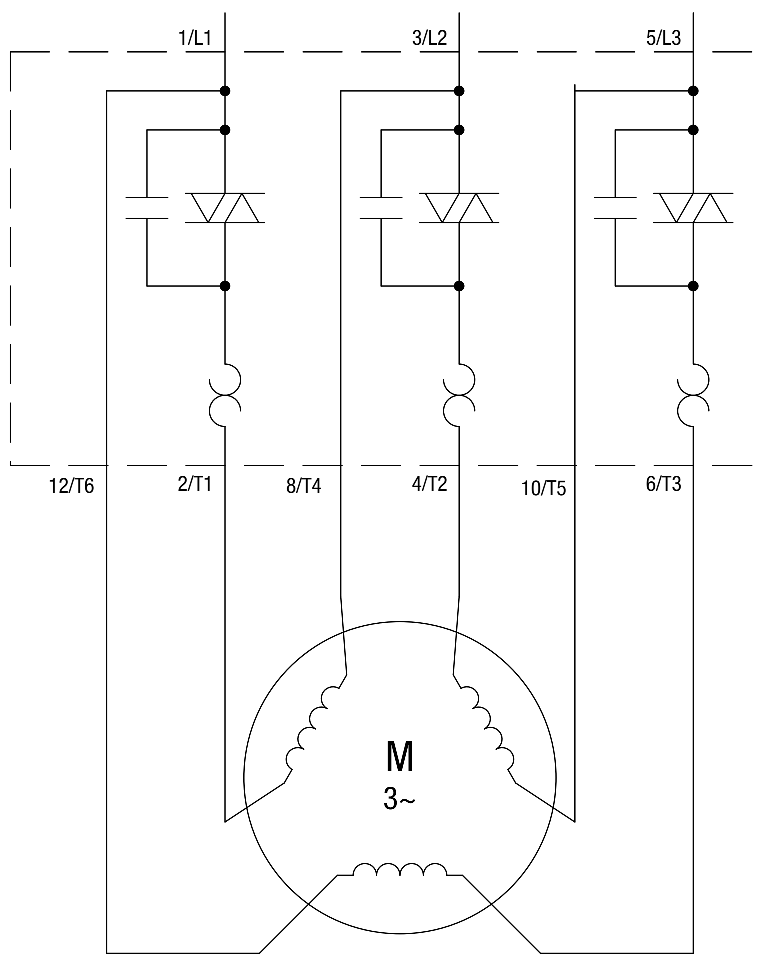
Wye-Delta

Wye-Delta is a traditional electro-mechanical method of reduced voltage starting. It requires a delta-wound motor with all its leads brought out to facilitate a wye connection. At the start command, approximately 58% of full line voltage is applied, generating about 33% of the motor's full voltage starting torque capability. After an adjustable time interval, the motor is automatically connected in delta.

To apply an PF Softstarter controller to a wye-delta motor, the power wiring from the PF Softstarter controller is simply wired in an inside-the-delta configuration to the motor. This connects all six motor connections back to the PF Softstarter. Because the PF Softstarter controller applies a reduced voltage start electronically, the transition connection is no longer necessary. Additionally, the starting torque can be adjusted with parameter programming.

Note: Increased Hp ratings are achieved with the PF Softstarter being connected to wye-delta motors.

Figure 55 - Inside-the-Delta Wiring.



Part Winding

Part winding motors incorporate two separate, parallel windings in their design. With the traditional part winding starter, one set of windings is given full line voltage, and the motor draws about 400% of the motor's full load current rating. Additionally, about 45% of locked rotor torque is generated. After a preset interval, the second winding is brought online in parallel with the first and the motor develops normal torque.

The part winding motor may be wired to an PF Softstarter controller by connecting both windings in parallel. Again, the starting torque can be adjusted to match the load with parameter programming.

Wound Rotor

Wound rotor motors require careful consideration when implementing PF Softstarter controllers. A wound rotor motor depends on external resistors to develop high starting torque. It may be possible to develop enough starting torque using the PF Softstarter controller and a single step of resistors. The resistors are placed in the rotor circuit until the motor reaches approximately 70% of synchronous speed. At this point, the resistors are removed from the secondary by a shorting contactor. Resistor sizing will depend on the characteristics of the motor used.

Please note that it is not recommended to short the rotor slip rings during start-up, as starting torque will be greatly reduced, even with full voltage applied to the motor. The starting torque will be even further reduced with the PF Softstarter controller since the output voltage to the motor is reduced on startup.

Synchronous

Synchronous, brush-type motors differ from standard squirrel-cage motors in the construction of the rotor. The rotor of a synchronous motor is comprised of two separate windings, a starting winding and a DC magnetic field winding.

The starting winding is used to accelerate the motor to about 95% of synchronous speed. Once there, the DC magnetic field winding is energized to pull the motor up to synchronous speed.

The PF Softstarter controller can be retrofitted to a synchronous controller by replacing the stator contactor with the PF Softstarter controller and maintaining the DC field application package.

Altitude De-rating

Because of the decreased efficiency of fans and heatsinks, it is necessary to de-rate the PF Softstarter controller above 6,500 feet (approximately 2,000 meters). When using the controller above 6,500 feet, use the next size device to guard against potential overtemperature trips.

Note: The motor FLA Rating must remain in the range of the PF Softstarter Amp rating.

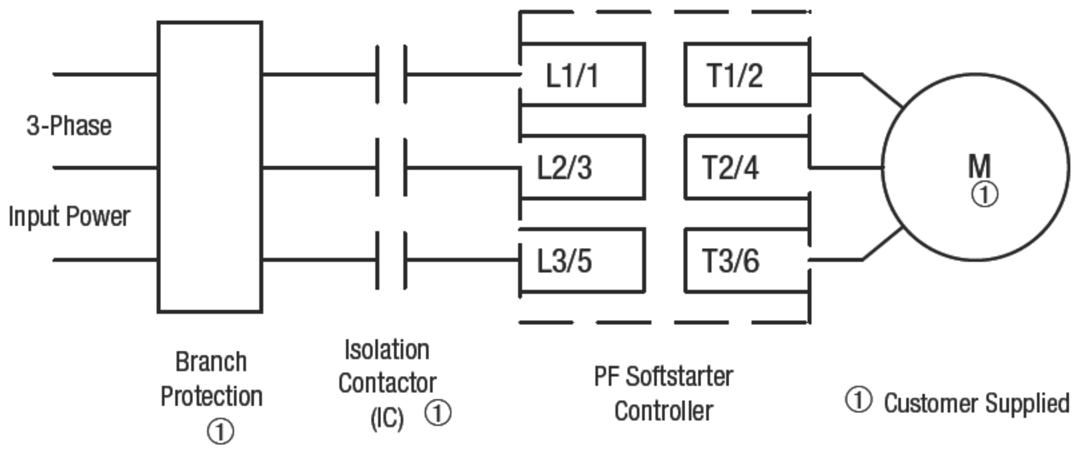
Isolation Contactor

When installed with branch circuit protection and an overcurrent device, PF Softstarter controllers are compatible with the National Electrical Code (NEC). When an isolation contactor is not used, hazardous voltages are present at the load terminals of the power module even when the controller is turned off. Warning labels must be attached to the motor terminal box, the controller enclosure, and the control station to indicate this hazard.

The isolation contactor is used to provide automatic electrical isolation of the controller and motor circuit when the controller is shut down. Shut down can occur in either of two ways: either manually, by pressing the stop button, or automatically, by the presence of abnormal conditions (such as a motor overload relay trip).

Under normal conditions the isolation contactor carries only the load current. During start, the isolation contactor is energized before the SCRs are gated "on." While stopping, the SCRs are gated "off" before the isolation contactor is de-energized. The isolation contactor is not making or breaking the load current.

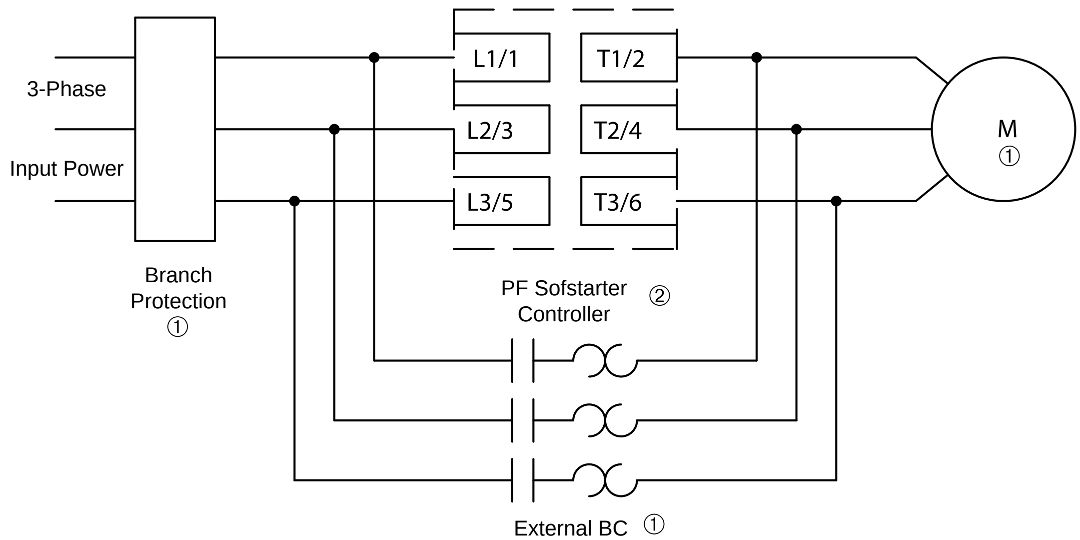
Figure 56 - Typical Connection Diagram with Isolation Contactor



PF Controller with Bypass Contactor (BC)

Controlled start and stop are provided by wiring the controller as shown in Figure 57. When the motor is up to speed, the external bypass contactor is "pulled in" for run. The bypass mode must have a separate overload as the PF Softstarter overload is not active in this configuration.

Figure 57 - Typical Application Diagram of a Bypass Contactor



① Customer Supplied

② Overload protection is included as a standard feature of the PF controller.

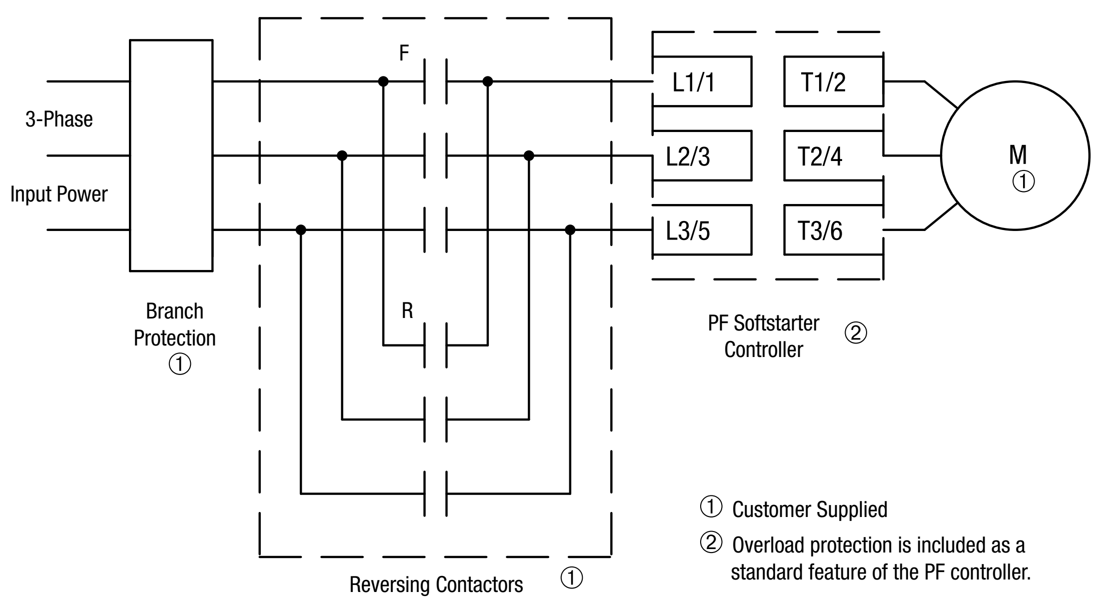
note: Aux Contact #1 must be set to Bypass.

PF Controller with Reversing Contactor

By using the controller as shown in Figure 58, the motor accelerates under a controlled start mode in either forward or reverse.

Note: Minimum transition time for reversing is ½ second. Phase Reversal must be OFF.

Figure 58 - Typical Application with a Single-Speed Reversing Starter



① Customer Supplied

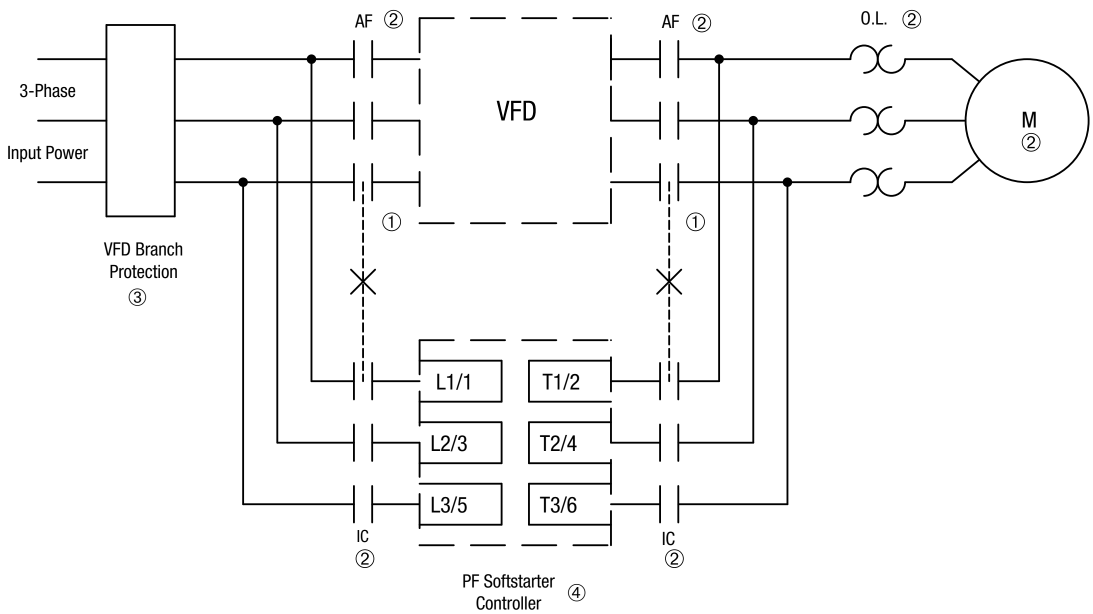
② Overload protection is included as a standard feature of the PF controller.

PF Controller as a Bypass to an AC Drive

By using the controller as shown in Figure 59, a soft start characteristic can be provided in the event that an AC drive is non-operational.

Note: A controlled acceleration can be achieved with this scheme, but speed control is not available in the bypass mode.

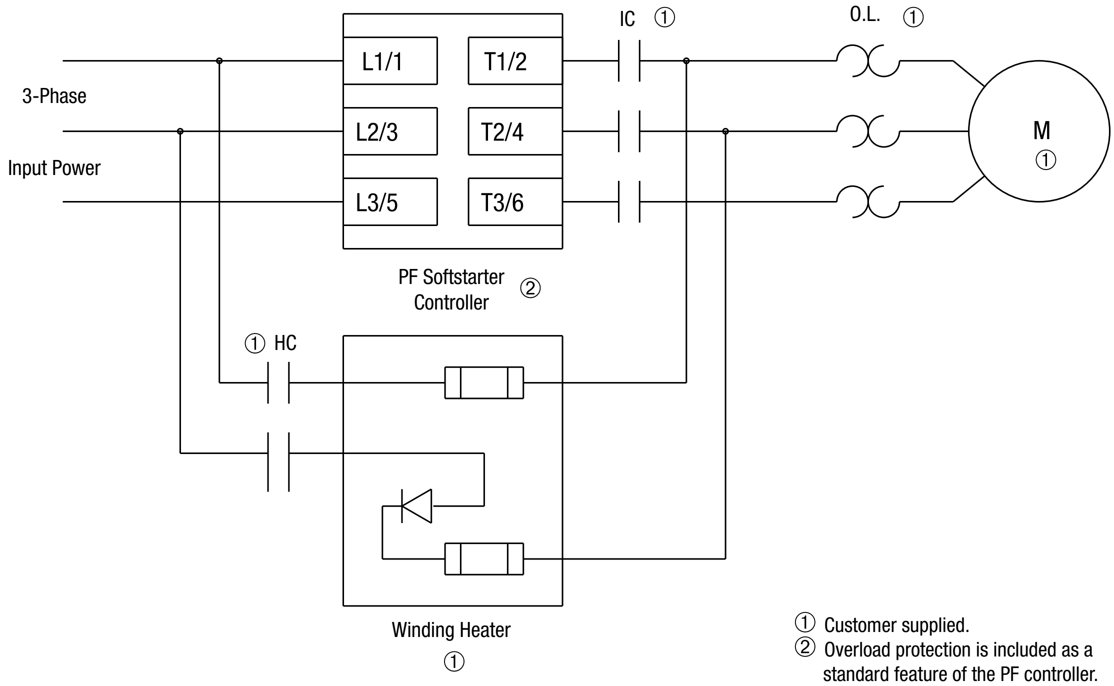
Figure 59 - Typical Application Diagram of a Bypass Contactor for an AC Drive



① Mechanical interlock required
② Customer supplied
③ Many VF drives are rated 150% FLA. Because the PF controller can be used for 600% FLA starting, separate branch circuit protection may be required.
④ Overload protection is included as a standard feature of the PF controller.

PF Controller with a Motor Winding Heater

Figure 60 - Typical Application Diagram of PF Softstarter Controller with a Bulletin 1410 Motor Winding Heater



Motor Torque Capabilities with PF Controller Options

SMB Smart Motor Braking

The stopping torque output of the PF Softstarter controller will vary depending on the braking current setting and motor characteristics. Typically the maximum stopping torque will be between 80…100% of the full load torque of the motor when set at 400% braking current.

Preset Slow Speed

Two torque characteristics of the Preset Slow Speed option must be considered. The first is the starting torque. The second is the available running torque at low speed (see Figure 61). These torque characteristics will also vary, depending on the speed selected. Refer to Table 12 for the approximate maximum available starting and running full load torque at maximum current settings. On adjustment (Slow Speed Current) will control the starting and running torque values.

Figure 61 - Starting and Running Torque

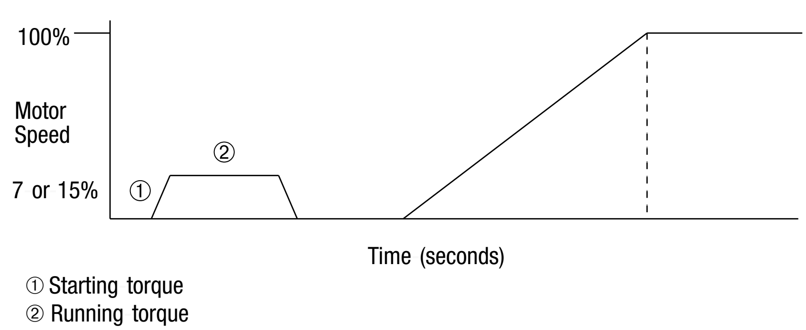


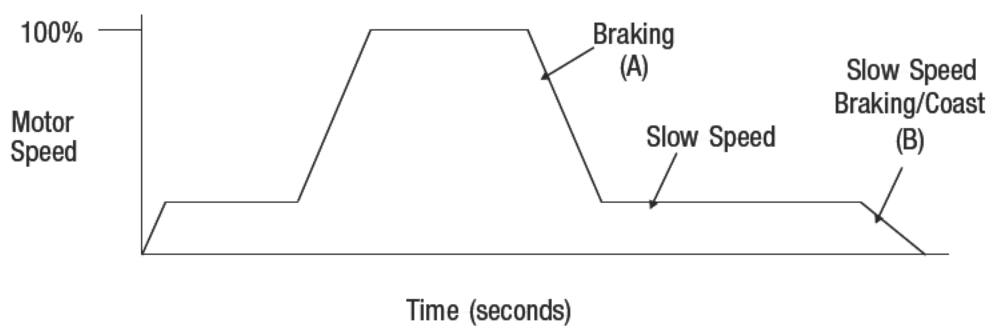
Table 12 - Maximum Torque at Maximum Current Settings

Present Slow Speed	Maximum Starting Torque as a Percentage of Full Load Torque	Maximum Running Torque as a Percentage of Full Load Torque
7%	90…100%	110…120%
15%	50%	100%

Accu-Stop

Two levels of braking torque are applied with the Accu-Stop option. There is the braking portion that brakes to slow speed, and the slow speed braking/coast (see Figure 62). The level of these braking currents are adjusted using one rotary digital switch. The maximum braking torque available from braking to slow speed and from slow speed to stop is approximately 80…100% of full load torque of the motor. Using the slow speed starting portion of the Accu-Stop option will result in the same starting and running torque characteristics as described in the Preset Slow Speed option.

Figure 62 - Accu-Stop Option



Chapter 4

Product Line Application Matrix

Description

Use this chapter to identify possible PF Softstarter controller applications. This chapter contains an application matrix which will identify starting characteristics, as well as typical stopping features that may be used in various applications.

Mining and Metals

Applications	Soft Start	Current Limit	Kickstart	Soft Stop	Pump Control	Accu-Stop	Smart Motor Brake	Preset Slow Speed	Slow Speed with Brake	Linear Speed Acceleration
Roller Mills	X	X					X		X	
Hammermills	X	X					X		X	
Roller Conveyors	X			X						
Centrifugal Pumps	X	X			X					
Fans	X	X	X							
Tumbler	X	X				X	X	X	X	
Rock Crusher	X	X								
Dust Collector	X	X								
Chillers	X	X								
Compressor	X	X								
Wire Draw Machine	X	X	X							
Belt Conveyors	X	X	X	X		X		X		
Shredder	X	X								
Grinder	X	X					X		X	
Slicer	X	X	X							
Overload Conveyor	X		X	X		X				X

Food Processing

Applications	Soft Start	Current Limit	Kickstart	Soft Stop	Pump Control	Accu-Stop	Smart Motor Brake	Preset Slow Speed	Slow Speed with Brake	Linear Speed Acceleration
Centrifugal Pumps	X	X			X					
Palletizers	X			X						
Mixers	X	X	X					X		
Agitators	X									
Centrifuges		X					X		X	
Conveyors	X		X	X		X				
Fans	X	X								
Bottle Washers	X			X						
Compressors	X	X								
Hammermill	X	X								
Separators	X	X								
Dryers	X	X								
Slicers	X	X	X							

Pulp and Paper

Applications	Soft Start	Current Limit	Kickstart	Soft Stop	Pump Control	Accu-Stop	Smart Motor Brake	Preset Slow Speed	Slow Speed with Brake	Linear Speed Acceleration
Compressors	X	X								
Conveyors	X	X	X	X		X		X		
Trolleys	X			X		X		X		
Dryers	X	X								
Agitators	X	X								
Centrifugal Pumps	X	X			X					
Mixers	X	X								
Fans	X	X								
Re-Pulper	X	X	X							
Shredder	X	X								

Petrochemical

Applications	Soft Start	Current Limit	Kickstart	Soft Stop	Pump Control	Accu-Stop	Smart Motor Brake	Preset Slow Speed	Slow Speed with Brake	Linear Speed Acceleration
Centrifugal Pumps	X	X			X					
Extruders	X	X								
Screw Conveyors	X	X	X							
Mixers	X	X						X		
Agitators	X	X								
Compressors	X	X								
Fans	X	X								
Ball Mills	X	X				X	X		X	
Centrifuge	X	X					X		X	

Transportation and Machine Tool

Applications	Soft Start	Current Limit	Kickstart	Soft Stop	Pump Control	Accu-Stop	Smart Motor Brake	Preset Slow Speed	Slow Speed with Brake	Linear Speed Acceleration
Material Handling Conveyors	X	X	X	X		X		X		
Ball Mills	X	X				X	X	X	X	
Grinders	X	X					X		X	
Centrifugal Pumps	X	X			X					
Trolleys	X			X		X		X		
Presses	X	X					X			
Fans	X	X								
Palletizers	X	X		X		X		X		
Compressors	X	X								
Roller Mill	X	X					X		X	
Die Charger	X					X				
Rotary Table	X					X		X		

OEM Specialty Machine

Applications	Soft Start	Current Limit	Kickstart	Soft Stop	Pump Control	Accu-Stop	Smart Motor Brake	Preset Slow Speed	Slow Speed with Brake	Linear Speed Acceleration
Centrifugal Pumps	X	X			X					
Washers	X	X				X	X	X	X	
Conveyors	X	X	X	X		X	X	X	X	
Power Walks	X	X		X						
Fans	X	X								
Twisting/Spinning Machine	X	X								

Lumber and Wood Products

Applications	Soft Start	Current Limit	Kickstart	Soft Stop	Pump Control	Accu-Stop	Smart Motor Brake	Preset Slow Speed	Slow Speed with Brake	Linear Speed Acceleration
Chipper	X	X					X		X	
Circular Saw	X	X					X		X	
Bandsaw	X	X					X	X	X	
Edger	X	X								
Conveyors	X	X	X	X		X		X		
Centrifugal Pumps	X	X			X					
Compressors	X	X								
Fans	X	X								
Planers	X	X								
Sander	X	X				X	X	X	X	
Debarker	X	X					X		X	

Water/Wastwater Treatment and Municipalities

Applications	Soft Start	Current Limit	Kickstart	Soft Stop	Pump Control	Accu-Stop	Smart Motor Brake	Preset Slow Speed	Slow Speed with Brake	Linear Speed Acceleration
Centrifugal Pumps	X	X			X					
Centrifuge	X	X					X		X	
Fans	X	X								
Compressors	X	X								

Design Philosophy

Philosophy

Sprecher + Schuh softstarter controllers are designed to operate in today's industrial environments. Our controllers are manufactured to provide consistent and reliable operation. Sprecher + Schuh has more than just an adequate solution to meet your needs; we have the right solution. With a broad offering of power device products and application services, Sprecher + Schuh can effectively address the productivity issues most important to you.

Line Voltage Conditions

Voltage transients, disturbances, harmonics and noise exist in any industrial supply. A solid-state controller must be able to withstand these noises and should not be an unnecessary source of generating noise back into the line.

Ease of selection for the required line voltage is achieved with a design that provides operation over a wide voltage range, at 50/60 Hz, within a given controller rating.

The controller can withstand 3000V surges at a rate of 100 bursts per second for 10 seconds (IEEE Std. 472). Further, the controller can withstand the showering arc test of 350…1500V (NEMA Std. ICS2-230) for higher resistance to malfunction in a noisy environment.

An optional MOV module is available to protect SCRs from voltage transients.

Current and Thermal Ratings

Solid-state controller ratings must ensure reliability under the wide range of current levels and starting times needed in various applications.

SCR packaging keeps junction temperatures below 125°C (257°F) when running at full-rated current to reduce thermal stress and provide longer, more reliable operation.

The thermal capacity of the PF Softstarter controllers meet NEMA standards MG-1 and IEC34 (S1).

Mechanical Shock and Vibration

Solid-state controllers must withstand the shock and vibration generated by the machinery that they control.

PF Softstarter controllers meet the same shock and vibration specifications as electromechanical starters. They can withstand a 5 G shock for 11 ms in any plane and one hour of vibration of 1.0 G without malfunction.

Noise and RF Immunity

This product meets Class A requirements for EMC emission levels.

Altitude

Altitudes up to 2000 meters (6560 ft) are permitted without de-rating. The products' allowable ambient temperature must be de-rated for altitudes in excess of 2000 meters (6560 ft). The allowable ambient temperature must be de-rated by –3°C (27°F) per 1000 meters (3280 ft), up to a maximum of 7000 meters (23000 ft). Current ratings of the devices do not change for altitudes that require a lower maximum ambient temperature.

Pollution

This product is intended for a Pollution Degree 2 environment.

Setup

Simple, easily understood settings provide identifiable, consistent results.

For ease of installation, the controllers include compact design and feed-through wiring. PF Softstarter controllers are global products rated at 50/60 Hz. All parameter adjustments are programmed into the controller through the built-in keypad. A full line of enclosures is available.

Reduced Voltage Starting

Introduction to Reduced Voltage Starting

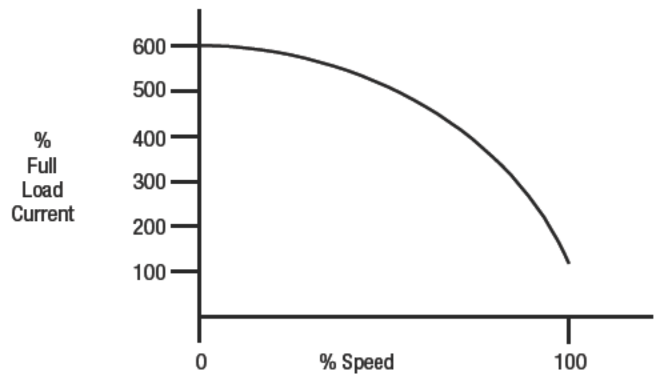
There are two primary reasons for using reduced voltage when starting a motor:

- Limit line disturbances
- Reduce excessive torque to the driven equipment

The reasons for avoiding these problems will not be described. However, different methods of reduced voltage starting of motors will be explored.

When starting a motor at full voltage, the current drawn from the power line is typically 600% of normal full load current. This high current flows until the motor is almost up to speed and then decreases, as shown in Figure 63. This could cause line voltage dips and brown-outs.

Figure 63 - Full-Load Current vs. Speed

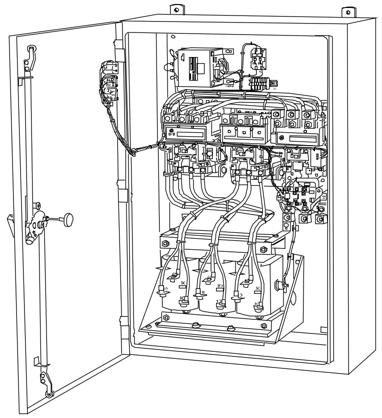


In addition to high starting currents, the motor also produces starting torques that are higher than full-load torque. The magnitude of the starting torque depends on the motor design. NEMA publishes standards for torques and currents for motor manufacturers to follow. Typically, a NEMA Design B motor will have a locked rotor or starting torque in the area of 180% of full-load torque.

In many applications, this starting torque can cause excessive mechanical damage such as belt, chain, or coupling breakage.

Reduced Voltage

Figure 64 - Autotransformer



The most widely used method of electromechanical reduced voltage starting is the autotransformer. Wye-Delta (Y-D), also referred to as Star-Delta, is the next most popular method.

All forms of reduced voltage starting affect the motor current and torque characteristics. When a reduced voltage is applied to a motor at rest, the current drawn by the motor is reduced. In addition, the torque produced by the motor is a factor of approximately the square of the percentage of voltage applied.

For example, if 50% voltage is applied to the motor, a starting torque of approximately 25% of the normal starting torque would be produced. In the previous full voltage example, the NEMA Design B motor had a starting torque of 180% of full load torque. With only 50% voltage applied, this would equate to approximately 45% of full load torque. Table 13 shows the typical relationship of voltage, current, and torque for a NEMA Design B motor.

Table 13 - Typical Voltage, Current and Torque Characteristics for NEMA Design B Motors

Starting Method	% Voltage at Motor Terminals	Motor Starting Current as a % of:		Line Current as a % of:		Motor Starting Torque as a % of:	
		Locked Rotor Current	Full Load Current	Locked Rotor Current	Full Load Current	Locked Rotor Torque	Full Load Torque
Full Voltage	100	100	600	100	600	100	180
Autotrans.							
80% tap	80	80	480	64	384	64	115
65% tap	65	65	390	42	252	42	76
50% tap	50	50	300	25	150	25	45
Part Winding	100	65	390	65	390	50	90
Wye-Delta	100	33	198	33	198	33	60
Solid-state	0…100	0…100	0…100	0…100	0…100	0…100	0…100

With the wide range of torque characteristics for the various starting methods, selecting an electromechanical reduced voltage starter becomes more application dependent. In many instances, available torque becomes the factor in the selection processes.

Limiting line current has been a prime reason in the past for using electromechanical reduced voltage starting. Utility current restrictions, as well as in-plant bus capacity, may require motors above a certain horsepower to be started with reduced voltage. Some countries require that any motor above 7½ Hp be started with reduced voltage.

Using reduced voltage motor starting also enables torque control. High inertia loads are a good example of an application in which electromechanical reduced voltage starting has been used to control the acceleration of the motor and load.

Electromechanical reduced voltage starters must make a transition from reduced voltage to full voltage at some point in the starting cycle. At this point, there is normally a line current surge. The amount of surge depends upon the type of transition being used and the speed of the motor at the transition point.

There are two methods of transition: Open Circuit Transition and Closed Circuit Transition. Open circuit transition means that the motor is actually disconnected from the line for a brief period of time when the transition takes place. With closed transition, the motor remains connected to the line during transition. Open circuit transition will produce a higher surge of current because the motor is momentarily disconnected from the line. Examples of open and closed circuit transition currents are shown in Figure 65 and Figure 66.

Figure 65 - Open Circuit Transition

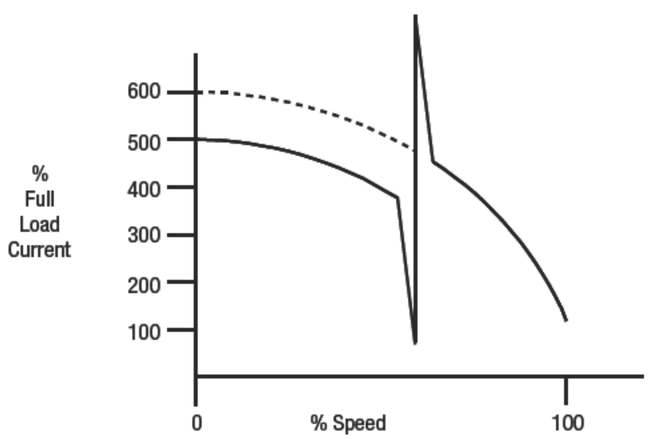
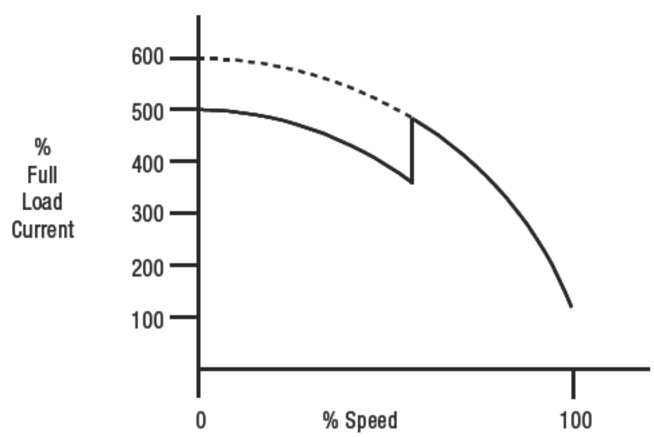


Figure 66 - Closed Circuit Transition



The motor speed can determine the amount of current surge that occurs at transition. Transfer from reduced voltage to full voltage should occur at as close to full speed as possible. This also minimizes the amount of surge on the line.

Figure 67 and Figure 68 illustrate transition at low motor speed and near full speed. The transition at low speed shows the current surge as transition occurs at 550%, which is greater than the starting current of 400%. The transition near full speed shows that the current surge is 300%, which is below the starting current.

Figure 67 - Transition at Low Speed

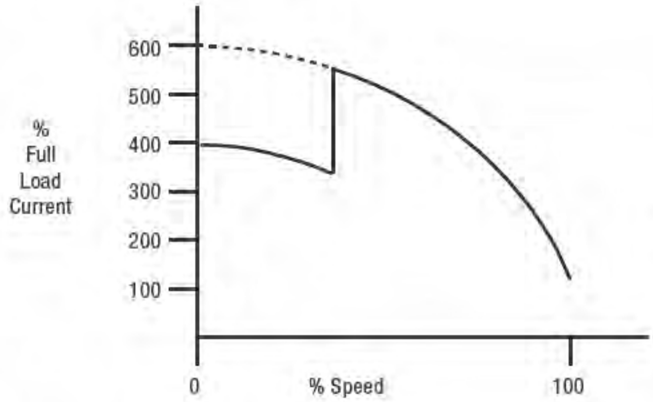
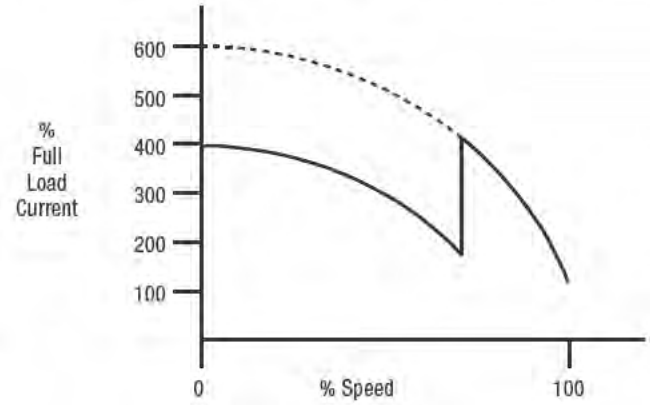


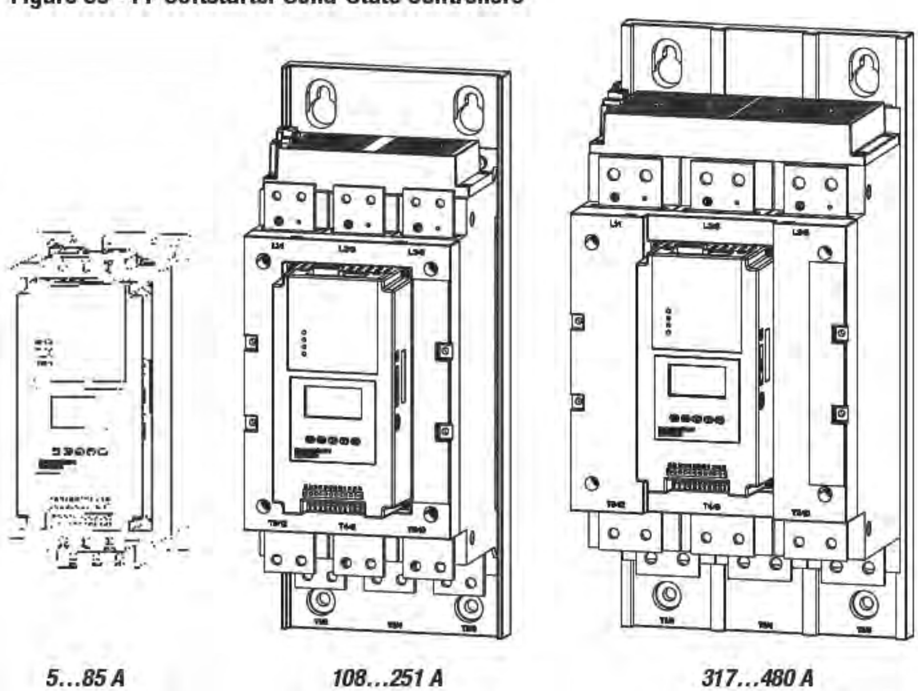
Figure 68 - Transition near Full Speed



PF Solid-State Controllers

The main function of solid-state controllers is their ability to provide a soft start or stepless reduced voltage start of AC motors. The same principles of current and torque apply to both electromechanical reduced voltage starters and solid-state controllers. Many solid-state controllers offer the choice of four starting modes: soft start, current limit start, dual ramp start, or full voltage start in the same device.

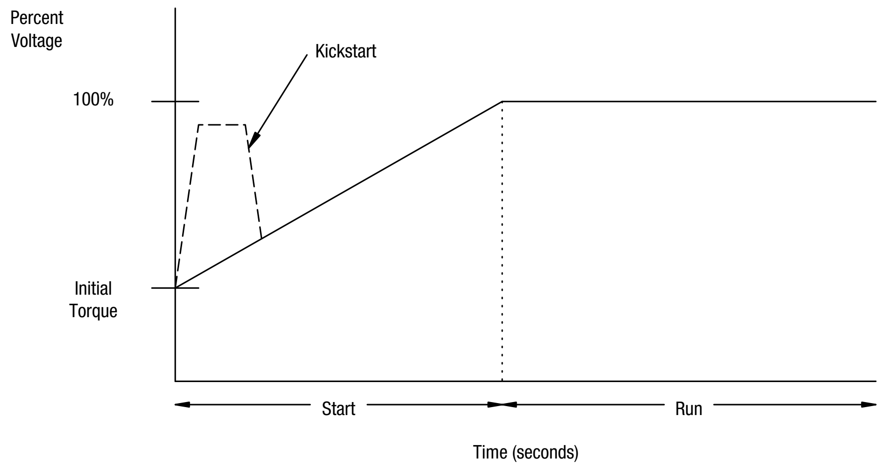
Figure 69 - PF Softstarter Solid-State Controllers



In addition to selecting the starting modes, the solid-state controller allows adjustment of the time for the soft start ramp, or the current limit maximum value, which enables selection of the starting characteristic to meet the application. The most widely used version is the soft start. This method provides a smooth start for most applications.

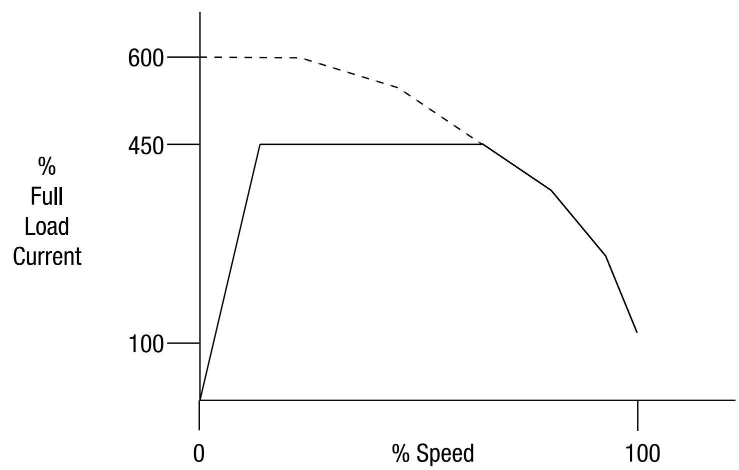
The major advantages of solid-state controllers are the elimination of the current transition point and the capability of adjusting the time to reach full voltage. The result is no large current surge when the solid-state controller is set up and correctly matched to the load, as illustrated in Figure 70.

Figure 70 - Soft Start



Current limit starting can be used in situations in which power line limitations or restrictions require a specific current load. Figure 71 shows a 450% current limit curve. Other values may be selected, such as 200%, 300%, or 400%, depending on the particular application. Current limit starting is also used in applications where higher starting torque is required compared to a soft start, which typically starts at less than 300% current. Current limit starting is typically used on low inertia loads, such as compressors.

Figure 71 - Current Limit Start



Other features available with solid-state controllers include additional protection to the motor and controller, and diagnostics to aid in setup and troubleshooting. Protection typically provided includes shorted SCR, phase loss, open load lead, SCR overtemperature, and stalled motor. Appropriate fault messages are displayed to aid in troubleshooting when one of these faults trip out the solid-state reduced voltage controller.

Solid-State Starters Using SCRs

Overview

In solid-state starters, silicon controlled rectifiers (SCRs) (see Figure 72) are used to control the voltage output to the motor. An SCR allows current to flow in one direction only. The amount of conduction of an SCR is controlled by the pulses received at the gate of the SCR. When two SCRs are connected back to back (see Figure 73), the AC power to a load can be controlled by changing the firing angle of the line voltage (see Figure 74) during each half cycle. By changing the angle, it is possible to increase or decrease the voltage and current to the motor. The PF Softstarter controller incorporates a microprocessor to control the firing of the SCRs. Six SCRs are used in the power section to provide full cycle control of the voltage and current. The voltage and current can be slowly and steplessly increased to the motor.

Figure 72 - Silicon Controlled Rectifier (SCR)

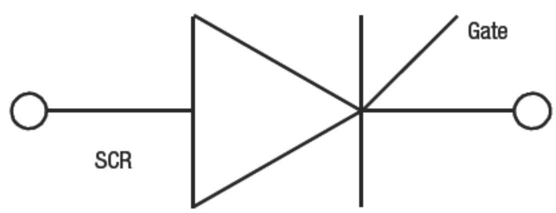


Figure 73 - Typical Wiring Diagram for SCRs

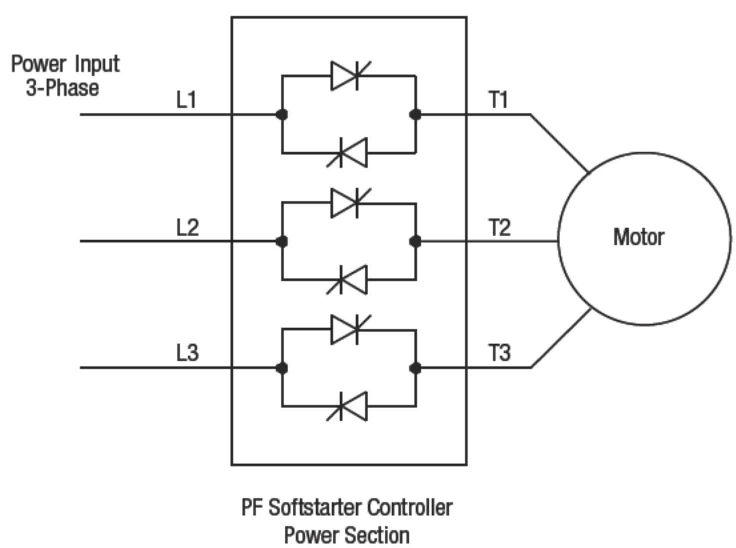
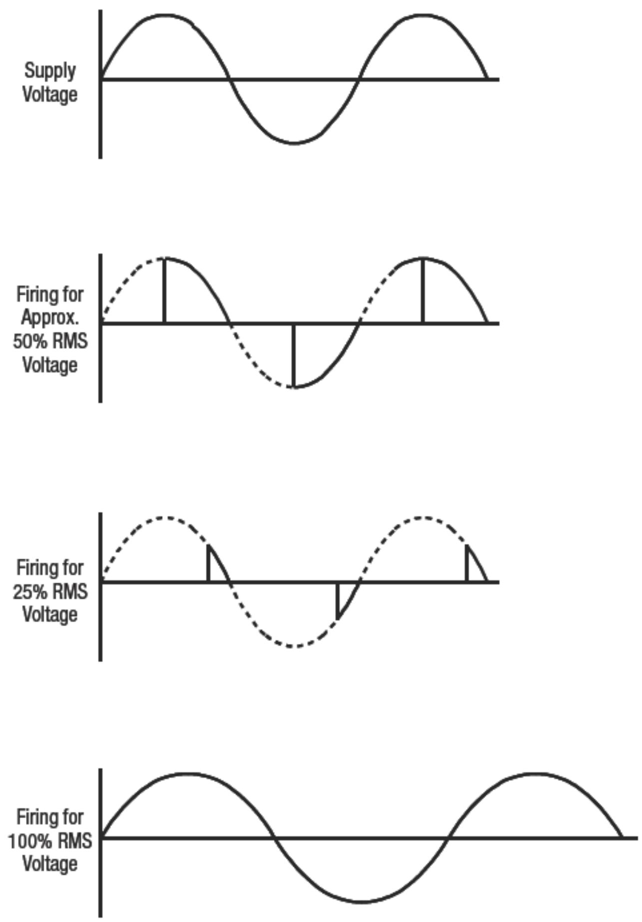


Figure 74 - Different Firing Angles (Single-Phase Simplification)



Reference

Certain mechanical parameters must be taken into consideration when applying motor controllers. The following section explains these parameters and how to calculate or measure them.

Motor Output Speed/Torque/Horsepower

The speed at which an induction motor operates depends on the input power frequency and the number of poles for which the motor is wound. The higher the frequency, the faster the motor runs. The more poles the motor has, the slower it runs. To determine the synchronous speed of an induction motor, use the following equation:

$$\text{Synchronous Speed} = \frac{60 \times 2 \times \text{Frequency}}{\text{Number of Poles}}$$

Actual full-load speed (the speed at which the motor will operate at nameplate rated load) will be less than synchronous speed. This difference between synchronous speed and full-load speed is called slip. Percent slip is defined as follows:

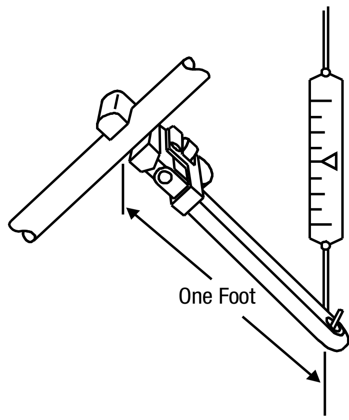
$$\text{Percent Slip} = \frac{\text{Synchronous Speed - Full Load Speed}}{\text{Synchronous Speed}} \times 100$$

Induction motors are built with slip ranging from less than 5% to as much as 20%. A motor with a slip of less than 5% is called a normal slip motor. Motors with a slip of 5% or more are used for applications requiring high starting torque.

Torque and Horsepower

Torque and horsepower, two important motor characteristics, determine the size of the motor required for a given application. The difference between the two can be explained using a simple illustration of a shaft and wrench.

Figure 75 - Shaft and Wrench



Torque is merely a turning effort. In the previous illustration, it takes one pound at the end of the one-foot wrench to turn the shaft at a steady rate. Therefore, the torque required is one pound × one foot, or one foot-lb. If the wrench were turned twice as fast, the torque required would remain the same, provided it is turned at a steady rate. Horsepower, on the other hand, takes into account how fast the shaft is turned. Turning the shaft rapidly requires more horsepower than turning it slowly. Thus, horsepower is a measure of the rate at which work is done. By definition, the relationship between torque and horsepower is as follows:

1 Horsepower = 33,000 ft.-lb./minute

In the above example, the one pound of force moves a distance of:

$$2 \text{ ft.} \times \pi \times 1 \text{ lb.} = 6.28 \text{ ft.-lb.}$$

To produce one horsepower, the shaft would have to be turned at rate of:

$$\frac{1 \text{ Hp} \times 33{,}000 \text{ ft-lb./minute}}{6.28 \text{ ft-lb./revolution}} = 5250 \text{ RPM}$$

For this relationship, an equation can be derived for determining horsepower output from speed and torque.

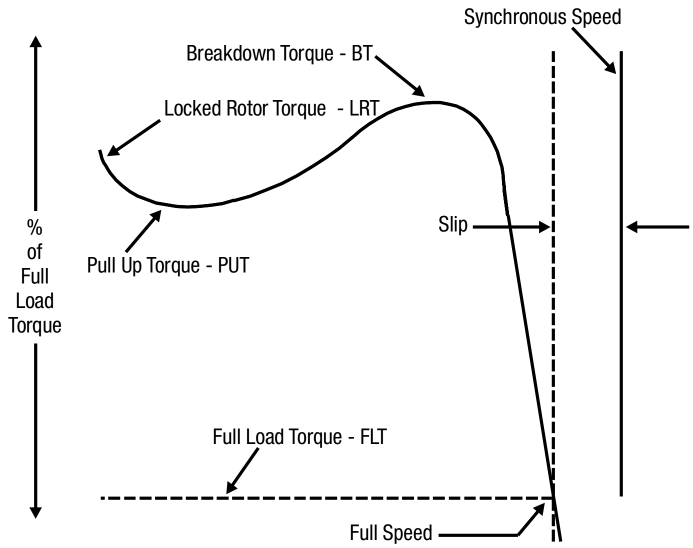
$$\text{Hp} = \frac{\text{RPM} \times \text{Torque} \times 2}{30{,}000} \quad \text{or} \quad \frac{\text{RPM} \times \text{Torque}}{5{,}250}$$

For this relationship, full-load torque is:

$$\text{Full-Load Torque in ft.-lb.} = \frac{\text{Hp} \times 5250}{\text{Full-Load RPM}}$$

Figure 76 illustrates a typical speed-torque curve for a NEMA Design B induction motor. An understanding of several points on this curve will aid in properly applying motors.

Figure 76 - Speed-Torque Curve



Full-load Torque (FLT)

The full-load torque of a motor is the torque necessary to produce its rated horsepower at full-load speed. In foot-lbs, it is equal to the rated horsepower, multiplied by 5250, divided by the full-load speed in RPM.

Locked-Rotor Torque (LRT)

Locked-rotor torque is the torque which the motor will develop at rest for all angular positions of the rotor, with rated voltage at rated frequency applied. It is sometimes known as “starting torque” and is usually measured as a percentage of full-load torque.

Pull-Up Torque (PUT)

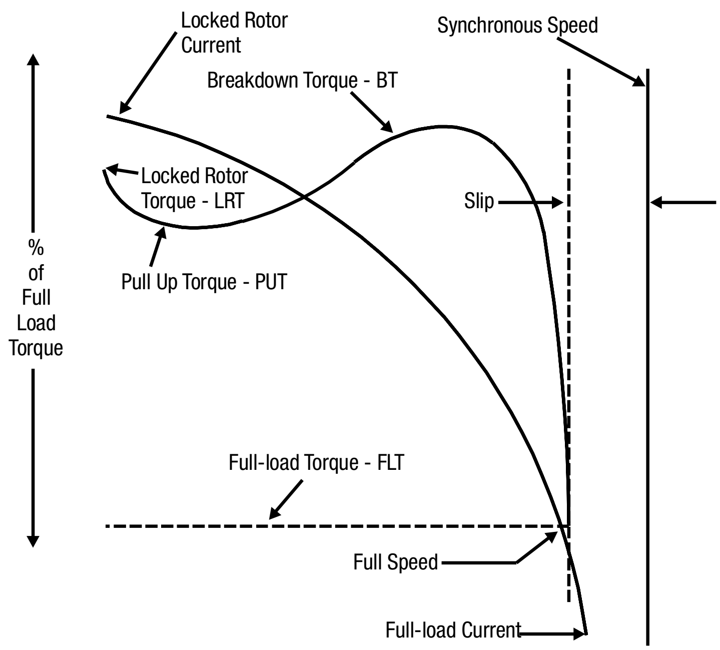
Pull-up torque of an induction motor is the minimum torque developed during the period of acceleration from locked rotor to the speed at which breakdown torque occurs. For motors that do not have definite breakdown torque (such as NEMA Design D), pull-up torque is the minimum torque developed, up to rated full-load speed, and is usually expressed as a percentage of full-load torque.

Breakdown Torque (BT)

The breakdown torque of an induction motor is the maximum torque the motor will develop with rated voltage applied, at rated frequency, without an abrupt drop in speed. Breakdown torque is usually expressed as a percentage of full-load torque.

In addition to the relationship between speed and torque, the relationship of current draw to these two values is an important application consideration. The speed/torque curve is repeated below, with the current curve added, to demonstrate a typical relationship.

Figure 77 - Speed-Torque Curve with Current Curve



Two important points on this current curve require explanation.

Full-load Current

The full-load current of an induction motor is the steady-state current taken from the power line when the motor is operating at full-load torque with rated voltage and rated frequency applied.

Locked-rotor Current

Locked-rotor current is the steady state current of a motor with the rotor locked and with rated voltage applied at rated frequency. NEMA has designed a set of code letters to define locked-rotor: Kilovolt-amperes-per-horsepower (kVA/Hp). This code letter appears on the nameplate of all AC squirrel-cage induction motors.

kVA per Hp is calculated as follows:

For three-phase motors:

$$\text{kVA/Hp} = \frac{1.73 \text{ x Current (in Amperes) x Volts}}{1000 \text{ x Hp}}$$

For single-phase motors:

$$\text{kVA/Hp} = \frac{\text{Current (in Amperes) x Volts}}{1000 \text{ x Hp}}$$

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

By manipulating the preceding equation for kVA/Hp for three-phase motors, the following equation can be used for calculating locked-rotor current:

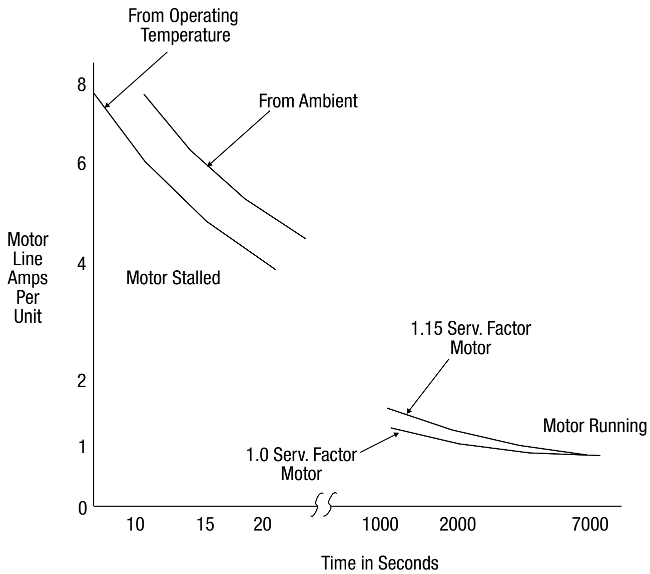
$$\text{kLRA} = \frac{1000 \text{ x Hp x KVA/Hp}}{1.73 \text{ x Volts}}$$

This equation can then be used to determine the approximate starting current of any particular motor. For instance, the approximate starting current for 7½ Hp, 230V motor with a locked-rotor kVA code letter of G would be:

$$\text{kLRA} = \frac{1000 \text{ x } 7.5 \text{ x } 6.0}{1.73 \text{ x } 230} = 113 \text{ A}$$

Operating a motor in a locked-rotor condition for an extended period of time will result in insulation failure because of the excessive heat generated in the stator. The following graph illustrates the maximum time a motor may be operated at locked-rotor without incurring damage caused by heating. This graph assumes a NEMA Design B motor with Class B temperature rise.

Figure 78 - Motor Safe Time vs. Line Current — Standard Induction Motors

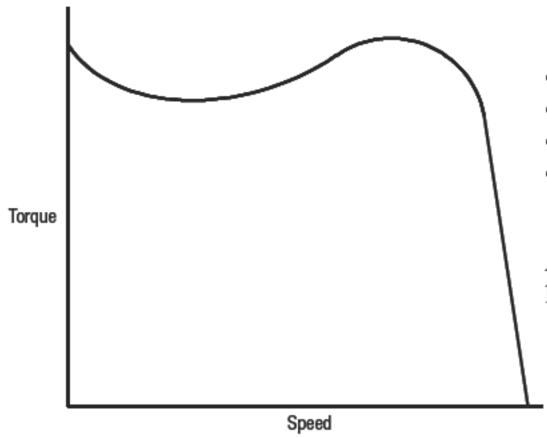


Motor protection, either inherent or in the motor control, should be selected to limit the stall time of the motor.

Motor Output for NEMA Design Designations Polyphase 1…500 Hp

NEMA has designated several specific types of motors, each having unique speed/torque relationships. These designs, along with some typical applications for each type, are described below. Following these descriptions are summaries of performance characteristics.

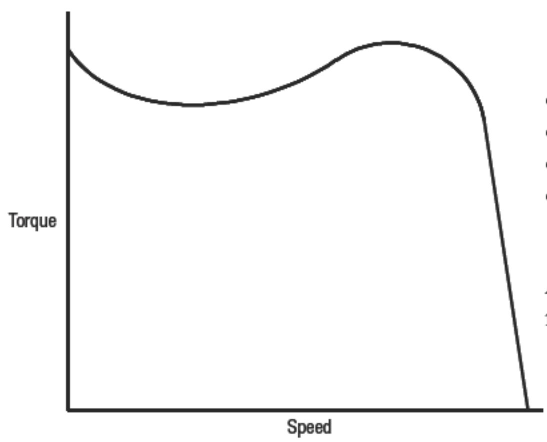
Figure 79 - Typical NEMA Design A Speed/Torque Curve



- Starting Current: High
- Starting Torque: High
- Breakdown Torque: High
- Full-load Slip: Low

Applications: Fans, blowers, pumps, machine tools, or other applications with high starting torque requirements and an essentially constant load.

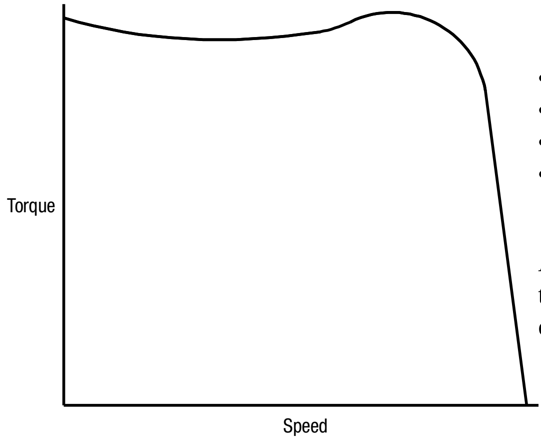
Figure 80 - Typical NEMA Design B Speed/Torque Curve



- Starting Current: Normal
- Starting Torque: Normal
- Breakdown Torque: Normal
- Full-load Slip: Normal

Applications: Fans, blowers, pumps, machine tools, or other applications with normal starting torque requirements and an essentially constant load.

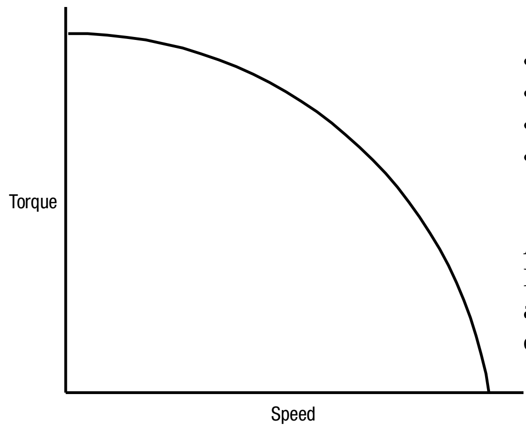
Figure 81 - Typical NEMA Design C Speed/Torque Curve



- Starting Current: Low
- Starting Torque: High
- Breakdown Torque: Low
- Full-load Slip: Low

Applications: The higher starting torque of NEMA Design C motors makes them advantageous for use on hard-to-start loads such as plunger pumps, conveyors, and compressors.

Figure 82 - Typical NEMA Design D Speed/Torque Curve



- Starting Current: Normal
- Starting Torque: High
- Breakdown Torque: None
- Full-load Slip: High (5…13%)

Applications: The combination of high starting torque and high slip make NEMA Design D motors ideal for use on very high inertia loads and/or in applications where a considerable variation in load exists. These motors are commonly used on punch presses, shears, cranes, hoists, and elevators.

Table 14 - Motor Output - Comparison of NEMA Polyphase Designs

NEMA Design	Starting Torque	Locked Rotor Torque	Breakdown Torque	% Slip	Applications
A	High	High	High	< 5%	Broad applications including fans, blowers, pumps, and machine tools.
B	Normal	Normal	Normal	< 5%	Normal starting torque for fans, blowers, rotary pumps, unloaded compressors, conveyors, metal cutting, machine tools, miscellaneous machinery.
C	Low	High	Low	Low	High inertia starts such as large centrifugal blowers, fly wheels and crusher drums.
D	Normal	High	None	High	Very high inertia and loaded starts. Choice of slip range to match application.
				5...8%	Punch press, sheers and forming machine tools.
				8...13%	Cranes, hoists, elevators and oil well pumping jacks.

Calculating Torque (Acceleration Torque Required for Rotating Motion)

Some machines must be accelerated to a given speed in a certain period of time. The torque rating of the drive may have to be increased to accomplish this objective. The following equation may be used to calculate the average torque required to accelerate a known inertia (WK^2). This torque must be added to all the other torque requirements of the machine when determining the drive and motor's required peak torque output.

$$T = \frac{WK^2 \times (\Delta N)}{308 \times t}$$

Where:

- T = Acceleration Torque (ft.-lb.)
- WK2 = total system inertia (ft.-lb.^{2}) that the motor must accelerate. This value includes motor armature, reducer, and load.
- ΔN = Change in speed required (RPM)
- t = time to accelerate total system load (seconds).

Note: The number substituted for (WK^2) in this equation must be in units of ft.-lb.^{2}. Consult the conversion tables for the proper conversion factor.

The same formula can be used to determine the minimum acceleration time of a given drive, or it can be used to establish whether a drive can accomplish the desired change in speed within the required time period.

Transposed formula:

$$T = \frac{WK^2 \times (\Delta N)}{308 \times t}$$

General Rule — If the running torque is greater than the accelerating torque, use the running torque as the full-load torque required to determine the motor horsepower.

Note: The following equations for calculating horsepower are meant to be used for estimating purposes only. These equations do not include any allowance for machine friction, winding or other factors that must be considered when selecting a device for a machine application. After the machine torque is determined, the required horsepower is calculated using the formula:

$$Hp = \frac{T \times N}{5250}$$

Where:

- Hp = Horsepower
- T = Torque (ft.-lb.)
- N = Speed of motor at rated load (RPM)

If the calculated horsepower falls between standard available motor ratings, select the higher available horsepower rating. It is good practice to allow some margin when selecting the motor horsepower.

Inertia

Inertia is a measure of the body's resistance to changes in velocity, whether the body is at rest or moving at a constant velocity. The velocity can be either linear or rotational.

The moment of inertia (WK^2) is the product of the weight (W) of an object and the square of the radius of gyration (K^2). The radius of gyration is a measure of how the mass of the object is distributed about the axis of rotation. Because of this distribution of mass, a small diameter cylindrical part has a much lower inertia than a large diameter part.

WK^2 or WR^2

Where:

- WR^2 refers to the inertia of a rotating member that was calculated by assuming the weight of the object was concentrated around its rim at a distance R (radius) from the center (e.g., flywheel).

WK^2 refers to the inertia of a rotating member that was calculated by assuming the weight of the object was concentrated at some smaller radius, K (termed the radius of gyration). To determine the WK^2 of a part, the weight is normally required (e.g., cylinder, pulley, gear).

Torque Formulas

$$T = \frac{Hp \times 5250}{N}$$

Where:

- Hp = Horsepower
- T = Torque (ft.-lb.)
- N = Speed of motor at rated load (RPM)

$$T = F \times R$$

Where:

- T = Torque (ft.-lb.)
- F = Force (lb.)
- R = Radius (ft.)

$$T\ (\text{Accellerating}) = \frac{WK^2 \times (\Delta RPM)}{308 \times t}$$

Where:

- T = Torque (ft.-lb.)
- WK^2 = Inertia reflected to the motor shaft (ft.-lb.^{2})
- ΔRPM = Change in speed
- t = Time to accelerate (s.)

Note: To change in-lb-sec.^{2} to ft.-lb.^{2}, multiply by 2.68.
To change ft.-lb.^{2} to in-lb-sec.^{2}, divide by 2.68.

AC Motor Formulas

$$\text{Synchronous Speed} = \frac{\text{Frequency x 120}}{\text{Number of Poles}}$$

Where:

- Synchronous Speed = Synchronous Speed (RPM)
- Frequency = Frequency (Hz)

$$\text{Percent Slip} = \frac{\text{Synchronous Speed - Full-Load Speed}}{\text{Synchronous Speed}} \text{ x 100}$$

Where:

- Full-Load Speed = Full Load Speed (RPM)
- Synchronous Speed = Synchronous Speed (RPM)

$$\text{Reflected WK2} = \frac{\text{WK}^2\text{ of Load}}{(\text{Reduction Rate})^2}$$

Where:

WK^2 = Inertia (ft.-lb.^{2})

Torque Characteristics on Common Applications

The following chart offers a quick guideline on the torque required to breakaway, start and run many common applications.

Table 15 - Torque Characteristics on Common Applications

Application	Load Torque as Percent of Full Load Drive Torque		
	Breakaway	Accelerating	Peak Running
Agitators:			
Liquid	100	100	100
Slurry	150	100	100
Blowers, centrifugal:			
Valve closed	30	50	40
Valve open	40	110	100
Blowers, positive-displacement, rotary, bypassed	40	40	100
Card machines, textile	100	110	100
Centrifuges (extractors)	40	60	125
Chippers, wood, starting empty	50	40	200
Compressors, axial-vane, loaded	40	100	100
Compressors, reciprocating, start unloaded	100	50	100
Conveyors, belt (loaded)	150	130	100
Conveyors, drag (or apron)	175	150	100
Conveyors, screw (loaded)	175	100	100
Conveyors, shaker-type (vibrating)	150	150	75
Draw presses (flywheel)	50	50	200
Drill presses	25	50	150
Escalators, stairways (starting unloaded)	50	75	100
Fans, centrifugal, ambient:			
Valve closed	25	60	50
Valve open	25	110	100
Fans, centrifugal, hot:			
Valve closed	25	60	100
Valve open	25	200	175
Fans, propeller, axial-flow	40	110	100
Feeders, (belt) loaded	100	120	100
Feeders, distributing, oscillating drive	150	150	100
Feeders, screw, compacting rolls	150	100	100
Feeders, screw, filter-cake	150	100	100
Feeders, screw, dry	175	100	100
Feeders, vibrating, motor-driven	150	150	100
Frames, spinning, textile	50	125	100
Grinders, metal	25	50	100
Ironers, laundry (mangles)	50	50	125
Jointers, woodworking	50	125	125
Machines, bottling	150	50	100
Machines, buffing, automatic	50	75	100
Machines, cinder-block, vibrating	150	150	70
Machines, keyseating	25	50	100
Machines, polishing	50	75	100
Mills, flour, grinding	50	750	100
Mills, saw, band	50	75	200

Continued on next page

Application	Load Torque as Percent of Full Load Drive Torque		
	Breakaway	Accelerating	Peak Running
Mixers, chemical	175	75	100
Mixers, concrete	40	50	100
Mixers, dough	175	125	100
Mixers, liquid	100	100	100
Mixers, sand, centrifugal	50	100	100
Mixers, sand, screw	175	100	100
Mixers, slurry	150	125	100
Mixers, solids	175	125	175
Planers, woodworking	50	125	150
Presses, pellet (flywheel)	150	75	150
Presses, punch (flywheel)	150	75	100
Pumps, adjustable-blade, vertical	50	40	125
Pumps, centrifugal, discharge open	40	100	100
Pumps, oil-field, flywheel	150	200	200
Pumps, oil, lubricating	40	150	150
Pumps, oil fuel	40	150	150
Pumps, propeller	40	100	100
Pumps, reciprocating, positive displacement	175	30	175
Pumps, screw-type, primed, discharge open	150	100	100
Pumps, Slurry-handling, discharge open	150	100	100
Pumps, turbine, centrifugal, deep-well	50	100	100
Pumps, vacuum (paper mill service)	60	100	150
Pumps, vacuum (other applications)	40	60	100
Pumps, vane-type, positive displacement	150	150	175
Rolls, crushing (sugar cane)	30	50	100
Rolls, flaking	30	50	100
Sanders, woodworking, disk or belt	30	50	100
Saws, band, metalworking	30	50	100
Saws, circular, metal, cut-off	25	50	150
Saws, circular, wood, production	50	30	150
Saws, edger (see edgers)			
Saws, gang	60	30	150
Screens, centrifugal (centrifuges)	40	60	125
Screens, vibrating	50	150	70
Separators, air (fan-type)	40	100	100
Shears, flywheel-type	50	50	120
Textile machinery	150	100	90
Walkways, mechanized	50	50	100
Washers, laundry	25	75	100

Electrical Formulas

Ohm's Law:

$$I = \frac{E}{R} \qquad R = \frac{E}{I} \qquad E = I \times R$$

Where:

I = Current (Amperes)
E = EMF or Voltage (Volts)
R = Resistance (Ohms)

Power in DC Circuits:

$$P = I \times E \qquad HP = \frac{I \times E}{746}$$

$$KW = \frac{I \times E}{1000} \qquad kWH = \frac{I \times E \times Hour}{1000}$$

Where:

P = Power (Watts)
I = Current (Amperes)
E = EMF or Voltage (Volts)
kW = Kilowatts
kWH = Kilowatt-Hours

$$kVA\ (1\text{-phase}) = \frac{I \times E}{1000} \qquad kVA\ (3\text{-phase}) = \frac{I \times E \times 1.73}{1000}$$

Where:

kVA = Kilovolt-Amperes
I = Current (Amperes)
E = EMF or Voltage (Volts)

$$kW\ (1\text{-phase}) = \frac{I \times E \times PF}{1000}$$

$$kW\ (2\text{-phase}) = \frac{I \times E \times PF \times 1.42}{1000}$$

$$kW\ (3\text{-phase}) = \frac{I \times E \times PF \times 1.73}{1000}$$

$$PF = \frac{W}{V \times I} = \frac{kW}{kVA}$$

Where:

kW = Kilowatts
I = Current (Amperes)
E = EMF or Voltage (Volts)
PF = Power Factor
W = Watts
V = Volts
kVA = Kilovolt-Amperes

Calculating Motor Amperes

$$\text{Motor Amperes} = \frac{\text{HP x 746}}{\text{E x 1.732 x Eff x PF}}$$

$$\text{Motor Amperes} = \frac{\text{kVA x 1,000}}{\text{1.73 x E}}$$

$$\text{Motor Amperes} = \frac{\text{kW x 1,000}}{\text{1.73 x E x PF}}$$

Where:

HP = Horsepower
E = EMF or Voltage (Volts)
Eff = Efficiency of Motor (%/100)
kVA = Kilovolt-Amperes
kW = Kilowatts
PF= Power Factor

Other Formulas

Calculating Accelerating Force for Linear Motion:

$$\text{F (Acceleration)} = \frac{\text{W x } \Delta\text{V}}{\text{1,933 x t}}$$

Where:

F = Force (lb.)
W = Weight (lb.)
ΔV = Change in Velocity (FPM)
t = Time to accelerate weight (seconds)

$$\text{LRA} = \frac{\text{HP x} \left(\frac{\text{Start kVA}}{\text{HP}}\right) \text{x 1,000}}{\text{E x 1.73}}$$

Where:

LRA = Locked Rotor Amperes
HP = Horsepower
kVA = Kilovolt-Amperes
E = EMF or Voltage (Volts)

$$\text{LRA @ Freq. X} = \frac{\text{60 Hz LRA}}{\sqrt{\frac{60}{\text{Freq. X}}}}$$

Where:

60 Hz LRA = Locked Rotor Amperes
Freq. X = Desired frequency (Hz)

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