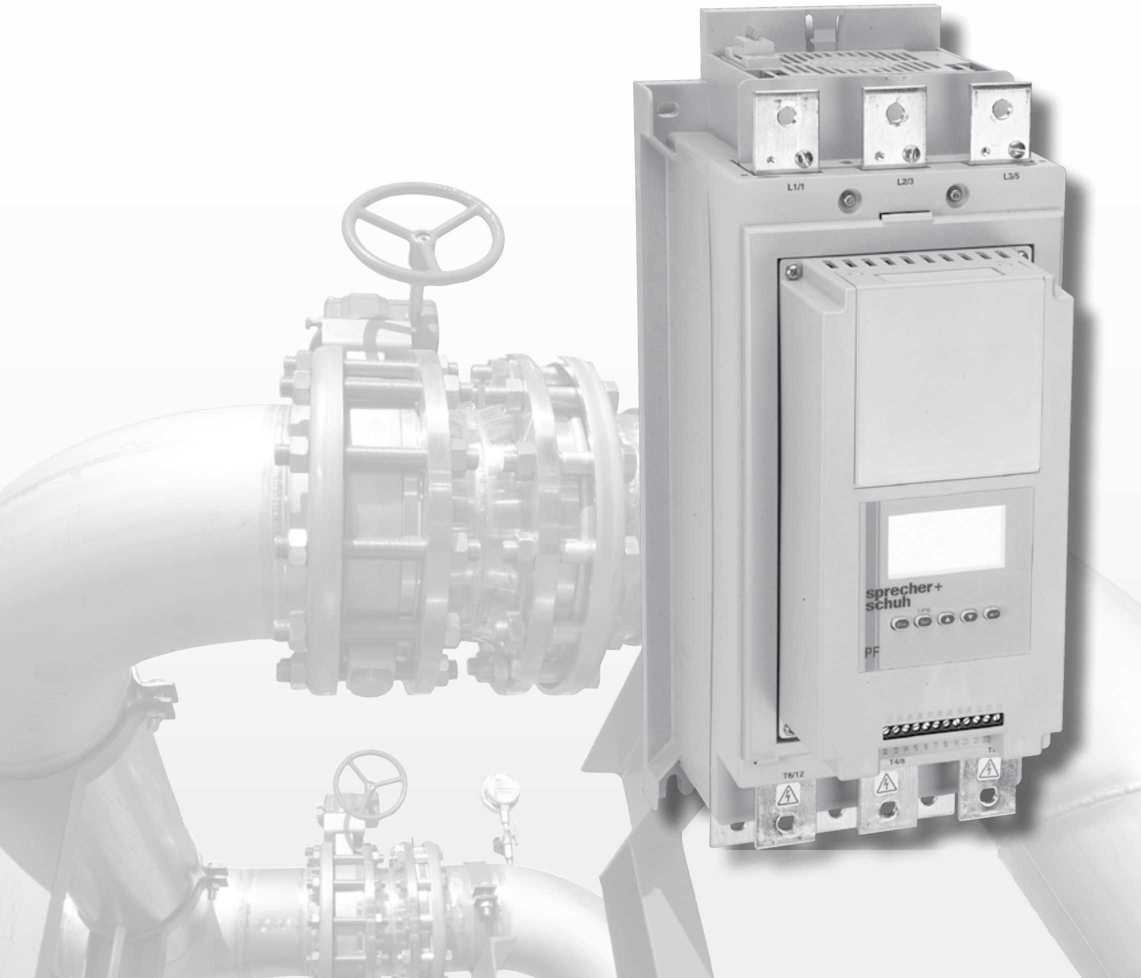
sprecher + schuh

PFB Softstarters
With Pump Control

A unique, cost-effective approach to reducing fluid "surges" or "hammering"



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Industry Overview

Surges or pressure transients occur in centrifugal pumping systems when any sudden change of flow is introduced. These surges can result from starting and stopping a pump, opening or closing valves, and many other sources in a particular system. There are a number of mechanical surge reduction techniques, but these tend to be costly and complex. Electronic starting and stopping of the pump motor will be explored as a cost-effective solution that reduces surges or hammering problems.

From the Affinity Laws for Pumps we see:

$$\frac{Q2}{Q1} \propto \frac{N2}{N1}$$

Where N = Pump Speed
Q = Flow (CFM)

Therefore, we can directly relate the percentage of change in pump speed to the percentage of change in flow output from the pump.

Centrifugal pumps are generally coupled directly to the shaft of an electric motor. When the motor is started by applying full line voltage, the pump is accelerated from zero speed to full speed very quickly—less than 1/4 second is not uncommon. This means that the flow out of the pump also increases from zero to total capacity in less than 1/4 second. Due to the fact that fluids are only slightly compressible and have momentum, this large change in flow over such a short period of time results in high and low pressure surges and cavitation as the system seeks equilibrium. This results in many undesirable effects.

Pressure surges stress the walls of the pipe and cause an audible noise. The sound is as if the pipe was struck with a mallet repeatedly. The noise is responsible for the term “water hammering” or “hammering” being applied to this phenomenon. The sound created is trivial when compared to the physical damage that pressure surges can cause. Extremely high pressure transients can cause the pipe to burst while extremely low transients can cause pipes to collapse. Cavitation produces zones of highly agitated liquid and partial vacuums whereby the pipe lining may be eroded and the liquid may be boiled off. These effects also damage the valves and fittings. All of the effects are objectionable.

Since hammering is caused by rapid changes in flow, the hammering caused by starting and stopping the pump can be minimized by controlling the acceleration and deceleration of the pump motor. To understand how fluid flow is affected during the starting and stopping of a pump motor, a review of the various starting and stopping methods is necessary.

The methods of starting and stopping a pump motor to be reviewed are as follows:

- Direct-on-line (closing a contactor and applying full voltage to the motor)
- Solid-state reduced voltage starting
- PFB Softstarter with Pump Control Option

Before comparing the methods of starting, the relationship between the pump system and pump motor must be established.

Pump System and Pump Motor Relationship

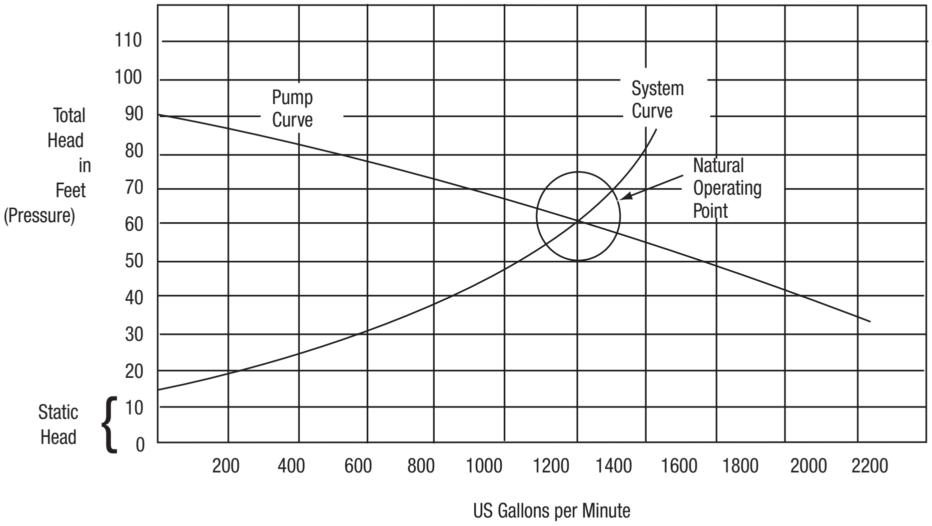

Figure 1. Pump Curve Versus System Curve.

Figure 1 shows two independent curves. One is the pump curve, which is solely a function of the physical characteristics of the pump.

The other is the system curve which is dependent on the pipe diameter and length, the number and location of elbows, and many other factors. The intersection of these two curves is called the natural operating point.

Another Affinity Law states:

$$\frac{P2}{P1} \propto \left(\frac{N2}{N1}\right)^2$$

Where N = Pump Speed
P = Pressure (Feet of Head)

Therefore, we can say that the change in pressure is proportional to the square of the speed.

For a pump motor (AC induction motor) driving a variable torque load, such as a centrifugal pump, the following is true:

$$\frac{T2}{T1} \propto \left(\frac{N2}{N1}\right)^2$$

Where N = Motor Speed
T = Motor Torque

Since the pump is directly coupled to the shaft of the motor:

$$\left(\frac{N2}{N1}\right)^2 \propto \frac{P2}{P1} \propto \frac{T2}{T1}$$

Therefore, change in pressure is directly proportional to change in motor torque.

Motor characteristics are described in terms of Speed/Torque curves. Since we have determined that flow is proportional to speed, and pressure is proportional to torque, we can plot the pump torque requirement and the motor torque curve on the same graph.

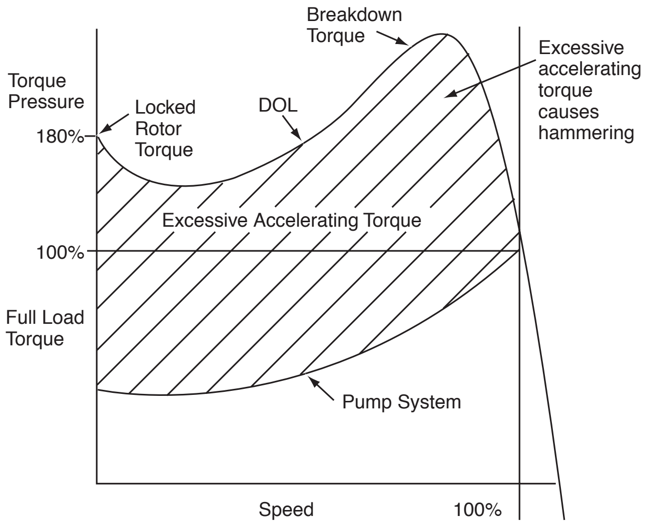

Figure 2. Direct on Line / Pump Speed Torque Curve.

Direct on Line Starting

Figure 2 shows the speed torque characteristics of a pump (AC induction) motor started direct on line (DOL) with the load requirements of a centrifugal pump superimposed. Note that at 100% speed the two curves intersect. The motor meets the full load requirements of the pump system. Motors are selected to meet the pump load requirements based on this single point in the two curves.

Unfortunately, the motor torque output more than exceeds the requirement of the pump during the start cycle. Locked rotor torque (LRT) is the torque developed by the motor the instant full voltage is seen at the motor terminals at zero speed. LRT can be as high as 180% of the torque the motor produces at full speed. Breakdown torque (BT) is the highest amount of torque the motor can develop. BT can be as high as 250% of full load torque. The difference between the torque produced by the motor and that required by the load is called Accelerating Torque.

Accelerating Torque is the torque that causes the motor to rotate the connected load. In the case of the pump, the excessive accelerating torque produced by starting the motor Direct on Line causes the pump to come up to speed very quickly, typically in less than 1/4 second. The result of this sudden change in speed (and therefore flow) is “surges” or “hammering” in the pipe system.

To look at the problem another way, as shown in Figure 3 on page 6, there is a very large change in flow (Q1) in a very short period of time (T1). This is due to the large acceleration torque shown in Figure 2, resulting in system hammering during starting of the pump motor.

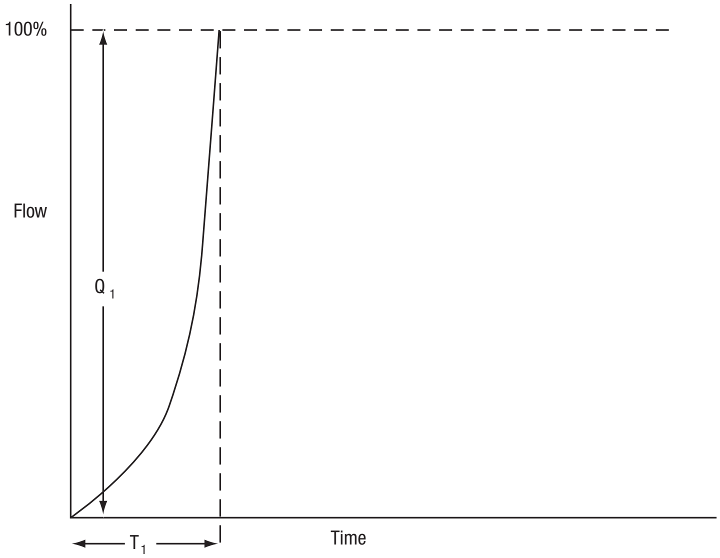

Figure 3. Change in Flow Versus Time — Direct on Line Starting.

Solid-State Reduced Voltage Starting

If the period of time in which the flow goes from zero to 100% can be increased, hammering can be reduced. This can be achieved by reducing the amount of accelerating torque delivered by the motor. Less accelerating torque means less force to turn the load and therefore more time required to change the speed of the pump. This can be done using a solid-state reduced voltage starter to slowly ramp the voltage applied to the motor from zero to full voltage over some preset time (adjustable from 2... 30 seconds).

The formula for torque in an induction motor is:

$$T \propto V2$$

Where T = Motor Torque
V = Voltage

From this equation we can see that the torque produced by a motor will vary by the square of the voltage. Therefore, reducing the voltage by 50% will reduce the torque to:

.5 x .5 = .25 or 25%

25% of the initial torque is now available. If the locked rotor torque was 180%, then:

180% x .25 = 45%

The new value of initial torque is 45% of the full load torque.

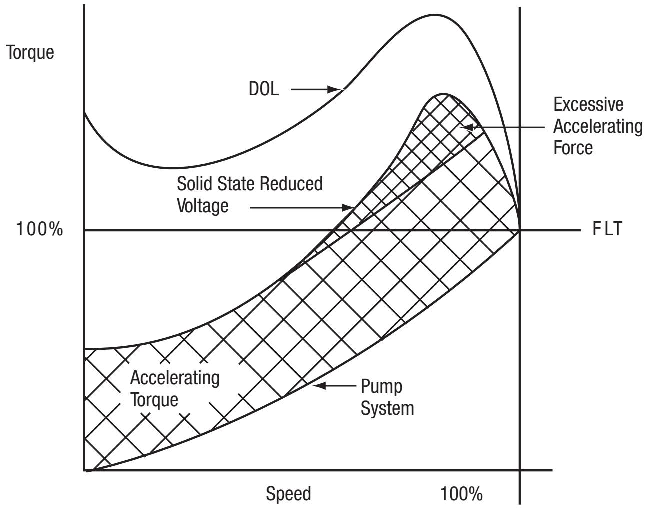

Figure 4. Solid-State Reduced Voltage / Pump Speed Torque Curve.

Figure 4 compares the Speed Torque characteristics for DOL starting and solid-state reduced voltage starting of an induction motor. Note that accelerating torque has been greatly reduced versus the Direct on Line method of starting the pump motor. This is caused by the solid-state motor controller's ability to start at a lower value of initial voltage and to "ramp " up to the full voltage value over an adjustable time period. The torque applied to the motor also "ramps" up.

At the end of the "ramp", however, there is an excessive acceleration torque as shown in Figure 4. This sudden change in torque generates a corresponding burst of speed (flow) at the end of the start cycle and results in hammering.

Again the nature of fluids comes into play. In Figure 5, flow (speed) versus time is compared for the two methods. Note the ultimate flows (Q1 and Q2) are the same, but the time varies. T2 is longer than T1 so there has not been a sudden surge on the system. However, when observing

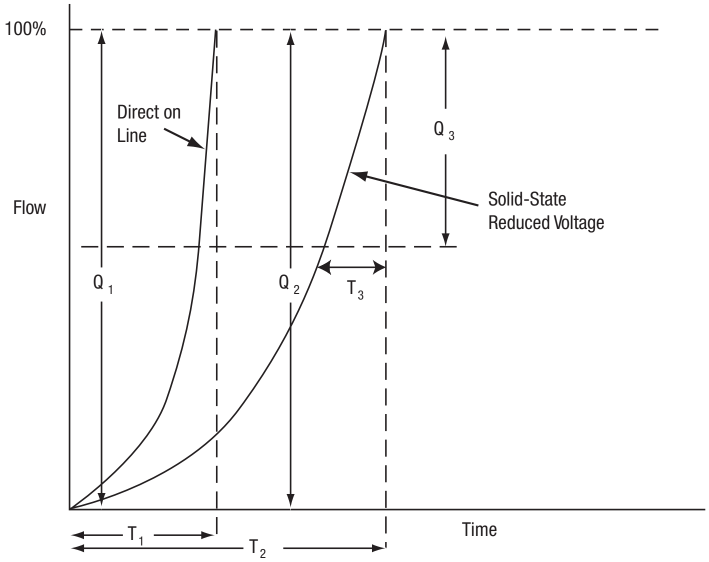

Figure 5. Change in Flow Versus Time.

Q3 versus T3 there is still a rapid change in flow (Q3) versus time (T3). There is still excessive acceleration torque as the pump motor rapidly approaches 100% speed. This is a result of the breakdown torque which is still present when using a solid-state reduced voltage starter. This sudden surge in pump motor torque at the end of the start cycle results in a flow surge.

The sudden surge in torque is due to the characteristics of the motor. It occurs because solid-state reduced voltage starting ramps the voltage up without regard to the motor's performance. In centrifugal pumping applications the result is hammering.

As shown, solid-state reduced voltage starting improves starting torque characteristics of the pump motor, but cannot control breakdown torque which causes surges.

This is where Sprecher + Schuh's innovative pump control option resolves this problem.

PFB Softstarter with Pump Control for Starting Pump Motors

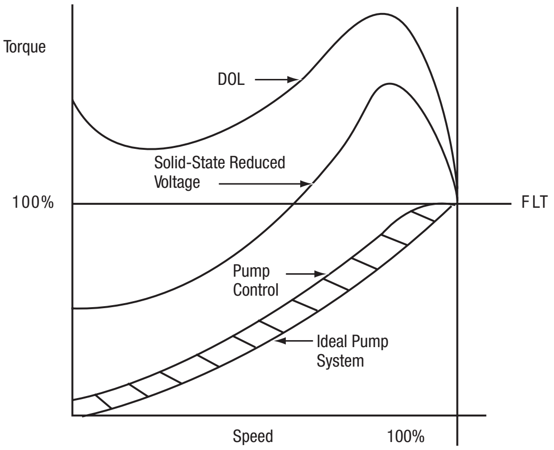

Figure 6. PFB Softsarter with Pump Control/Pump Speed Torque Curve.

Figure 6 compares direct on line starting, solid-state reduced voltage, and pump control starting speed torque curves.

With pump control, the surge produced during DOL and solid-state reduced voltage is greatly reduced. This is done by using the microprocessor in the PFB Softstarter to carefully control the torque output of the motor.

Since there are no sudden changes in torque, this translates into a smooth acceleration of the motor minimizing surges or hammering in the system.

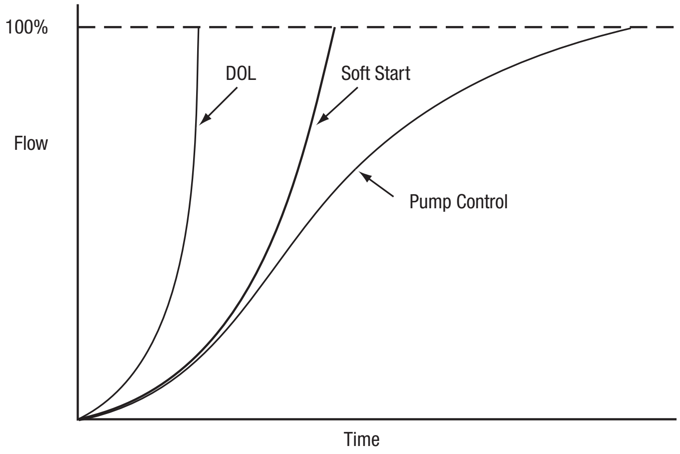

Figure 7. Change in Flow Versus Time.

In Figure 7, flow versus time is compared for the three starting methods.

Pump control reduces sudden change in flow by controlling the accelerating torque of the pump motor and extending the time to produce a 100% flow, thus minimizing "hammering." This is the desired effect and is the key to the pump control option: There are no sudden changes in torque. This is what is needed to reduce surges. Therefore, hammering is reduced in the pumping system.

PFB Softstarter with Pump Control for Stopping Pump Motors

So far, we have only discussed starting techniques. Stopping the pump is as critical in reducing surges and hammer as starting. In this discussion we will limit the examples to speed (flow) versus time. Refer to Figure 8.

When a direct on line starter is applied, the pump motor will coast when a stop command is initiated (see Figure 8).

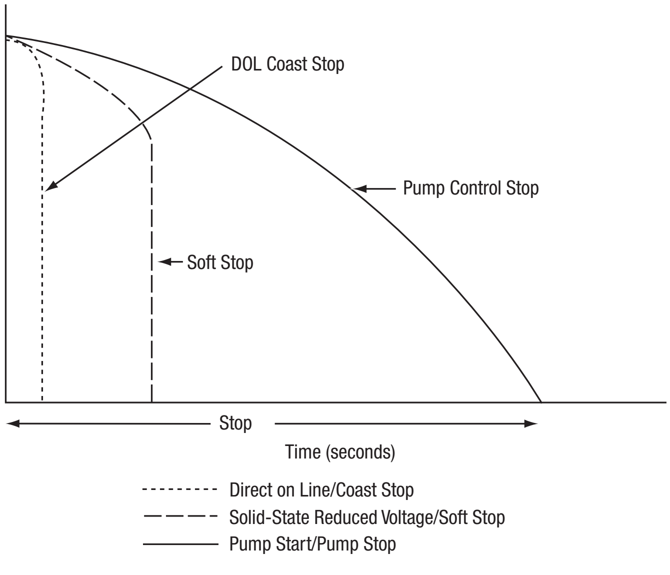

Figure 8. PFB Softstarter with Pump Control for Stopping Pump Motors.

The system head will quickly overcome the motor inertia and the pump will come to a rapid stop. The fluid, which is in motion and has momentum, must come to a complete halt as well. This action causes pressure surges on the pipes and valves. This is undesirable due to the damage caused in the system.

Many control manufacturers are promoting a solid-state reduced voltage starter with a soft or extended stop as a solution to surge or hammering problems. In most applications, a soft stop cannot prevent sudden changes in motor torque required on pumping applications. When a soft stop is initiated, the voltage is ramped from full voltage to zero volts over a time selected by the user (see Figure 8). As shown before, reduction in voltage results in reduction of torque and the pump begins to slow down. However, a point is quickly reached where the load torque demand exceeds the motor torque supply and the motor stalls. The effect, though not as severe, is the same as slamming a valve closed, and hammering occurs.

The PFB Softstarter with pump control will control the deceleration of the pump motor in a method similar to the control of the acceleration. When a stop command is initiated, the controller reduces the motor speed to prevent any sudden changes in torque, minimizing surges in the system. The PFB Softstarter continues to reduce the torque of the pump motor resulting in a speed characteristic as shown in Figure 8. This type of pump motor deceleration curve results in minimal surges or hammering in the system as there will not be sudden changes in flow.

PFB Softstarter with Pump Control for Starting and Stopping Pump Motors

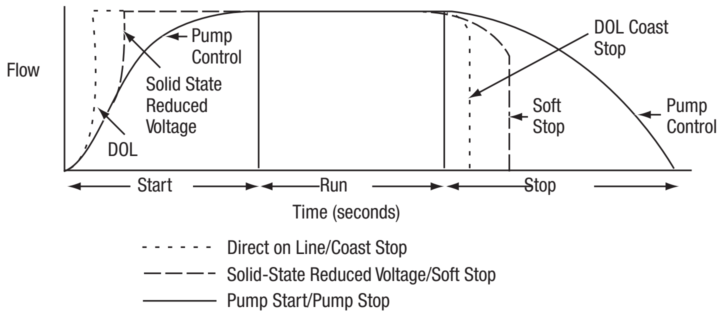

Figure 9. PFB Softstarter with Pump Control for Starting and Stopping Pump Motors

To summarize, Figure 9 compares flow versus time when different starting/stopping techniques are employed. The Sprecher + Schuh PFB Softstarter with pump control produces the most desirable flow characteristics when starting and stopping centrifugal pump motors. There are no sudden peaks or breaks in flow which result in surges or hammering in the system.

When analyzing what is to be done about a hammering problem, an electrical solution should be considered before a mechanical solution. The initial cost for the electrical solution tends to be less than that of a specialized control valve, and less complex. In addition, the frequent maintenance/system shutdown that would be required with the specialized valve is not required with an electrical solution.

The PFB Softstarter with pump control is the preferred starting and stopping method of centrifugal pump systems.

PF Softstarter Features

The PF Softstarter is used on applications other than pumps for controlling the starting and stopping of AC induction motors. During starting, the PF Stoftstarter minimizes mechanical shocks to the system. It can also be applied to minimize line disturbances that occur on the power system when a motor is started direct on line.

The PF Softstarter provides microcomputer-controlled starting for standard three- phase squirrel cage induction motors and wye-delta motors with the inside-the-delta wiring configuration. While the PF Softstarter 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. The following modes of operation are available within a single controller:

PFS Softstarter Standard Controller

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

Pump Control and Braking Control are optional features on the PF Softstarter.

PFB Pump Control Option

– Pump Control with Selectable Kickstart

PFD Brake Control Option

– Smart Motor Braking

– Accu-Stop

– Slow Speed with Braking

The PF Softstarter is a compact, modular, multi-functional solid-state controller used in both starting three-phase squirrel-cage induction motors with wye-delta motors controlling resistive loads. The PFB Softstarter contains, as standard, a built-in SCR bypass and a built-in overload. The PFB Softstarter product line covers voltages of 200... 600V, 50/60 Hz. This device is available as a non-combination and combination controller.

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