White Paper

Allen-Bradley

SMC™-50 Technology and Control Advances

Sensorless Linear Acceleration and Energy Management

Additional Resources

These documents contain additional information concerning related products from Rockwell Automation.

Resource	Description
Industrial Automation Wiring and Grounding Guidelines, publication 1770-4.1	Provides general guidelines for installing a Rockwell Automation industrial system.
Product Certifications website, http://www.ab.com	Provides declarations of conformity, certificates, and other certification details.

You can view or download publications at http://www.rockwellautomation.com/literature/. To order paper copies of technical documentation, contact your local Allen-Bradley distributor or Rockwell Automation sales representative.

Introduction

Given increasing costs and environmental awareness, energy conservation is a growing concern, and the need for energy efficiency throughout a plant or manufacturing floor is a priority. According to the US Department of Energy, motors consume 64% of domestic manufacturer's total electricity. Motors that run pumps and fans comprise greater than half of the load. Worldwide, pumps account for 20% of the total electrical demand. More and more attention is paid to motor starting methods as a cost savings to the bottom line. Using just enough energy to start and run motors helps to control the demand charges imposed by the local electric utility company by reducing the amount of wasted energy.

Some of the technology options for starting a motor include using contactors, variable frequency drives (VFDs), or soft starters such as the Smart Motor Controller (SMC™), the Allen-Bradley family of soft starters (SMC Flex, SMC-3, and the new SMC-50). Each of these technologies represents a different set of cost and performance attributes that can vary between applications. Traditional options for using contactors for starting include simple on or off, or more complex configurations such as a wye-delta starter, multi-speed starters, autotransformer starters, and other similar starters. Traditional Direct On Line (DOL) starting is accomplished with a contactor and simple or advanced overload relay. VFD technology has advanced rapidly over the past 20 years and has been the default starting solution for torque control or linear speed applications, because a VFD uses advanced techniques to control voltage and frequency for exacting control during starting, running, and stopping a motor.

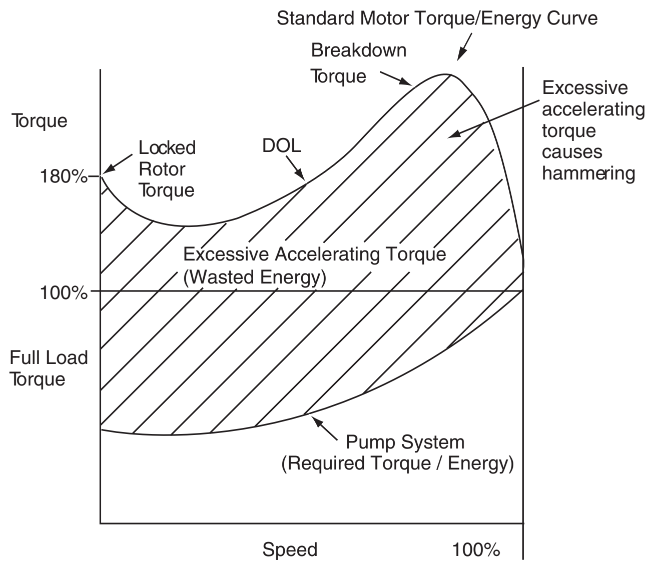
The SMC family of Allen-Bradley soft starters control voltage and current during starting and stopping. The starting control consists of functions such as soft start, current limit, pump control, slow speed, and full-voltage starting. For stopping, the SMC is able to perform pump stop, smart motor braking, and soft stop. Special slow speed operation is possible in one of two selected modes. All of these functions can be performed with an integrated bypass contactor as standard, using an SMC-3 or SMC Flex. The advantage of the integrated bypass is a smaller product footprint and reduced heat dissipation of the controller once the motor is up to speed, because the internal electromechanical bypass carries the load.

While the SMC Flex and SMC-3 are suitable for most applications, the need for true torque and speed control starting of centrifugal pumps and high-inertia loads has led Rockwell Automation to develop new soft start technology. The new functionality of linear acceleration/deceleration and torque control can be found in the new SMC-50 solid-state motor controller. All of the key features of the SMC Flex and the SMC-3, along with the legacy products of SMC Dialog and SMC Plus are now incorporated into the SMC-50 control module core. The new control module core is aligned with a completely solid-state power structure (no integral bypass), offering customer scalability and reliability. This means that one SMC can now perform most of the starting functions for a given motor, whether linear acceleration is needed, or just a soft start. This gives the customer the ability to start and control a wide range of load types all with one controller.

Energy Effectiveness with Appropriate Starting Method

When starting a typical NEMA Design B motor, the energy used can be viewed using these common torque/speed curves of a pump system using a DOL, Soft Start, Pump Control, and Torque Control method. Acceleration torque is the difference between applied torque and the load. The goal is to have the smallest acceleration torque to achieve the most efficient start.

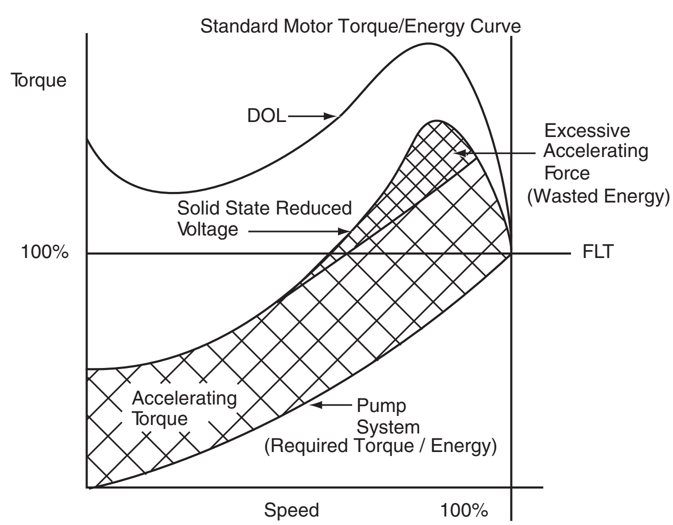
Figure 1 - DOL Starting



For all plots, the pump system line is the demanded load torque.

Using the standard DOL starter, note the amount of excess energy used to start the pump.

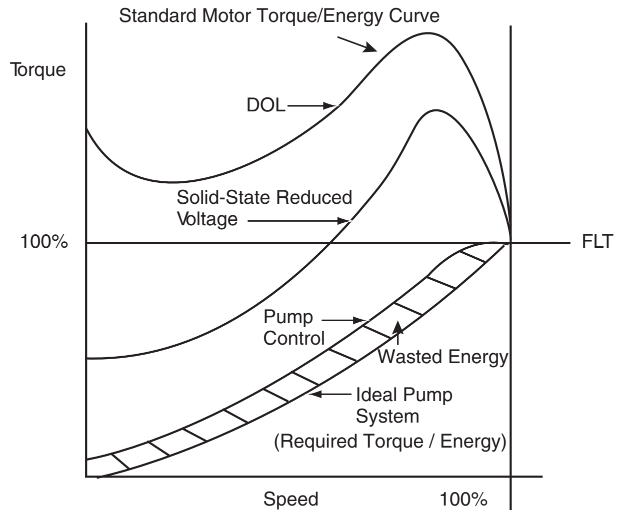
Figure 2 - Soft Start



Soft Start reduces the overall energy required to start the load.

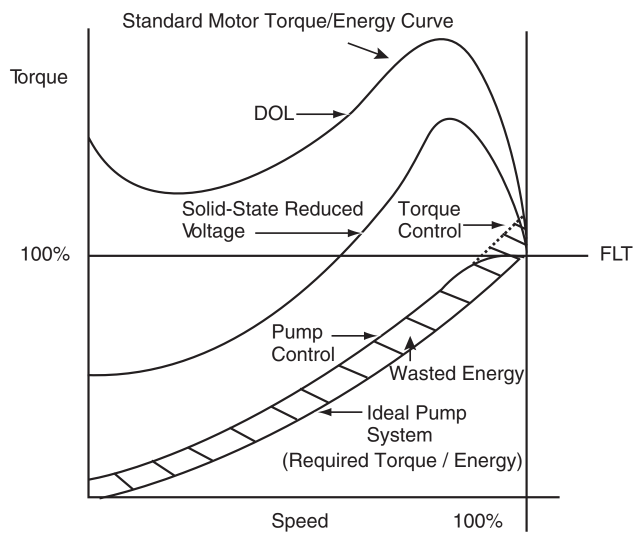
However, because this starting method is simply a voltage ramp, motor characteristics cause excess torque to remain

Figure 3 - Pump Control



Using the Pump Control option of the SMC-50 will provide even more control, which provides an even larger reduction in energy usage at startup.

Figure 4 - Torque Control



The enhanced Torque Control algorithm provides even tighter control, providing just enough control for a smooth start.

The SMC-50 can be enabled to perform the same as the SMC Flex in all operating modes, including Soft Start and Pump Control starting modes. However, with the SMC-50, there are also the more advanced options of Torque Control and Linear Acceleration, which provide even greater control in pumping and other applications. The flexibility for mode selection helps users optimize performance manually or allow the controller to do what it does best. By selecting the proper starting method, you will be able to reduce the amount of energy consumed and matching the start/stop profile to the load, enabling the greatest savings.

For more information on the SMC Flex or SMC-50 controllers with pump control, please see the white paper, “SMC Controllers with Pump Control”, publication 150-WP003.

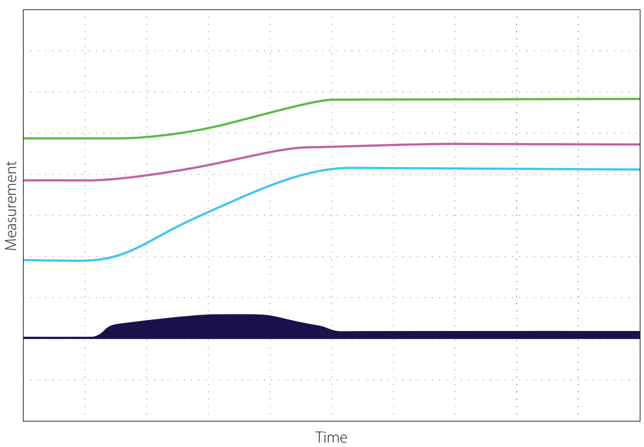
SMC-50 Starting Modes

Linear Acceleration

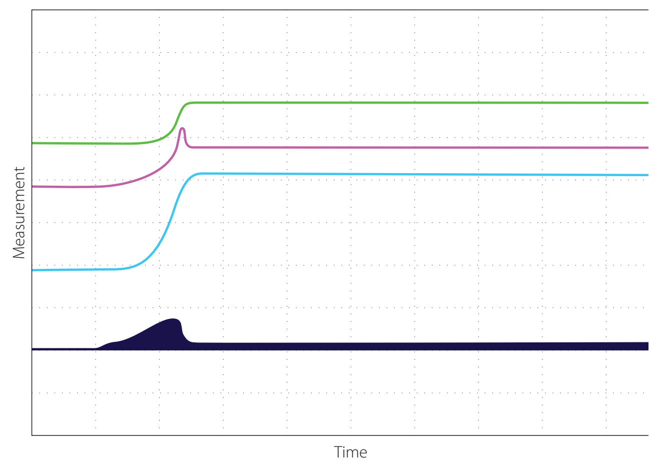
Linear Acceleration control offers the simplest and most consistent starting and stopping using a linear ramp of speed. Regardless of the load type or condition, this starting method will attempt to start the motor in the requested time, without the need for an external tachometer. Typical parameters that need to be adjusted include: changing the start mode from the default Soft Start to Linear Speed, and setting the ramp time if a time other than the default 10 seconds is needed.

Figure 5 - Linear Acceleration vs. Pump Start — Centrifugal Pump Load

Linear Acceleration Mode



Pump Mode



Note:

- Actual start time difference of linear vs. pump modes
- **Smoother torque curve** for linear acceleration
- Higher peak current with pump mode

Parameter settings = Start time: 10 seconds

Motor Current
Motor Torque
Motor Speed
Reference Torque

Once up to speed, the motor is at full voltage, and the Linear Acceleration control is no longer in effect until a stop command is given. The stop command can be a simple coast-to-stop or a more advanced command, such as pump control or Linear Deceleration. The proprietary algorithm allows the controller to use just enough energy for starting and stopping, regardless of load conditions. This can be ideal for applications that may have different load conditions at different times (e.g. conveyor loaded or unloaded). This type of control can eliminate the need for a Dual Ramp mode and means that the user does not have to change the settings on the SMC-50 to accommodate different percentage of loads or conditions. For applications that may also need to control the maximum level of current, the current limit feature can be combined with Linear Acceleration during starting and stopping. The algorithm does all the work, making linear speed the easiest starting method on the SMC-50.

Torque Ramp

Torque Ramp offers true torque control using a proprietary algorithm. The ramp goes from an initial 'starting torque' to a maximum torque level. By default, the starting torque is set to 70% and the maximum torque is set to 250%. As with Linear Acceleration, the ramp time is also adjustable from the default 10 seconds. However, unlike Linear Acceleration, the time of the ramp may vary depending on the load. To assist with the torque ramp, the controller uses an automatic tuning process that measures motor parameters such as resistance and inductance. This tuning process also detects the motor connection (line or delta). Having adjustability of the initial and maximum torque of a defined ramp time, provides the user precise control when starting the motor. Compared to the Soft Start mode, which uses a voltage ramp, torque control is much more linear and potentially will result in less stress on the mechanical components of the system and provide the proper torque to start the motor. Constant acceleration torque is provided for both constant and variable torque loads.

Full Voltage

This starting method essentially uses the SMC-50 as a solid-state contactor, perhaps for high duty cycles. Full current and full voltage is used at the start. A customer may choose to do this as a troubleshooting aid, or to use the diagnostics of the SMC-50 versus a traditional electromechanical starter.

Current Limit

By limiting the current, the SMC-50 can assist meeting utility demand requirements, limit line disturbances and meet internal plant distribution limitations. Keep in mind, limiting the current also limits the amount of torque to the motor when starting. Current Limit Start can be used in conjunction with Soft Start, Torque Control and Linear Acceleration.

Soft Start

Soft Start ramps up the voltage linearly to start the motor and does not directly control motor speed or torque. Starting torque is approximately proportional to the square of the applied voltage. **% Torque** $\propto$ **Voltage**^{2}

Given the above equation, a 60% reduction in the applied voltage will result in approximately an 84% reduction in generated torque. In this example, 40% voltage is used. (0.4)2 = 0.16 or 16% of Locked Rotor Torque will be present. The current during the start is directly related to the voltage applied to the motor.

$$\frac{Voltage\ (applied)}{Line\ Voltage} = \frac{Current\ (drawn)}{Current\ (maximum)}$$

Pump Control

Unlike actual torque control found with the Torque Ramp option, Pump Control is a torque control variation representing a proprietary algorithm optimized for the starting and stopping of a pump. This reduces the surges created in a fluid piping system, reducing both water hammer and pump cavitation.

Slow Speed Control

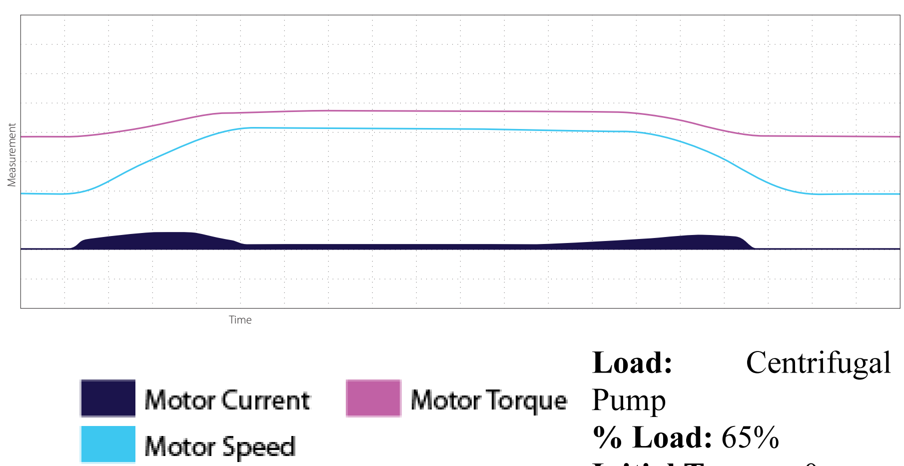
The SMC-50 has an enhanced option for speed control of ±15 % of zero speed. Some soft starters, including the SMC Flex, can only provide fixed slow speeds, typically one or two settings. The enhanced control has improved torque capabilities and the ability to select the precise speed of operation. The performance could be considered as a potential alternative for simple positioning and specialty VFD applications. The new SMC-50 will give you more control of your system, when the system needs it.

Note: entering a negative value will cause the motor to turn in the opposite direction.

Scope Plot Comparisons

Following are the actual starting/stopping comparisons of Linear Acceleration, Torque Control, Pump Control, and soft start for a centrifugal pump. The pump load was chosen as one of the more dynamic starting characteristics and represents an important part of the soft starter market. Valve type, placement of the valves, length of piping runs, direction of runs, etc, will determine the specific starting characteristics for a given pump motor. One of the benefits of the SMC-50 is that you can use any starting method with the same unit without having to purchase a different control module.

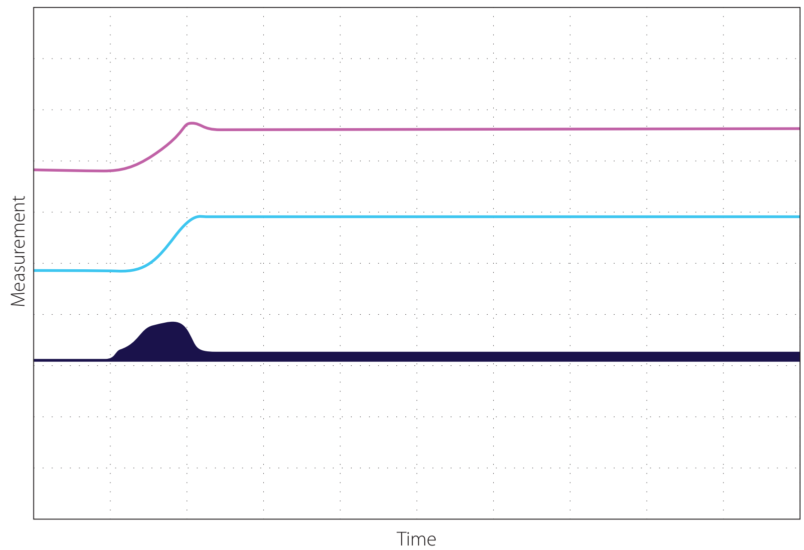
Figure 6 - Linear Speed Start and Stop Mode; Load Type = Pump



Load: Centrifugal Pump
% Load: 65%
Initial Torque: 0
Ramp Time: 10 s

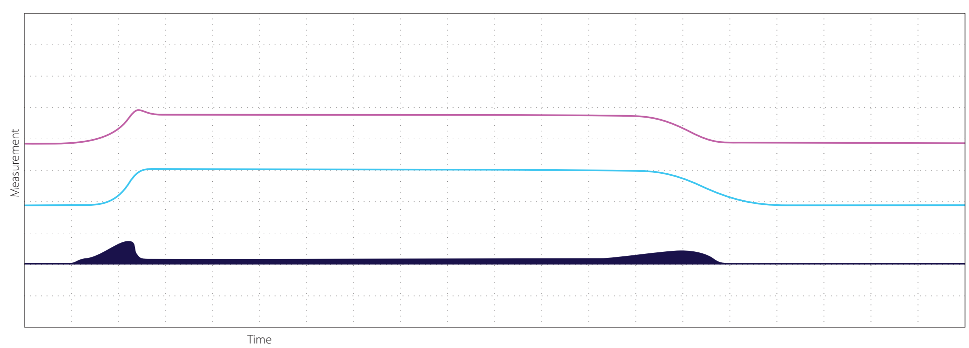
By using Linear Acceleration and Deceleration to start and stop the pump, just enough energy is used to provide a smooth start and stop, regardless of the load condition. Note the smooth motor torque curve with no excessive torque or peak currents. During starting, it is easy to identify the smooth acceleration, even with a lightly loaded motor. During stopping, you can see the ability to control the speed and torque applied to the motor, reducing fluid surge and mechanical disturbances. See Figure 6 on page 7.

Figure 7 - Torque Start Mode; Load Type = Pump



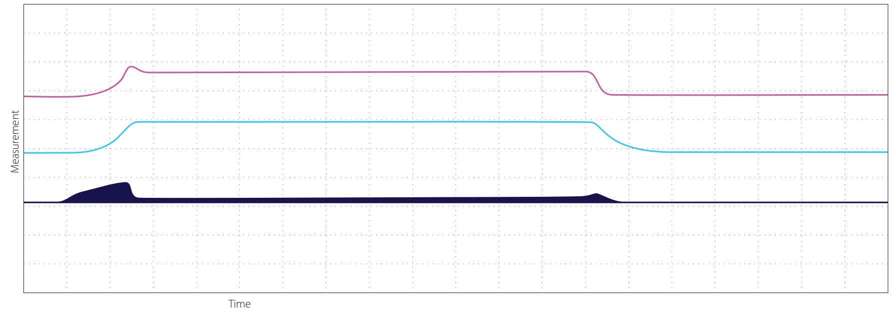
Torque Control brings the pump motor up to speed with a linear torque ramp from beginning to end of the ramp. The resultant motor speed curve will be linear when the load matches the torque profile in time. Note the higher peak current and torque pulse occurring as the motor comes up to speed.

Figure 8 - Pump Start and Stop Mode; Load Type = Pump



With Pump Control start and stop mode, the motor is brought up to speed efficiently using a form of torque control that uses the algorithm and the microprocessor of the SMC-50. This enables smooth starts and stops in centrifugal pump applications, thereby reducing water hammer. Note the improvement in stopping performance compared to the Soft Stop mode shown in Figure 9.

Figure 9 - Soft Start and Stop Mode; Load Type = Pump



The soft start mode illustrates the current is being ramped up in proportion to the voltage ramp. Note the shorter starting time, higher peak current during starting. Depending on system dynamics, the soft start may work well in reducing water hammer during starting. Stopping is accomplished by linearly decelerating the voltage, which does not always equal a smooth ramp of speed or torque.

Difference in stopping methods

Stopping control is just as important as starting; this is especially true in a pumping applications. In a pumping application, a lack of control during stopping will result in sever water hammer and potential expensive repairs on valves and supporting structures. The differences between soft stop, pump, and Linear Deceleration are illustrated in the next two scope plots. Given the same settings as before:

Figure 10 - Torque Comparison

Load: Centrifugal Pump
% Load: 65%

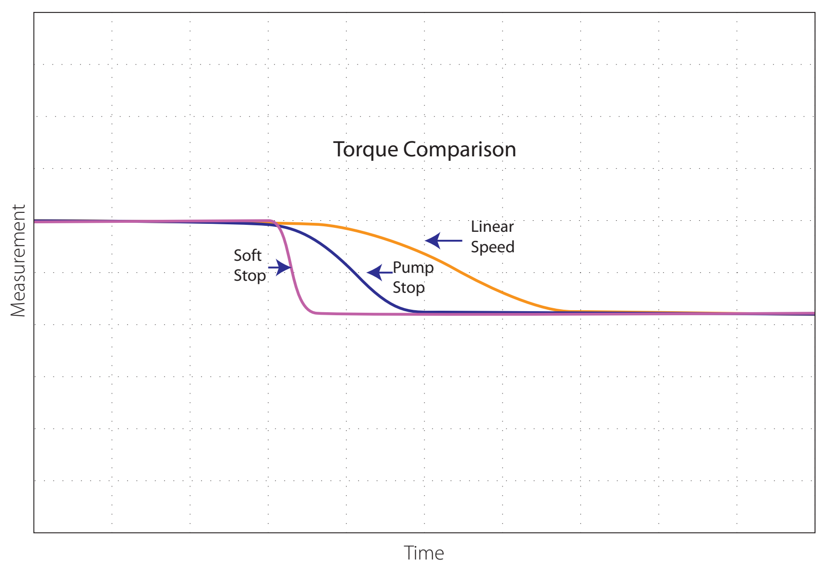
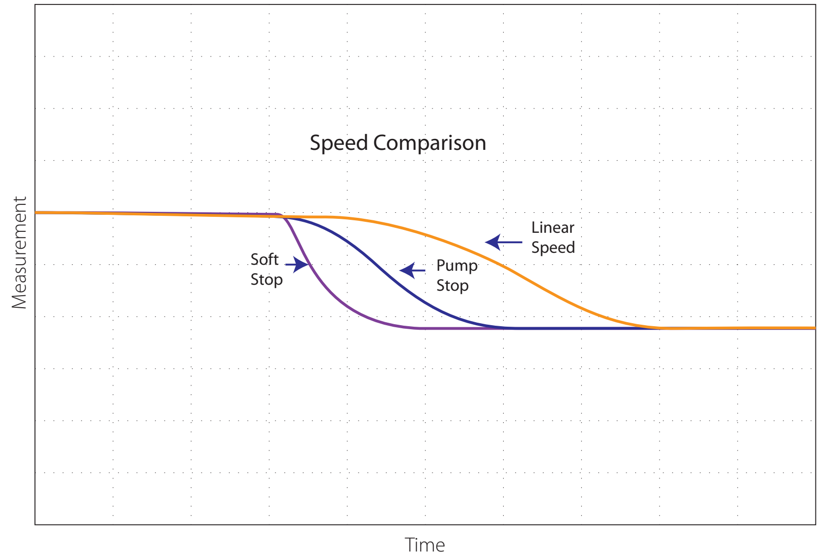


Figure 11 - Speed Comparison



Notice the characteristics of the motor torque and motor speed when stopping. In this specific example, soft stop mode, in comparison to the motor speed, the torque drops to minimum torque at about ¼ of the deceleration time. During pump stop, the torque drops off in approximately ½ the deceleration time. Linear Deceleration during the stop provides the most torque control for approximately 2/3 of the deceleration time. The ability to maintain control of the motor and load much longer into the stop cycle translates directly to reductions in water hammer, fluid surge, and mechanical shock.

It is important to note that actual time differences in the torque and speed curves of different stopping modes will vary depending on the system dynamics and the load. In almost all cases, Linear stopping mode will boast a torque curve that better "follows" the profile of the load.

When would you use Linear Acceleration or Torque Control ramp?

Linear Acceleration:

- Ease of use and consistent performance
- Lowest starting peak current per start
- Not load dependent
- No external tachometer needed

Torque Control Ramp:

- Fully configurable torque ramps
- Constant acceleration rate
- Ability to develop only the torque needed for accelerating the load

Many legacy starting modes such as soft start and pump control are load dependent, meaning the starts and stops can be shorter than the actual programmed time. This is often experienced when a user programs a 10 second soft start ramp and the motor comes up to speed in 4 seconds. This phenomenon is related to the way the motor is loaded and the settings of the device. In many cases it is possible to optimize the settings, but requires trial and error along with knowledge of the application. If a customer would like to have a more consistent start regardless of load condition, the Linear Acceleration mode is an ideal option because it is not load dependent.

Figure 6 through Figure 9 illustrate different start methods on a centrifugal pump load. These curves are very similar to what is found in centrifugal fan or blower applications with the same load values, since these are also variable torque loads. Variable torque loads require an increase in acceleration torque as speed increases. A load that increases exponentially is ideally suited for soft starts and specifically Linear Acceleration or torque-controlled starts. By comparing the Torque Control start and the Linear Acceleration graphs, you can see the linearity of the motor speed as motor accelerates from 0 to full speed. Using soft start or pump control, you will see lower acceleration rates in the beginning of the start and higher acceleration rates toward the end of the start. The difference in rates of acceleration along with the peak current experienced will manifest themselves in system inefficiencies such as fluid surge and mechanical vibration. In variable torque applications like this, speed of the motor can be critical to performance of the equipment.

A linear ramp in variable torque loads, whether from Linear Acceleration or from Torque Control, will provide the best starting performance from 0 to full speed versus older starting modes. One difference in the two modes is that torque control only provides a linear ramp if the torque profile matches the load torque profile in time. Acceleration rate with torque control is the same at the beginning and end of the ramp and thus some potential for misalignment. Linear Acceleration factors motor speed into the equation for more exacting control with less user interaction. In either case, the benefit of these two methods, like traditional soft start methods, is a reduction in system mechanical stress and the use of only the energy/torque needed for that application to accelerate the load.

The performance improvements are not limited to variable torque loads. High-inertia loads such as band saws, centrifuges, mixers, flywheels, rock crushers, and hammer mills can also be improved using Linear Acceleration and Torque Control. With either mode the acceleration from 0 to full speed will be consistent and linear, resulting in less stress on the system components. Linear Acceleration offers some additional advantages by automatically optimizing the lowest peak starting current profile per start and independent on the loading condition. The result is consistent starting time on every start.

Applications such as conveyors can also be enhanced using either torque control or linear acceleration. Load independence can reduce the need for a dual ramp mode and the result is smoother starts and stops, regardless of the load condition. In fan and conveyor systems, a more linear start helps to minimize belt slippage and other mechanical wear.

The proprietary speed-sensing and motor control algorithms on the SMC-50 allow the user to adjust the linear acceleration and deceleration of a motor. Why is this important? Exacting control and flexibility eliminate wasted energy, lower peak currents, reduce mechanical wear and maximize the user's investment.

How can the SMC-50 optimize energy usage?

Less Peak Energy Consumption:

When it comes to starting lightly loaded motors, typical DOL starters use more energy than needed in the start process. With the SMC-50, the Linear Acceleration mode manages the entire starting process to ensure that just enough energy is used to accelerate the motor in the time requested.

Less Mechanical Wear and Tear:

Reduced mechanical wear and tear can pay back in many ways, including fewer maintenance requirements, less downtime or production losses, and a system that is operating more efficiently

Metering System:

If energy can be measured and monitored, it can be better managed. The SMC-50 provides a diverse set of metering and energy management features, allowing the customer to monitor and optimize the performance of the application.

Current: The RMS current value is provided for each phase, plus the average current of all three.

Voltage: The RMS line-to-line and line-to-neutral voltage values are provided while the motor is running and when stopped. The average of all three is also provided.

Line Frequency: Measures and provides user access to the line frequency (Hz).

Power: Real, Reactive, and Apparent power values are calculated for each phase plus the total for all three phases. In addition, the current power demand and the maximum power demand is provided.

Power: Factor The value of the power factor is provided for each phase and as a total of all three.

Peak Starting Current and Time: The SMC-50 stores the peak average RMS motor current consumed along with the actual stating time for the last five start cycles.

Total Harmonic Distortion (THD): The SMC-50 calculates and provides user access to the THD for the three line voltages and three motor currents, along with the average value of each.

Voltage Unbalance: The calculation of the voltage unbalance signal is provided.

Current Imbalance: The calculation of the current imbalance signal is provided.

Energy Savings: The SMC-50 provides the percentage of energy saved when it is running the motor in the Energy Savings mode.

Motor Torque: Electromechanical motor torque is calculated based on current and voltage feedback from the motor.

Motor Speed: The SMC-50 provides a calculated estimate of motor speed in percent of full speed when operating in the linear speed acceleration starting or deceleration stopping mode.

Running Time: The running time meter accumulates time (in hours) from the point the motor start command is given up to the point when the motor stop command is issued. When a new start command is given, the meter resets to zero and begins accumulating time again.

SnapShot record: On a fault, the SMC-50 captures the state of several operational characteristics (e.g. current, voltage) before the fault occurred.

Energy Savings Feature:

In addition to selecting the proper starting method using the SMC-50, Rockwell Automation has also implemented an Energy Saver mode that allows the SMC-50 to optimize energy usage during the running operation of lightly loaded motors. It can be used in applications such as conveyors, material handling equipment, escalators, variable volume air handling, pumps, compressors and other applications that may run for long periods of times lightly loaded or completely unloaded.

When operating in solid state mode, the SCRs control the output voltage, thus motor power losses may be reduced by decreasing the motor terminal voltage. The Energy Saver mode is enabled via a parameter, and when enabled monitors its internal feedback circuitry. The percentage of energy savings can be monitored or viewed via a metering parameter.

Losses within a motor are divided into a number of different components. There are friction and windage losses, I^2R losses, core losses, and magnetic losses. The friction and windage losses remain constant at full load and no load. However, at no load, I^2R losses, core losses, and magnetic losses can be reduced by decreasing the applied voltage.

For example, a 30 kW (40 Hp) motor draws 30 kW from the line to produce work. An additional amount of energy is drawn from the line due to the internal losses to the motor. If the motor is 95% efficient, an additional 1.5 kW or a total of approximately 31.5 kW is drawn from the power line when the motor is operating at full load. It is not practical to assume that all losses can be eliminated (e.g. friction, windage) therefore an approximation is 50% could be saved. Using this approximation with the 30 kW (40 Hp) motor, one-half of the 1.5kW losses could be saved. The maximum theoretical savings would be equal to 0.75 kW. Actual applications would probably yield less than the theoretical 0.75 kW.

Energy Saver Application Considerations

Figure 12 was developed on 10, 50,and 125 Hp motors. Based on test results and supporting data, savings above 50% loading is unlikely. This is illustrated by the upper curve in Figure 13. In reviewing the test data for lower limits, it could be estimated that 20% losses are saved at no load and no losses saved at 20% load. This is illustrated by the lower curve in Figure 13.

Figure 12 - % kW Saved vs. % Rated. Load

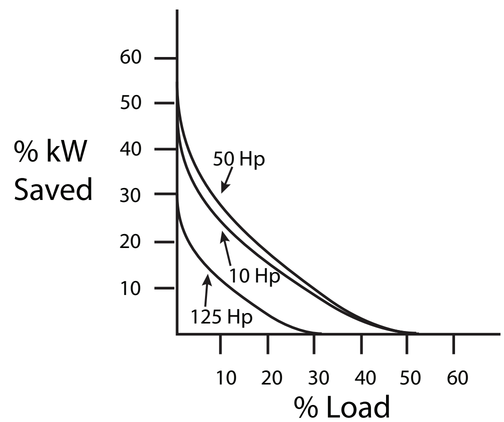
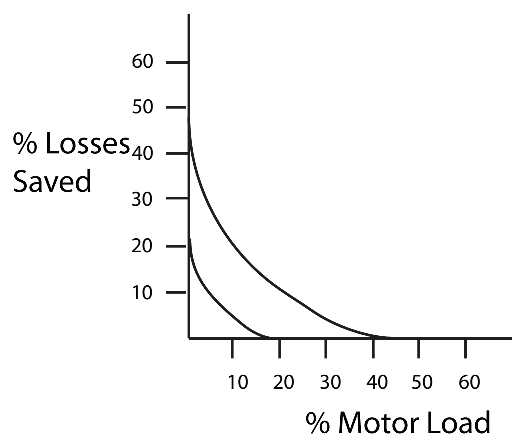


Figure 13 - Estimated Energy Savings



A simple “full load-no load” preliminary estimate for the application of an energy saver can be made by using the following procedure:

1. Convert horsepower to kilowatts.
2. Determine the total kilowatts used by the motor by dividing the horsepower kilowatts by motor efficiency.
3. Determine the motor losses by subtracting converted horsepower kilowatts from total kilowatts.

4. Calculate the maximum theoretical savings in kilowatts by multiplying motor losses by 0.50.
5. Determine kilowatt hours saved by multiplying the maximum theoretical savings in kilowatts times the number of hours per year the motor is operated at no load.
6. Maximum theoretical savings dollars can then be determined by multiplying kilowatt hours saved times the cost of electricity per kilowatt hour.

Sample Calculation

Given:	Motor Efficiency: 95% Motor loading duty Cycle: 50% (ON 15 min., OFF 15 min.) Motor Horsepower and run time: 50 Hp, 8 hours per day, 2080 hours per year Calculations assume that normal load = full load rating of the motor, and that loading level is a no-load condition	
Using the above data and the following procedure for theoretical max.energy savings:		
Step No.	**Calculation**	**Result**
1	kW = 0.746 (50)	kW = 37.3
2	kW total = (37.3)/0.95	kW total = 39.26 kW
3	Losses = 39.26-37.3	Losses = 1.96 kW
4	Max. Theoretical Savings = (1.96 kW) (0.50)	Max. Theoretical Savings = 0.98 kW
5	(0.98) (0.5) (2080) = 1019 kWh/year	
6	At a cost of $0.2/kWh, estimated savings = (0.2) (1019)	Estimated Savings = $203.84/year

It is highly recommended that additional detailed calculations be made to get a more exact figure on the potential savings. Variables in duty cycle and loading cycles must be accurately estimated. Note that a motor running unloaded and not connected to equipment is not the same as when the motor is connected to the equipment and the losses associated with the system. Motor manufacturers should be contacted to determine the actual no-load characteristics.

These calculations have been done on the basis that a solid-state controller was required for reasons other than energy savings. If energy savings is the main reason for purchasing this type of device, the savings would be less. The reason is that there is approximately a 1 volt drop across each solid-state power pole. For example, a solid-state controller for a three-phase motor drawing 50 amperes will have a loss ranging from 150 to 225 watts above an equivalent electromechanical device. Therefore, these losses should be deducted from the total energy savings if the energy saver were replacing an electromechanical device.

When to use a VFD versus an SMC?

Soft Starters and VFDs can be applied across many of the same applications. The most important aspects of this decision include the level of performance required for the application, available space, and level of installation complexity.

The SMC primarily has control of the motor only during starting and stopping with only a couple of exceptions (slow speed and energy saver modes). VFDs maintain control throughout the start, stop, and run time all while delivering rated torque. It is fair to say that a VFD can fulfill almost all functions of a soft starter. If the application concern is only starting and stopping, the SMC can be a good alternative. If more control is needed beyond the point of starting, stopping, and the range of ±15% for slow speed, a drive is more appropriate.

In almost all cases, the soft start will have a significantly smaller panel footprint and, in the case of the SMC-3 and SMC Flex, have reduced heat dissipation due to the integrated bypass contactor. A soft starter operating in bypass is operating at nearly 99% efficiency. A VFD typically generates more heat and has more environmental considerations than an SMC.

The last point of consideration is based on the complexity of the installation including the costs associated with additional equipment needed to maintain control over environmental conditions (air conditioning) and CE conformance. The addition of VFDs into a system can introduce a negative impact to the system power quality unless properly installed and operated. Therefore considerations such as EMC filters, isolation, and special cabling can increase the total cost of the installation versus soft starters. In addition, as the size of a system increases in horsepower, the cost difference between an SMC and a VFD begins to widen substantially.

Conclusion

The SMC-50 adds more options to the feature-full Rockwell Automation family of Smart Motor Controllers. The latest development offers end users the opportunity to have one device that can do all the features of previous models, but adds linear acceleration, torque control, enhanced slow speed operation, and improved Energy Saver mode. No more swapping out control modules to try different starting methods. Just change a parameter, and the process can begin, or leverage Linear Acceleration for the simplest to use starting mode on the market. Combine the advanced control with a powerful assortment of power monitoring parameters and you have a highly integrated soft start solution that can assist a plant manager in controlling operating costs or maximizing the investment of a remote pumping station.

Documentation Feedback

Your comments will help us serve your documentation needs better. If you have any suggestions on how to improve this document, complete this form, publication RA-DU002, available at http://www.rockwellautomation.com/literature/.

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