Unit 5

Reduced AC Voltage Starters

UNIT OBJECTIVE

Upon completion of this unit, you will be able to utilize a primary resistor starter and a soft starter. You will also understand the underlying principles of reduced AC voltage starters.

DISCUSSION OUTLINE

The Discussion of Fundamentals covers the following points:

- The need for reduced current starting
- Typical starting methods

DISCUSSION OF FUNDAMENTALS

The need for reduced current starting

Induction motors started with full voltage draw high inrush currents from power lines. When large motors are started, this phenomenon can result in power line disturbances and spikes in the electrical power demand (often leading to higher utility bills). Sudden starts are also tougher on the mechanical elements of the system, because the acceleration is more abrupt.

Figure 5-1 shows the current used by an induction motor at various speeds. Note how the starting current is high compared to the running current, until the motor reaches its fully rated speed.

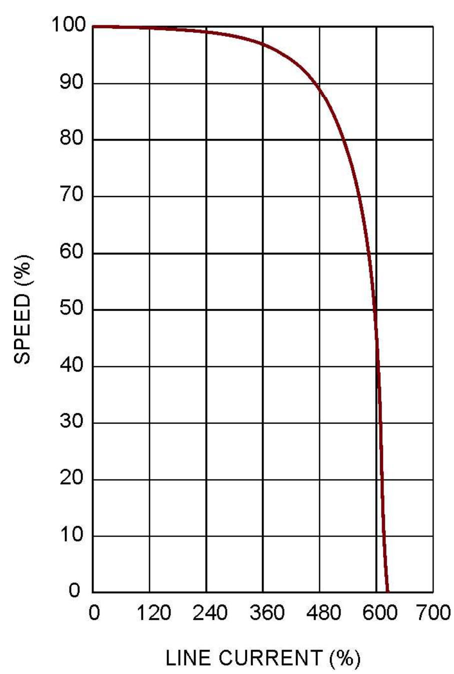


Figure 5-1. Induction motor current at various speeds.

Typical starting methods

Reduced voltage and current methods are often employed to limit the negative consequences of direct-on-line starting. Common alternate motor starting techniques are:

- **Primary resistor starters**: A resistive device is connected in series with the motor to produce a voltage drop for starting. The resistive device is shorted after the motor has accelerated to a certain point.
- **Autotransformer starters**: A tapped autotransformer is included in the circuit to provide specified reduced voltage for starting the motor.
- **Part-winding starters**: This starting method requires the stator windings of the motor to be divided into two or more equal parts. During starting, only a part of the winding is powered by full voltage, thus limiting the current and torque. All parts of the windings are later connected in parallel for normal operation.
- **Wye-delta starters**: The stator is **wye** connected for starting and **delta** connected for running. This method requires a motor designed for this purpose, in which no internal connection is made.
- **Solid-state starters**: A soft starter provides gradually increased voltage to the motor. The device is shorted once in running operation.
- **Variable frequency drive**: AC drives initially apply low frequency and voltage to the motor. This avoids high inrush current, while producing high starting torque.

In the following Unit, you will experiment with two reduced AC voltage methods, namely the primary resistor and the solid-state starters.

Primary Resistor Starters

EXERCISE OBJECTIVE Understand how primary resistor starters operate.

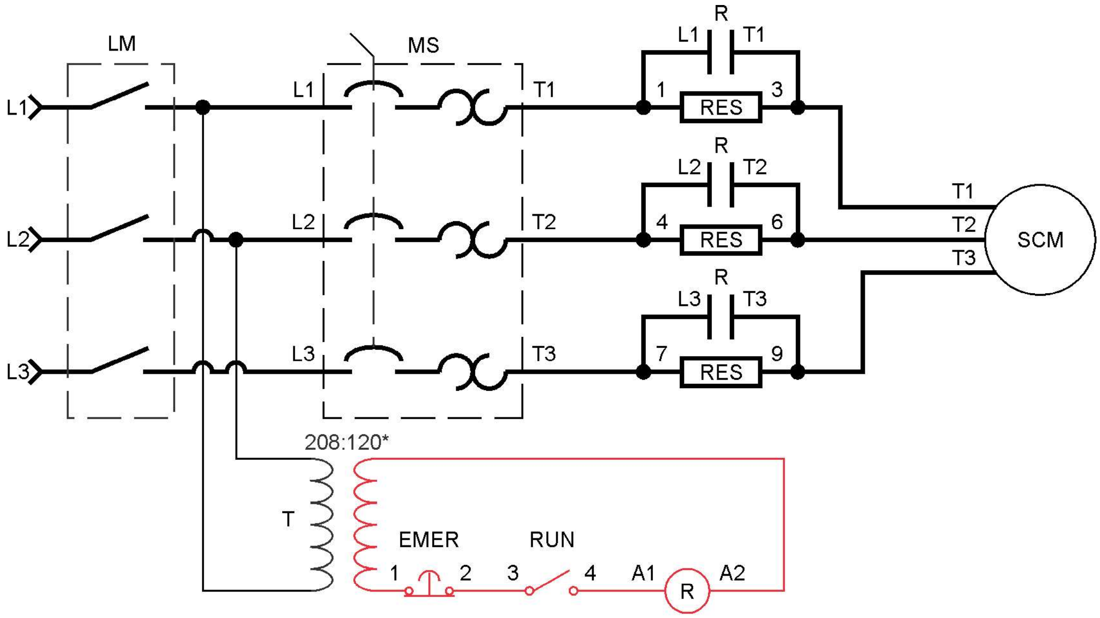
DISCUSSION

High starting torque can result in sudden acceleration and damage to the driven machinery. Excessive current inrush is likely to provoke unwanted power line disturbances. Primary resistor starters can be used to start motors where limited torque or inrush current is required. This type of starter provides smooth acceleration without the line current surges usually experienced with other reduced voltage methods.

Primary resistor starters have resistors connected in series, between each line and the motor. The presence of resistors reduces the voltage applied to the motor, but they produce heat. The lesser potential results in minimized motor starting current. But since motor torque is proportional to the square of the potential, the starting torque is low. As a result, this solution is impractical for systems such as conveyors, which require high torque upon starting.

One or more stages of resistors can be implemented, depending upon the motor size and the desired starting smoothness. More steps provide a more gradual acceleration. The resistors are bypassed by contactors when the motor reaches a certain speed, so that the motor eventually runs on full line voltage.

A typical resistor starter circuit is shown in Figure 5-2. When the Manual Starter is turned on, the resistors are connected in series with the motor. A voltage drop occurs across the resistors and the motor starts on reduced voltage. Once the motor has reached a sufficient speed, the operator shorts the resistors by closing the selector switch commanding the run contactor. The motor is then connected across full line voltage.



*208:120 FOR 120 V - 60 Hz NETWORK
380:110 FOR 220 V - 50 Hz NETWORK
415:110 FOR 240 V - 50 Hz NETWORK
380:120 FOR 220 V - 60 Hz NETWORK

LEGEND

MS	=	MANUAL STARTER (CIRCUIT BREAKER WITH OVERLOAD)
R	=	FULL VOLTAGE RUNNING CONTACTOR
RES	=	STARTING RESISTOR
RUN	=	RUN SELECTOR SWITCH (MAINTAINED CONTACT)
SCM	=	SQUIRREL CAGE MOTOR
T	=	CONTROL VOLTAGE TRANSFORMER
EMER	=	EMERGENCY PUSH BUTTON (MAINTAINED CONTACT)
LM	=	LOCKOUT MODULE

Figure 5-2. Primary resistor circuit.

Procedure Outline

The Procedure is divided into the following sections:

- Basic setup
- Brake motor locked rotor current without resistors
- Brake motor locked rotor current with resistors
- Motor power line voltage with primary resistors
- Motor power line voltage without primary resistors

Procedure

In the first part of this exercise, you will set up a circuit to measure the Brake Motor locked rotor current. You will then compare this value with the motor full-load current (FLA) to see that it is many times higher.

In the second part of the exercise, you will implement a circuit including resistors in series with the motor. You will observe that the presence of the resistors diminishes the motor locked rotor current, and consequently, the motor starting current.

Finally, you will start the motor with primary resistors. You will discover that resistors are bypassed during normal operation to avoid making the motor run under lower voltage and lose power through resistors.

⚠ WARNING

The AC Power Supply provides high voltages. Do not change any AC connection with the power on.

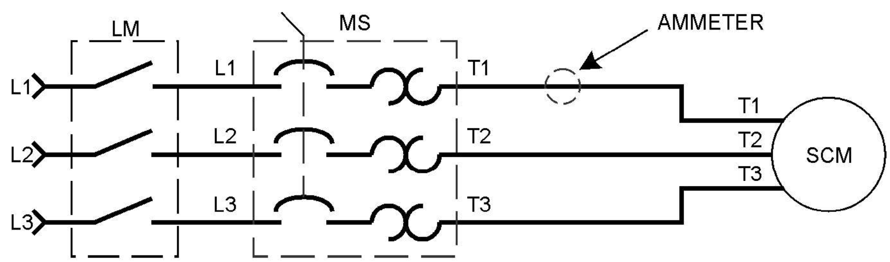
Basic setup

1. Perform the Basic Setup and Lockout/Tagout procedures.

Brake motor locked rotor current without resistors

2. Install the Brake Motor, Inertia Wheel, and Safety Guard.

Connect the circuit shown in Figure 5-3.



LEGEND

MS = MANUAL STARTER (CIRCUIT BREAKER WITH OVERLOAD)
SCM = SQUIRREL CAGE MOTOR
LM = LOCKOUT MODULE

Figure 5-3. Manual Starter circuit.

3. Apply the friction brake.

Clamp an ammeter around a motor power lead.

Set the knob of the Manual Starter to the O position.

Perform the Energizing procedure.

CAUTION

Turn off power after a maximum of 3 seconds to prevent damage to the equipment.

4. Observe the ammeter display as you set the knob of the Manual Starter to the I position for three seconds.

Note the locked rotor current going through the power line. Repeat once to confirm the result.

Locked rotor current: ______

5. What prevents the motor from rotating?

6. Set the knob of the Manual Starter to the O position.

What is the full-load ampere rating (FLA) indicated on the nameplate of the Brake Motor?

Full-load ampere rating: ______

7. By how many times is the locked rotor current higher than the full-load ampere rating (FLA)?

Number of times (current ratio): ______

8. Perform the Lockout/Tagout procedure.

Brake motor locked rotor current with resistors

9. Connect the circuit shown in Figure 5-2. Use the SS-1 contact of the Selector Switches module.

10. Apply the friction brake.

Set the RUN selector switch of the Selector Switches to the O position (open contact).

Clamp an ammeter around a motor power lead.

Perform the Energizing procedure.

The resistors must be connected by their extremities and not by the intermediate taps, to obtain maximum resistance.

CAUTION

Turn off power after a maximum of 3 seconds to prevent damage to the equipment.

11. Observe the ammeter display as you set the knob of the Manual Starter to the I position for three seconds.

Note the locked rotor current going through the power line. Repeat once to confirm the result.

Locked rotor current: _____

12. Set the knob of the Manual Starter to the O position.

By how many times is the locked rotor current measured with resistors higher than the full-load ampere rating (FLA)?

Number of times (current ratio): ______

13. Does the presence of primary resistors diminish the motor locked rotor current? Explain why.

____

____

Motor power line voltage with primary resistors

14. Remove the ammeter and install a voltmeter between two motor power lines.

Manually disengage the friction brake.

Set the knob of the Manual Starter to the I position, and wait for the motor to reach full speed.

What is the voltage between the power lines?

Voltage between the lines with primary resistors: ______

Motor power line voltage without primary resistors

15. Set the RUN selector switch of the Selector Switches to the L position (closed contact) to bypass the resistors via the R contactor. Note the voltage between the two lines.

Voltage between the lines without primary resistors: ______

16. Is motor input voltage higher or lower, if resistors are not bypassed during motor operation?

❑ Higher ❑ Lower

17. Do resistors dissipate power if they are not bypassed?

❑ Yes ❑ No

CAUTION

The Starting Resistors module may be hot. Please be careful when you handle this module after use.

18. Turn the individual power switch of the AC Power Supply off, disconnect the circuit, remove the magnetic labels, and return the equipment to the storage location.

CONCLUSION

Primary resistor starters can be used for starting motors at a reduced voltage. Resistors are inserted in series with the motor terminals and power lines to create a drop in the input voltage.

Reduced voltage is utilized to protect machinery from the shock of sudden acceleration and prevent power line disturbances resulting from high inrush currents. Once the motor reaches a sufficient speed, the starting resistors are bypassed by a set of contactors, allowing the motor to operate at full line voltage.

REVIEW QUESTIONS

1. What is a primary resistor starter used for?

   a. Limits the inrush current.

   b. Prevents line disturbances.

   c. Provides smoother acceleration.

   d. All of the answers above are correct.

2. How are the resistors connected?

   a. In parallel with the coil of the corresponding starting contactor.

   b. In series with the motor terminals and power lines.

   c. In series with the contacts of the corresponding starting contactor.

   d. All of the answers above are correct.

3. What causes fast acceleration and damage to the driven machinery?

   a. Reduced motor input voltage.

   b. High starting torque.

   c. Low inrush current.

   d. None of the answers above is correct.

4. When are the resistors of a primary resistor starter bypassed?

   a. As soon as power is applied to the motor.

   b. As the motor approaches its nominal speed.

   c. As the overload trips.

   d. Never

5. In the Figure 5-2 circuit, what control device is used to switch the RUN contactor on and off?

   a. Control relay

   b. Timing relay

   c. Plugging switch

   d. Selector switch

Soft Starters

EXERCISE OBJECTIVE Understand how soft starters operate.

DISCUSSION

Soft starters are solid-state devices providing gradual voltage increase, for the purpose of starting a motor smoothly. Most soft starters also perform soft stops, to make the motor run-down longer than if the motor were merely to coast to a stop. Compared to primary resistor starters, soft starters present major benefits:

- No wearing parts
- Easy adjustments
- Less space needed
- Gradual voltage increase (no steps)
- Reduced power losses

By lowering the input voltage, a soft starter diminishes the motor current. The motor torque, which is proportional to the square of motor voltage, is also lessened. This explains why a soft started motor does not accelerate suddenly. However, if the starting voltage is too low, the motor will not start immediately, but will nevertheless heat up during that time.

For example, if the starting voltage is at 30%, the torque produced will only be about 9 % of the normal value. This might not be enough to start the motor. A soft starter is correctly set when the motor starts smoothly and runs up rapidly to its rated speed.

Figure 5-4 shows the Soft Starter, Model 3186. This device has three adjustment potentiometers, which are controlling:

- Ramp-up time, in the range from 0 to 20 seconds
- Starting voltage, in the range from approximately 40 to 100% of motor full voltage
- Ramp-down time, in the range from 0 to 20 seconds

Terminals of the Soft Starter are as follows:

- A2-A1: supply voltage
- IN1-A1: auxiliary control voltage
- 1L1, 3L2, and 5L3 connect to three-phase power supply
- 2T1, 4T2, and 6T3 connect to motor terminals

CAUTION

Supply voltage must be provided to the Soft Starter before power is applied to terminals 1L1, 3L2, and 5L3, in order for the Soft Starter to work properly.

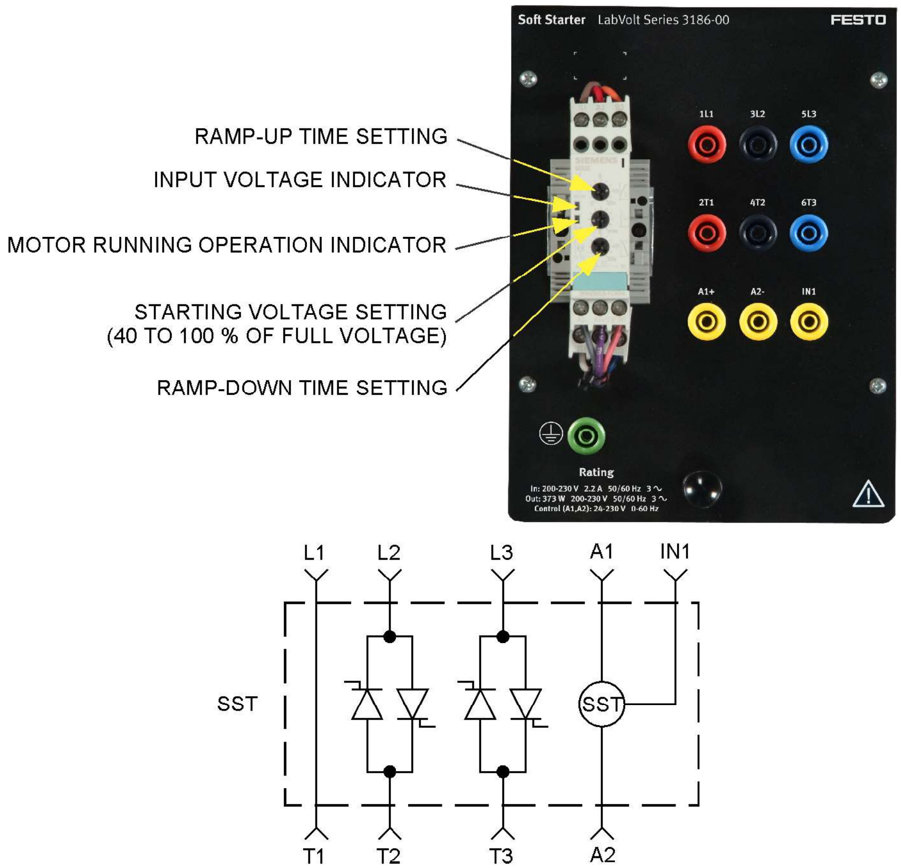
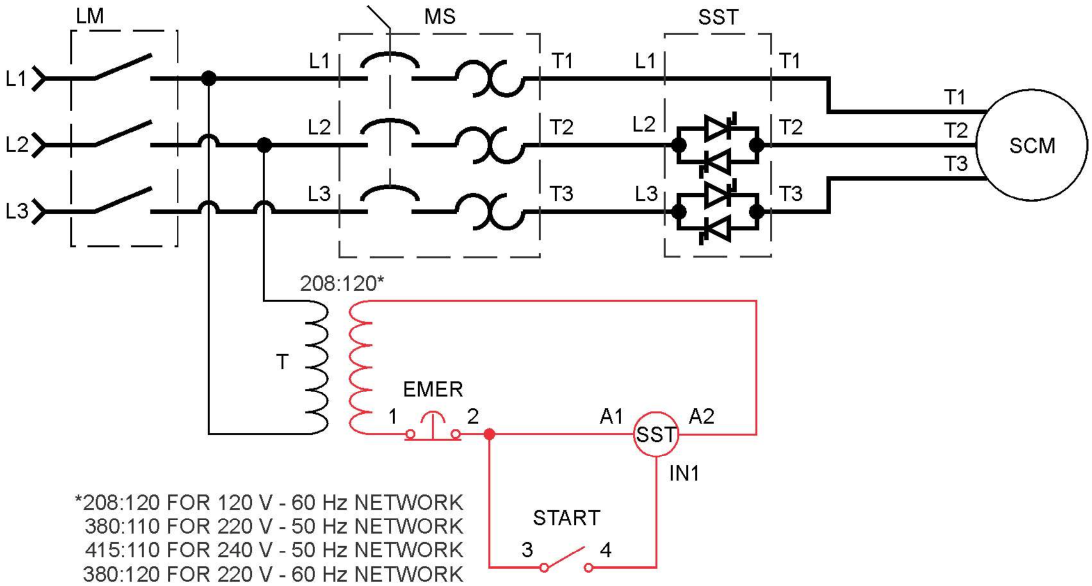


Figure 5-4. Soft Starter, Model 3186.

The settings of the three potentiometers are scanned before each auxiliary voltage switching operation. If, for example, the starting time setting is changed while the motor is running up, the change does not come into effect until the next start.



LEGEND

MS	=	MANUAL STARTER (CIRCUIT BREAKER WITH OVERLOAD)
SCM	=	SQUIRREL CAGE INDUCTION MOTOR
SST	=	SOFT STARTER
START	=	START SELECTOR SWITCH (MAINTAINED CONTACT)
T	=	CONTROL VOLTAGE TRANSFORMER
EMER	=	EMERGENCY PUSH BUTTON (MAINTAINED CONTACT)
LM	=	LOCKOUT MODULE

Figure 5-5. Soft Starter circuit.

A simple soft starter control circuit is presented in Figure 5-5. When power is applied to the circuit, supply voltage is applied to the Soft Starter, as shown by the READY indicator on the device. When the Manual Starter is turned on, the Soft Starter input terminals are energized. When the START selector switch actuates, the Ramp-up function begins, and the READY indicator begins flashing. The motor is then gradually energized. Once the READY light turns off and the RUN indicator turns on, it is a sign that the device has switched to normal (full voltage) running operation. When the selector switch is turned off, the Ramp-down function starts, the RUN light turns off, and the READY indicator begins flashing. When the READY indicator lights up continuously, the Ramp-down function is over.

Like other control devices, soft starters have their own IEC utilization categories. AC-53a are starters that are not bypassed and AC-53b are starters that are bypassed during run to cool them down. The Soft Starter, Model 3186, is AC-53a rated.

Figure 5-6 is an example of the Soft Starter behavior. The ramp-up time is set to 10 s, the starting voltage to 50%, and the ramp-down time to 15 s. Power is applied to the circuit at t = 0 s. At t = 5 s, the selector switch is turned on and starting voltage is applied to the motor. The voltage is gradually increased to its nominal value over the next 10 s (ramp-up time). The motor then runs under normal conditions until the selector switch is turned off at t = 40 s. During the following 15 seconds (ramp-down time), the motor voltage is gradually reduced to zero.

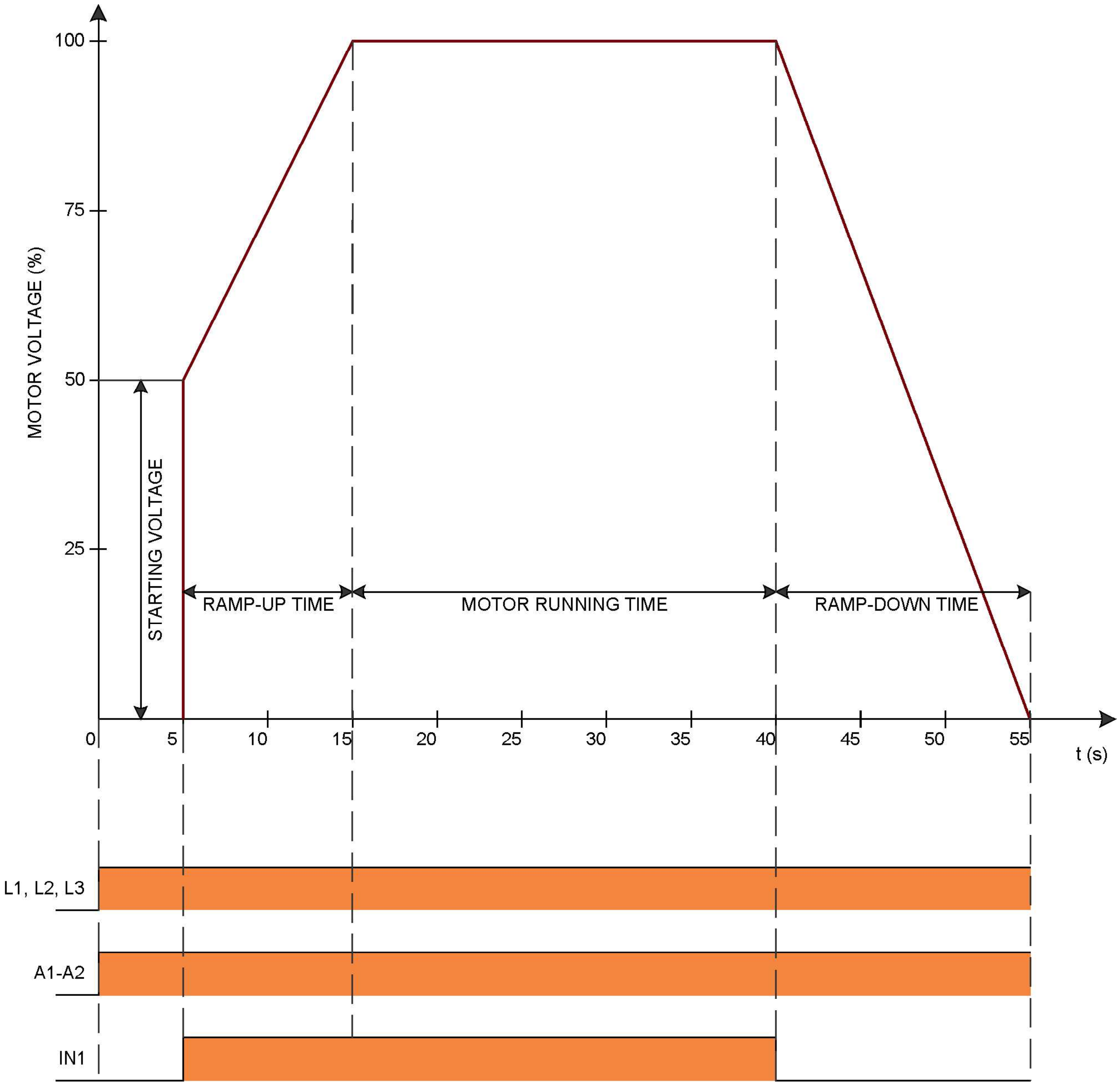


Figure 5-6. Example of Soft Starter behavior.

PROCEDURE OUTLINE

The Procedure is divided into the following sections:

- Basic setup
- Starting voltage setting
- Ramp-up time setting
- Ramp-down time setting

PROCEDURE

In the first part of this exercise, you will observe the influence of low starting voltage values. You will see that a starting voltage that is too low is not effective, because the motor does not start promptly.

In the second and third parts of the exercise, you will test the influence of different ramp-up and ramp-down time settings on accelerating and decelerating times. You will observe how voltage is gradually increased and decreased with the help of a voltmeter.

⚠ WARNING

The AC Power Supply provides high voltages. Do not change any AC connection with the power on.

Basic setup

1. Perform the Basic Setup and Lockout/Tagout procedures.

Starting voltage setting

2. Install the Brake Motor, Inertia Wheel, and Safety Guard.

Connect the circuit shown in Figure 5-5. Use the SS-1 contact of the Selector Switches module.

3. Manually disengage the friction brake.

Set the knob of the Manual Starter to the I position.

Set the START selector switch of the Selector Switches to the O position (open contact).

Set the Soft Starter with the following parameter values:

- Ramp-up time: 10 s
- Starting voltage: min position
- Ramp-down time: 0 s.

Perform the Energizing procedure.

4. Set the START selector switch to the L position (closed contact) for three seconds, then return the knob to the O position.

Does the motor start easily (during these three seconds)? Describe the motor acceleration.

____

____

5. Set the starting voltage potentiometer of the Soft Starter to the 12-o'clock position.

Set the START selector switch to the L position for three seconds, then return the knob to the O position.

Does the motor start more easily when the starting voltage is higher? Describe the motor acceleration.

____

____

Ramp-up time setting

6. Install a voltmeter between the motor's terminals T1 and T2.

Set the Soft Starter with the following parameter values:

- Ramp-up time: 20 s
- Starting voltage: 12-o'clock position
- Ramp-down time: 0 s.

7. Start the chronometer as you set the START selector switch to the L position. Observe the gradual increase of motor voltage.

How long does the Soft Starter take to supply full voltage to the motor?

Time: ______

8. Set the START selector switch to the O position.

Set the ramp-up time to 10 seconds.

Start the chronometer as you set the START selector switch to the L position. Observe the gradual increase of motor voltage.

How long does the Soft Starter take to supply full voltage to the motor?

Time: ______

Ramp-down time setting

9. Start the chronometer as you set the START selector switch to the O position. Observe the decrease of motor voltage.

   How long does the Soft Starter take to stop supplying voltage to the motor (less than 2 V)?

   Time: ______

10. Set the ramp-down time to 20 seconds.

    Set the START selector switch to the L position, and wait for the RUN indicator of the Soft Starter to turn on.

    Start the chronometer as you set the START selector switch to the O position. Observe the decrease of motor voltage.

    How long does the Soft Starter take to stop supplying voltage to the motor (less than 2 V)?

    Time: ______

11. Does increasing the ramp-down time make the motor stop more softly?

    ❑ Yes ❑ No

12. Turn the individual power switch of the AC Power Supply off, disconnect the circuit, remove the magnetic labels, and return the equipment to the storage location.

CONCLUSION

Soft starters enable smoother starting than direct-on-line starters. Besides, they offer many advantages compared to primary resistor starters: they have no wearing parts, are easy to adjust, need less space, provide gradual voltage changes, and do not dissipate much power.

Soft starters usually have three adjustments: starting voltage, ramp-up time, and ramp-down time

A lower starting voltage reduces the inrush current upon starting. However, when the starting voltage is too, the motor produces heat and does not start immediately.

The ramp-up time is the time the soft starter takes to reach the rated motor voltage. The longer the time, the softer the start.

Ramp-down time is used to gradually reduce the motor voltage to zero for slower stop. Ramp-down is useful in applications where a controlled stop is needed.

REVIEW QUESTIONS

1. The motor starting torque is proportional to the

   a. square of motor voltage.

   b. motor starting voltage.

   c. ramp-up time.

   d. ramp-down time.

2. In the Figure 5-5 circuit, what happens when the starting voltage is too low for the load?

   a. The motor starts as if with a DOL starter.

   b. The motor does not start easily.

   c. The motor starts smoothly.

   d. The motor runs in reverse direction.

3. In the Figure 5-5 circuit, what voltage is applied to the motor when the RUN indicator is lit?

   a. Full voltage

   b. Starting voltage

   c. No voltage

   d. Increasing voltage

4. Which of the following characteristics is not an advantage of a soft starter compared to a primary resistor starter?

   a. No wearing parts

   b. Easy adjustments

   c. Smaller size

   d. Larger heat losses

5. What is the effect of adding a ramp-down time?

   a. Reduces stopping time

   b. Increases stopping time

   c. Reduces starting time

   d. Increases starting time

Unit Test

1. Which of the following starters does not provide reduced voltage upon starting?

   a. Primary resistor starter
   b. Soft starter
   c. Across-the-line starter
   d. Wye-delta starter

2. What can be done to primary resistor starters to obtain a more smooth start?

   a. Reduce the resistor values.
   b. Short the resistors sooner upon starting.
   c. Add resistor stages.
   d. All of the answers above are correct.

3. Why are primary resistors bypassed once the motor is started?

   a. To heat up the motor.
   b. To diminish the voltage applied to the motor.
   c. To avoid power losses through the resistors.
   d. All of the answers above are correct.

4. What advantage(s) do soft starters have over primary resistor starters?

   a. More power losses
   b. No wearing parts
   c. More space needed
   d. All of the answers above are correct.

5. If the ramp-up time of a soft starter is increased, what is the effect on starting time?

   a. Reduced stopping time
   b. Increased stopping time
   c. Reduced starting time
   d. Increased starting time

6. What happens when primary resistors are used to start a motor?

   a. Energy is lost through heat produced by the resistors.
   b. Reactive energy is stored within the resistors.
   c. No energy is lost or stored.
   d. None of the answers above is correct.

7. What motor starter provides a voltage that increases following the shape of a ramp?

   a. Primary resistor starter
   b. Autotransformer starter
   c. Wye-delta starter
   d. Soft starter

8. What adjustment potentiometers can usually be found on a soft starter?

   a. Starting voltage, coast time, and ramp-down time.
   b. Ramp-up time, starting resistance, and starting current.
   c. Ramp-down time, starting resistance, and coast time.
   d. Starting voltage, ramp-up time, and ramp-down time.

9. If the ramp-down time of a soft starter is diminished to zero, what is the effect on stopping time?

   a. Reduced stopping time
   b. Increased stopping time
   c. Reduced starting time
   d. Increased starting time

10. What variable do soft starters modify to start motors smoothly?

   a. Motor input voltage
   b. Driven load
   c. Friction applied by the brake
   d. Motor resistance