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TechTopics No. 133

Motor starting: autotransformer or soft starter?

The issue of reduced-voltage starting techniques comes up frequently in connection with medium-voltage motors and their starters. A reduced-voltage motor starter offers many advantages, and a few drawbacks as well.

The reduced-voltage motor starter reduces the inrush current required of the primary system, and hence, the voltage drop on the system during starting. The serving utility often has limitations on the allowable inrush current, and may impose severe economic penalties if violated. In addition, excessive voltage drop on the system during starting may have unacceptable consequences for the rest of the system.

Once the decision is made to use reduced-voltage starting, the next step is to determine which type is best for your application: a traditional autotransformer starter (commonly referred to as reduced-voltage autotransformer or RVAT starter) or a modern solid-state reduced voltage starter (SSRVS, often called a “soft starter”).

Characteristic	Autotransformer (RVAT) starter	SSRVS (soft starter)
Cost	Lower	Higher
Space	Typically larger than a SSRVS starter, except for small size machines	Typically smaller than an autotransformer starter, especially for larger machines, i.e., with full-load current over 400 A
Weight	Usually heavier than an equivalent SSRVS starter	Usually lighter than an autotransformer starter
Number of starts/ hour	Generally, motors must be capable of two starts in succession, coasting to rest between starts, with the motor initially at ambient temperature. This is the basis of fuse selection as discussed in TechTopics No. 105.	Standard SSRVS has same capability as the equivalent autotransformer starter and typical motors.
Stop control	None. Motor switched off under load and decelerates accordingly. May impose high forces on driven equipment.	Soft-stop settings available to reduce mechanical shock loading on the driven equipment.
Start control	Usually, only one starting voltage (50% or 65% or 80% of system voltage), start on reduced-voltage tap and then switch over to full voltage, so two inrush currents and two episodes of voltage reduction on primary system.	Smooth starting, with only initial starting current (parameterizable). Starting process profile adjustable, along with current limits, timing of transfer to running mode, etc.

Table 1: SSRVS and RVAT comparision

What are the characteristics of each type of reduced-voltage starter? These are summarized in a tabular form.

Autotransformer starting

In an autotransformer (RVAT) starter, the motor is connected to the secondary of an autotransformer during the early stage of the starting process, and then the autotransformer is disconnected when the machine is transferred to full voltage to complete the starting process and subsequent normal operation.

The basic schematic for an autotransformer starter is as shown in Figure 1. The sequence of operation is:

- Close isolation switch.
- Close shorting contactor.
- Close start (main) contactor – this connects motor at the particular voltage tap of the autotransformer for which the starter is configured (typical taps are 50 percent, 65 percent, and 80 percent). The motor begins to accelerate.
- After a preset time delay (timer in control circuit or setting in protective relay), the shorting contactor opens. In lieu of a timer, it is also possible to initiate the transfer to full voltage as a function of the line current, using modern microprocessor protective relays. At least in theory, the transfer from reduced voltage to full voltage is made when the motor torque equals the torque required by the motor / load combination, at which point, acceleration ceases. In practice, the transfer is seldom so precisely timed.
- After a very short time delay, the run contactor closes, connecting the motor to full voltage.
- The autotransformer remains connected to the system, but with no voltage across the autotransformer winding.
- Once the run contactor closes, the motor completes acceleration to full speed and is then in normal operating mode.

The starting torque and the starting current of the starter at reduced voltage is a function of the selected tap on the autotransformer. Refer to table on page three.

The tap connection on the autotransformer must be selected so that the motor produces sufficient

Characteristic	Autotransformer (RVAT) starter	SSRVS (soft starter)
Transition to full voltage	Transfer from reduced voltage to full voltage operation should be delayed until the motor speed is high enough to insure that the current change during switching will not exceed power company requirements. Protective relays may initiate transition to full voltage by monitoring current, or at preset time delay, or a combination. Increased current and voltage dips on transfer are unavoidable.	Current surge and impact on system voltage avoided on transfer to running mode. Starting current reduced from about 6 x FLA to about 3 x FLA, or even as low as 2 x FLA for some applications.
Utility power constraints	Difficult to meet utility power demand constraints (i.e., system voltage drop) due to limited available taps (50/65/80 percent).	Start profile can be tailored to meet utility imposed limits.
Mechanical shock imposed on driven load	Torque transients during initial start and during transfer to full voltage.	Initial torque reduced, and smooth acceleration provided up to full voltage and full speed - reduced mechanical impact on the driven load.
Mechanical complexity	Three contactors required for autotransformer start.	Two contactors required for SSRVS start.
Protection	Sophisticated protection available with modern microprocessor relays.	Software configurable settings for starting and control of machine, as well as for protection. Can be supplemented with modern microprocessor relays.
Self-monitoring	Protective relays include self-monitoring features, but not of the controller itself.	SSRVS control system includes self-monitoring of the SCR power stack assembly, but not of the contactors.
Electromagnetic interference/ compatability	Output of controller is a sine wave with no harmonic distortion introduced. No special shielding or cable distance limits. Provides maximum torque with minimum line current.	SCR power stack assembly introduces some electronic transients of limited magnitude, controlled using built-in R-C networks. In any event, SCR power stack assembly is only connected during the short starting period.
Heat generation	Heat generation during starting is significant due to higher currents during starting but duration is very short.	Soft starter has little heat generation compared to an autotransformer. Heating only present during very short starting period.
Application for starting multiple motors in sequence?	No.	SSRVS can be designed to start multiple motors (of same power) in sequence. SCR power stack assembly must accommodate increased heat generation, and motor controller lineup requires transfer bus to switch soft starter to each motor in sequence.
Power factor correction capacitors or surge capacitors; load-side capacitance	Suitable for connection on load side of circuit. No limitations on load-side cable length.	Do not connect capacitors (either power factor capacitors or surge capacitors) on the load side of the controller, to avoid damage to the electronic power modules. Load-side cable must be less than 1,000 ft to limit capacitance.

torque to accelerate, while reducing the impact on system voltage during starting and controlling starting current.

The autotransformer starter uses three contactors for starting and running operation of the machine, making the power circuit connections somewhat complex.

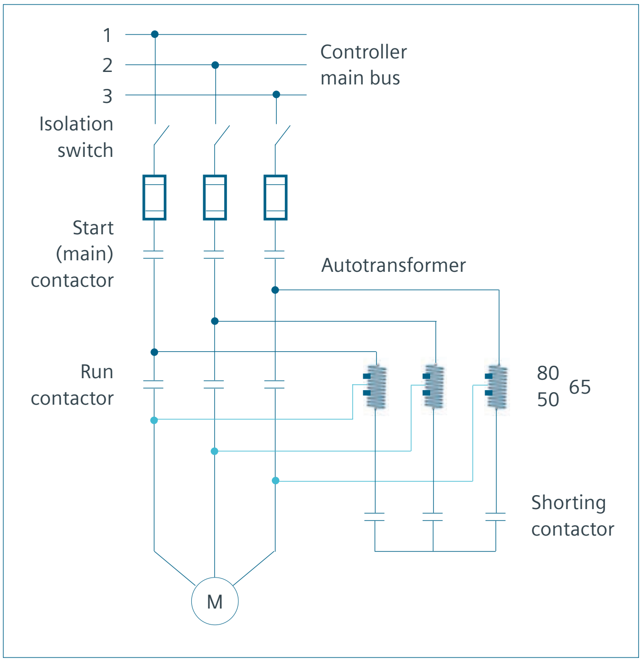

Figure 1: Autotransformer starter configuration

Table 2: RVAT voltages, starting current, and torque

Item	Tap	Tap	Tap
Autotransformer connection (voltage tap)	50%	65%	80%
Motor torque during starting	25%	42%	64%
Motor current during reduced-voltage starting stage (percent of locked rotor current at full voltage)	50%	65%	80%
Percent of system voltage applied at initial start	50%	65%	80%
Starting current drawn from line (percent of locked-rotor current at full voltage)	25%	42%	64%

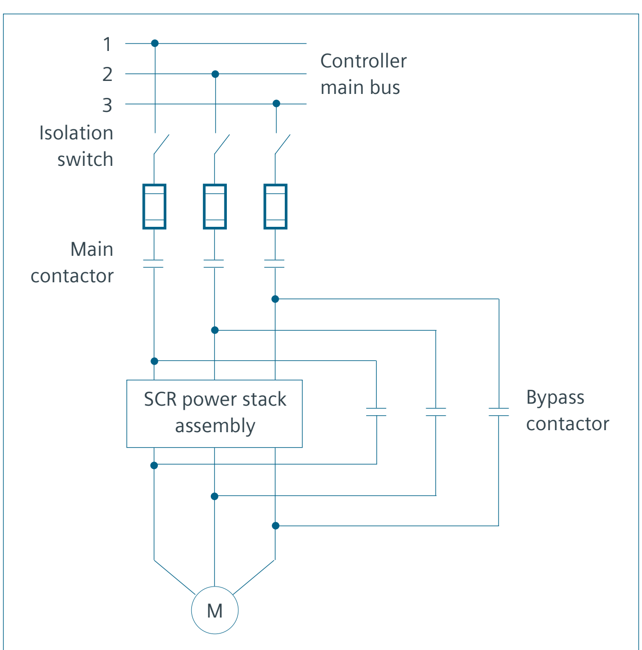

Figure 2: SSRVS soft-starter configuration

The autotransformer scheme has been in use for many decades and is well proven in experience.

The autotransformer imposes two inrush transients on the power system, the first when the starting sequence is initiated, and the second when the machine is transferred from reduced voltage to full voltage. When the start sequence is initiated, the machine produces the reduced level of torque indicated in the table, and when the machine is transferred to full voltage, the full torque of the machine is available to complete the acceleration to full speed. To reduce the impact of these starting transient currents, it is desirable not to use the 80-percent tap connection. On the other hand, the 50-percent tap connection often does not provide sufficient torque to accelerate the machine. For this reason, the 65-percent tap is the most frequently used connection.

There are some reports in the literature of damage to autotransformers resulting from the voltage transients associated with the transfer from reduced voltage to full voltage, but these seem to be related to use of a two-coil autotransformer design rather than the three-coil autotransformer configuration shown in Figure 1. Siemens has not experienced such problems in the past.

The autotransformer is a custom component, whose characteristics must be tailored to those of the machine that the unit controls. As a result, in the event of a failure of an autotransformer, the time required to obtain a duplicate unit can be excessive.

Solid-state, reduced-voltage starter (SSRVS) (soft starter)

A solid-state, reduced-voltage starter uses electronic control of the voltage applied to the machine during starting.

This allows control of the starting current throughout the accelerating process, reducing the impact of starting transients on the system. This facet is why such controllers are often referred to as “soft starters”.

SSRVS controllers have been available for several decades but adoption was initially slow due to significantly higher purchase cost of the soft-starter unit compared to an autotransformer starter. More recently, the purchase cost differential has declined as the usage of SSRVS starters has become dominant in the market, but there is still a premium for a soft starter over the purchase cost of an autotransformer starter.

The normal operation of a soft starter imposes a preselected initial voltage on the machine (referred to as voltage ramp), and the voltage is gradually ramped up until full voltage is reached, at which point the soft starter electronics are disconnected (or bypassed) and the machine is operated at full voltage. The starting time is typically selected by the user and is of the order of up to 30 seconds. An alternative approach is to use the soft starter to limit starting current (referred to as current ramp) to some value, typically 300 percent - 600 percent of full-load current, although limiting to 600 percent would essentially be full-voltage starting and hence not an attractive setting.

The current-limit value during starting must be sufficient to allow the machine to accelerate the machine and the connected load.

A soft starter allows for fine tuning of the allowed current during starting. In an autotransformer starter, the starting current can only be adjusted in fixed intervals, from 300 percent of full-load current (at 50-percent tap) to 390 percent (at 65-percent tap) to 480 percent (at 80-percent tap), based on an assumed locked rotor current of 600 percent of full-load current. In contrast, the user can adjust the current limit with a soft starter to any intermediate values, for example, 280 percent or 320 percent, to fine tune the actual start conditions.

SSRVS starters also allow more sophisticated motor-control profiles, including pump-control profiles, soft stop, and the like. A pump-control profile recognizes the load imposed by a typical pump application, adjusting the voltage imposed on the motor at the end of the acceleration period so as to minimize the chances of water hammer (pressure surges) in pumping applications.

SSRVS units can also be configured for pulse-starting profile, for loads that have a high starting friction and thus require a higher torque at the beginning of the start process, with the voltage reduced after the relatively short pulse start time.

SSRVS units have complex electronics but the power circuit for an SSRVS starter is less complicated than with an autotransformer starter.

The electronics portion of the starter is quite sophisticated and typically requires that the manufacturer be involved in any commissioning and troubleshooting.

Modern SSRVS power stack assemblies usually have provisions for testing and troubleshooting using a low-voltage source and a small motor, simplifying initial configuration and subsequent maintenance activities.

Capacitors, whether power factor correction capacitors or surge capacitors, must not be connected the load side of an SSRVS soft starter. Capacitors, if used, must be connected on the line side of the controller, and arranged so that the capacitors are disconnected during starting and during stopping of the machine. For more information on this topic, consult TechTopics issue no. 125.

A growing application for SSRVS starters is for applications that have multiple motors of the same horsepower rating, where additional motors are brought on-line as the load demands dictate. For such applications, it is possible to arrange the equipment so that one soft-starter electronic module is shared among the motors, with the electronic module used repetitively to start each additional machine. While this complicates the arrangement of the power circuit of the motor control lineup, it has the advantage of needing only one expensive SCR power stack assembly. The SCR power stack assembly must, of course, be engineered to accommodate the increased heat associated with use for multiple starts over a short period of time.

Published by Siemens Industry, Inc. 2017.

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Article No. EMMS-T40086-00-4AUS

Printed in U.S.A.