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TechTopics No. 125

Do not connect surge arresters or capacitors on the load side of solid-state, reduced-voltage (SSRVS) controllers

Users often require that surge arresters and/or surge capacitors be provided in the motor terminal box of medium-voltage machines, and occasionally, at the controller itself. This was historically a common practice to protect the relatively weak machine insulation between turns from voltage transients, especially lightning strikes.

This was a logical result of the consideration of the relative dielectric strength of the components in the power distribution system. A liquid-filled power transformer has relatively robust insulation, as does the metal-clad switchgear to which the transformer often is closely connected. The power cables also have high dielectric strength, as well as the motor control equipment. However, the motor does not have an impulse rating specified in rotating machine standards, and is thus the weak (dielectric) link in the distribution system.

For example,

System element	Impulse capability
Power transformer, liquid filled, 13.2 kV-4.16 kV, secondary winding impulse rating	60 kV
Power cable between transformer and switchgear[1]	60 kV
4.16 kV metal-clad switchgear	60 kV
4.16 kV medium-voltage motor controller	60 kV
Power cable between controller and motor[1]	60 kV
Motor - estimated impulse capability[2]	15 kV

Footnotes:

1. Cables do not have an assigned impulse capability, but it is generally considered that the cable impulse capability exceeds that of liquid-filled transformers
2. IEEE 241-2001 (the IEEE Buff Book), table 10-2.

This example is a bit simplistic but illustrates the potential problem. One note is that a motor does not have an impulse capability, but a 4.0 kV motor is often considered to be able to withstand a transient equal to 125 percent of the crest value of the motor's power-frequency, one-minute, high-potential test voltage. See TechTopics No. 108 for a discussion of estimated motor dielectric strength.

This illustrates why many users specify arresters and/or surge capacitors to protect the rotating machine from lightning surges. While this is still often desirable for machines that are started across-the-line, it is unnecessary for machines that are started using a soft starter (SSRVS) as machines started with soft starters are generally larger size machines.

A machine that is controlled by a soft starter is not directly connected to the distribution system during starting, but is isolated from lightning surge voltages by the soft starter itself. Therefore, there is little value provided by specifying surge arresters or surge capacitors on the load side of an SSRVS, or at the motor in the terminal box. In fact, connecting power-factor correction capacitors, surge capacitors, or surge arresters to the load side of the SSRVS will cause damage to the silicon-controlled rectifiers (SCR) in the SSRVS.

If a user wishes to have surge arresters for protection from lightning surges when the motor is running at full voltage (i.e., in bypass mode), the arresters must be connected on the line side of the controller.

Only the motor and the interconnecting cables from the SSRVS to the motor should be connected to the load side of an SSRVS soft starter. Power-factor correction capacitors, surge capacitors, and surge arresters should not connected to the output side of the SSRVS. An SSRVS, during starting, uses phase control of the voltage output, and applies a train of small, chopped voltages to start the machine and limit the motor current (and consequently, motor torque). The controller accelerates the machine from zero speed to full speed gradually, reducing the mechanical impact on the machine and the electrical impact on the power system.

While the machine is being brought up to full speed, the output of the soft starter is not a pure sine wave. It is a waveshape containing higher order frequencies that are multiples of the system frequency. During the start process, the soft starter uses phase control of the SCRs, which can produce short-duration voltage transients. Capacitive devices connected on the load side of the soft starter, including power-factor correction capacitors and surge capacitors, will appear to the soft starter as short circuits, imposing high di/dt on the SCRs and causing failure of the SCRs, perhaps on the first starting attempt.

Also, some surge arresters present a capacitive characteristic to the soft starter, which would have the same effect, except that damage to the SCRs will accumulate over time and produce ultimate failure. During the SSRVS' voltage ramp during the starting process, the voltage transients may cause the surge arrester to conduct current to ground, which would appear as a short circuit (and high di/dt) to the SCRs, albeit of lower magnitude that during a lightning discharge. Not all surge arresters present a capacitive characteristic, but our policy of prohibiting surge arresters on the load side of the soft starter is a conservative approach.

Applications where power-factor correction capacitors are necessary must have the capacitors located on the line side of the SSRVS soft starter, and switched by a dedicated contactor so that the capacitors are disconnected during the start process and disconnected when the machine is switched off.

If the system insulation coordination study determines that surge arresters are necessary, whether to mitigate lightning strikes or for other reasons, they also must be connected upstream of the soft starter for the reasons discussed.

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