A How-To Guide to Synchronous Motor Protection

In our Tech Talk, **A How-To Guide to Synchronous Motor Protection**, learn about the unique protection and control requirements of synchronous motors—often used in constant-speed applications and for power-factor correction. Start-sequence control, squirrel-cage rotor thermal protection, and specific stator considerations must be part of a complete protection strategy.

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GE VERNOVA

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QUESTION	ANSWER
How do we detect rotor earth faults in brushless synchronous motor?	Detecting rotor earth faults in a brushless system is difficult because the excitation system has no external connection... it is all on the shaft. One older method is to attach a brush set to the shaft just for the purpose of monitoring shaft resistance to ground. These "measurement" brushes are applied periodically to check for a rotor field ground fault. You can do this with the GPM-F module. (If brush lift-off protection is applied, the brush lift-off function must be blocked during the time interval the measurement brush is disconnected.) However, measurement brushes add the problems of a brushed system—wear, contamination, unreliability. A new method is to use a wireless connection to a rotor ground-fault sensor. A special transmitter that runs on the field excitation power sends a resistance signal to a sensor, which alarms if the resistance to ground becomes low. The device injects a pulsed voltage between the field negative bus and the rotor ground. Then, it monitors the current flowing from the ground terminal into the device, digitized with high resolution and transmitted off the rotor using wireless techniques. It computes resistance from the current pulse transitions, and location. This is like the low-frequency injection method that GE Vernova uses in the GPM-F for detecting rotor ground faults in brushed synchronous generators.
What are the advantages of using synchronous motors over induction motors? Why do we use synchronous motors with VFDs when we have induction motors with VFD speed control?	Synchronous motors can handle any load driven by a NEMA design B squirrel-cage motor. Whether you should do this depends on some parameters. One design guideline is that synchronous motors are less expensive than squirrel-cage motors if the rating exceeds 1 hp per rpm. However, that considers only initial cost and does not consider these advantages of synchronous motors: • Greater efficiency of the synchronous motor • Power-factor improvement • Constant speed These advantages are especially prevalent at speeds less than 500 rpm. However, synchronous motors have some challenges, which are the following: • Need for excitation source and field control • Lesser starting torque/kVA efficiency • Greater maintenance cost, especially for motors with slip rings and brushes The LCI drive (also commonly referred to as VFD, or variable frequency drive) consists of an incoming section which supplies direct current via a current-smoothing choke to an inverter section. The inverter supplies DC power to the synchronous motor by switching it between phases at the desired frequency corresponding to speed. During reduced-speed operation it is important to avoid overfluxing the motor, so we want to use ANSI 24, volts-per-hertz protection.

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What advice do you have for updating protection schemes for a 50-year-old synchronous motor replacement project?	Consider a modern relay like the Multilin 869. It is a real advantage because you don't have to use two devices, the induction-motor protection relay (older 469) and an SPM relay. The SPM functions are built-in to the 869 relay.
How many CTs are mandatory and what protection topology is used to cover all significant fault scenarios? What protections must be used in motors?	This is a good question, to which applies the general response of "it depends." A better way to ask the question depends on the size of the motor and the criticality of the motor application. For large motors, where a stator rewind would be expensive and time consuming, you need three terminal and three neutral-side CTs for differential protection. Even in applications from 500 to 1000 horsepower, differential is very helpful. These CTs also cover short-circuit, current-unbalance, and mechanical-jam fault scenarios, and feed the start-inhibit controls. Also, consider the thermal model. Modern relays run a thermal model on the stator, and RTDs can modify the trip point. In the synchronous motor we need to protect the squirrel-cage bars, so the relay runs a speed-dependent thermal model to protect this part of the rotor assembly. Properly set, the thermal model inhibits starting until the motor has cooled sufficiently for a safe re-start.
We start the motor and the field winding at the same time. What issue does this cause?	When applying the field at the same time as starting the motor, you overtax the field circuit. It must supply more power than designed, often leading to premature failure. Use the start-sequence control capability in the relay to apply the field when near synchronous speed, according to the motor manufacturer's specifications.
How is the out-of-step protection implemented?	To implement out-of-step protection, you will need to do these things: 1. First, you need a power-system transient study to analyze many operating conditions and stressed system operating scenarios. The study identifies the power-system components that limit angular stability and the generators' sensitivity to out-of-step during system disturbances. The study identifies the optimal location of out-of-step tripping and power-swing blocking protection relay systems in relationship to the apparent impedance locus. 2. The study determines the locations of the swings during various system conditions 3. Find what disconnections keep the system intact, based upon subsystems. 4. Establish the maximum slip rate and OOS timer settings between subsystems. 5. Configure the limits of the power-swing blocking zones, and for the out-of-step tripping zones. 6. Verify with modern mathematical modeling tools—model the relays for proper settings operation.

QUESTION	ANSWER
What's the best way to monitor power factor for a synchronous motor?	For power factor, you need both voltage and current. The minimum operating voltage and current are set as a threshold below which the element is reset. You can do this in the 869 relay. The power-factor feature is inhibited from operating unless both the voltages (open-delta VT connection) or all three voltages (wye VT connection) are above the selected voltage threshold and one or more currents are above the selected current threshold. Power factor element delay timers time when the voltage threshold is exceeded on all phases and current threshold is exceeded on one phase. If the phase voltages fall below the threshold and one phase current threshold falls below, then the timer has timed-out, the element resets without operating. A loss of voltage during any state returns both power-factor elements to the Reset state. For details on the convention used for measuring power, consult the relay instruction manual. A synchronous machine can operate in lagging (under excitation), leading (over excitation) or unity power factor conditions depending on the applied field current. In the V-curves provided by the machine manufacturer, you can determine the relationship between the field current and power factor. In the 869, you can choose two lagging modes: • **Ride-thru**: Field current not removed. Relay trips if PF lag is sustained for delay. • **Resync**: Field current is removed. The synchronous motor operates as an induction motor until resuming speed, then the relay reapplies field current. If no resync before delay timeout, then the relay trips.
Is there any option for auto-excitation system to manage the power factor within a set-point?	Yes, that is the 90F function. The PF regulator manages power factor within a setpoint. It is a built-in, closed-loop transfer function that that senses phase-angle error and gives feedback to the exciter. It measures the power-factor dip that occurs when the motor is loaded, and it signals the silicon-controlled rectifier (SCR) exciter to respond with a boosted output. As a result, the pull-out torque of the synchronous motor is increased for the duration of the transient load. After the load subsides, the regulator senses an excessive leading power factor and signals the exciter to reduce its output. This automatic boosting of field current to avoid pull-out is called field forcing. Thus, the power-factor regulator provides automatic boosting when field forcing is required and economical low-field operation when the motor is idling. Another application of the power-factor regulator is to control power-factor swings resulting from various levels of loading, to smooth fluctuations in the plant system voltage. Typical output ranges are analog outputs 0 to 10 V, -10 to 10 V, 0 to 20 mA, and 4 to 20 mA. Tune this function during commissioning initial setup.

QUESTION	ANSWER
What is best method for protection for high-current-start motors?	Many motors use a reduced-voltage starting system. The 869 has specific and advanced features for high-inertia loads and reduced-voltage starting motors. It controls the transition of a reduced voltage starter from reduced to full voltage, based on starting FLA “Current Only”, “Current and Timer”, or “Current or Timer” (whichever comes first). Reduced-voltage starting methods include a starting reactor (autotransformer) or part-winding starting.
Can you provide guidance to protect for coupling broken (twisted) by load?	Set an underpower, 32U, element. You set it a little lower than the least power demanded in the application. You could use two elements, one for alarm, with a small delay, and one for tripping, with a larger delay.

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