Today’s P&C Approach to Generator Protection

In our Tech Talk, **Today’s P&C Approach to Generator Protection**, we reviewed the correct application of modern generator protection to avoid expensive equipment damage and failure, while maintaining system performance and increasing availability. We explored in depth the anatomy of major faults encountered in generators. We also learned about protection configurations for stator phase faults and differential protection, stator interturn faults, unbalance, and split phase, as well as stator ground faults and restricted ground-fault elements.

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LET’S GO!

GE VERNOVA

Today's P&C Approach to Generator Protection

QUESTION	ANSWER
What is a black start in generators?	A black start is when we start a generator without the significant power needed to operate the generator. Normally, generator operation includes items like blowers and scrubbers, compressors, and pumps for fuel, lubrication, cooling and similar ancillary functions, as well as the power needed for excitation and control. Utilities specify certain special generation sites, with batteries, that can provide sufficient power to get the black-start generators running. Then, they use this power to start the larger generators. The problem occurs when switching the black-start generator onto the line. Which leads us to the next question...
Why does the generator trip when the generator step-up transformer (GSU) is energized?	Switching energizes transformers, which exhibit large magnetization current inrush upon initial energization. The large currents can trip the black-start generator relays if the settings are not properly configured. Black start generator protection includes a differential, 87G function that "rides-through" transformer inrush. Modern digital relays can detect the inrush and block generator differential protection. In addition, dual-slope generator differential elements compensate for CT saturation during the switched-in, large current demand when connecting a black-start generator. The GE Vernova-patented differential method includes a saturation and direction detector to keep the 87S differential element secure. Note that 87 refers to any differential; 87S designates the stator differential and 87G is the restricted ground fault differential.
What minimum protection functions need to be in place for datacenter generators?	Usually, datacenter generators are small (1 to 4 megawatts). A bank of paralleled generators takes about 15 seconds to start and synchronize—the datacenter is on an uninterruptible power source (UPS) during this time. At a minimum, it is important to protect the generator windings from too much current (51V voltage-controlled time overcurrent would be good, but is slower than 87 differential protection). Modern protection relays are fast, so coming online quickly is an effective strategy. Other protection elements include reverse power 32R and loss-of-field 40 elements. Switching the generators onto the datacenter power system can cause downstream transformer inrush and CT saturation, so good inrush blocking, dual differential slopes, and differential saturation detection are needed.
Why is there distance protection in a generator protection relay?	Often, engineers want to detect faults in the power system beyond the point of interconnection. A generator relay with a distance element can sense faults in the power system and take the generator offline. This function provides time-delayed protection for system faults that have not been cleared by system protections and provides back-up protection for stator faults. Of course, it's important to consider NERC PRC-024 and PRC-025 standards that define frequency and voltage excursions and generator loadability during which the generator must provide power. Modern protection relays use phase-distance elements to compensate for the transformer impedance and CT and VT positions to provide good coverage of the power system. The distance element can "look" through the generator step-up transformer (GSU). Although we can detect phase faults, when there is a wye-delta GSU transformer the delta winding interrupts the path for the zero-sequence circuit. Generally, the generator relay cannot use ground distance protection to respond to faults behind the transformer.

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QUESTION | ANSWER

Why can't we run the generator at a unity power factor?

Typically, a generator runs at a lagging power factor around 0.8, not at unity power factor of 1. This is because when operating near unity power factor the field excitation current is small, so there is little room for the voltage regulator to have control. Operating at a 0.8 lagging power factor leaves sufficient room for the exciter to control the terminal voltage.

What are recommendations for setting the reverse power 32R function?

Set the reverse power element at half of the generator-rated motoring power. To prevent misoperation on power swings, delay the element for 20 to 30 seconds. For sequential-tripping applications in a steam-turbine generator it is important to wait for the steam inlet valve to open, then the 32R delay is 2 to 3 seconds. In addition, this reverse-power element should be blocked when the generator is offline.

Which method of ground fault is more reliable: auxiliary neutral current through the transformer/resistor combination or neutral voltage monitoring across the transformer secondary resistor?

In the arrangement shown in Figure 1, the generator is grounded via the primary winding of a distribution transformer. The secondary winding has a loading resistor to limit the ground-fault current. A time-overcurrent 51N protection element has input from a CT connected in the resistor circuit to measure secondary ground-fault current. The relay should have an effective setting equivalent to 5% of the maximum earth fault current at rated generator voltage to protect 95% of the stator winding. The relay should filter the third-harmonic current to prevent incorrect operation when a sensitive setting is applied. Also, for a sensitive setting, add a delay to prevent misoperation in transient conditions and to coordinate with generator VT primary protection (for a VT primary earth fault). An operation time in the range 0.5 to 3 seconds is normal. You can add less-sensitive, instantaneous overcurrent protection 50 to provide fast tripping for a heavier ground-fault condition.

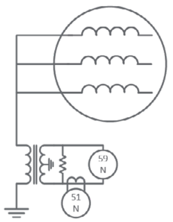

Figure 1

A voltage-measuring element 59N in the secondary circuit detects the voltage across the grounding resistor. Setting considerations are similar to the current-operated protection, transposed to voltage.

Application of both voltage- and current-operated elements to a generator with distribution transformer grounding provides advantages. The current-operated function continues to operate for a short-circuited loading resistor and the voltage-operated protection remains functioning for an open-circuited resistor.

However, neither scheme operates for a flashover on the primary terminals of the grounding transformer or the neutral cable between the generator and the grounding transformer during a ground fault. You could add a CT in the neutral connection close to the generator that operates a high-set overcurrent 50 to detect this fault. However, this fault current is sufficient to operate the phase-differential (87S).

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What is volts/hertz 24 protection and why is it needed in generator protection?	When the ratio of voltage to frequency is too large the generator experiences overfluxing; the iron saturates and results in stray flux occurring in components not designed to carry flux. As a result, overheating and damage occurs. Either excessive voltage or low frequency, or a combination of both results in overfluxing; a voltage-to-frequency ratio in excess of 1.05 p.u. indicates this condition. Transient excessive flux is not a problem for the generator. For example, a generator can be subjected to short-term, high voltage at nominal frequency immediately after full load rejection. Because this condition is transient, it is not a problem for the generator. However, sustained overfluxing can happen during generator run-up if excitation is applied too early with the automatic voltage regulator (AVR) in service, or if the generator is run down with the excitation still applied. Other overfluxing occurs from loss of the AVR voltage feedback signal, when a VT fuse is lost. A sustained overfluxing condition must be detected by dedicated volts/hertz 24 protection that raises alarm and forces an immediate reduction in excitation. Most exciter AVRs have overfluxing protection but this protection might operate only when the generator is on open circuit, and therefore fail to detect overfluxing conditions during abnormally low system frequency. Exciter overfluxing detection does not respond like a protection relay; you should not rely on the exciter protection to prevent overfluxing. A separate protective relay 24 element provides a definite-time alarm setting and an instantaneous or inverse time trip setting, to match the withstand characteristics of the protected generator and transformer. It is very important that the VT reference for overfluxing protection is not the same as that used for the AVR.
How do we achieve rotor/field circuit ground-fault protection in brushless excitation?	A brushless generator has an excitation system consisting of the following: • A main exciter with rotating armature and stationary field windings • A rotating rectifier assembly, carried on the main shaft • A controlled rectifier producing the DC field voltage for the main exciter field from an AC source (often a small "pilot" exciter) Therefore, no brushes are required in the generator field circuit. All control is performed in the field circuit of the main exciter. It is still necessary to detect a rotor circuit ground fault. Devices are available that have a dedicated, rotor-mounted system with a telemetry link to a receiver that provides field data and an alarm. Interface these to the generator protection relay via contact inputs.

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Why do we need to use thermal protection 49 on generators?	Stator overheating occurs from the following: • Overload • Failure of the cooling system • Overfluxing • Core faults Accidental overloading might occur through a combination of full active load current, governed by the prime-mover output, and an abnormally large reactive current component, governed by the level of rotor excitation and/or step-up transformer tap. With a modern protection relay, it is easy to provide a current-driven thermal model 49 element that estimates the thermal state of the stator windings and issues an alarm or trip to prevent damage. However, the current-driven thermal model cannot account for the effects of ambient temperature and uneven heat distribution in the stator. Resistance temperature detectors (RTDs) are applied as a back-up for direct stator temperature measurement for stator high-current conditions. GE Vernova relays can use the RTD inputs to bias the current-driven thermal model to obtain a more accurate stator temperature. You can monitor the actual stator temperature of a large generator to detect insulation degradation from overheating. The large-generator manufacturer embeds RTDs in the stator winding at hot-spot locations. The elements are connected to the 49RTD elements to provide alarm and trip outputs. The settings depend on the type of stator winding insulation and the permissible temperature rise for the winding classification.

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