Use of Impedance Grounding with Cummins Gensets

Commercial standby generators characteristically will produce a relatively high level of current on a line to ground fault vs. a three-phase fault. Designers may review the zero sequence reactance in the generator and may specify a grounding impedance to limit the generator line to ground fault current level. The grounding impedance ideally is sized so the overall system ratio of positive sequence reactance to zero sequence reactance stays greater than 3 to limit over voltage conditions during faults.

These actions are unnecessary with Cummins PowerCommand™ generator sets with AmpSentry protection. The rationale for that position is as follows:

Some major differences between power from a typical synchronous generators and power delivered from the utility grid are:

- On a single phase fault, as noted, a typical synchronous generator will produce considerably more single phase fault current than 3-phase fault current.
- On a three phase fault, the machine output will collapse due to insufficient excitation power to maintain output (even when a permanent magnet generator powers the exciter). It will only recover to about 3-times rated current when a permanent magnet generator (PMG) excitation support system is used. However, on a single phase fault there is plenty of excitation power available to maintain the fault indefinitely. (A single phase fault takes less excitation power to maintain a single phase fault than to operate the generator at full load.) So, on a single phase fault there will be a high level of fault current and it will not decay like it does on a 3-phase fault.
- On a single phase fault a generator with traditional excitation controls, the machine will produce a damaging level of overvoltage that is likely to damage loads and is likely to damage the alternator, particularly in a medium voltage application.

So, overcurrent and thermal heating isn't the main issue. Overvoltage is the key problem to resolve.

So, we have two goals in protecting the alternator:

- Protecting the generator from damage due to thermal overload, and
- Preventing damage in both the distribution system and the generator due to the overvoltage condition that can occur on a single phase fault.

Most textbooks (and often-referenced IEEE standards such as IEEE Standard C37.102 (Guide for AC Generator Protection) miss a few of major points related to these goals, particularly when dealing with the relatively small, high production volume machines used for standby applications:

Some IEEE standards recommend that a designer specifies optimum machine reactances to minimize the damaging conditions. In the standby world, that is impractical. The hardware available is optimized for performance and power quality, and the characteristic response to single phase faults is far down on the list of objectives for the alternator designer. So, you can't address the single phase fault issues with a custom-designed machine with the right ratios of reactance values. And, even if you could, you probably wouldn't be satisfied with the performance characteristics of the machine.

A standby generator with its integral excitation systems can't produce enough fault current on an external single phase fault to damage itself due to thermal overload in less than 1 second, regardless of the excitation system used. (The magnitude of single phase fault current is relatively high compared to 3-phase current, but usually low relative to what could be delivered from a utility source.) So, it's reasonable to be mostly concerned with overcurrent protection of the alternator vs. protection of other parts of the system.

Most single phase faults occur at the utilization levels of the system, and are relatively high impedance faults, so they look to the generator more like a mild overload than a fault. A low impedance fault close to the generator is very rare.

However, if a low impedance fault does occur, the root cause of the overvoltage condition is generally glossed over in the explanations of the phenomena:

On a typical large (>200kW or so) generator, the excitation system control is based on a 3-phase sensing voltage regulator. When a low impedance single phase fault occurs close to a generator, the following sequence will occur:

- The machine regulates excitation based on the average voltage sensed across all three phases.
- On a single phase fault, the voltage on the un-faulted phases (before the excitation system responds) is relatively unaffected but the faulted phase goes low, so the average voltage sensed for regulation goes low.
- The voltage regulator senses this and increases excitation, attempting to increase the average voltage to a nominal level.
- Voltage on the faulted phase can't go higher due to the fault, so voltage increases (usually to damaging values) on the un-faulted phases until the fault is cleared or something shuts down the generator.

Notice that the problem here isn't the nature of the alternator, but rather a characteristic of the excitation control system. (As noted before, trying to solve the issue by manipulating alternator design is impractical and ineffective.)

Over 20 years ago Cummins recognized the issue and dealt with it by dealing with the source of the problem: the excitation system[1].

The excitation control system on a Cummins generator is integrated with the generator set control and metering systems. So, the control always "knows" the voltage, current, kW, kVAR, kVA on all three phases, as well as frequency.

When a fault occurs that causes current flow greater than 110% of nominal on any phase, the generator control does I^2t calculations to determine when the generator is approaching a thermal damage point, and shuts it down if it becomes necessary. This protection is listed by UL and certified by CSA as a utility grade relay. The time/current characteristic for tripping matches the thermal damage curve of the alternator. (All circuit breakers are designed to protect conductors, so they do a miserable job of protecting an alternator, which is much more susceptible to damage than the conductors connected to it.)

When the Cummins control senses current flow of more than 3 times rated current on any phase, it switches from excitation control based on voltage, to excitation control based on the highest measured current in any phase and regulates that current level to three times rated. This allows the machine to provide a definite current output rather than what is done in traditional AVR designs, where the machine simply goes full field for a timed period on a fault[2].

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[1] Competitive literature indicates that some other competitors may also be taking similar measures, but the explanations of their operation are not detailed enough to verify what they are doing. Cummins has no way of knowing exactly how these systems work; or if they even function properly.

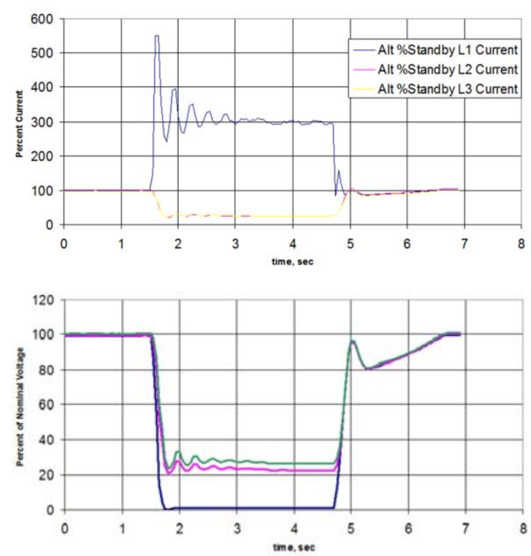
[2] Without fault current regulation that is in Cummins controls you may get more fault current, or less than 3x rated. If you get more, you may fail the alternator since shutdown is based on time rather than measured current; if you get less, you may not coordinate tripping correctly. Note that it is easy to tell if a voltage regulation system has this function. If it does not have 3-phase current sensing in the voltage regulator, it cannot provide regulated fault current functions.

The most important consequence of fault current regulation, however, is that it prevents overvoltage conditions on a single phase fault.

Unlike a utility source, a generator has very little stored energy in the machine and it doesn't have the advantages/disadvantages of the stored energy in the balance of the utility distribution system. Consequently, if you have a generator without an excitation support provision (such as a permanent magnet generator), the machine will simply collapse on a low impedance 3-phase fault because the only energy available to drive into the fault is what is stored in the field of the machine. The damage that traditionally would occur on a single phase fault is most severe with an excitation support system like a PMG is in place (which is true on most larger commercial generators) but will even occur on shunt-excited machines since the excitation level necessary to maintain a single phase fault is actually less the excitation level required to run the machine at full load.

When a single phase fault occurs on a machine with fault current regulation functions, the very first response of the Cummins control system is to *turn down excitation rather than turn it up* as would occur with most voltage regulator designs.

Remembering that with fixed excitation any increase in load will cause a voltage drop, and with the initial response of the machine to drop excitation, the over voltage condition that is the major (but generally unstated) concern of the IEEE textbook/standard recommendations can't occur. Further, because the excitation system is turning down excitation on a single phase fault, the voltage on the un-faulted phases "browns out" until the single phase fault condition clears, or the machine is shut down due to potential thermal damage to the alternator due to high current flow on the faulted phase, which will take around 6-8 seconds. When the fault clears, the generator ramps all phases back to normal without exposing the system to an overvoltage condition.



Current and voltage response on a low impedance single phase fault with a generator set utilizing fault current regulation.

This results in several major advantages:

- Ground resistors are not needed and the cost of the ground fault resistor is eliminated
- The cost of the monitoring system for the grounding resistor is eliminated
- The cost of downstream transformers to produce neutral connections to serve loads is minimized or eliminated (for line voltage systems)
- Detecting a failure of the grounding resistor is not always covered, and if that does occur, the system is ungrounded, so if a single phase fault occurs with a failed resistor, very serious damage will occur.
- The alternator is able to provide a surge of fault current to clear downstream devices quickly to clear the fault if possible, rather than leaving the system with a fault in place (which may be difficult to find and clear).   This also improves the ability to selectively coordinate the distribution system.

A few other points should be made:

The condition we're talking about here is not particularly related to grid-intertied systems—if anything it it's more of an issue for isolated systems. If a fault occurs on a modern grid-intertied control system with the generator connected, the generator is not regulated by voltage, but rather by measured kVAR output, so the generator probably would not even recognize that the fault existed.

More than 99% of all generators installed historically, and today use a solidly grounded generator design, which results in the most fault current to be generated regardless of the nature of the fault. This is good, because most distribution systems are required to be selectively coordinated, and having the most current available from a limited source like a generator definitely helps to make that critical design feature more practical.

In the prototype testing of each generator set model, Cummins performs short circuit testing to validate the system design. In those tests all types of faults are applied (3-phase, 2-phase, 1-phase). It is not unusual for a generator set to be subjected to over 100 short circuit conditions during this testing. At the completion of the tests, the generator set is disassembled and inspected to verify that no damage or degradation of the machine (including the alternator) has occurred. Clearly, if a machine can easily survive, without damage, 2 or 3 dozen single phase faults, there's no reason to go to the expense (with its incumbent disadvantages) of a resistance grounded system for the purpose of protecting the alternator from an overcurrent condition.

The latest Cummins control systems also incorporate negative sequence protection, which effectively deals with another issue in alternator protection with heavily unbalanced loads, and that is rotor heating. By regulating current and providing negative sequence protection, the entire alternator is effectively protected against damage due to any fault condition, without the risks traditionally associated with generators that do not have impedance grounding.

Recommendations

As a consequence of the sensing and fault current regulation functions in PowerCommand, Cummins does not require grounding resistors for use in protecting the generator set or distribution system from faults of any kind. Cummins recommends use of a solidly grounded generator set for most applications, except process-control.

Process control applications which are very susceptible to damage due to power interruption are required to run for an indefinite period with a fault in place without shutting down. In that situation, the 10-second resistor design as is used in most standby applications would be insufficient, and a more capable (and much more expensive) system that allows for continuous operation under fault conditions would be required.

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