Alternator protection, part 2: Alternatives

> **White paper**
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Generators sets are commonly to be protected from the effects of overload conditions by equipment that is required by local codes and standards. The standards generally do not stipulate what type of protection device that is required, so a system designer can select protective devices based on the needs of the application and the preferences of the user. This document provides an overview of overload protection alternatives that are available for generator sets.

Power topic #6002 Part 1 identified requirements for protection of alternators based on North American codes.

Inherent overcurrent protection

The "US *National Electrical Code*® Handbook" (page 606) notes that generator sets can be designed so that a short term overcurrent condition causes a collapse of the voltage on the output of an alternator. This limits the current and output kW of the alternator during an overload or short circuit condition so that it can considered inherently self-protected.

In practice, this can be achieved with a shunt-type excitation system design. In this type of generator excitation system, both the sensing and power leads of the voltage regulator are connected to the output of the alternator. When an overload or short circuit occurs, the collapsing voltage on the power supply to the voltage regulator effectively limits the power available to the alternator excitation system, thus causing alternator output voltage to collapse until the overload is removed from the system.

The weakness of this design is that shunt-type systems typically utilize single phase sensing voltage regulators, so a single-phase fault or overload may not cause the system to collapse immediately. If a fault or overload occurred on a phase which is not used for sensing or regulation power, the overcurrent condition would be maintained until the fault spread far enough to affect the power supply to the voltage regulator. By that time, alternator damage may have occurred.

Shunt-type excitation systems have other weaknesses related to motor starting and coordination (discrimination) on generator sets, so they are not often specified, particularly for large or critical systems. However, their historical acceptance without other overcurrent protection is a precedent for acceptance of other types of inherent protection for alternators.

Other inherent protection systems are available which address the concerns stated here for shunt-type systems.

Circuit breaker protection

Molded case breakers with thermal-magnetic trip units

Generator sets that are rated for operation at less than 1000 volts, and 1200 amps and smaller are often provided with a molded case circuit breaker for alternator protection. The molded case breaker is usually provided with a thermal-magnetic trip unit. The "conventional wisdom" is that this device will protect the alternator and the feeder connecting it to the first level of distribution, and these devices are often accepted for alternator protection by authorities. However, it is difficult (if not impossible) to design an effective alternator protection system using this equipment.

North American requirements for generator (alternator) protection

The 2005 US *National Electric Code*® (NEC®), NFPA 70®, makes the following references to generator protection:

240.21 Location in circuit: (G) Conductors from Generator Terminals. Conductors from generator terminals that meet the size requirement in Section 445-13 shall be permitted to be protected against overload by the generator overload protective device(s) required by Section 445-12.

445.12 Overcurrent protection: (A) Constant Voltage Generators. Constant voltage generators, except AC exciters, shall be protected from overloads by inherent design, circuit breakers, fuses, or other acceptable overcurrent protective means suitable for the conditions of use. *Exception to (A) through (E): Where deemed by the authority having jurisdiction, a generator is vital to the operation of an electrical system and the generator should operate to failure to prevent a greater hazard to persons. The overload sensing device(s) shall be permitted to be connected to an annunciator or alarm supervised by authorized personnel instead of interrupting the generator circuit.*

445.13 Ampacity of conductors: The ampacity of the conductors from the generator terminals to the first distribution device(s) containing overcurrent protection shall not be less than 115 percent of the nameplate current rating of the generator. It shall be permitted to size the neutral conductors in accordance with Section 220.61. Conductors that must carry ground fault currents shall not be smaller than required by Section 250.24(C)… *Exception: Where the design and operation of the generator prevent overloading, the ampacity of the conductors shall not be less than 100 percent of the nameplate current rating.*

ALTERNATOR THERMAL DAMAGE CURVE AND MOLDED CASE BREAKER TRIP CURVE

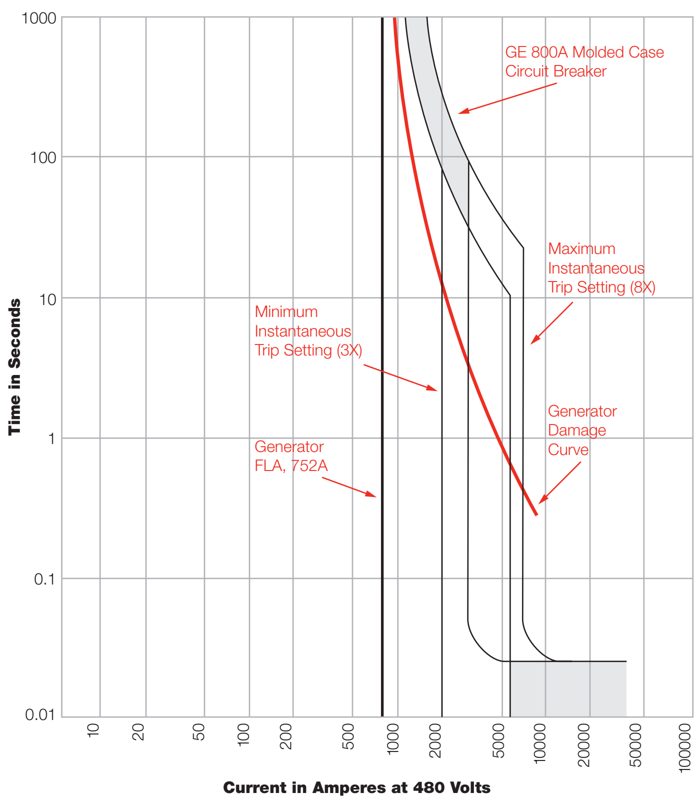

FIGURE 1 – At current levels less than 2000 amps the molded case breaker cannot provide protection for the alternator.

In FIGURE 1 you can see an illustration of a typical generator set thermal damage curve that has been overlaid on a time overcurrent characteristic curve for a molded case circuit breaker with thermal-magnetic trip unit. A problem is apparent from the first glance at the chart: The thermal damage curve of the alternator overlaps the trip curve of the circuit breaker. For proper protection the damage curve must be entirely to the right of the trip curve of the breaker, illustrating that for any current level, for any time duration, the breaker will positively trip before alternator damage will occur.

In general, a molded case breaker that is sized to carry the full output of a generator set on a continuous basis will overlap the alternator thermal damage curve. Use of a larger breaker would make the situation even worse.

If the generator set is exposed to a bolted fault close to the terminals of the generator set, the circuit breaker may trip in it's instantaneous region as much as several seconds before it needs to trip to protect the alternator. Tripping in the instantaneous region of the breaker curve can also occur due to surge currents from starting of large motors, or due to transformer magnetizing current. In many cases, this would be considered a nuisance trip, because there is no potential damage to any part of the system, but the breaker has cleared anyway. If this happens in the "real world", the operator would probably re-adjust the trip curve of the genset breaker to delay tripping, thus making the trip curve move further to the right, and providing even less protection to the alternator.

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If a low level overcurrent condition occurs the alternator will be damaged long before the breaker trips to protect the alternator. For example (see FIGURE 1), with a 1000 amp load, the alternator will be damaged after 300 seconds, but the breaker would not trip until the condition had lasted at least 1000 seconds.

Clearly, a molded case breaker with a thermal-magnetic trip, sized for the full output of the genset, does not provide effective alternator protection under all potential failure modes and conditions. There is another facet to the problem, and that is the reliability of service to loads when using molded case breakers.

Molded case breakers with thermal-magnetic trip units are generally not continuously rated devices. Unless a breaker is specifically listed and labeled to carry a 100% rating, it will carry only 80% of its nameplate rating on a continuous basis. Use of a breaker that is equal in rating to the generator output rating can limit the ability of the generator set to operate at high current levels (which it is designed to do) for extended periods of time (particularly at high ambient temperatures). If the generator set is operating at a high load level, the molded case breaker can trip in the 80-100% current range, especially in high ambient conditions, causing an unnecessary interruption of service to critical loads.

ALTERNATOR PROTECTION
USING A MOLDED CASE BREAKER WITH SOLID STATE TRIP UNIT

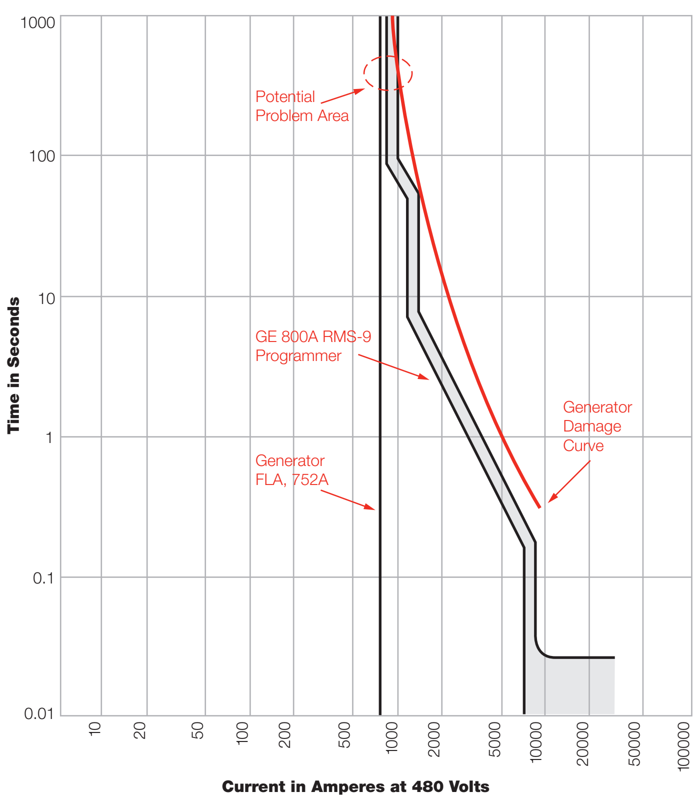

FIGURE 2 – This breaker provides better protection than one with a thermal-magnetic trip unit.

Some designers attempt to address the derating problem by application of oversized breakers or by use of continuously rated breakers. Note that a larger capacity breaker would probably trip later, making protection less effective for the alternator. It also would require larger generator feeder conductors that add cost to the installation because the feeder conductor size and the breaker must be coordinated to protect the feeder. Any continuously rated breaker would still need to be matched to the thermal damage curve of the alternator in order to protect the alternator through all overload conditions.

Another potential solution is to use multiple smaller breakers to feed smaller transfer devices or system loads. If a molded case breaker with thermal-magnetic trips is rated for approximately half the rating of the alternator, it will generally protect the machine through all overcurrent levels and duration's. (The designer should verify this for each application by comparison of the breaker trip curves and alternator thermal damage curve.) This strategy can be used where the loads on a generator set can be split and fed to multiple circuits directly from the generator set.

However, in general we can say that the most commonly specified and applied protective system for low voltage generator sets (molded case/thermal-magnetic breakers) will not provide necessary protection under all circumstances, and will subject the power system to nuisance power failures due to unnecessary breaker tripping.

An alternative that can be investigated is the use of "generator" type circuit breakers. These breakers are available from a few manufacturers, and allow better coordination of the genset thermal damage curve by modifying the characteristic trip curve to be more like the genset curve.

Molded case (and other) breakers with solid state trip units

Better alternator protection can also be achieved by use of breakers with more capable trip units. In FIGURE 2 an 800 amp insulated case breaker with solid state trip is overlaid on the alternator thermal damage curve. In this case the breaker characteristic curve shape more closely resembles the thermal damage curve of the alternator and it falls almost completely to the left of the alternator damage curve, so much better protection is provided to the generator set. There is the potential for damage due to a sustained low level overload condition for an extended period of time.

Insulated case breakers are not often applied on generator sets since they are considerably more expensive than molded case breakers, and may be too large or fragile for direct mounting on many generator sets. Most molded case breakers are available with solid state trip units (usually higher ampacities). These allow the designer to more closely match the breaker operation characteristic to the alternator provided. However, they do need to be adjusted for each alternator, and they may not provide complete protection in some operating regions, or may be misadjusted in the field due to what are perceived by an operator as nuisance trips.

AMPSENTRY PROTECTIVE RELAY WITH DECREMENT CURVE AND ALTERNATOR THERMAL DAMAGE CURVE

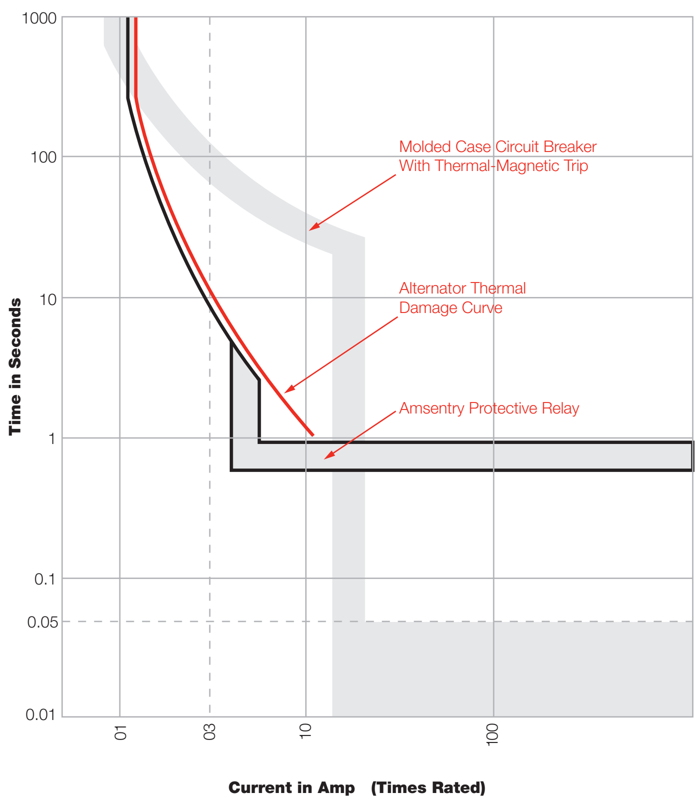

FIGURE 3 – PowerCommand generator sets include an overcurrent and short circuit protection algorithm that is designed specifically for alternator protection. The I^2t portion of the curve is matched to the alternator provided on the genset.

All breakers that include instantaneous trips are susceptible to nuisance tripping under some surge load conditions on a generator set. (Tripping that occurs due to peak inrush current which is less than the thermal damage limit of the alternator, but higher than the instantaneous pickup setting.)

A final point: The natural reaction to a breaker trip (and generator shutdown) by most operators would be to reset the breaker and immediately restart the machine. If the fault were still present on the machine, the machine could be damaged on the second operation. This is because the breaker would theoretically take the same time to clear as on initial trip, but since the machine is at higher internal temperatures at the start of the fault, it would reach a higher than expected temperature, potentially damaging the machine. This problem is present in all breakers, and most overcurrent relays.

Overcurrent protective relays

Specific overcurrent protective relays could be provided for alternator protection. These are often used for alternators operating at over 1000 volts AC. Relays are available in the marketplace that will provide good protection for the alternator, and may include overcurrent, differential overcurrent, zero or negative sequence devices. The drawback to these devices is cost, both in terms of the design (device selection and settings decisions on the part of the system designer) and installation of the relay(s) selected. For small generator sets the cost of a installed utility grade relay could approach the cost of the generator set! Installation cost increases may be significant, since many protective devices are not designed for mounting or long term operation on a generator set due to vibration or harsh temperature extremes that are common on a generator set. Depending on the devices chosen, maintenance costs may be increased due to the need for calibration and other maintenance on the relays compared to other protective devices.

Another solution

Cummins PowerCommand® generator sets with AmpSentry™ protective relay provide the alternator protection that is required by codes and standards and by facility owners desiring good alternator protection. Because AmpSentry protective relay is specifically designed for alternator protection, it can provide necessary protection without the compromises and limitations that are necessary with other approaches. (FIGURE 3)

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AmpSentry™ protective relay function

Overload conditions

PowerCommand generator set controls continuously monitor the output current and voltage on each phase of the alternator. On sensing a current level of more than 110% of the steady state rating of the generator set for more than 60 seconds on any phase, an alarm condition is initiated to alert the operator that an abnormal condition is present on the machine. The control also logs the time and nature of the fault condition.

If the overload continues, the control continuously monitors the current level and duration and performs I^2t calculations to determine when the overload has reached a point that it may damage the machine. Prior to reaching that point, the excitation system is switched off, thus protecting the alternator and system loads from the affects of the condition. Depending on the version of the PowerCommand control provided, the machine may or may not operate for a short time (with excitation switched off) to allow the engine and alternator to cooldown prior to being shut down. This reduces the risk of damage to the engine and presents no danger to the installation since the alternator excitation system is switched off.

Short circuit conditions

Under 3-phase short circuit conditions, the operation of the control is slightly different than operation under overcurrent conditions. Again, the PowerCommand control continuously monitors the output current and voltage on all phases of the machine. If the control senses current on any phase greater than 3 times rated, it will switch to current regulation mode. The control will adjust the excitation system output to the field of the alternator based on sensed current level rather than sensed voltage level. The control, using a permanent magnet excitation support system provided with the alternator, will regulate the output current to 300% of the rated output current. The 300% current level is intended to be sufficient to clear downstream overcurrent protective devices. The generator set may also enter this state during starting of motors that are large relative to the size of the alternator. When the fault clears (or the motor starts), the control returns to voltage regulation mode, and softly ramps the system voltage back to normal levels, without a voltage overshoot.

The overcurrent protective functions of an AmpSentry protective relay does not completely reset after the fault is cleared. The control system "remembers" the overcurrent energy expended by the machine, and the time since clearing. It will progressively move the trip curve left to maintain protection for the alternator if it is not fully cooled down after a fault.

AmpSentry protective relay protections in PowerCommand controls effectively eliminates the need for a main generator set circuit breaker. AmpSentry provides both positive alternator protection and protection for the feeder connecting the generator set to the next level of downstream protective devices, as long as the feeder is sized to operate under the full rated output of the generator set.

Throughout this document another significant assumption has been made: That the engine has sufficient horsepower available to drive the alternator at rated speed during the overload or short circuit condition. It is possible that under some fault conditions the horsepower load on the engine will be sufficiently large to cause the engine speed to drop or even collapse. PowerCommand gensets with AmpSentry protective relay include a kW overload function and under frequency protection to respond to these conditions.

Medium voltage applications

There are no specific special protection requirements for medium voltage applications versus low voltage applications. Medium voltage alternators must meet the same general protection requirements as low voltage machines—they must be protected.

Several IEEE documents provide recommendations for system design for medium voltage alternators. These usually incorporate many more protective functions than are commonly provided low voltage machines. In addition, the IEEE recommendations often include neutral grounding resistors for medium voltage generator sets. The grounding resistor will limit line to ground fault magnitude and limit the magnitude of over voltage that occurs on a ground fault, so that there is more time to clear downstream faults before alternator damage and less probability of damage to the alternator due to the over voltage condition.

Generally, system designs utilize Overcurrent and other protective relays to provide alternator protection rather than depending on a circuit breaker trip unit.

Cummins generator sets that incorporate AmpSentry protective relay functions provide the necessary overcurrent functions that are coordinated with the alternator thermal damage curve, other protective functions, and fault current regulation capability that limits ground fault current without impeding coordination and also prevent the over voltage condition that will occur on a ground fault due to overexcitation in the system.

About the author

Gary Olson graduated from Iowa State University with a Bachelor of Science Degree in Mechanical Engineering in 1977, and graduated from the College of St. Thomas with a Master of Business Administration degree in 1982.

He has been employed by Cummins Power Generation for more than 25 years in various engineering and management roles. His current responsibilities include research relating to on-site power applications, technical product support for on-site power system equipment, and contributing to codes and standards groups. He also manages an engineering group dedicated to development of next generation power system designs.

For additional technical support, please contact your local Cummins Power Generation distributor. To locate your distributor, visit www.cumminspower.com.

Suggested protection specifications:
Alternator shall be protected per the requirements of NFPA 70 section 445.12. The protection provided shall be coordinated with the thermal damage curve of the alternator. Damage curve and protection curve shall be submitted to verify performance.

The protection shall allow operation of the generator set continuously at its rated output.

The protection equipment provided shall be 3rd party certified to verify performance.

Generator set shall be provided with individual phase line to neutral over voltage protection that is adjustable and set to operate at more that 110% of nominal voltage for more than 0.5 seconds.

References

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