Alternator protection, part 1: Understanding code requirements

> **White paper**

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This paper identifies requirements for protection of alternators based on North American code. The paper also provides insight on how the codes should be interpreted based on the characteristics of alternators used in emergency and legally required generator set applications.

North American code requirements for alternator protection

It is nearly universal practice to protect electrical distribution systems from the effects of electrical overloads and short circuits, since these conditions can cause major damage, loss of revenue, and may even cause loss of life. The use of overcurrent and short circuit protection are well-accepted and practiced for grid-powered distribution systems, but special attention is needed for alternator protection due to the characteristics of the generator sets themselves, and the differences in the objectives of protection on emergency systems compared to systems served by normal power.

The design of power systems requires an appreciation of the balance between protection and reliability. In general, as protection is made more certain, reliability of electrical service is compromised. North American codes and standards recognize not only the technical differences in protection needs between generator equipment and systems, but also the need to strike the right balance between protection and reliability in specific applications.

Defining "alternator damage"

One of the major objectives of established codes and standards is to prevent alternator damage, so it is important to understand what constitutes "alternator damage." Alternator windings, like other electrical conductors, will operate at increasingly higher temperature as load level increases. Under overload conditions temperatures will increase to sufficiently high levels to cause thermal stress and ultimately insulation (and alternator) failure. Even if the alternator does not fail, even a single overload may cause the effective life of the alternator to be dramatically reduced without causing an immediate failure.

In a simplistic sense, an alternator is damaged due to the effects of an overcurrent condition whenever an alternator fails to function, or its life is unacceptably shortened. "Fails to function" is pretty clear—the alternator ceases to produce usable output, and perhaps causes damage to the facility around it. "Unacceptably shortened life" is not a precise engineering definition for alternator damage. Alternator manufacturers typically will provide curves that describe the magnitude of 3-phase current and duration of current flow that can be carried by a specific alternator without causing an alternator failure, or shortening of insulation system life to the point that the effective life of the machine is shortened too much.

Since we know that high alternator temperature is one symptom of impending damage, it may be expected that one method that might be used to detect damage would be to instrument the alternator with temperature sensing devices (usually thermocouples) throughout the windings, and then define the damage point as any time that the temperature at any thermocouple reaches a predefined value. However, the response characteristics of imbedded temperature detectors and their monitoring devices are not suitable for reporting damage before it becomes severe, and even if they could detect damage, the machine can be damaged

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 DAMAGE CURVE

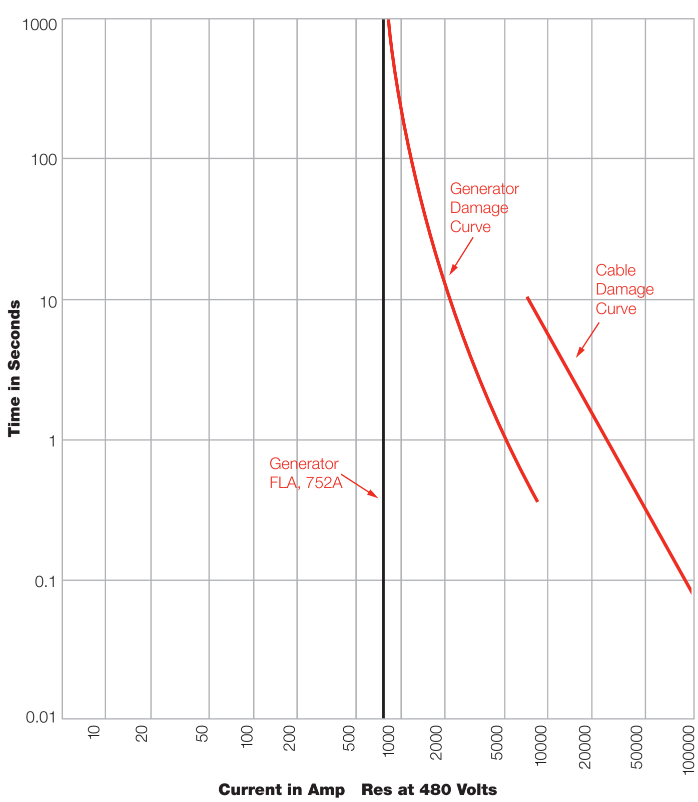

FIGURE 1 – Alternator and fully rated cable thermal damage curves. Note that the alternator curve falls to the left of the cable curve, so any device that fully protects the alternator will also protect the feeder cable. Cable is 2-600 MCM/Phase Cu 75C.

under other conditions, such as rotor (field) damage which can occur on unbalanced faults.

Consequently, alternator manufacturers define alternator damage due to overloads based on a conservative engineering estimate of the capability of the alternator to resist damage on over current conditions. These estimates are based on testing of alternators under short circuit conditions, measurement of current flows and temperatures inside the machine, and an understanding of the characteristics of the insulation system used in a specific machine. (See FIGURE 1.) The curves that are drawn and provided to customers and consultants as a result of this testing and evaluation do not necessarily define the exact failure point of a specific machine. Rather, they provide an accepted guideline for when the life of the machine is unacceptably shortened. Use of the alternator manufacturer's damage curve in conjunction with protective device operation curves will result in optimum system protection while maintaining system reliability at acceptable levels.

The above references cite the need for overcurrent protection both for the conductors connecting the generator set to the first level of distribution devices (240.21) and the alternator itself (445.12). Several points are significant. Note that the authority having jurisdiction (AHJ) may allow an exception to the requirement for protection, especially when the premature operation of the protection may cause hazards to people. In other words, the code would allow the generator set to operate without any protection at all, in some cases,

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The Canadian Electrical Code

28-902 Protection of constant voltage generator sets

(1) Constant voltage generators, whether direct-current or alternating-current, shall be protected from excess current by overcurrent devices, except that:

(a) When the type of apparatus used and the nature of the system operated make protective devices inadvisable or unnecessary, the protective device need not be provided…

CSA C282-00 Emergency electrical power supply for buildings, requires:

7.7.1
The overcurrent devices in the emergency distribution system shall be coordinated to maximize the selective tripping of branch circuit breakers when a short circuit occurs. Short circuit currents of sufficient magnitude shall be made available from the generator to satisfy this coordination ability.

if failure would cause a greater risk to people in the facility served. This is a direct indication of the principal of balance noted earlier—protection of hardware should not be done at expense of putting people at risk.

Note also that the code allows the alternator protection to be used as the protective equipment for the feeder conductors from the generator set to the first level of distribution as long as it is sized properly. Adding another protective device for protection of a fully rated feeder would provide no better protection, increase the risk of nuisance tripping, and make coordination more difficult.

This is a reasonable practice, as can be seen in FIGURE 1, which illustrates that the generator damage curve for an alternator falls well to the left of the damage curve for a fully rated feeder cable. So, any protective system that fully protects the alternator will also protect the feeder cable.

Note also that if there is overload protection in the generator control system, feeder sizing can be limited to 100% of the generator rating. (Section 445.13 requires feeder protection to be 115% of the protective device rating.)

The Canadian Electrical Code (22.1-1990) includes requirements that are similar to the US *NEC*. Specific requirements for generator protection are described in Section 28-902.

In addition to these requirements in both the US and Canadian codes, it is only reasonable that the system be designed so that nuisance protective device operations (i.e., circuit breaker tripping) are avoided. The loss of system operation is as disruptive and dangerous when on a generator set as the loss of normal facility power when generator set power is not available.

There is some specific recognition of this problem in the *NEC*. In the exception at the end of section 445.12, it is noted that sometimes keeping the generator set running to protect human life is more important than protecting the generator set itself. NFPA 110-2002 , which is particularly applicable to emergency and legally required applications, states:

6.5.1 General. The overcurrent protective devices in the EPSS shall be coordinated to optimize selective tripping of the circuit overcurrent protective devices when a short circuit occurs.

In summary, one can say that generator sets in critical applications can be protected in a less rigorous fashion than other equipment, but effective protection is generally required; that effective protection depends on coordinating the thermal damage curve of the alternator with the protective device; and that electrical system coordination (discrimination) is also required in most critical applications.

Protection for the generator set can come in many forms. The *NEC* only requires that the generator set be provided with appropriate protection. It specifically allows overcurrent sensing devices, and inherent overcurrent protection.

That being said, it should be noted that the thermal damage curve of an alternator generally follows an I²t characteristic, so circuit breakers that don't have operating characteristics with that curve shape through the overload operating range of the alternator will be difficult or impossible to apply in a way that adequately protects an alternator. For example, in FIGURE 2 we see an example situation where a 500 kW/480 VAC alternator is being "protected" by a typical 800A molded case circuit breaker with thermal magnetic trip unit.

Note that for this situation for nearly any overload condition the breaker operation curve lies to the right of the thermal damage curve of the alternator, so it can provide no protection at all. Obviously, protection is not present even though a reasonably sized, typical breaker is provided.

System designers must verify that the protection provided is coordinated with the thermal damage curve of the alternator, and verify that coordination with downstream devices is provided. It cannot be assumed that "any circuit breaker" will work—rather it is often the case that breakers, especially thermal-magnetic trip breakers sized to the capability of the alternator will often provide inadequate protection through all or part of the possible overload range. Better protection can be provided by breakers with electronic trip units, or microprocessor-based protective relaying equipment.

ALTERNATOR THERMAL DAMAGE CURVE AND MOLDED CASE BREAKER TRIP CURVE

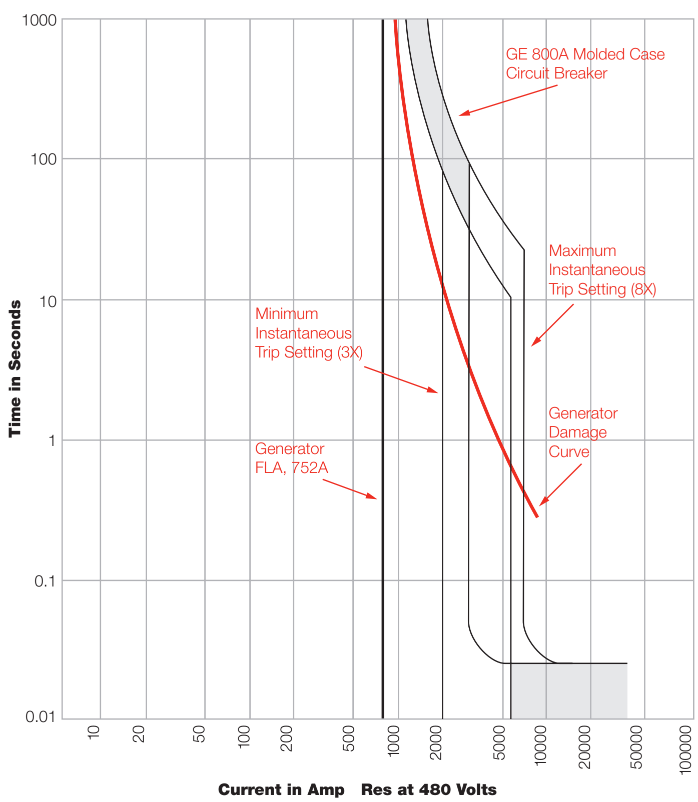

FIGURE 2 – Alternator thermal damage curve and molded case breaker trip curve. At current levels less than 2000 amps the molded case breaker cannot provide protection for the alternator.

Recommendations

Alternators must be protected from the effects of overcurrent and short circuit conditions, but this protection must be carefully chosen with full knowledge of the capabilities and limitations of the generator set. Protective devices that can provide proper protection include:

- Circuit breakers with solid state trip units that are fully coordinated with the alternator thermal damage curve.
- Fuses also could be applied, but many owners prefer not to use them because of the danger of single phase operation and problems with fuse replacement in an emergency situation.
- Individual phase protective relaying properly coordinated with the alternator thermal damage curve.

Note that whatever protective device is chosen, it must be specifically matched to the alternator thermal damage curve so that potential nuisance tripping or incomplete protection is avoided. Protection should be 3-phase sensing with I²t characteristic shape.

Whatever protective system is used, system designers should review the capabilities of the protection system and the thermal limits of the alternator to be certain that the machine is adequately protected. Circuit breaker operation curves are commonly available, but alternator thermal damage curves are generally not published and widely distributed by alternator manufacturers. In any case, they are needed to ascertain the viability of the protection proposed by the supplier.

The protective system design should recognize the fact that single-phase faults are much more common than 3-phase faults, and provide proper protection for the alternator under that condition. This may include accelerated tripping to compensate for the additional heating effects of single-phase faults.

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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.

An AmpSentry™ protection relay specification:
Controls shall be provided to monitor the output current of the generator set and initiate an alarm when load current exceeds 110% of the rated current of the machine for more than 60 seconds. The controls shall shut down and lock out the generator set when the output current level approaches the thermal damage point of the alternator.

Controls shall be provided to monitor the kW load on the generator set, and initiate an alarm condition when the total load on the generator set exceeds the generator set rating for more than 5 seconds.

Control shall include a load shed control to operate a set of dry contacts for use in shedding designated loads when the generator set is overloaded.

An individual phase AC over voltage monitoring system monitoring all three phases of the alternator shall be provided to initiate shutdown of the generator set when alternator output voltage exceeds 110% of the operator set voltage level for more than 10 seconds. Shutdown shall occur with no intentional delay if alternator output voltage exceeds 130%. Under voltage shutdown shall occur when the alternator output voltage is less than 85% of the operator set voltage for more than 10 seconds.

References

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