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# Sizing Equipment Grounding Conductors Based on Thermal Damage Curves

In solidly grounded power systems, where separate equipment grounding conductors are used inside conduit or other raceways, sizing the equipment grounding conductor (EGC) per the minimum specified in NEC Article 250-122, Table 250-122, can result in an inadequate ground-fault circuit design. Depending upon the magnitude of the ground-fault current and the specific rating or settings of the overcurrent protective device, an EGC can be damaged or completely destroyed before an upstream overcurrent device can clear the fault. Maximum thermal damage to an EGC often results from low-level ground faults, where currents fall below the short delay pickup setting for the protective circuit breaker.

It should be recognized that Table 250-122 of the NEC [1] serves only as a guide in determining the minimum size of an EGC. This is emphasized by the note added beneath the table, which states "Equipment Grounding Conductors may need to be sized larger than specified in this table in order to comply with Section 250-2(d)." Section 250-2(d), states than an effective grounding path shall "have the capacity to conduct safely any fault current likely to be imposed on it." Unfortunately, Table 250-122 is often used as the only basis for selecting an EGC. Here we present an example that illustrates how selecting an EGC based only on Table 250-122 can result in a ground-fault circuit design that may violate Section 250-2(d).

## Sizing of EGC

A feeder circuit showing a circuit breaker providing overcurrent protection for three, 1/C, 500 kcmil phase conductors is presented in Fig. 1. The long-delay pickup (LDPU) of the breaker is set at 400 A. From Table 250-122, a minimum #3 copper EGC would be required for this application. This is based on the LDPU setting of the breaker. The remaining settings for long delay time (LDT), short-delay pickup (SDPU), short-delay time (SDT), and instantaneous are not considered in selecting the EGC.

Also presented in Fig. 1 is a typical coordination curve for a 400-A circuit breaker, along with various thermal damage curves for different sized EGCs. The settings for the circuit breaker are as follows: LDPU = 400 A, LDT = 36 s at 2400 A, SDPU = 4000 A, and SDT = 0.18 s. Actual settings would be dependent upon downstream devices. The thermal damage curves are based on the following expression [2] for a copper EGC:

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$$\left(\frac{I}{CM}\right)^2 t = 0.0297 \log_{10}\left(\frac{T2+234}{T1+234}\right)$$

where

- T1 = the initial temperature of conductor
- T2 = the final temperature of conductor
- I = current flow
- t = time that current flows ≤ 10 s
- CM = the area of conductor in circ. mils.

The individual thermal damage curves along with their parameters are identified as follows:

#3 EGC, 250 °C: T1 =75°C, T2 = 250 °C, CM = 52,620

#3 EGC, 1083 °C: T1 =75°C, T2 = 1,083 °C, CM = 52,620

#4/0 EGC, 250 °C: T1 =75°C, T2 = 250 °C, CM = 211,600

350 kcmil, 150 °C: T1 = 75°C, T2 = 150 °C, CM = 350,000

500 kcmil, Phase Conductor: T1 = 75 °C, T2 = 150 °C, CM = 500,000

#3 EGC, 250 °C, 50%: T1 =75 °C, T2 = 250 °C, CM = 52,620

An initial temperature of 75 °C was selected in all cases. Various final temperatures were chosen. A final temperature of 250°C relates to the amount of energy that could cause a copper conductor to loosen at its point of attachment after it had been heated due to a fault and then cooled back to ambient temperature [3]. A final temperature of 1083 °C establishes the thermal damage curve for melting a copper conductor. For the 350-kcmil EGC and the 500-kcmil phase conductor, thermoplastic insulation was assumed, with a temperature rating of 150 °C [2]. Other possibilities exist for selecting final temperatures [4], [5]. The last curve assumes that we have a #3 EGC inside a metallic conduit and that 50% of the fault current returns back to the supply on the conduit rather than the EGC.

Referring to Fig. 1, there are intervals of fault current where the final temperature of a #3 EGC conductor can exceed both 250 °C and 1083 °C before the circuit breaker could operate and clear the fault. For ground-fault currents less than 3500 A, the thermal damage curves for both #3 EGC, 250 °C and #3 EGC, 1083 °C MELT lie below the LDT time-current characteristics for the breaker. Therefore, should a ground-fault current occur below 3500 A, a #3 copper EGC would melt before the 400-A circuit breaker could operate. If the EGC melts, ground-fault protection would be lost and considerable damage to the phase conductors and raceway system could result. A #4/0 copper EGC would be required to limit worst-case temperatures to 250 °C for all possible fault currents. Even in this case, however, damage to the ground-fault circuit might result if terminations loosened upon cooling to ambient temperatures. To prevent any thermal

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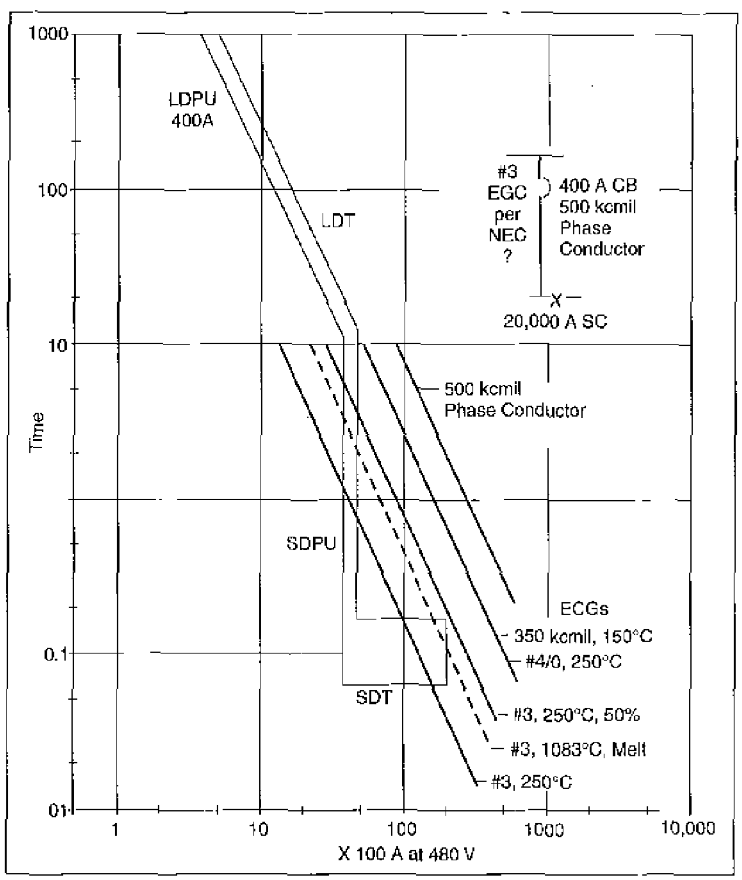


*Fig. 1. EGC thermal damage curves.*

*Selecting an EGC based only on Table 250-122 can result in a ground-fault circuit design that may be in violation of Section 250-2(d).*

damage, a 350-kcmil EGC would be required. This assumes thermoplastic insulation with a temperature rating of 150 °C. The size of the EGC, in this case, was calculated using the thermal damage equation by setting $T1 = 75$ °C, $T2 = 150$ °C, $I = 5800$ A, $t = 10$ s, and solving for CM.

The above example represents a worst-case scenario by assuming that all ground-fault current returns back to the supply via the EGC rather than through a conduit or raceway. Furthermore, it was assumed that separate ground-fault protection was not used.

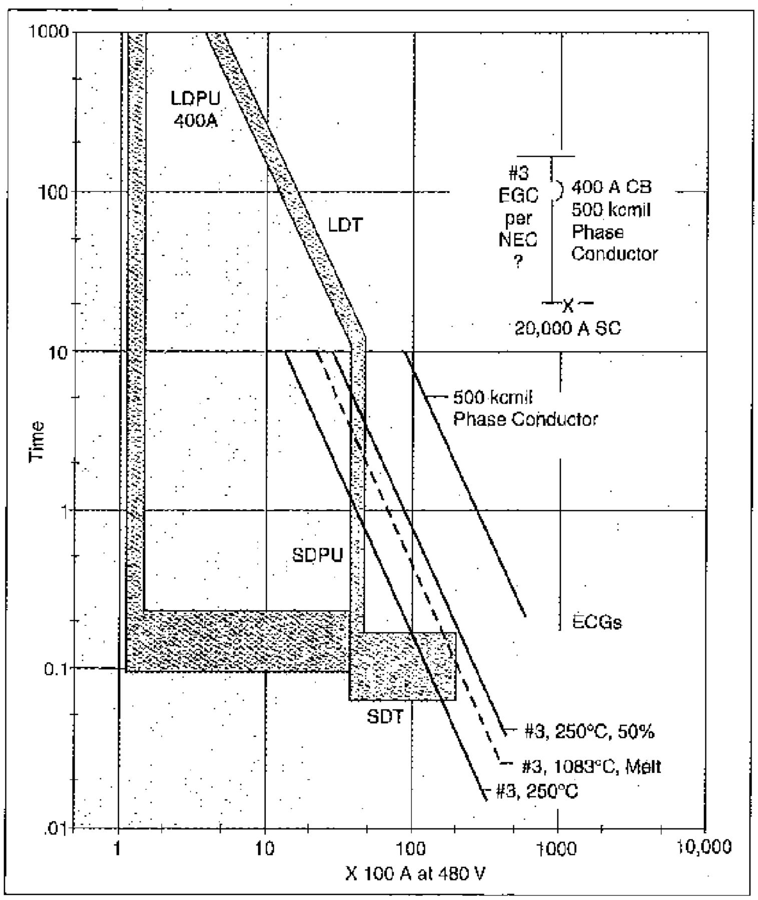


*Fig. 2. Ground-fault protection included.*

In cases where a separate EGC is installed inside a metal conduit, as much as 50% of the ground-fault current can return back to the supply via the conduit instead of the EGC [6]. This would reduce damage to the EGC under ground-fault conditions. To evaluate the adequacy of a #3 EGC in this case, consider curve #3 EGC, 250 °C, 50%. This curve was obtained by replacing $I$ by $I/2$ in the expression for the thermal damage curve. While this curve lies above #3 EGC, 250 °C, indicating that less damage would result from a fault current, it still lies below the time-current characteristic of the circuit breaker for ground-fault currents less than 3500 A. Once again, therefore, for ground-fault currents less than 3500 A, damage to the ground-fault circuit could result.

In cases where separate ground-fault protection is used, sizing the EGC based only on Table 250-122 provides sufficient protection for all but the highest levels of ground-fault current. This is illustrated in Fig. 2, where the same feeder circuit is presented, but ground-fault protection has been added. It is now seen that the time-current characteristic of the ground-fault-protection curve lies below the thermal damage curves for the EGCs except near maximum fault conditions where #3 EGC, 250°C falls underneath the protection.

This article has addressed the issue of sizing the EGC based on thermal damage considerations only. Other considerations, such as voltage developed on equipment during a ground fault, have not been addressed. In addition, the protection afforded the ground-fault circuit by other upstream overcurrent devices, such as fuses, could be evaluated in similar fashion.

## Conclusions

It is recommended that EGC thermal damage curves be used to evaluate the adequacy of a ground circuit design once the time-current characteristics of the protective overcurrent devices have been established. This would be particularly important in cases where separate ground-fault protection is not used.

## References


[1] *National Electrical Code*, ANSI/NFPA 70, 1999.

[2] *IEEE Recommended Practice for Protection and Coordination of Industrial and Commercial Power Systems*, ANSI/IEEE Std. 242, 1986.

[3] S. Schaffer, "Minimum (?) Size of Equipment Grounding Conductor," *EDI*, Aug. 1991, pp. 35-37.

[4] *IEEE Guide for Safety in ac Substation Grounding*, ANSI/IEEE, Std. 80, 1986.

[5] *IEEE Recommended Practice for Grounding of Industrial and Commercial Power Systems*, IEEE Std 142, 1991.

[6] W.C. Broderick and J.E. Szalkay, "Phase-to-Ground Faults," in *Techniques of Electrical Construction and Design*, vol. 4, 2nd ed. New York: McGraw-Hill, 1979, pp. 8-15.