Underground Installations – Not Rocket Science

Jean Courteau, Eng.

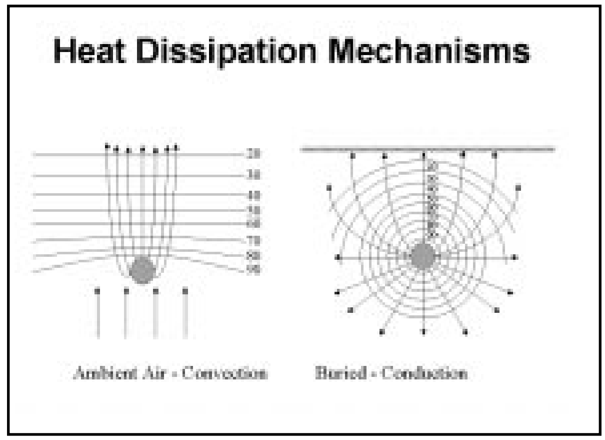
ALCAN CABLE

A Growing Trend

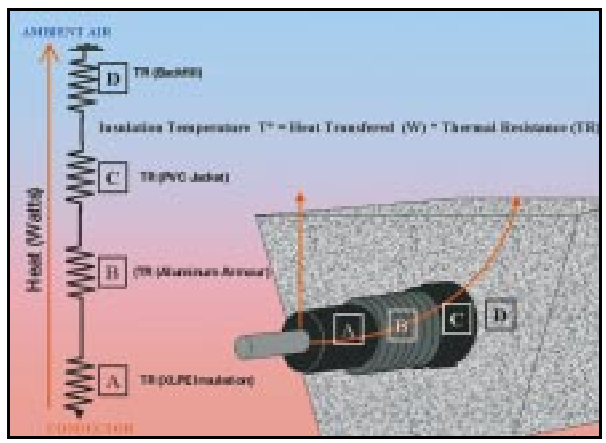
Since 1985, the use of underground service conductors in Canada has grown annually by 1%, on average. Despite greater installation costs that range from 3-1/2 to 6 times those of overhead installations, this ongoing trend is sometimes motivated by purely aesthetic reasons, or by very practical ones, especially in the wake of the devastating effects of the 1998 ice storm on Hydro-Quebec's grid. Given the ever-increasing number, and high cost of underground installations, makes understanding the underlying theory and principles of the Electrical Code in this respect all the more important.

Conductors as a Heat Generator

All electrical conductors, except superconductors, generate heat as a result of resistance losses (I^2R), magnetic effects (skin effect and Eddy currents), and dielectric effects (heating of insulating materials by the electric field, especially in medium and high voltage conductors). Since the conductor current determines heat losses, it must be limited in order to protect the insulator from overheating, hence *allowable ampacity*.



Determining the allowable ampacity of a conductor is analogous to calculating heat loading for a building. One first calculates the thermal resistance of the walls, ceilings, doors, and windows (R factor), then the thermal load needed to maintain a given interior ambient temperature relative to an exterior temperature. With conductors, one first determines the thermal resistances of the electric insulation, armour, jackets and air contained within the cable. The maximum allowable ampacity is the current value that will generate sufficient heat to bring the insulation to its maximum allowable temperature, namely 90°C for an RW90, or 75°C for an NS-1 construction.



Heat Transfer is the Key

Calculating the maximum allowable ampacity requires an understanding of heat transfer mechanisms, namely how heat is transmitted from the conductor metal to the ambient air through successive insulating layers. In free air, heat is dissipated by convection, whereas conduction is the mechanism used in buried conductors (Figure 1). This explains why the same conductor has different allowable ampacities depending on the type of installation used. Heat dissipation underground depends on the depth of burial, and on the thermal conductivity of the surrounding backfill. It is estimated however, that for conductors sizes AWG #0 and smaller, heat dissipation takes place at the same rate whether underground or in free air. Hence, the same allowable ampacities are used in both cases.

Unlike conductors in ambient air, ampacity calculations for underground conductors must include the thermal conductivities of backfill material, concrete, conduits, and ducts to determine the rate of heat conduction from conductor metal to the ambient air (Figure 2). Despite these differences, all allowable ampacity values found in the Code are determined using IEEE method 835, which in turn is based on the Neher-McGrath method (see insert). The method is used whether the installations are in ambient air (Tables 1, 2, 3 and 4), or underground (Appendix D).

NEHER-MCGRATH METHOD*
The allowable ampacity from following general formula:

$$I = \sqrt{\frac{Tc - (Ta + \triangle Td)}{Rdc\ (1+Yc) \times Rca}}$$

Where
Tc = maximum insulation temperature
Ta = ambient temperature
△Td = temperature rise due to dielectric losses
Rdc = direct current electrical resistance
(1+Yc) = skin and proximity effects
Rca = total thermal resistivity between conductor and ambient air

* J.H. Neher of the *Philadelphia Electric Company* and M.H. McGrath of the *General Cable Company* presented their method at the 1959 AIEE conference in Montreal. This method is a combination of the various methods used until then by electric utilities and cable manufacturers in North America.

The Electrical Code on Underground Installations

The Canadian Electrical Code deals with underground installations by providing two types of guidelines:

1. Specifications for directly buried conductors are described in sections 6-300 (Underground Consumer's Services); 12-012 *(Underground Installations)*; 12-112 *(Conductor Joints and Splices)*; and in Table 53 *(Minimum Cover Requirements for Direct Buried Conductors, Cables, or Raceways)*.

2. Allowable ampacities are addressed in sections 4-004 (1[d]), 4-004 (2[d])*(Ampacity of wires and Cables)*, and tables of values are provided in Appendix D for the standard configurations shown in Appendix B, section 4-004. These include: *Single Conductors Directly Buried in Earth* (Diagram B4-1); *Single Conductors in Underground Ducts* (Diagram B4-2); *Multiple Conductors Directly Buried in Earth* (Diagram B4-3); and *Multiple Conductors in Underground Raceways* (Diagram B4-4).

Changes to the latest edition of the CEC have made underground ampacities a sensitive issue for many installers, who sometimes question their pertinence. Understanding the underlying motivation behind these changes will help clear any misunderstandings. Unlike its earlier versions, the 18th edition of the Canadian Electrical Code no longer allows the use of underground allowable ampacities based on open-air values. Rather, the latest edition deals with underground installations distinctly and explicitly. Allowable currents are limited to the values specified by section 8-104 (7) *(Maximum Circuit Loading)*, out of concern for protecting connected equipment. The values in Appendix D tables therefore never exceed:

- 85% of the values shown in Tables 1 and 3 if the equipment is suitable for continuous service at 100% of the protective device's nominal current;

- 80% of the values shown in Tables 2 and 4 or 75% of Tables 1 and 3 if the equipment is suitable for continuous service at 80% of the protective device's nominal current.

Despite these guidelines, the Code still allows users to calculate the allowable ampacity with IEEE method 835 (see article 4-004 of the CEC). However, the value obtained must remain within the limits established by section 8-104 (7) mentioned previously.

Method

As the title of this article implies, determining the allowable ampacity and conductor sizes for underground installations is relatively simple. However, to use the tables provided in the Code, the installation dimensions must comply with configurations B4-1, B4-2, B4-3, and B4-4 shown in Appendix B4-004, since the Code tables are calculated using these specific dimensions. The following steps should therefore be followed (Figure 3):

1. First, determine the conductor metal used, for example, copper, aluminum or ACM. For copper conductors, refer to tables D8, D9, D13 and D15. When using aluminum or ACM conductors, refer to tables D10, D11, D14 and D16.

2. Next, determine whether the load is continuous, or non-continuous based on the criteria given in CEC 8-104 (3) *(Maximum Circuit Loading)*.

3. Determine which ampacity tables to use in Appendix D, according to the type of load and equipment used.

   3.1 For any equipment other than a circuit breaker, service box, fusible switch, circuit breaker, or panelboard, refer to the "A" tables, e.g. D8A

   3.2 For a circuit breaker, service box, fusible switch, circuit breaker, or panelboard, refer to the "A" tables for non-continuous loads, e.g. D8A

   3.3 For continuous loads refer to the "B" tables, e.g. D8B. Within these tables select the appropriate column according to the equipment nameplate ratings: use the 80% column if the nameplate indicates the equipment can carry 80% of the nominal continuous load, or the 100% column if it can carry 100% of the nominal continuous load.

4. To obtain the conductor size, select the specific ampacity table and column based on the installation configurations (B4-1, B4-2, B4-3, B4-3) shown in Appendix B. If the conductor size is less than AWG #0, use tables 1, 2, 3 and 4 (see heat dissipation mechanisms discussed previously). Please note that allowable ampacities found in Appendix D tables are for 90°C insulation temperatures.

5. Calculate the voltage drop. The conductor size obtained in step 4 above is only a baseline value. Voltage drop must always be calculated to determine if the selected conductor size will maintain a voltage drop within the allowable 3% limit when energized.

The Electrical Code – Your Best Source of Information

Although it may seem a long and tedious chore, a careful review of Appendices B and D will provide specific information that goes beyond the scope of this article. These chapters provide de-rating factors to apply when using 60° or 75°C insulation, or when the backfill temperature exceeds 20°C. Other provisions cover installations that use a different number of conductors than those shown in Appendix B.

Summary

The Electrical Code deals with the most practical aspects of underground installations, ranging from the allowable ampacity to the required conductor size. However, since the Electrical Code only serves as a guideline, only the most common configurations are presented. When using a configuration not shown in the Code, the installer can contact the local inspection authority, conductor manufacturer, or electric utility to obtain further technical assistance. Unfortunately, since these resources are often limited, much wasted time and frustration can be avoided by simply following the configurations shown in the Code to obtain the ampacities and conductor sizes in the tables provided.