



Practical Power Cable Ampacity Analysis

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Course Author: Velmir Lackovic

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Introduction

Cable network usually forms a backbone of the power system. Therefore, complete analysis of the power systems includes detailed analyses of the cable network, especially assessment of the cable ampacities. This assessment is necessary since cable current carrying capacity can depend on the number of factors that are predominantly determined by actual conditions of use. Cable current carrying capability is defined as “the current in amperes a conductor can carry continuously under the conditions of use (conditions of the surrounding medium in which the cables are installed) without exceeding its temperature rating limit.”

Therefore, a cable current carrying capacity assessment is the calculation of the temperature increment of the conductors in an underground cable system under steady-state loading conditions.

The aim of this course is to acquaint the reader with basic numerical methods and methodology that is used in cable current sizing and calculations. Also use of computer software systems in the solution of cable ampacity problems with emphasis on underground installations is elaborated.

The ability of an underground cable conductor to conduct current depends on a number of factors. The most important factors that are the biggest concerns to the designers of electrical transmission and distribution systems are the following:

- Thermal details of the surrounding medium
- Ambient temperature
- Heat generated by adjacent conductors
- Heat generated by the conductor due to its own losses

Methodology for calculation of the cable ampacities is described in National Electrical Code[®] (NEC[®]) which uses Neher-McGrath method for calculation of the conductor ampacities. Conductor ampacity is presented in the tables along with factors that are applicable for different laying formations. Alternative approach to the one presented in the NEC[®] is the use of equations for determining cable current carrying rating. This approach is described in NFPA 70-1996.

Underground cable current capacity rating depends on various factors and they are quantified through coefficients presented in the factor tables. These factors are generated using Neher-McGrath method. Since the ampacity tables were developed for some specific site conditions, they cannot be uniformly applied for all possible cases, making problem of cable ampacity calculation even more challenging. In principle, factor tables can be used to initially size the cable and to provide close and approximate ampacities. However, the final cable ampacity may be different from the value obtained using coefficients from the factor tables. These preliminary cable sizes can be further used as a basis for more accurate assessment that will take into account very specific details such as soil temperature distribution, final cable arrangement, transposition etc.

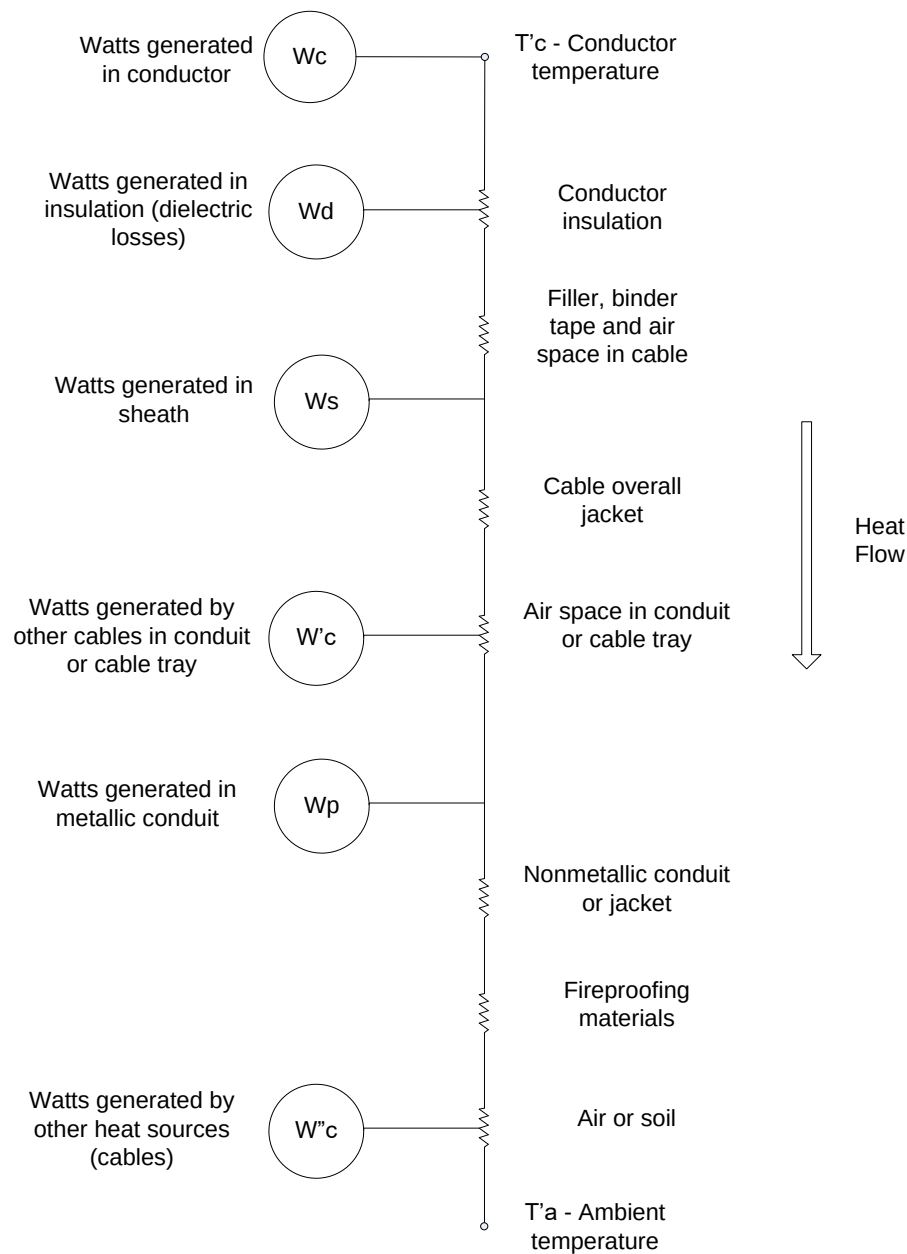
Assessment of the heat flow in the underground cable systems

Underground cable sizing is one of the most important concerns when designing distribution and transmission systems. Once the load has been sized and confirmed, cable system must be designed in a way to transfer required power from the generation to the end user. The total number of underground cable circuits, their size, the method of laying, crossing with other utilities such as roads, telecommunication, gas or water network are of crucial importance when determining design of the cable systems. In addition, underground cable circuits must be sized adequately to carry the required load without overheating.

Heat is released from the conductor as it transmits electrical current. Cable type, its construction details and installation method determine how many elements of heat generation exist. These elements can be Joule losses (I^2R losses), sheath losses etc. Heat that is generated in these elements is transmitted through a series of thermal resistances to the surrounding environment.

Cable operating temperature is directly related to the amount of heat generated and the value of the thermal resistances through which it flows. Basic heat transfer principles are discussed in subsequent sections but a detailed discussion of all the heat transfer particularities is well beyond the scope of this course.

Calculation of the temperature rise of the underground cable system consists of a series of thermal equivalents derived using Kirchoff's and Ohm's rules resulting in a relatively simple thermal circuit that is presented in the figure below.



Equivalent thermal circuit involves a number of parallel paths with heat entering at several different points. From the figure above it can be noted that the final conductor temperature will be determined by the differential across the series of thermal resistances as the heat flows to the ambient temperature T'_a .

Fundamental equation for determining ampacity of the cable systems in an underground duct follows the Neher-McGrath method and can be expressed as:

$$I = \left[\frac{T'_c - (T'_a + \Delta T_d + \Delta T_{int})}{R_{ac} \cdot R'_{ca}} \right]^{1/2} kA$$

Where:

T'_c is the allowable (maximum) conductor temperature (°C)

T'_a is ambient temperature of the soil (°C)

ΔT_d is the temperature rise of conductor caused by dielectric heating (°C)

ΔT_{int} is the temperature rise of conductor due to interference heating from cables in other ducts (°C). It has to be noted that simulations calculation of ampacity equations are required since the temperature rise, due to another conductor depends on the current through it.

R_{ac} is the AC current resistance of the conductor and includes skin, AC proximity and temperature effects ($\mu\Omega$ /ft)

R'_{ca} is the total thermal resistance from conductor to the surrounding soil taking into account load factor, shield/sheath losses, metallic conduit losses and the effect of multiple conductors in the same duct (thermal- Ω /ft, °C-ft/W).

All effects that cause underground cable conductor temperature rise except the conductor losses $I^2 R_{ac}$ are considered as adjustment to the basic thermal system.

In principle, the heat flow in watts is determined by the difference between two temperatures ($T'_c - T'_a$) which is divided by a separating thermal resistances. Analogy between this method and the basic equation for ampacity calculation can be made if both sides of the ampacity equation are squared and then multiplied by R_{ac} . The result is as follows:

$$I^2 R_{ac} = \frac{T'_c - (T'_a + \Delta T_d + \Delta T_{int})}{R'_{ca}} W/ft$$



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