Application Demonstration
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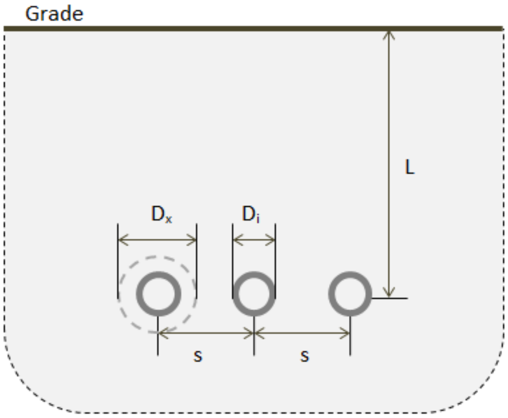
Cable Ampacity using the Nehers-McGrath Method

Introduction

Heat is generated when current flows through a cable. The ampacity of a cable is the amount of current a cable can carry without exceeding its temperature rating. Accurately estimating ampacity is critical to minimizing the total lifetime cost of a cable installation, and minimizing maintenance issues.

Nehers and McGrath (1957) published a steady-state method to compute the temperature rise in cables. This method forms the the basis of the cable ampacity tables in The National Electrical Code (NEC) 2017 and IEEE 399-1997.



This application implements the Nehers-McGrath equations and cross-checks the results against those tabulated in the NEC; the good agreement means that this worksheet can be the basis of more complex cable ampacity calculations.

The NEC gives cable ampacity for a range of standard conductors, cable arrangements and duct configurations, and assumes

- a soil temperature of 20°C at a depth of 36 inches and thermal resistivity of 90 K cm/W
- 100% load factor
- one of several duct configurations
- a burial depth of 36 inches and cable separation of 7.5 inches
- all cables have the same ampacity

This narrow range of conditions are not always applicable. For example, the southern US states often reach a soil temperature of 25°C at a depth of 36 inches, reducing the ampacity by 5% or more. Implementing the Nehers-McGrath method in Maple can assist electrical power systems engineers with modeling non-standard configurations.

This table confirms the results of the application for several standard NEC conductors.

CONFIRMATION OF RESULTS

Parameters (three single insulated conductors, directly buried in earth, T_a = 20°C, ρ = 90 K cm W^{-1}, arranged as Figure B.310.15 Detail 9)	Ampacity given by NEC 2017 (A)	Ampacity c application
#4/0 copper RHH, d_c = 0.475 in, D_i = 0.778 in, R_{dc} = 0.0608×10^{-3} ohm/ft, R_{ac} = 0.062 × 10^{-3} ohm/ft, T_c = 75°C, L = 36 in, s = 7.5 in	394	392.5
#4/0 aluminium RHH, D_i = 0.778 in, d_c = 0.475 in, R_{dc} = 0.100×10^{-3} ohm/ft, R_{ac} = 0.10 × 10^{-3} ohm/ft, T_c = 75°C, L = 36 in, s = 7.5 in	307	306.7
750 kcmil copper RHH, d_c = 0.908 in, D_i = 1.348 in, R_{dc} = 0.0171 × 10^{-3} ohm/ft, R_{ac} = 0.019 × 10^{-3} ohm/ft, T_c = 75°C, L = 36 in, s = 7.5 in	767	774.5
1000 kcmil copper RHH, D_i = 1.502 in, d_c = 1.060 in, R_{dc} = 0.0129 × 10^{-3} ohm/ft, R_{ac} = 0.015 × 10^{-3} ohm/ft, T_c = 75°C, L = 36 in, s = 7.5 in	887	906.1

References

J. H. Neher and M. H. McGrath, "The calculation of the temperature rise and load capability of cable systems," Power Apparatus and Systems, Transactions of the American Institute of Electrical Engineers, vol.76, no.3, pp.752,764, April 1957.

Parameters

restart :
with(*Units*[*Simple*]) :

Thermal resistance of the RHH (Rubber High Heat) insulation

$\rho_i := 500\ \mathrm{K}\cdot\mathrm{cm}\cdot\mathrm{W}^{-1}$:

Thermal resistance of the soil

$\rho_{soil} := 90\ \mathrm{K}\cdot\mathrm{cm}\cdot\mathrm{W}^{-1}$:

Soil diffusivity factor

$\delta := 0.5 \times 10^{-6}\ \mathrm{m}^2\,\mathrm{s}^{-1}$:

Temperature coefficient of conductor (3.93 × 10^{-3} for copper, 4.29 × 10^{-3} for aluminium)

$\alpha_n := 3.93 \times 10^{-3}$:

Electrical resistivity (1.7241 × 10^{-8} ohm m for copper, 2.62 × 10^{-8} ohm m for aluminum

$\rho := 1.7241 \times 10^{-8}\,\mathrm{ohm}\cdot\mathrm{m}$:

Maximum allowable conductor temperature

$T_c := (273.15 + 75)\,\mathrm{K}$:

Ambient soil temperature

$T_a := (273.15 + 20)\,\mathrm{K}$:

Burial depth

$L := 36\,\mathrm{inch}$:

Axial separation

$d := 7.5\,\mathrm{inch}$:

Load factor (fraction of the cable's daily loading)

$lf := 1$:

System frequency

$f := 60\,\mathrm{Hz}$:

Skin effect coefficient for this type of conductor

$k_s := 1$:

Proximity effect (0 since cables are unsheathed, not touching and axial separation is much greater than cable diameter

$y_p := 0.0$:

Parameters from National Electric Code 2017

Diameter outside of insulation (NEC Table 5 RHH w/out covering page 684)

$\mathrm{D}_i := 1.502\,\mathrm{inch}$:

Diameter over bare conductor (NEC Table 5A page 688)

$d_c := 1.060\,\mathrm{inch}$:

DC resistance of the uncoated conductor at 75°C (NEC Table 8 page 689)

$R_{dc\_75} := 0.0129 \times 10^{-3}\,\mathrm{ohm}\cdot\mathrm{ft}^{-1}$:

AC resistance (NEC Table 9 page 690, PVC conduit)

$R_{ac\_75\_NEC} := 0.015 \times 10^{-3}\,\mathrm{ohm}\,\mathrm{ft}^{-1}$:

Rated ampacity for this problem (NEC Table B.310.10 page 707). The calculated ampacity should closely match the NEC value.

$I_{NEC} := 887\ \text{A} :$

Conductor

Diameter where contact with soil starts

$D_e := D_i :$

Insulation thickness

$t_i := 0.5 \cdot \left(D_i - d_c \right) = 0.221\ \text{in}$

Area of the conducting material

$$S := \frac{\pi \cdot d_c^{\,2}}{4} = 0.882\ \text{in}^2$$

Skin Effect

Tendency of curent density to be concentrated near the conductor surface

Nehers-McGrath

Skin effect factor using Neher-McGrath

$$F_k := \frac{8\ s^2 \cdot 2 \cdot \pi \cdot f^2 \cdot 10^{-7}}{R_{dc\_75} \cdot 10^6\ \text{ft} \cdot \text{ohm}^{-1}} = = 1.403 \times 10^{-3}$$

Skin effect

$y_s := k_s \cdot F_k = 1.403 \times 10^{-3}$

AC resistance

$$R_{ac\_75} := R_{dc\_75} \cdot \left(1 + y_s + y_p \right) = 1.292 \times 10^{-5}\ \frac{\Omega}{\text{ft}}$$

Full skin effect needed in rating equation

$Y_c := y_s + y_p = 1.403 \times 10^{-3}$

Anders

DC resistance at 75°C with 2% laying factor

$$R_{prime} := \frac{1.02 \cdot \rho}{S} \cdot \left(1 + \frac{\alpha_n}{\text{K}} \cdot \left(T_c - T_a \right) \right) = 1.145 \times 10^{-5}\ \frac{\Omega}{\text{ft}}$$

Skin effect factors

$$F_{k2} := \frac{8 \cdot s^2 \cdot 2 \cdot \pi \cdot f^2 \cdot 10^{-7}}{R_{prime} \cdot 10^6 \text{ft} \cdot \text{ohm}^{-1}} = 1.580 \times 10^{-3}$$

$x_s := F_{k2} \cdot k_s = 1.580 \times 10^{-3}$

$$y_s := \frac{x_s^{\,2}}{192 + 0.8 \cdot x_s^{\,2}} = 1.301 \times 10^{-8}$$

AC resistance

$$R_{ac\_75} := R_{prime} \cdot \left(1 + y_s + y_p\right) = 1.145 \times 10^{-5} \, \frac{\Omega}{\text{ft}}$$

Full skin effect needed in the rating equation

$Y_C := y_s + y_p = 1.301 \times 10^{-8}$

Thermal Resistance of Insulation

Nehers-McGrath equation 44

$$R_i := 0.012 \, \frac{\text{ft}}{\text{cm}} \cdot \rho_i \cdot \log10\left(\frac{D_i}{d_c}\right) = 0.908 \, \frac{\text{ft K}}{\text{W}}$$

Anders

$$T_1 := \frac{\rho_i}{2 \cdot \pi} \cdot \ln\left(1 + \frac{2 \cdot t_i}{d_c}\right) = 0.910 \, \frac{\text{ft K}}{\text{W}}$$

Thermal Resistance External to Cable

Loss factor where an allowance is made for cyclical loading

$LF := 0.3 \cdot lf + 0.7 \cdot lf^2 = 1.0$

Fictitious diameter at which the effect of the loss factor commences (Neher& McGrath equation 45)

$$D_x := 1.02 \cdot \sqrt{\delta \cdot 24 \text{ hour}} = 0.212 \text{ m}$$

Mutual heating effect of other cables from Kenelly

$$F := \left(\frac{\sqrt{(2 \cdot L)^2 + d^2}}{d}\right)^2 = 93.160$$

External thermal resistivity for direct buried cables

$$T_{\mu 4} := \frac{\rho_{soil}}{2 \cdot \pi} \cdot \left(\ln\left(\frac{D_x}{D_e}\right) + lf \cdot \ln\left(\frac{4 \cdot L \cdot F}{D_x}\right)\right) = 4.275 \, \frac{\text{ft K}}{\text{W}}$$

Total Thermal Resistivity

Effective total resistivity, including the effects of the conductor, soil, sheath and conduit (where applicable)

$$R_{ca} := T_1 + T_{\mu 4} = 5.185\ \frac{\text{ft K}}{\text{W}}$$

As a check, this is the total resistivity calculated from the amapacity given in the NEC.

$$\left(1 + Y_c\right) \cdot R_{ca\_NEC} := \frac{T_c - T_a}{R_{dc\_75} \cdot I_{NEC}^{\ 2}} = 5.419\ \frac{\text{ft K}}{\text{W}}$$

Maximum allowable current

$$I_{calc} := \sqrt{\frac{T_c - T_a}{R_{dc\_75} \cdot \left(1 + Y_c\right) \cdot R_{ca}}} = 906.15\ \text{A}$$

Percentage error to NEC tabulated value.

$$\frac{I_{calc} - I_{NEC}}{I_{NEC}} \cdot 100 = 2.16$$