Cable Ampacity Calculations: A Comparison of Methods

Carson Bates, *Member, IEEE*, Keith Malmedal, *Senior Member, IEEE*, and David Cain

***Abstract*—When designing electrical power systems, it is often necessary to determine underground cable ampacity. Various methods are in use today, including computer simulation, ampacity tables, and a method that has recently been suggested that includes the effects of moisture migration through soil. Each of these methods can yield substantially different ampacity results for the same installation. Regardless of the method, using the correct value of soil thermal resistivity is critical and using the wrong value can result in cables that are incorrectly sized. This paper examines several commonly used methods and their underlying assumptions. Examples are provided to illustrate the differences in the results obtained from various methods and the consequences of using incorrect assumptions. It is hoped that these examples will provide guidance on the implementation of each method.**

***Index Terms*—Cable ampacity, power cable installation, power distribution, soil thermal resistivity, soil thermal stability, solar power generation, underground power distribution lines, underground power transmission lines, wind power generation.**

I. Introduction

USING accurate cable ampacities is critical to electrical power system design. An optimally sized cable results in minimum cost and high reliability. Wind and solar power plants, in particular, strive to optimize cable design by using ampacities that closely match maximum generation.

Cable ampacities have been estimated over the years based on engineering assumptions and site conditions. Various configurations require different parameters and assumptions. Cables placed underground require information about the ambient earth temperature, cable separation distance, soil thermal resistivity, etc. If these values are inaccurately estimated, the resulting cable size will be inaccurate. This may lead to cable overheating, if the cable is undersized, or increased cable cost, if the cable is oversized.

Underground cable ampacity is difficult to estimate because a primary factor determining ampacity, i.e., soil thermal resistivity, varies from moist to dry conditions, which in turn varies with cable loading [1]. This paper compares the difference in results obtained when using various methods, including one recently proposed [1], to include the effects of soil thermal instability. These methods will include cable ampacities calculated using the Neher–McGrath method, IEEE Cable Ampacity tables, and a commercially available computer program.

Each of these methods requires some values that must be collected at the location where the cable will be installed. These include the soil thermal resistivity, also known as “rho” and measured in Kcm/W (°C*cm/W), and the maximum expected ambient temperature, at the depth of the hottest cable. The soil thermal resistivity, while critical, may not be as readily available as the ambient temperature. IEEE Std. 835 states:

> “In the past, when the thermal resistivity of the earth was not known a rho of 90 was recommended for rating the cable. However, the ratings for buried cables are significantly affected by the earth’s portion of the thermal circuit and therefore correct knowledge of the effective soil thermal resistivity and soil thermal stability is paramount in establishing the correct rating for a buried cable system [2].”

Measuring the *in situ* thermal resistivity is not a difficult process, as described in [5], but it is frequently not performed. It is likely that a cable size will be selected that is either smaller or larger than the optimal, if this step is skipped.

II. Ampacity Calculation Methods

A. Black Books

The “Black Books,” entitled *AIEE-IPCEA Power Cable Ampacities* [3], were the first tabulated ampacities using the Neher–McGrath method and were published in 1962. This allowed an engineer to look up the appropriate cable size based on current rather than calculating the cable size using Neher–McGrath calculations [4]. Considering the number of calculations needed to determine ampacity using the Neher–McGrath method, it is obvious why engineers would prefer using this simplified tabular method. These same tables are still used by some engineers today as their primary method of sizing underground cables.

It is important to understand the assumptions used to create these tables. For example, one assumption used in the tables is that the ambient temperature of the earth is 20 °C. Many locations in the Southwest USA experience the maximum underground soil temperature of 25 °C–30 °C, which reduces the ampacity by 5%–8% below the tabulated values. The tabular values must be adjusted using methods included in the introductory pages.

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Another assumption is that the cable depth is 36 in and the cable spacing is 7.5 in. If the burial depth was 18 in, this would increase the ampacity by approximately 10%, and doubling the spacing would increase it by approximately 6%. Adjustment factors for these assumptions are not given in the tables; hence, the Neher–McGrath calculations must be done if conditions of depth or spacing vary from the assumptions. Furthermore, modern cables use different insulation material and thickness than those used in these older tables. In addition, these tables assume that the cables are not jacketed. All of these assumptions may present difficulties for a modern user and, if differences are ignored, can result in cables that are sized too large or too small.

The key assumptions in these tables are listed as follows:

- 20 °C ambient earth;
- 90 °C maximum conductor temperature;
- cable shields are single-point grounded;
- 36-in depth;
- 7.5-in spacing;
- generic rubber insulation;
  - thicker than modern insulations for equivalent voltage rating;
  - higher thermal resistivity (500 Kcm/W versus modern 350 Kcm/W);
  - higher insulation power factor resulting in higher dielectric losses (3.5% versus modern 0.5%).

B. IEEE 835 Cable Ampacity Tables

In 1994, a new set of tabulated ampacities was issued by IEEE in order to "update the cable constructions and design changes that had taken place since the original publication" [2]. While maintaining the fundamental calculations set forth by Neher and McGrath, the tables include updated information on cable properties and adjust some of the original assumptions. This includes assuming a 25 °C ambient earth temperature and cable shields that are shorted (grounded at both ends) for most cable sizes. The standard also includes some step-by-step examples of the Neher–McGrath method, with updates to address changes in assumptions of the original method. The steps given allow an engineer to develop a spreadsheet to calculate ampacity for any cable configuration, which eliminates the need for the tables except as a convenient check.

The key assumptions for these tables are given as follows:

- 25 °C ambient earth;
- 90 °C maximum conductor temperature;
- cable shields shorted;
- 36-in depth;
- 7.5-in spacing.

C. Computer Modeling

Commercially available computer software allows for the calculation of cable ampacity by modeling the cable properties and the physical configuration. The cables can be modeled with the intended design geometry and with the intended cable type. Programs utilize values of cable constituent thermal resistivity as specified by IEEE 835 [2] for each material type (e.g., ethylene propylene rubber (EPR) is 350 Kcm/W), allowing the thickness and order of the components to be adjusted. Programs are typically advertised as using the Neher–McGrath method to determine ampacity, meaning that the only assumptions necessary are those inherent to the Neher–McGrath method.

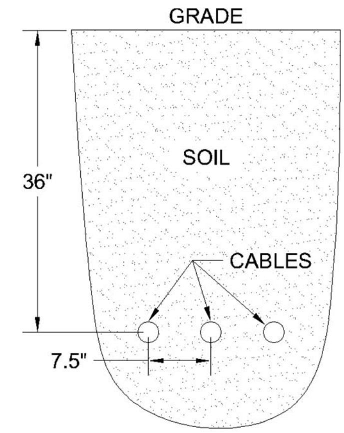

Fig. 1. Cable configuration.

D. Neher–McGrath Adaptation

The method proposed in [1] focuses on the thermal stability of the soil. All soils increase in resistivity as moisture content decreases. The suggested method addresses the issue of moisture migration, with a simple procedure to approximate the effective thermal resistance to ambient earth, including the effects of drying. The nondrying heat rate (NHR) and the completely dried soil resistivity must be known, in addition to the *in situ* soil resistivity. These are used to calculate a dried soil diameter, which is then included in the Neher–McGrath method. The cable ampacity may be calculated with the aid of a spreadsheet, by hand, or by using a computer program that includes the capability of adding concentric layers of thermal resistance surrounding the cable. Another notable feature of this method is that it does not assume that the only heat transfer mechanism of the cable is conduction to ambient earth. Rather, it includes the effects of heat transfer by moisture moving through the soil.

III. Comparison

In order to highlight the differences between these methods, some examples are provided. Each example involves three single copper conductors that are directly buried 36 in underground, as shown in Fig. 1, which is the same configuration as figure "k" of IEEE 835 [2]. In addition, each example involves single-point grounded cables, and the design requires an ampacity of at least 500 A at 15 kV, with EPR insulation and tape shielding. A load factor of 100% is assumed.

A. Site-Specific Data Collection

To begin the design the *in situ* soil thermal resistivity and the moisture content must be measured, as described in IEEE

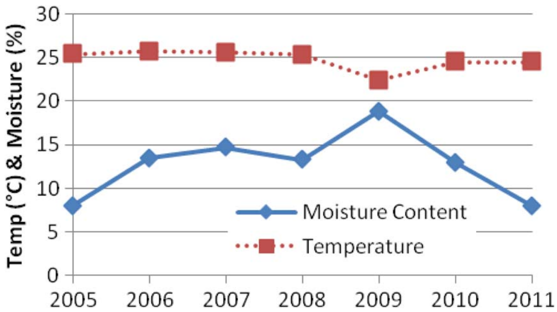

Fig. 2. Maximum soil temperature and minimum moisture content per year.

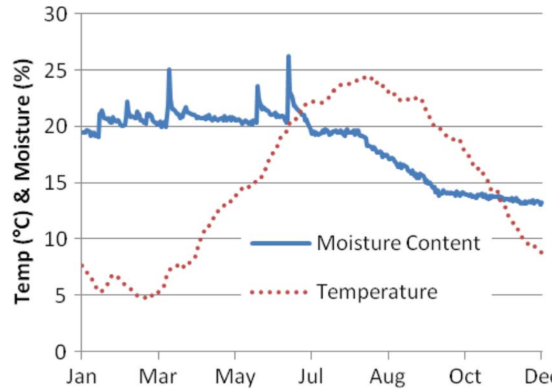

Fig. 3. Soil temperature and moisture content over one year.

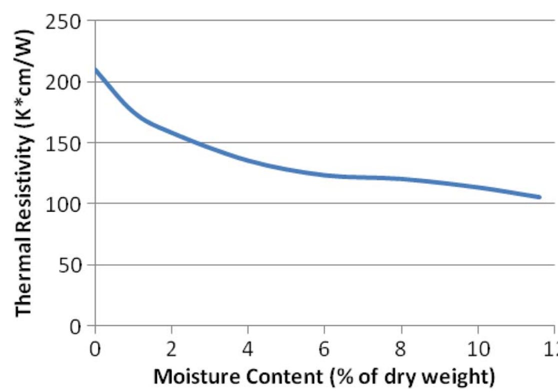

Fig. 4. Soil dry out curve.

Std. 442 [5] and ASTM D4643 [6]. For this example, the *in situ* soil thermal resistivity has been measured at 90 Kcm/W, at an *in situ* moisture content of 8%. It is important to measure soil resistivity at the minimum soil moisture content occurring at the site since moisture content has a large effect on resistivity. In addition, moisture content and resistivity should be measured at the depth that the cables will be installed.

Determining the minimum moisture content is often difficult because it may occur at any time during the year and, for most projects, it is impractical to measure the moisture content throughout the year. In addition, the minimum moisture content will vary from year to year, and the year when the soil resistivity was measured for the design may be abnormally high. This would result in a low soil resistivity and a cable size that is too small during a drought.

A practical method to determine the approximate minimum soil moisture content involves using the data provided by the Soil Climate Analysis Network (SCAN) operated by the National Water and Climate Center [7]. This publicly available data provide soil moisture content and soil temperature for various soil depths up to 40 in at locations across the United States. From this data, the minimum soil moisture content and maximum soil temperature can be found over a period of several years. A plot of the minimum soil moisture and maximum soil temperature over a given year at a depth of 40 in below grade for the soil used in this example is show in Fig. 2.

The maximum soil temperature and the minimum soil moisture content are the conditions that result in the lowest cable ampacity. Using these extremes will result in a design adequate for all expected environmental conditions. In the case of Fig. 2, the lowest moisture content is 8%, and the highest soil temperature is 25 °C. Of course, the lowest moisture content may not occur concurrently with the highest soil temperature. A plot of the soil moisture content and the soil temperature over one year is shown in Fig. 3. This shows the maximum temperature occurring four months before the minimum moisture content.

The designer may choose to use the moisture content and temperature that occur simultaneously rather than the yearly minimum moisture content and yearly maximum temperature. This would require the examination of multiple combinations of moisture content and temperature. The combination that results in the lowest ampacity would be the one used in the design. The designer must determine the *in situ* thermal resistivity for each moisture content level that is evaluated for determining the ampacity. For example, after examining multiple cases, the minimum moisture content and maximum temperature that result in the minimum ampacity may occur in September compared with the maximum temperature occurring in July with the minimum moisture content in December. This is obviously more time consuming than using the minimum annual moisture content and maximum temperature, which will result in a more conservative design.

Another piece of information that is needed for the method proposed in [1] is the soil dry out curve. This curve is derived from laboratory tests rather than *in situ*. The laboratory test of the soil in this example is shown in Fig. 4.

This curve provides information on the soil thermal resistivity over a range of moisture contents. It should not be used to replace the *in situ* moisture content and thermal resistivity measurements, and the *in situ* soil resistivity at the *in situ* moisture content may not match that measured in the laboratory. This curve is used for determining the dry soil resistivity and the resistivity at moisture contents other than the one measured in the field. Before it can be used, the curve must be calibrated to match the *in situ* measured data. One calibration method is to use a calibration factor, as suggested in [8], which calibrates the curve found in the laboratory using a comparison between the resistivity found *in situ* and that shown on the laboratory curve.

Laboratory tests allow for complete dehydration of the soil but do not permit the ingress of moisture from the surrounding soil that would normally be experienced *in situ*. Furthermore, a reconstituted laboratory sample is unlikely to match the soil

TABLE I
AMPACITY WITH RHO-90

Method	Ampacity	Cable Size
Neher-McGrath	**541A**	**350kcmil**
Black Book P.210	**534A**	**350kcmil**
IEEE 835 P.465	**519A**	**350kcmil**
Computer Program	**549A**	**350kcmil**

qualities found in the field. As a result, laboratory measurements of thermal properties may not match those measured *in situ.*

B. Cable Sizing Example

After the soil data specific to the site has been determined, the ampacity can be found using various methods. Table I shows the calculated values of cable ampacity using four different methods, assuming that the soil resistivity remains at 90 Kcm/W, i.e., the soil does not dry out.

All of these methods result in an equivalent cable size, although there are slight discrepancies in the resulting ampacity. These differences can be attributed to the different assumptions used by each method.

C. Soil Drying Consideration

The effect of soil drying can be checked by measuring the NHR, as described in [1]. This example will use a value of 0.53 W/cm as the NHR measured, using a standard probe diameter of 1.5875 cm, as per IEEE 442 [5]. In order to determine if soil drying occurs, the NHR can be compared to the cable heat rate. The cable heat rate for a simple underground nonshielded low-voltage cable is simply I^2R W/cm, where R is the cable resistance per unit length, and I is the expected current in amperes. For more complex shielded cables and cables at higher voltages, the heat rate can be calculated, as describe by Neher and McGrath [4]. A computer program may also be used to find the heat rate. The amount of heat a cable can generate before causing the soil to dry is a function of the diameter of the cable. The NHR found using the standard probe must be adjusted for the cable diameter before it can be compared to the actual cable heat rate. This can be accomplished by first calculating the conductive heat flow rate of the test probe at the NHR using (1), which is (7) in [1]. That is

$$\dot{q}_{c,\text{probe}} = \frac{2\pi(T_1 - T_2)}{\rho \ln\left(\frac{4L}{D_{\text{probe}}}\right)} \tag{1}$$

where

$\dot{q}_{c,\text{probe}}$	conductive heat rate at the NHR for the test probe (W/cm);
L	length of the test probe (cm);
T_1	maximum temperature of the NHR test (°C);
T_2	ambient temperature of the NHR test (°C);
ρ	*in situ* soil thermal resistivity (using [5]);
D_{probe}	outside diameter of the test probe (cm).

The NHR for the cable diameter using the NHR measured with a test probe can be derived by beginning with (19) in [1], which is shown in the per-unit-length form in (2) as follows:

$$D_{\text{cable}} = \frac{D_{\text{probe}}(\dot{q}_{w,\text{cable}} + \dot{q}_{v,\text{cable}})}{\dot{m}_{\text{NHR,probe}}(h_v + C_w \Delta T_{\text{cable}})} \tag{2}$$

where

D_{cable}	is the outside diameter of the cable (cm);
$\dot{q}_{w,\text{cable}}$	is the heat rate due to inflowing water (W/cm);
$\dot{q}_{v,\text{cable}}$	is the heat rate due to water vapor (W/cm);
$\dot{m}_{\text{NHR,probe}}$	is the mass flow rate of water at the probe diameter (lb/sec*cm);
h_v	is the latent heat of vaporization of water (1025 kJ/lb);
C_w	is the specific heat of water (1.89 kJ/lb°C);
ΔT_{cable}	is the temperature difference between ambient earth and the dried soil interface, which is the cable diameter in the case of the NHR (°C).

The mass flow rate of water is given in (13) of [1], as shown in the per-unit-length form in (3) as follows:

$$\dot{m}_{\text{NHR}} = \frac{\dot{q}_{\text{NHR,cable}} - \dot{q}_c}{h_v + C_w \Delta T} \tag{3}$$

where $\dot{q}_{\text{NHR,cable}}$ is the total heat rate at the NHR for the cable (W/cm).

The heat absorbed by inflowing water and the heat transferred by water vapor are shown in (4), which is the per-unit-length form of (12) in [1]. That is

$$\dot{q}_{w,\text{cable}} + \dot{q}_{v,\text{cable}} = \dot{q}_{\text{NHR,cable}} - \dot{q}_{c,\text{cable}} \tag{4}$$

where $\dot{q}_{c,\text{cable}}$ is the conductive heat rate at the NHR for the cable (W/cm).

The conductive heat rate at the NHR for the cable can be found, in terms of the NHR, using the same assumption as in (1): that the increase in total heat rate from the NHR at the probe diameter to the NHR at the cable diameter will result in a proportional increase in each component of the heat rate, i.e., the heat transferred by conduction, water, and vapor. This is shown in (5), which is the per-unit-length form of (20) in [1]. That is

$$\dot{q}_{c,\text{cable}} = \frac{\dot{q}_{\text{NHR,cable}}}{\dot{q}_{\text{NHR,probe}}} \dot{q}_{c,\text{probe}}. \tag{5}$$

The NHR for the cable diameter can now be calculated using (2)–(5), as shown in the following derivation.

Begin by inserting (3) into (2). That is,

$$D_{\text{cable}} = \frac{D_{\text{probe}}(\dot{q}_{w,\text{cable}} + \dot{q}_{v,\text{cable}})}{\frac{\dot{q}_{\text{NHR,probe}} - \dot{q}_{c,\text{probe}}}{h_v + C_w \Delta T_{\text{probe}}}(h_v + C_w \Delta T_{\text{cable}})}. \tag{6}$$

The terms $h_v + C_w \Delta T_{\text{cable}}$ can be cancelled by $h_v + C_w \Delta T_{\text{probe}}$, if the same assumption is made as that in [1]. Inserting (4) into (6) and cancelling the equivalent terms results in

$$D_{\text{cable}} = \frac{D_{\text{probe}}(\dot{q}_{\text{NHR,cable}} - \dot{q}_{c,\text{cable}})}{\dot{q}_{\text{NHR,probe}} - \dot{q}_{c,\text{probe}}}. \tag{7}$$

Inserting (5) into (7) results in

$$D_{\text{cable}} = \frac{D_{\text{probe}}\left(\dot{q}_{\text{NHR,cable}} - \frac{\dot{q}_{\text{NHR,cable}}}{\dot{q}_{\text{NHR,probe}}}\dot{q}_{c,\text{probe}}\right)}{\dot{q}_{\text{NHR,probe}} - \dot{q}_{c,\text{probe}}}. \quad (8)$$

Rearranging the terms in (8) completes the derivation, which is shown as

$$\dot{q}_{\text{NHR,cable}} = \frac{D_{\text{cable}}(\dot{q}_{\text{NHR,probe}} - \dot{q}_{c,\text{probe}})}{D_{\text{probe}}\left(1 - \frac{\dot{q}_{c,\text{probe}}}{\dot{q}_{\text{NHR,probe}}}\right)}. \quad (9)$$

Using test data of $T_1 = 36$ °C, $T_2 = 20$ °C, and the IEEE 442 [5] standard probe dimensions yield the following $\dot{q}_{c,\text{probe}}$ based on (1):

$$\dot{q}_{c,\text{probe}} = \frac{2\pi(36\ {}^\circ\text{C} - 20\ {}^\circ\text{C})}{90\frac{\text{Kcm}}{\text{W}} * \ln\left(\frac{4*120\ \text{cm}}{1.5875\ \text{cm}}\right)} = 0.196\ \text{W/cm}.$$

Using a cable diameter of 3.2 cm (compact stranded 350 kcmil) yields the following NHR that is corrected for the cable diameter using (9)

$$\dot{q}_{\text{NHR,cable}} = \frac{3.2\ \text{cm}(0.53\ \text{W/cm} - 0.196\ \text{W/cm})}{1.5875\ \text{cm}\left(1 - \frac{0.196\ \text{W/cm}}{0.53\ \text{W/cm}}\right)} = 1.06\ \text{W/cm}.$$

Now that the NHR is known for the cable diameter in question, a direct comparison can be made to the calculated cable heat flow rate needed in the design. The Neher–McGrath method yields values for the cable heat "W" that are the sum of the losses developed in a cable [4]. The value W is the sum of all of the other losses (W_c, W_s, W_p, and W_d), the most important of which will be the I^2R losses. For a direct-buried cable operating at 15 kV, the conduit losses (W_p) and dielectric losses (W_d) are zero. For this particular example, the cable heat rate, W or $\dot{q}_{\text{cable}}$, is equal to 0.373 W/cm. This is well under the 1.06 W/cm calculated for this soil; hence, soil drying is not expected to occur, and no modification is needed for the calculations due to soil thermal instability [1].

D. Laboratory Testing Versus In Situ Testing

A common concern when sizing cables is that the cable will heat up the surrounding soil enough to dry the soil, thereby raising its resistivity. This phenomenon is thermal instability. The result of thermal instability is an increase in the temperature of the cable, causing further drying of the soil and resulting in additional temperature rise. This would continue until the temperature rating of the cable was exceeded. This dramatic increase in temperature is sometimes referred to as *thermal runaway*, but even a small amount of soil drying may be sufficient to result in exceeding a cable's temperature rating. To avoid this problem, an engineer might choose to use a value of resistivity that is higher than the value measured *in situ*.

If *in situ* measurements are unavailable, the laboratory thermal measurements similar to those in Fig. 4 may need to be relied upon. These are commonly higher than *in situ* measurements, and the designer may choose the highest value shown on the graph for safety.

TABLE II
AMPACITY WITH RHO-120

Method	Current	Cable Size
Neher-McGrath	**483A**	**350kcmil**
Neher-McGrath	**569A**	**500kcmil**
Black Book P.210	**485A**	**350kcmil**
Black Book P.210	**588A**	**500kcmil**
IEEE 835 P.465	**462A**	**350kcmil**
IEEE 835 P.465	**536A**	**500kcmil**
Computer Program	**489A**	**350kcmil**
Computer Program	**591A**	**500kcmil**

Using this method, a value of soil resistivity will be selected from the laboratory test based on the minimum moisture content of 8%. The other values are the same as those used in the first example. The value of resistivity found from laboratory was approximately 120 Kcm/W. Using the same methods used in Table I, results in the ampacities and cable sizes are shown in Table II.

Comparing Tables I and II shows that all of the cables had to be increased in size from a 350-kcmil to a 500-kcmil cable, in order to carry the desired 500-A design current. Using a cost of \$9900/1000 ft for 350 kcmil and \$12 600/1000 ft for 500 kcmil, increasing the size from 350 kcmil to 500 kcmil would result in a 25% cost increase of \$2700.00/1000 ft.

If the designer relied upon a typical rho of 90 Kcm/W, and the actual field rho was 120 Kcm/W, the cable would have been undersized. It would also be operating at higher the desired temperature, possibly resulting in early failure. Conversely, if the designer decided to use the conservative value of $\text{rho} = 120$, and the rho was only 90, the costs of the larger cable size would be unnecessarily high. In either case, the desirability of obtaining accurate soil resistivity data is evident.

E. Sand Backfill Cable Sizing Example

Sand is often used to backfill cable trenches in a direct-buried configuration. This protects the cables from damage that might otherwise occur if native backfill were used containing rocks or other debris. Protection against cable damage is required by section 300.5 of the National Electrical Code, which states, "Where necessary to prevent physical damage to the raceway or cable, protection shall be provided in the form of granular or selected material" [8]. In addition, some cable manufacturers recommend that "sand or stone-free earth" be used "within 4 inches of the cable" [9].

Sand has poor thermal properties compared with many native soils when it is dry, and it dries with relatively low heat rates if the surrounding soil does not have high moisture content. For the next example, a value of resistivity equal to 90 Kcm/W is used for the *in situ* soil with a moisture content of 8%. All other values are the same as in the first two examples. In addition, a dry resistivity of 350 Kcm/W is used for the surrounding sand layer, and an NHR of 0.1 W/cm will be assumed. Converting

TABLE III
AMPACITY WITH DRIED SOIL INCLUDED

Method	Current	Cable Size
Adapted Neher-McGrath	**504A**	**350kcmil**

the NHR at the test probe diameter to the cable diameter using (1), based on test data in sand, yields the following:

$$\dot{q}_{c,\text{probe}} = \frac{2\pi(25\ ^\circ\text{C} - 20\ ^\circ\text{C})}{90\frac{\text{Kcm}}{\text{W}} * \ln\left(\frac{4*120\ \text{cm}}{1.5875\ \text{cm}}\right)} = 0.061\ \text{W/cm}.$$

Note that this equation uses the maximum temperature reached during the NHR test for sand, as well as the thermal resistivity of sand. That is,

$$\dot{q}_{\text{NHR,cable}} = \frac{3.2\ \text{cm}(0.1\ \text{W/cm} - 0.061\ \text{W/cm})}{1.5875\ \text{cm}\left(1 - \frac{0.061\ \text{W/cm}}{0.1\ \text{W/cm}}\right)} = 0.20\ \text{W/cm}.$$

Because the cable heat rate is 0.37 W/cm and the NHR of the sand surrounding the cable is 0.2 W/cm, soil drying will occur. Equation (8) can be used to determine the extent of drying. That is,

$$D_{\text{dry soil}} = \frac{1.5875\ \text{cm} * 0.373\ \text{W/cm}\left(1 - \frac{0.061\ \text{W/cm}}{0.1\ \text{W/cm}}\right)}{0.10\ \text{W/cm} - 0.061\ \text{W/cm}} = 5.9\ \text{cm}.$$

This diameter of dried soil can be accounted for by adding its resistance to R'_{ca}, as stated by [1] using (34) in the same reference and shown in (5) as follows:

$$R_{\text{dry soil}} = 0.012\rho_{\text{dry soil}} \log\left(\frac{D_{\text{dry soil}}}{D_{\text{cable}}}\right) \quad (10)$$

where $R_{\text{dry soil}}$ is the resistance of the dried soil (thermal ohms) and $\rho_{\text{dry soil}}$ is the resistivity of the dry sand (Kcm/W).

Solving for the resistance added by the dried sand yields

$$R_{\text{dry soil}} = 0.012 * \frac{350\ \text{Kcm}}{\text{W}} * \log\left(\frac{5.9\ \text{cm}}{3.2\ \text{cm}}\right) = 1.12\Omega_{\text{thermal}}.$$

The effective resistance of the earth portion of the circuit, i.e., R'_e in [4], must be recalculated for the new diameter of the dried soil. It can then be added to R'_{ca}. This yields a new ampacity of 504 A rather than the 541 A previously calculated in Table I, which did not include the dried sand. It confirms that a 350 kcmil will be adequate to handle the design current of 500 A but is much less than the ampacities calculated in Table I. This result is stated in Table III.

This method addresses the issue of soil drying and the possibility of thermal runaway by calculating an expected dried soil diameter rather than assuming that the surrounding soil all dries to a larger resistivity, which would result in installing larger than necessary cables. The engineer may still include a factor of safety when sizing cables because of the large impact that slight variations of soil resistivity have on the ampacity. However, this factor of safety no longer needs to include the risk of thermal runaway.

IV. CONCLUSION

The assumptions included in several methods for determining underground cable ampacity have been discussed. The older Black Books use an ambient earth temperature of 20 °C, whereas the IEEE 835 tables use an ambient earth temperature of 25 °C. However, the IEEE tables assume that the cable shields are shorted, whereas the Black Books assume that the shields are single-point grounded. Overall, IEEE 835 results in a lower ampacity than the Black Books. Designers must understand that the assumptions used in preparing these tables may not match field conditions where cable is to be installed. Soil resistivity and ambient temperatures are particularly variable from site to site.

Using the Neher–McGrath method, or a software program using that method, allows for calculating cable ampacities using various soil resistivities, ambient temperatures, and shield grounding configurations. This reduces the error in the calculated ampacity by eliminating the assumptions used in the tables.

Regardless of the method, it is recommended that an *in situ* soil thermal resistivity study be performed rather than attempting to utilize only laboratory thermal resistivity measurements or "typical" values. Performing an *in situ* test also allows for the measurement of the NHR, which can be used in determining the possibility and resulting effects of soil thermal instability. Using a higher value of resistivity, whether because the actual value is uncertain or because of concerns for thermal instability, can result in larger cable sizes and unnecessary cost increases. It may also result in underestimating the effects of thermal instability, resulting in future cable failure.

The method proposed in [1], along with sufficient field and laboratory testing, allows for a more accurate assessment of the cable size and includes the effects of soil thermal instability. Soil thermal instability is not otherwise included in the Neher–McGrath method and computer programs derived from it or in the tables. Including all design and environmental factors relevant to cable ampacity will minimize cable costs by preventing oversized cables while preventing early cable failure due to overheated cables.

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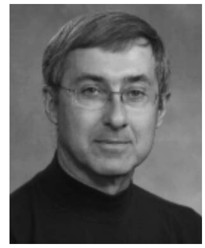

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