

# A Computer Program to Calculate the Current-Carrying Capacity of Overhead Power Lines

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**Abstract**—Due to the national grid expansion the exact current-carrying capacity of overhead power lines is of crucial importance for the grid operator. This paper describes a new, free-to-use computer program called CCC, which allows the user to easily determine the current-carrying capacity of overhead power lines. The algorithm used is based on the Webs-model of 1963. With this computer program it is possible to calculate the current-carrying capacity at any given ambient condition for different conductors. By using ambient conditions differing from the European standard EN 50182, higher current-carrying capacities can be achieved than those defined in the standard. Realistic ambient conditions are specified, representing the worst-case for three different periods of the year. This approach results in up to 20 % higher currents for the winter period compared to the standard EN 50182. The computer program enables grid operators to easily and reliably calculate additional transmission capacities. These results can be integrated into the grid control system to optimize the congestion management.

**Index Terms**—ACSR; overhead power lines; current rating; computer program

## I. INTRODUCTION

The German power grid has been undergoing change for some time. Due to the energy transition in Germany, which does not only lead to a higher amount of decentralized power plants, a reinforced and optimized grid is necessary to distribute the electric energy. Instead of focusing on expanding the existing power lines, it is possible to use the capacities of the current infrastructure optimally. Overhead power lines play a decisive role, because the conductors are directly exposed to the ambient influences and the transmission capacity is decisively influenced by them.

Using the prevailing ambient conditions, it is possible to calculate the transferable electric power of overhead power lines, respectively the transmission capacity. Frequently it is possible to operate conductors with a higher current depending on the season, than defined in the standard EN 50182 [1]. With the obtained information, the transmission capacities can be increased in a targeted manner so that an expansion is not always necessary. Furthermore, the exact determination of the transmission capacity offers the possibility of realizing a secure grid operation even in the event of failure of equipment, for example transformers. For a simple use of this method, a computer program, called CCC has been developed in C sharp (C#). This computer program enables the user to quickly

calculate the current-carrying capacity under diverse ambient conditions.

## II. WEBS-MODEL

The current-carrying capacity defined in EN 50182 and previous German standards have been determined using the so-called Webs-model [2] [3]. The Webs-model was published in 1963 by Alfred Webs. It has been verified by several field tests and is accepted in practice. There are also other models for the calculation of the current-carrying capacity such as the Kirn-model [4]. For the calculation of the current-carrying capacity under worst case conditions, the Webs-model is recommended since the number of parameters is smaller.

### A. Physical basics

The energy balance of the conductor in the stationary state is considered. The energy balance consists of four heat streams:

$P'_I$  Ohmic-Heat Gain

$P'_S$  Solar-Heat Gain

$P'_C$  Convected-Heat Loss

$P'_R$  Radiated-Heat Loss

The differential equation for the conductor is as follows [5]:

$$P'_I + P'_S - P'_C - P'_R = c_{Co} \cdot m_{Co} \cdot \frac{dT_{Co}}{dt} \quad (1)$$

where

$c_{Co}$  is the specific heat capacity of the conductor in J/(kg·K);

$m_{Co}$  is the mass of the conductor in kg;

$T_{Co}$  is the conductor temperature in K.

In steady state the time derivative is zero the differential equation is simplified to an algebraic equation. The heat gain is equal to the heat loss [6]:

$$P'_I + P'_S = P'_C + P'_R \quad (2)$$

Fig. 1 illustrates the heat streams in the system conductor. In the further process, the individual heat flows must be determined.

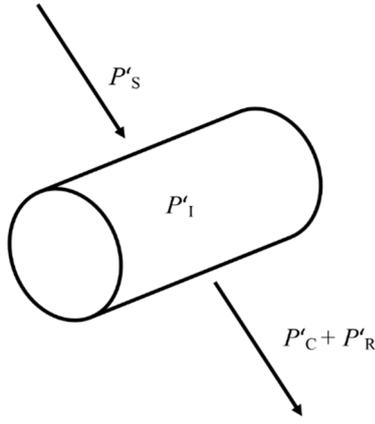


Fig. 1. Heat flows of the conductor according to [7]

### B. Ohmic-Heat Gain

The ohmic-heat gain can be described by the following formula [4]:

$$P'_1 = I^2 \cdot R'_{20} \cdot (1 + \alpha_{C_0} \cdot (T_{C_0} - 293.15 \text{ K})) \quad (3)$$

where

$I$  is the conductor current in A;

$R'_{20}$  is the conductor resistance at 20 °C in  $\Omega/\text{km}$  ;

$\alpha_{C_0}$  is the conductor temperature coefficient in 1/K.

Only the DC resistance at the respective temperature is considered. Skin effect and other electrical losses are not considered [8]. Due to the neglect of the skin effect, considerable errors occur by calculation with larger conductor diameters [6].

### C. Solar-Heat Gain

The solar-heat gain of the conductor, caused by direct and sky radiation, is calculated according to the following formula [9]:

$$P'_S \approx d_C \cdot \varepsilon_{C_0} \cdot G \cdot \sin(\delta) \quad (4)$$

where

$d_{C_0}$  is the conductor diameter in m;

$G$  is the global radiation in  $\text{W}/\text{m}^2$ ;

$\delta$  is the angle of incidence in  $^\circ$ ;

$\varepsilon_{C_0}$  is the thermal-emissivity coefficient.

The angle of incidence can be calculated according to formula [9]:

$$\delta = \arccos(\cos(h_S) \cdot \cos(180^\circ - \psi)) \quad (5)$$

where

$h_S$  is the solar altitude in  $^\circ$ ;

$\psi$  is the azimuth of the conductor in  $^\circ$ .

The thermal-emissivity coefficient of the conductor can be calculated in good approximation as a function of the installation years  $t_C$  [8]:

$$\varepsilon_{C_0} = 0.3 + \frac{0.6 \cdot t_C}{1 + t_C} \quad (6)$$

### D. Convected-Heat Loss

The determination of the heat emission by convection is much more complex than the determination of the other heat flows. In this paper only the heat emission by forced convection is considered, that is by wind-moved air at the level of the conductor. In the case of doldrums, the heat emission occurs via the thermal self-propulsion of the air. The latter is only relevant in practice for special cases. In general, a minimum wind speed of 0.6 m/s can be applied perpendicular to the conductor. The convected-heat loss can be calculated as follows [6]:

$$P'_C = \pi \cdot \lambda_{\text{Air}} \cdot (T_{C_0} - T_A) \cdot Nu \quad (7)$$

where

$Nu$  is the Nusselt number;

$T_A$  is the ambient temperature in K;

$T_{C_0}$  is the conductor temperature in K;

$\lambda_{\text{Air}}$  is the thermal conductivity of the conductor in  $\text{W}/(\text{K}\cdot\text{m})$ .

The thermal conductivity of the air and the Nusselt number have to be determined further. The Nusselt number can be determined from the Reynolds number by the following relation [9]:

For  $0.1 \leq Re \leq 10^3$  :

$$Nu = 0.32 + 0.43 \cdot Re^{0.52} \quad (8)$$

For  $10^3 \leq Re \leq 5 \cdot 10^4$  :

$$Nu = 0.24 \cdot Re^{0.6} \quad (9)$$

The Reynolds number is calculated as follows [10]:

$$Re = \frac{v_{\text{Air}} \cdot d_{C_0} \cdot \rho_{\text{Air}}}{\eta_{\text{Air}}} \quad (10)$$

where

$v_{\text{Air}}$  is the wind speed in m/s;

$\eta_{\text{Air}}$  is the dynamic viscosity of air in  $\text{kg}/(\text{m}\cdot\text{s})$ ;

$\rho_{\text{Air}}$  is the air density in  $\text{kg}/\text{m}^3$ .

The equation can be simplified by (11), where  $\nu_{\text{Air}}$  is the kinematic viscosity of air:

$$\eta_{\text{Air}} = \nu_{\text{Air}} \cdot \rho_{\text{Air}} \quad (11)$$

Consequently, the density of the air is no longer necessary for the calculation of the Reynolds number:

$$Re = \frac{v_{\text{Air}} \cdot d_{C_0}}{\nu_{\text{Air}}} \quad (12)$$

Finally, the two matter constants  $\lambda_{\text{Air}}$  and  $\nu_{\text{Air}}$  have to be determined. According to [9] the average temperature of  $T_{\text{Co}}$  and  $T_{\text{A}}$  is necessary for the calculation of  $\lambda_{\text{Air}}$  and  $\nu_{\text{Air}}$ . The matter constants can be calculated with regression lines [4], whereby the average temperature has already been considered:

$$\lambda_{\text{Air}} = 3.66 \cdot 10^{-5} \cdot (T_{\text{Co}} + T_{\text{A}} + 124.78) \quad (13)$$

$$\nu_{\text{Air}} = 4.75 \cdot 10^{-8} \cdot (T_{\text{Co}} + T_{\text{A}} - 264.61). \quad (14)$$

### E. Radiated-Heat Loss

The last heat flow which must be defined is the radiated-heat loss [6]:

$$P'_{\text{R}} = \pi \cdot d_{\text{Co}} \cdot \varepsilon_{\text{Co}} \cdot \sigma \cdot \left( \frac{3}{4} \cdot (T_{\text{Co}}^4 - T_{\text{A}}^4) + \frac{1}{4} \cdot (T_{\text{Co}}^4 - T_{\text{H}}^4) \right) \quad (15)$$

where

$T_{\text{H}}$  is the temperature of the outer atmosphere in K;

$\sigma$  is the Stefan-Boltzmann constant in  $\text{W}/(\text{m}^2 \cdot \text{K}^4)$ .

The thermal-emissivity coefficient can be defined with (6).

If the individual heat flows have been determined, (2) can be converted according to the permissible current:

$$I_{\text{per}} = \sqrt{\frac{P'_{\text{C}} + P'_{\text{R}} - P'_{\text{S}}}{R_{20} \cdot (1 + \alpha_{\text{Co}} \cdot (T_{\text{Co}} - 293.15 \text{ K}))}} \quad (16)$$

This formula can be easily integrated into a computer program to determine the current-carrying capacity.

## III. AMBIENT CONDITIONS & CONDUCTOR PARAMETERS

The current-carrying capacity and thus the transmission capacity are decisively defined by the ambient conditions. In the following, the year is subdivided into three periods, which differ in the ambient conditions. In these three periods, the current-carrying capacity is determined and compared to the standard EN 50182 [1]. The standard EN 50182 only defines one set of ambient conditions for the entire year, so there is a subdivision into different periods. The ambient conditions are worst case conditions. This means that the applied values are not exceeded or the probability of the exceeding is small (at the ambient temperature, an exceeding cannot be excluded).

In this paper a 110 kV overhead power line in the region Bielefeld was examined. The defined ambient conditions for the location in Bielefeld (52°N) can be found in Table 1. The values for date and the max. ambient temperature were taken after checking from [3]. The max. solar altitude was determined by using [11] and by using these values the global radiation was determined using [6]. The min. wind speed was used analogously to EN 50182 [12]. In addition to the ambient conditions, the conductor parameters also influence the model. A 264-AL1/34-ST1A conductor was used for the calculations. This conductor is installed on the mentioned overhead power line. "264" designates the rounded cross-sectional area of the aluminum wires in  $\text{mm}^2$  and "34" designates the rounded cross-sectional area of the steel wires in  $\text{mm}^2$ . The numbers according to the abbreviations "AL" and "ST" indicate the exact type of material used. The letter after the abbreviation "ST" denotes the galvanizing class of steel.

TABLE I. AMBIENT CONDITIONS

	<i>Winter</i>	<i>Interim period</i>	<i>Summer</i>
Date	1/11 – 15/02	16/02 – 31/04; 16/09 – 30/10	1/05 – 15/09
Max. $T_{\text{A}}$	20	27.5	35
Max. $G$	650	850	1000
Max. $h_{\text{S}}$	25	53	61
Min. $\nu_{\text{Air}}$	0.6	0.6	0.6

The necessary values for the conductor parameters can be found in Table 2 [12] [13]. The thermal-emissivity coefficient is calculated by (6), the installation years are set to 35 years.

TABLE II. CONDUCTOR PARAMETERS

	$R'_{20}$	$\alpha_{\text{Co}}$	$d_{\text{C}}$	$\varepsilon_{\text{Co}}$
264-AL1/34-ST1A	0.1095	0.004	0.0224	0.88

The azimuth of the conductor was set to 80 °, which is the largest value of  $\psi$  all over the 6 km long overhead power line. A temperature of 80 °C was set for the conductor temperature, which is the highest permissible temperature for Al/St-Conductors (ACSR) in Germany [12].

## IV. COMPUTER PROGRAM

In order to simplify the calculations, an event-driven computer program was developed in C sharp which implements the model described in this paper. CCC is available free of charge on the website of Bielefeld University of Applied Sciences [15]. It offers a free alternative to commercial computer programs for the calculation of the current-carrying capacity. Fig. 2 shows the main-screen of the mentioned computer program in mode "Plotting". The plot illustrates the current-carrying capacity of three different conductors. The computer program is divided into two different applications: Calculation and Plotting.

In mode "Calculation" the current-carrying capacity can be calculated depending on the conductor parameters and the ambient conditions for a single operating point. It is possible to choose conductors from an implemented database. By doing so, the conductor parameters of the chosen conductor are automatically displayed and added to the calculation. In Germany and Austria commonly used conductors can be selected from the database [12] [13] [14]. By clicking the button "Calculate" and starting the calculation an instance of the class "Conductor" and an instance of the class "AmbientConditions" are created. The following code is an extract from the classes "Conductor" and "AmbientConditions", getters are omitted:

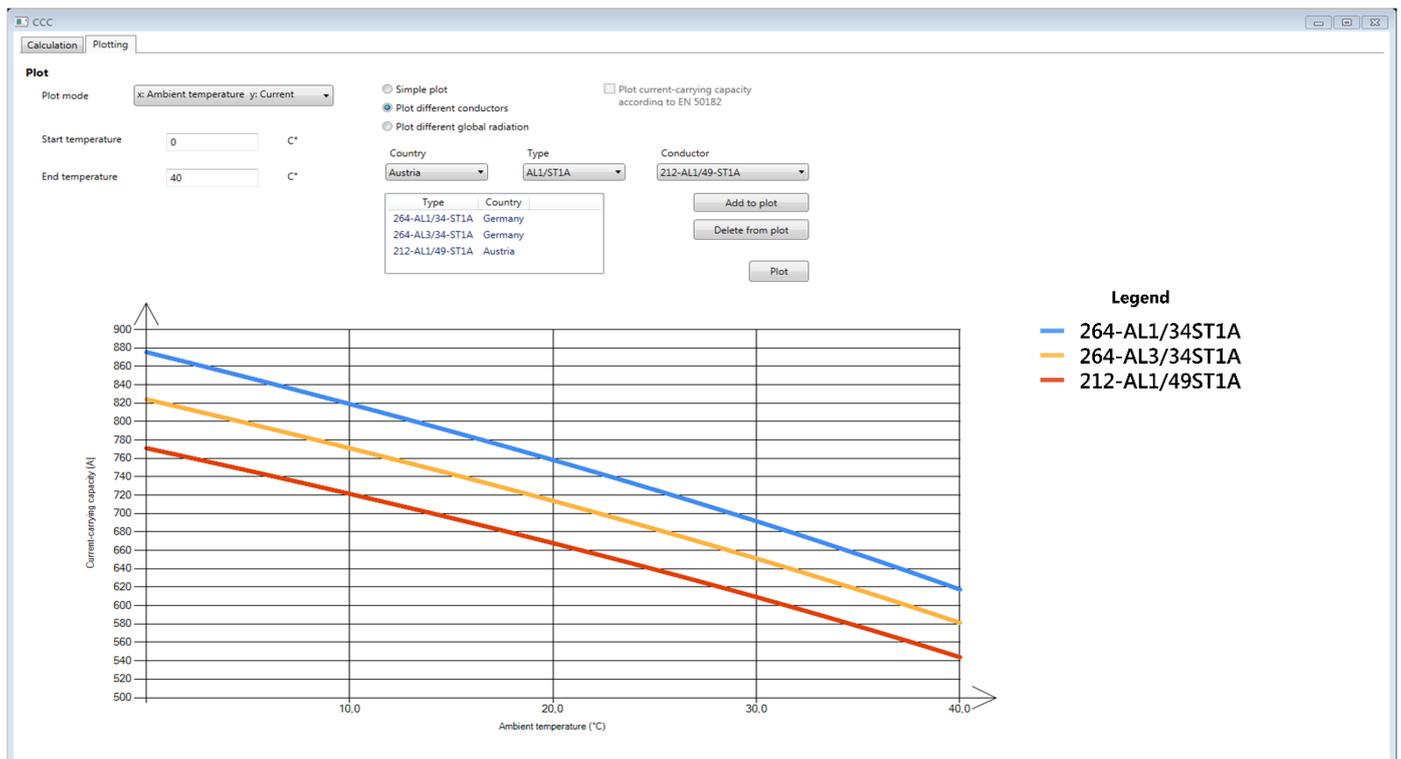


Fig 2. CCC main-screen

```

class Conductor
{
    private float dC_Resistance = 0;
    private float diameter = 0;
    private float temperatureCoefficient = 0;
    private float emissionCoefficient = 0;
    private float conductorTemperature = 0;
    string title = "";
    private float currentCapacityStandard = 0;
    public Conductor(float dC_Resistance, float diameter,
        float temperatureCoefficient, float emissionCoefficient,
        float conductorTemperature)
    {
        this.dC_Resistance = dC_Resistance;
        this.diameter = diameter;
        this.temperatureCoefficient = temperatureCoefficient;
        this.emissionCoefficient = emissionCoefficient;
        this.conductorTemperature = conductorTemperature;
    }
    .....
}
class AmbientConditions
{
    private float ambientTemperature;
    private float globalRadiation;
    private float solarHeight;
    private float conductorAngle;
    private float windSpeed;
    public AmbientConditions(float ambientTemperature,
        float globalRadiation, float solarHeight,
        float conductorAngle, float windSpeed)
    {
        this.ambientTemperature = ambientTemperature;
        this.globalRadiation = globalRadiation;
        this.solarHeight = solarHeight;
    }
}

```

```

this.conductorAngle = conductorAngle;
this.windSpeed = windSpeed;
}
.....
}

```

To calculate the current-carrying capacity of a specific operation point, an instance of class "OperationPoint" is created. The constructor of this class takes an instance of class "Conductor" and an instance of class "AmbientConditions". Moreover class "OperationPoint" contains the method "calculateCurrentCapacity" to determine the current-carrying capacity. In the following code of class "OperationPoint" the defining of the variables is omitted:

```

class OperationPoint
{
    .....
    private float calculateCurrentCapacity
        (float solarHeatGain,
        float convectedHeatLoss, float radiatedHeatLoss,
        float dC_Resistance, float temperatureCoefficient,
        float conductorTemperature)
    {
        float amperes = (float)Math.Sqrt((convectedHeatLoss
        + radiatedHeatLoss - solarHeatGain) /
        (dC_Resistance * (1 + (temperatureCoefficient *
        (conductorTemperature - 293)))));
        return amperes;
    }
}
public OperationPoint(Conductor conductor,
    AmbientConditions ambientConditions)
{
    this.dC_Resistance =

```

```

conductor.getDC_Resistance;
this.diameter =
conductor.getDiameter;
this.temperatureCoefficient =
conductor.getTemperatureCoefficient;
this.conductorTemperature =
conductor.getConductorTemperature;
this.emissionCoefficient =
conductor.getEmissionCoefficient;
this.ambientTemperature=
ambientConditions.getAmbientTemperature;
this.globalRadiation =
ambientConditions.getGlobalRadiation;
this.solarHeight =
ambientConditions.getSolarHeight;
this.conductorAngle=
ambientConditions.getConductorAngle;
this.windSpeed =
ambientConditions.getWindSpeed;
// Calculation of heat streams and current-carrying
capacity
.....
}
public float getCurrentCapacity
{
get { return currentCapacity; }
}
//getters for ambient and conductor parameters
.....
}

```

In mode “Plotting” the current-carrying capacity can be displayed graphically. Two plot modes are available: current-carrying capacity against ambient temperature and current-carrying capacity against wind speed. Additionally it is possible to plot the current-carrying capacity for different conductors and different global radiations, regardless of the selected plot mode. When plotting different conductors, the conductors have to be chosen from the implemented database.

To create data points for the plot two classes are used. The class “OperationPointPlotTemperature” is used while plotting current-carrying capacity against ambient temperature and the class “OperationPointPlotWindSpeed” while plotting current-carrying capacity against wind speed. The constructors of these classes take an instance of class “OperationPoint” and the respective plot attribute. By plotting the current-carrying capacity against the ambient temperature, the plot attribute is the ambient temperature and by plotting the current-carrying capacity against the wind speed, the plot attribute is the wind speed. For each data point of the plot an instance of the respective class is created by altering the plot attribute. The instance of class “OperationPoint” remains the same during a single plot. The following code describes the structure of the class “OperationPointPlotTemperature”:

```

class OperationPointPlotTemperature
{
private float convectedHeatLoss;
private float radiatedHeatLoss;
private float reynoldsNumber;
private float nusseltNumber;
private float currentCapacity;

```

```

private float calculateCurrentCapacity
(float solarHeatGain, float convectedHeatLoss,
float radiatedHeatLoss, float dC_Resistance,
float temperatureCoefficient,
float conductorTemperature)
{
// Same method as in the class “OperationPoint”
.....
}
public OperationPointPlotTemperature(OperationPoint
p, float plotAttribute)
{
//Calculation of heat streams
.....
currentCapacity =
calculateCurrentCapacity(p.getSolarHeatGain,
convectedHeatLoss, radiatedHeatLoss,
p.getDC_Resistance,
p.getTemperatureCoefficient,
p.getConductorTemperature);
}
public float getCurrentCapacity
{
get { return (float)Math.Round(currentCapacity, 2); }
}
}

```

## V. RESULTS

Starting from the defined ambient conditions in Table 1 and Table 2, the current-carrying capacity was determined for the three time periods. The results are shown in Fig. 3:

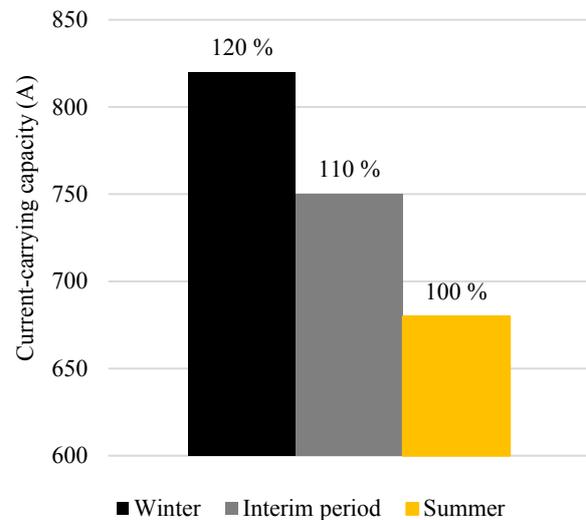


Fig. 3. Current-carrying capacity depending on period

In winter, the permissible current-carrying capacity is 820 A. This corresponds to an increase of 20 % to the normative value of 680 A. In the interim period, an increase of 10 % is possible, this corresponds to an absolute value of 750 A. In summer, according to the methodology used, no increase in the current-carrying capacity is possible. This is caused by applying the ambient conditions described in EN 50182, which are the worst-case conditions in the entire year.

## VI. CONCLUSION

Even without the use of overhead power line monitoring, it is possible to increase the transmission capacities of overhead power lines seasonally. By using ambient conditions, which represent a realistic limit value in the fixed period, season-dependent current-carrying capacities can be determined. The largest gains in transmission capacity can be obtained in winter, with no increase in transmission capacity in the summer. The presented computer program is a suitable solution to calculate the current-carrying capacity of overhead power lines. Furthermore, it is an alternative to commercial computer programs.

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