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Determining Current Capacity of Vehicle Cables

Preface

This Standard in the present issue is based on LV 112-3, which was drawn up by representatives of automobile manufacturers Audi AG, BMW AG, Daimler AG, Porsche AG, and Volkswagen AG.

Deviations from the LV 112-3 are listed on the cover sheet of this Standard. If modifications to individual test sections become necessary in individual cases, these must be agreed upon separately between the appropriate department and the relevant manufacturer.

Test reports will be accepted as long as the tests were performed by an independent testing institute that is accredited as per DIN EN ISO/IEC 17025. Acceptance of the test reports does not automatically result in a release.

NOTE 1 The LV numbers listed in this document will be converted as per table 1.

Table 1

LV	VW
LV 112-1	VW 60306-1
LV 112-2	VW 60306-2

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1. Scope

This Supply Specification (LV) describes the procedure to be complied with for mathematically determining

- the current capacity
- the voltage drop
- and the heating time

of single-wire vehicle cables.

The thermal behavior is modeled by a few separate, characteristic cable parameters. This approach has an advantage, in that thermal behavior can be done through simple calculation processes when these parameters are known. This can be done in various ambient conditions.

Starting from known physical parameters (e.g., specific heat capacity, specific electrical conductor resistance), the characteristic cable parameters can be calculated on the basis of known and documented procedures. The computation is not presented in detail in this Supply Specification. However, measuring methods will be indicated, which allow a verification with the aid of several measurements.

Caution: The values calculated by means of this Standard are ideal data for cables installed freely in air. Practice-oriented adaptations for other use conditions must be conducted.

Outlook: As a further consequence, the behavior of multi-wire cables (i.e., of bundles of single-wire vehicle cables) with and without sheath insulation will be calculable. Therefore, it will be possible to dimension the cables in a cable set in a practice-oriented manner, without using complex mathematical models (e.g., finite elements). (Not part of this Supply Specification!)

2. General information

The following is described in this document:

- The definition of the characteristic parameters of single-wire cables
- The measuring methods to verify the calculated characteristic cable parameters of single-wire cables
- Application examples for using the characteristic parameters

3. Basics for single-wire cables

3.1. Current capacity

The current capacity of single-wire vehicle cables depends on the following factors:

- Conductor cross section
- Conductor material
- Conductor composition
- Conductor diameter (inner diameter of insulation)
- Insulation material
- Conductor diameter (outer diameter of insulation)
- Ambient temperature
- Installation conditions
- Heat dissipation

3.2. Heating by current

In the measurements described below, the application of a constant current is always assumed!

If a cable has current flowing through it, heating takes place, the extent of which depends on conductor resistance, time, and on the square of the current.

In principle when heating occurs, the dynamic transition status and the static condition must be distinguished after a long period of current supply.

3.2.1 Dynamic transition status

The rate of the heating is determined above all by the electrical power input in the conductor material, the specific heat capacity of the conductor and the insulation, and the heat dissipation ratios. A thermal time constant τ is characteristic over the course of time, which may range from several seconds (10 s to 20 s at 0,35 mm²) to several minutes in large battery cables, depending on nominal cross section.

3.2.2 Steady state

The resulting temperature increase leads to a heat flow through the insulation material to the surface of the cable, and from there by irradiation and convection to the ambient air. A thermal equilibrium state takes place over time when current is supplied. In the process, the conductor temperature converges asymptotically on an upper limit. The rate of heating is determined by the time constant τ described below. One can assume in good approximation that the temperature at the conductor no longer changes if the current supply lasts longer than ~5 τ.

3.3. Maximum permissible conductor temperature

The highest temperature occurs at the conductor. When a cable is in operation, care must be taken that the specific limits for temperature resistance of the insulation material are not exceeded, taking into account the ambient temperature and self-heating.

3.4. Derating

The connection between the ambient temperature and the permissible current load is described by derating.

4. Simplified computational method

The thermal behavior of a single-wire cable can be described using simplified equations. 6 characteristic cable parameters are required in these equations.

4.1. Definition of parameters

4.1.1 Characteristic cable parameters

a	Linear current dependence of the conductor heating in the steady state	in K/A
b	Quadratic current dependence of the conductor heating in the steady state	in K/A^2
R'_{20}	Length-related conductor resistance at +20 °C	in Ω/m
α_ρ	Linear temperature coefficient of the material-specific conductor resistance	in 1/K
β_ρ	Quadratic temperature coefficient of the material-specific conductor resistance	in $1/K^2$
τ	Heating time constant, characteristic value for the rate of heating of the conductor	in s

4.1.2 Additional parameters used

I	Current that leads to conductor heating	in A
T_O	Permissible long-term service temperature (3 000 h) of the cable class	in °C
T_L	Temperature of the conductor	in °C
T_a	Temperature of the ambient air around the cable, excluding the convective layer, (a for ambient)	in °C
$T_L(t)$	Progress of the conductor temperature in the dynamic transition area after abrupt change of the load current	in °C
T_{Lmin}	Beginning temperature of the conductor in the steady state before abrupt change of the load current	in °C
T_{Lmax}	End temperature of the conductor after abrupt change of the load current at the end of the dynamic transition area	in °C

4.2. Simplified equations

The following simplified equations are used to calculate the temperature increase as a result of current supply.

Note: This simplified representation exactly describes only one definite area of application; however, it is sufficiently precise for the design of single-wire vehicle cables in practice. If, however, the expected ambient temperatures deviate heavily from the temperatures at which the measurements described below were made, new parameters must be determined for this.

4.2.1 Conductor temperature difference ΔT in the steady case in K

$$\Delta T = a \cdot I + b \cdot I^2 \quad \text{(eq. 1)}$$

$$\Delta T = T_L - T_a \quad \text{(eq. 2)}$$

ΔT in K; conductor temperature difference as compared to the ambient temperature in the steady state (after at least ~5 τ).

4.2.2 Conductor temperature difference ΔT(t) in the dynamic transition status

$$\Delta T(t) = \Delta T_{\max}\left(1 - e^{-\frac{t}{\tau}}\right) \quad \text{(eq. 3)}$$

$$\Delta T(t) = T(t) - T_{L\min} \quad \text{(eq. 4)}$$

$$\Delta T_{\max} = T_{L\max} - T_{L\min} \quad \text{(eq. 5)}$$

ΔT(t) in K describes the chronological sequence of the difference in the latest conductor temperature as compared to the conductor temperature before the abrupt change of current supply. If the conductor was previously exposed to the ambient temperature T_a without current and for a sufficiently long time (> ~5τ), the conductor temperature T_{Lmin} corresponds to the ambient temperature T_a.

4.2.3 Conductor resistance R'(T) in Ω/m

$$R'(T_L) = R'_{20} \cdot \left[1 + \alpha_\rho \cdot (T_L - 20\ °C) + \beta_\rho \cdot (T_L - 20\ °C)^2\right] \quad \text{(eq. 6)}$$

4.2.4 Voltage drop per length E in V/m

$$E = R'(T_L) \cdot I \quad \text{(eq. 7)}$$

5. Load cases for the cable comparison

The simplified computational procedure described in this Supply Specification enables the conductor heating to be calculated with great accuracy, depending on a different current load and ambient temperature of the cable. However, often not the evaluation of a specific loading situation is desired, but rather the comparison between different cables.

For this comparison, currents in ambient conditions are defined as follows, with reference to the aging temperatures for short- and long-term aging designated in LV 112-1:

I_D	Long-term use current (derating current), defined as the current which, in steady operation at an ambient temperature of T_O – 50 K, results in a conductor temperature of $T_L = T_O$. The associated test in LV 112-1 is the long-term aging of 3 000 h at T_O	in A
I_{KU}	Short-term current, defined as the current which, in steady operation at an ambient temperature of T_O – 50 K, results in a conductor temperature of $T_L = T_O$ + 25 K. The associated test in LV 112-1 is the short-term aging of 240 h at T_O + 25 K	in A
$I_{ÜL}$	Overload current, defined as the current which, in steady operation at an ambient temperature of T_O – 50 K, results in a conductor temperature of $T_L = T_O$ + 50 K.	in A

The associated test in LV 112-1 is the
thermal overloading test of 6 h at T_O + 50 K

These three currents must be indicated by the cable manufacturer in addition to the characteristic parameters of the cable in supplement 1.

6. Measuring methods

Starting from known physical parameters (e.g., specific heat capacity, specific electrical conductor resistance), the characteristic cable parameters can be calculated on the basis of known and documented procedures. The computation is not presented in detail in this Supply Specification. However, measuring methods are indicated, which allow a verification with the aid of the example measurement at selected cables.

6.1. Recording the calibration curve R(T)

Because the resistance of the cable is used later to determine the temperature of the conductor, this calibration measurement is conducted first, provided the temperature coefficients of the conductor material used are not inherently known.

The cable to be tested is heated to defined temperatures in a heatable bath with silicone oil.

As an alternative, measurements are permissible in suitable heating ovens.

6.1.1 Sample length

Nominal cross section	Length
<2,5 mm²	10 m
≤2,5 mm² to 10 mm²	5 m
≥10mm²	2 m

At least 80% of the specimen must be immersed in the oil.

6.1.2 Four-point measurement

The injected current must be kept constant and selected such that the current does not considerably heat the conductor.

Nominal cross section	Max. permissible current
<2,5 mm²	10 mA
≤2,5 mm² to 10 mm²	50 mA
≥10mm²	200 mA

Contacting for the voltage measurement takes place directly in the oil. A measuring instrument with sufficiently high internal resistance (>1 MΩ) must be provided to measure the voltage. The length between the voltage measuring points must be defined as ±2 mm exactly.

The resistance of the conductor must be determined by measuring current and voltage for each adjusted temperature.

6.1.3 Temperatures to be adjusted

Beginning with room temperature, measuring points must be selected with an interval every approx. 20 K up to T_O +50 K.

Note: T_O as per temperature class of the sample.

The temperature of the oil bath must be measured and regulated. It must be ensured through suitable circulation that the bath has a uniform temperature distribution. After the temperature is increased to the next level, wait until the temperature measurement of the oil does not change for longer than 1 min by more than ±3 K and the resistance value not by more than $0{,}4^{0}/_{00}$.

6.1.4 Evaluation, determination of R'_{20}, α_ρ, and β_ρ

A calibration curve T(R') must be determined from the measured values.

T	Temperature	in °C
R'	Resistance	in Ω/m
ΔT = T – 20 °C		in K

The resistance temperature value pairs R'(ΔT) – ΔT obtained must then be "fitted" with the following resistance curve, and the parameters c, d, and e must be determined.

$$R'(\Delta T) = c \cdot \Delta T^2 + d \cdot \Delta T + e \quad \text{(eq. 8)}$$

However, the representation as in (eq. 6) is common for the temperature dependence of the resistance. Rewriting (eq. 6) results in the following:

$$R'(\Delta T) = \beta_\rho \cdot R'_{20} \cdot \Delta T^2 + \alpha_\rho \cdot R'_{20} \cdot \Delta T + R'_{20} \quad \text{(eq. 9)}$$

R'_{20}	Length-related conductor resistance at +20 °C	in Ω/m
α_ρ	Linear temperature coefficient of the material-specific conductor resistance	in 1/K
β_ρ	Quadratic temperature coefficient of the material-specific conductor resistance	in 1/K²

The constants R'_{20}, α_ρ, and β_ρ result from comparing coefficients with the following formulas:

$$R'_{20} = e \quad \text{(eq. 10)}$$

$$\alpha_\rho = \frac{d}{e} \quad \text{(eq. 11)}$$

$$\beta_\rho = \frac{c}{e} \quad \text{(eq. 12)}$$

Note: The following approximate temperature coefficients can be assumed:

Conductor material	Temperature coefficients [1]			
	α_ρ		β_ρ	
Cu ETP1	4,0	10^{-3} 1/K	0,0	1/K²
Al 99,7	4,1		0,0	
CuMg 0,2	3,2		0,0	
CuAg 0,1	3,8		0,0	
CuSn 0,3	2,9		0,0	

[1] Apply as average values for the temperature interval +20 °C to +200 °C

6.2. Current-loading test with determination of conductor temperature T

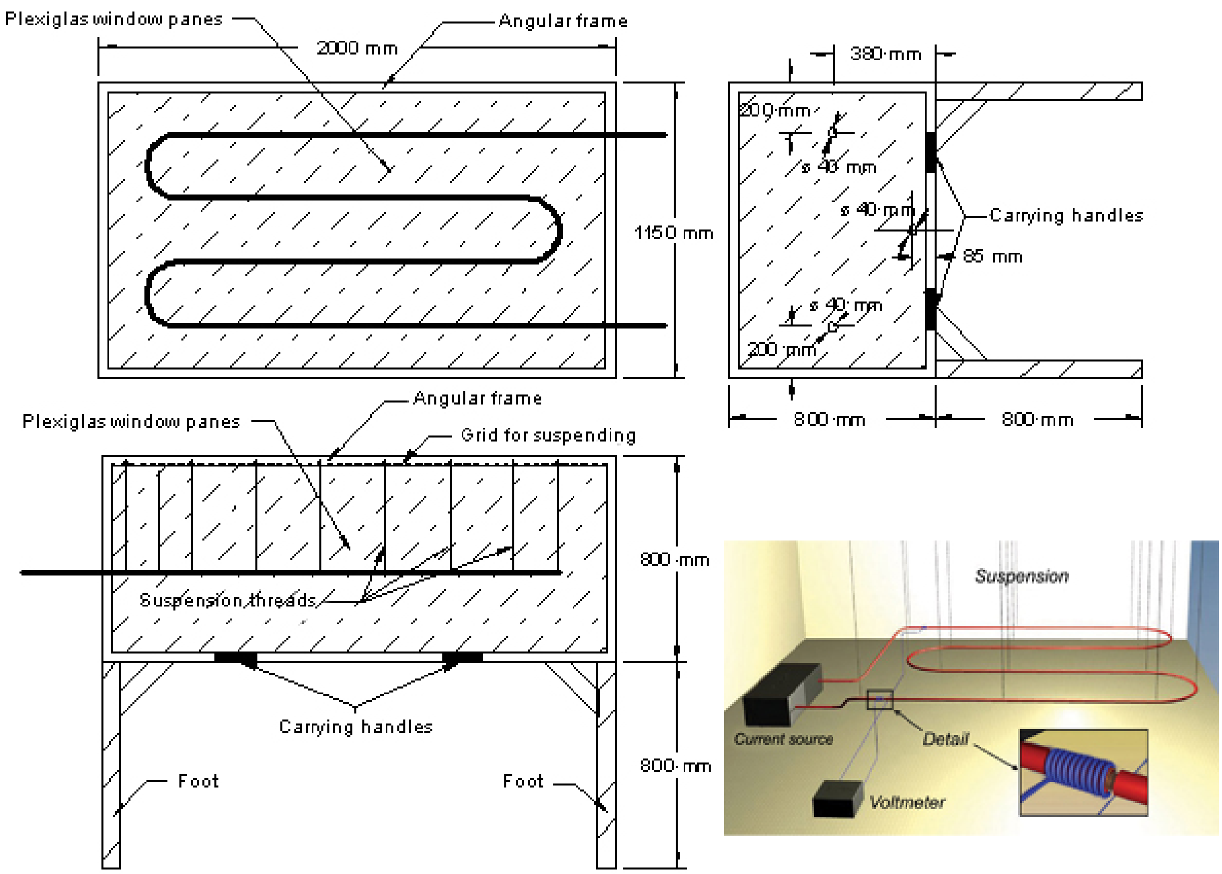
6.2.1 Measuring setup

The cable to be tested must be suspended from non-metallic cords in a rectangular-shaped chamber to prevent a draft of air. The chamber must have the approximate (i.e., with ±50 mm tolerance in the main dimensions) dimensions of (figure 1) below. The number of required suspension points may be decreased by tightening the straight conductor segments with horizontal cords.

Heat dissipation by the suspension must be prevented as much as possible. The distance to the floor must be at least 300 mm, the distance of the cables to one another at least 200 mm, and the distance of the cable to the room walls at least 50 mm. If necessary, the cable may be laid in a meandering pattern.

To achieve proper measuring accuracy, the length of the chosen cable to be tested must be as large as possible, particularly for large nominal cross sections. It is limited in practice by the dimensions and measuring chamber. For small nominal cross sections with a high length-related resistance, the largest possible length is determined by the dimensions of the test chamber as well as by the maximum possible supply voltage of the current source.

Figure 1



The required length of the sample may either be determined experimentally, or mathematically using a theoretical computation of the overload current $I_{ÜL}$ to be expected as per the following formula.

$$l_{max} = \frac{U_{max}}{I_{ÜL} \cdot R'(T_O + 25K)} \qquad \text{(eq. 13)}$$

l_{max}	Largest possible length of the sample, including the required length up to the external supply points	in m
U_{max}	Highest possible supply voltage of the current source	in V
$R'(T_O + 25K)$	Length-related resistance of the sample at T_O + 25 K, calculated as per eq. 6	in Ω/m

The measurement length between the voltage tapping points must, however, not be less than 1 m, even with small nominal cross sections.

The nominal cross section of both voltage measurement cables must be significantly smaller than that of the cable to be tested, in order to minimize thermal influence on the measuring point. A better thermal coupling is achieved e.g., by winding the measuring cable around the test line before voltage tapping.

In order to retain a uniform temperature over this range, it is important that at least 1,5 m long cable segments for supplying the current are located on both sides up to the voltage tapping point. This results in a minimum possible cable length of 4 m.

6.2.2 Measurement of room temperature and initial resistance

Because the conductor temperature is determined using the resistance of the sample measured during current-loading and taking into account the temperature coefficients α_ρ and β_ρ of the electrical conductor resistance, the starting situation must be recorded exactly, in order to arrive at an exact temperature statement.

After the measuring setup has been allowed to dwell at least 4 h without current, so that the conductor assumes room temperature, the initial resistance and the associated conductor temperature = room temperature is measured with a current/voltage measurement.

When conducting the current-voltage measurement, do not select a current that is too low, in order to ensure the required accuracy of reading during the voltage measurement. Care must be taken to keep the measurement as short as possible to prevent a distortion of the measured value by heating the conductor too much. Tested values are, e.g., 1 A for 0,35 mm² with a reading time for voltage under 2 s.

The initial resistance is converted using the known length between the voltage taps to the length-related resistance.

$$R'(T_a) = \frac{U}{I \cdot l_{Sp}} \qquad \text{(eq. 14)}$$

U	Measured voltage	in V
I	Measured current	in A
l_{Sp}	Distance between the voltage taps	in m
$R'(T_a)$	Measured length-related resistance at room temperature T_a	in Ω/m

Next, this value pair is used to calibrate the conductor temperature measurement, in which the latest R'_{20} value from the rewritten (eq. 6) is calculated as follows, with the known temperature coefficients α_ρ and β_ρ.

$$R'_{20} = \frac{R'(T_a)}{1+\alpha_\rho \cdot (T_a - 20°C) + \beta_\rho \cdot (T_a - 20°C)^2} \qquad \text{(eq. 15)}$$

As an alternative to this approach, the value for R'_{20} can also be determined with a temperature-compensated resistance measuring bridge, which can compensate for the conductor material used. (Use caution with alloys!)

6.2.3 Measurement of the resistance change with various current supplies

The current to be injected is always kept constant, but is increased in a number of steps (at least 10) suitable for the expected bend of the current-temperature curve until the conductor temperature T_O +50 K is reached. Subsequently, it is returned to the zero value with the same steps.

The voltage drop between the voltage taps is measured for each current step, and its average value determined after the dynamic transition status. The steady state is deemed to be reached when the measured voltage does not change by more than ±1% over a period of at least ~5 τ.

τ must therefore be estimated beforehand using a theoretical computation.

As an alternative, one can analyze the measured chronological resistance process parallel to the measurement, preferably in graphic form. A decision can then be made from this, whether the steady state has already been reached in sufficient quantities.

The room temperature T_a slightly below the level of the cable suspension is always documented as well.

Direct current (DC) must be used for the measurement. As an alternative, the actual shape of signal must be taken into account in the computations by suitable corrective factors.

From the quotient R(I), derived from voltage U(I) and current I, taking into account the length between the voltage taps l_{Sp}

$$R'(I) = \frac{U(I)}{I \cdot l_{Sp}} \qquad \text{(eq. 16)}$$

the conductor temperature T_L is calculated by solving (eq. 9) for ΔT as follows. Here, in many cases (in small quadratic coefficients β_ρ), only the linear coefficient $\alpha_\rho$can be taken into account, in order to simplify the calculation:

- By neglecting the quadratic temperature coefficient β_ρ:

$$T_L - 20\ °C = \Delta T = \frac{1}{\alpha_\rho} \cdot \left(\frac{R'(I)}{R'_{20}} - 1 \right) \qquad \text{(eq. 17)}$$

- By taking into account both temperature coefficients α_ρ and β_ρ:

$$T_L - 20\ °C = \Delta T = \frac{-\alpha_\rho + \sqrt{\alpha_\rho{}^2 + 4 \cdot \beta_\rho \cdot \left(\frac{R'(I)}{R'_{20}} - 1 \right)}}{2 \cdot \beta_\rho} \qquad \text{(eq. 18)}$$

Since (eq. 18) can be too highly influenced by measuring errors due to quotients near zero, the root is replaced by the first three terms of the Taylor series:

$$\sqrt{1+x} \approx 1 + \frac{x}{2} - \frac{x^2}{8} \qquad \text{(eq. 19)}$$

which leads to the following more precise result with a small β_ρ:

$$T_L - 20\,°C = \Delta T \approx \frac{1}{\alpha_\rho}\left(\frac{R'(I)}{R'_{20}} - 1\right)\cdot\left[1 - \frac{\beta_\rho}{\alpha_\rho{}^2}\left(\frac{R'(I)}{R'_{20}} - 1\right)\right] \qquad \text{(eq. 20)}$$

6.2.4 Determining the characteristic cable parameters a and b

A table with (at least 8) current values and the assigned conductor temperatures arises as a result of the measurement and subsequent computation in section 6.2.3.

The characteristic cable parameters a and b must be determined using suitable methods by "fitting" from the determined values. Only measured values for a conductor temperature of T_O -50 K to T_O +25 K must be taken into account in the process.

When using the computational tool, the same temperature range must be taken into account.

The functional association between (eq. 1) and (eq. 2) (see section 4.2.1) must be observed here.

After determining the constants a and b, it is possible to calculate the required load current I_{zu} from (eq. 1) and (eq. 2) with the specification of the ambient temperature T_a and the permissible conductor temperature T_{Lzu}:

$$I_{zu} = \frac{1}{2 \cdot b} \cdot \left[-a + \sqrt{a^2 + 4 \cdot b \cdot (T_{Lzu} - T_a)}\right] \qquad \text{(eq. 21)}$$

Note: By solving the quadratic equation (eq. 1), the "+" before the root expression must be used.

6.2.5 Determining the time constant τ , dynamic heating characteristics

The time constant τ is preferably determined mathematically by means of the computational tool [6]. These values can be confirmed by the measuring method described below in cases of doubt.

Note: This measuring method will be more optimized in the next revision of LV 112-3.

The time constant τ is measured in the measuring chamber at room temperature, where the conductor temperatures T_{Lmin} and T_{Lmax} are adjusted to the following default values, by entering load currents that were previously calculated with the help of (eq. 21) (see section 6.2.4):

Conductor temperature T_{Lmin}	Required current at T_a = RT Room temperature	Conductor temperature T_{Lmax}	Required current at T_a = RT Room temperature
T_O –50 K	I_{To-50}	T_O +25 K	$I_{Ku} = I_{To+25}$

6.2.5.1. Determining the time constant τ

The temperature of the conductor is monitored and recorded in the measurements described below by measuring the current and voltage, and determining the conductor resistance as per equation (eq. 17) or (eq. 20) (see section 6.2.3)

The cable that is built on a measuring setup as per section 6.2.1 in a room at room temperature of around 20 °C and at the start of the measurement is loaded with the current I_{To-50} until no change to the measured conductor temperature is any longer discerned. The conductor should then exhibit a temperature approximate to T_O –50 K.

Next, the cable to be measured is heated with a jump to the current I_{Ku} = $_{To+25}$ as long as necessary until any change to the measured conductor temperature is no longer discerned. By loading with I_{To+25}, the temperature at the conductor ultimately arrives at T_O +25 K.

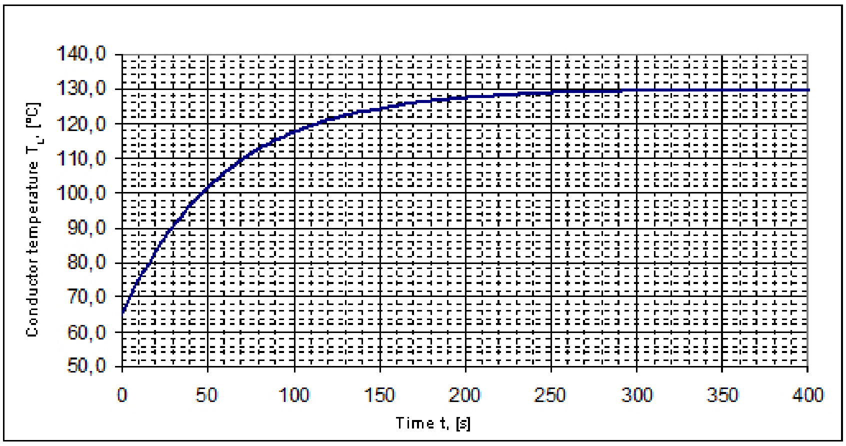
A time constant is determined by this procedure, which corresponds to a continuous load current approximate to I_{KU} at $T_a = T_O$ –50 K; however, the measurement can take place here at room temperature.

The periodic intervals between the individual recorded measured values must be selected such that at least 20 measured values are available for the dynamic transition area. The following time intervals have proven useful:

Nominal cross section	Time intervals
<0,5 mm²	1 s
≤4 mm²	3 s
6 mm² to 10 mm²	10 s
≥10 mm²	20 s

The time constant $\tau$from the values determined by "fitting" must be determined. The functional association in the process as per (eq. 3) (see section 4.2.2) must be observed.

Example: Unscreened low-voltage cable with thin-walled PVC insulation (FLRY) 2,5-B, a = 0,25, b = 0,041, T_a =20 °C, τ = 60,6 s
$I_{To\ -50K}$ = 30,2 A; $I_{Ku} = I_{To+25K}$ = 48,8; T_O = 105 °C; $T_{O\ -50K}$ = 65 °C, $T_{O\ +25K}$ = 130 °C



7. Documentation of the parameters to calculate the current capacity

The cable manufacturers must enter the parameters defined in LV 112-3, supplement 1 for each cable, and provide them to the appropriate design engineering department.

8. Application of the simplified description model

8.1. Calculating the current capacity – steady behavior

The permissible current capacity of a cable depends on the following parameters:
- the ambient temperature to be expected
- the maximum permissible long-term service temperature T_O, depending on the cable class used or on the insulation material
- the characteristic cable parameters of the cable used

8.1.1 Temperature increase and voltage drop with specified current

The conductor temperature during continuous loading results from (eq. 1) and (eq. 2) (see section 4.2.1) with the specified ambient temperature T_a and load current I:

$$T_L(I, T_a) = T_a + aI + bI^2 \qquad \text{(eq. 22)}$$

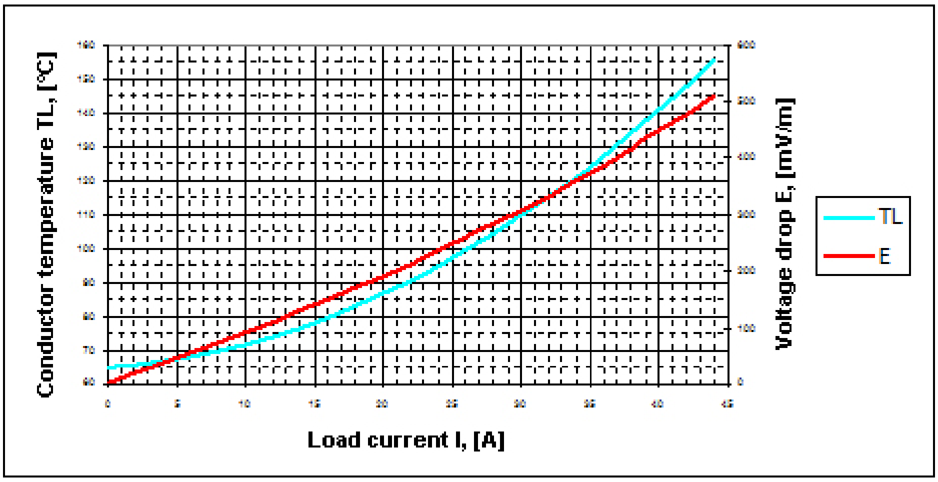
Note: This formula yields a correct result only with positive current values!

The associated voltage drop per 1 m results from (eq. 6) (see section 4.2.3) and (eq. 7) (see section 4.2.4)

$$E(I) = I \cdot R'_{20} \cdot \left[1 + \alpha_\rho \cdot (T_L - 20) + \beta_\rho \cdot (T_L - 20)^2\right] \qquad \text{(eq. 23)}$$

In order to take into account the worst-case in voltage drop, the maximum permissible resistance for R'_{20} is taken as a basis from LV 112-1 for the respective cable.

Example: FLRY 2,5-B, a = 0,25, b = 0,041, T_a = 65 °C,
R_{20} = 7,6 mΩ/m, $\alpha_\rho = 3{,}81 \cdot 10^{-3}$ 1/K, $\beta_\rho = 6 \cdot 10^{-7}$ 1/K^2



8.1.2 Permissible current depending on ambient temperature – derating

The maximum permissible current must be determined such that, under continuous loading, taking into account the ambient temperature to be expected, the temperature at the conductor remains lower than the long-term service temperature T_O.

At maintained T_O and varied ambient temperature T_a, the desired functional association for the permissible current also results from (eq. 1) and (eq. 2) (see section 4.2.1)

Two representations are possible, where the same information can be derived from both consequent diagrams. However, (eq. 24) or (eq. 25) are better suited for calculating a specific load case, depending on the problem.

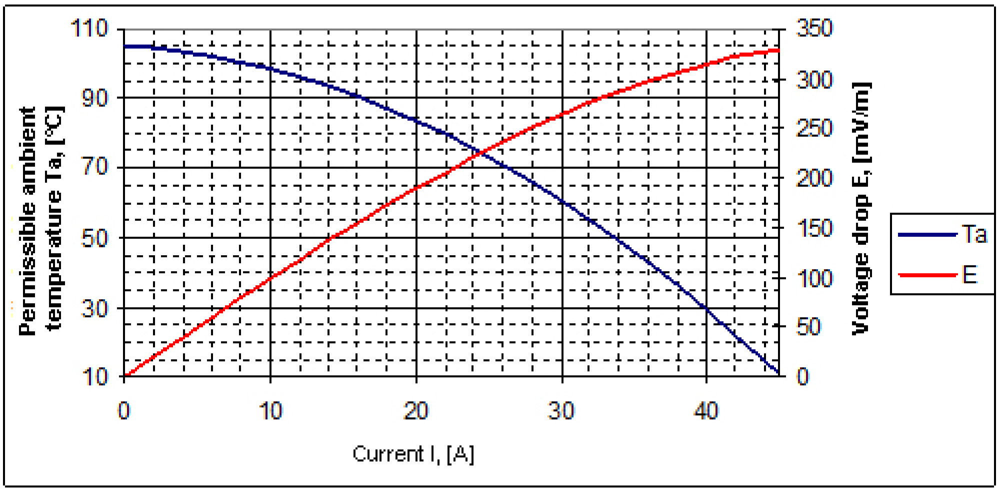
(eq. 23) is used again to calculate the voltage drops.

8.1.2.1. Permissible ambient temperature with specified current

$$T_a(I,T_O) = T_o - aI - bI^2 \qquad \text{(eq. 24)}$$

Note: This formula yields a correct result only with positive current values!

Example: FLRY 2,5-B, a = 0,25, b = 0,041, T_O = 105 °C,
R_{20} = 7,6 mΩ/m, $\alpha_\rho = 3{,}81 \cdot 10^{-3}$ 1/K, $\beta_\rho = 6 \cdot 10^{-7}$ 1/K²

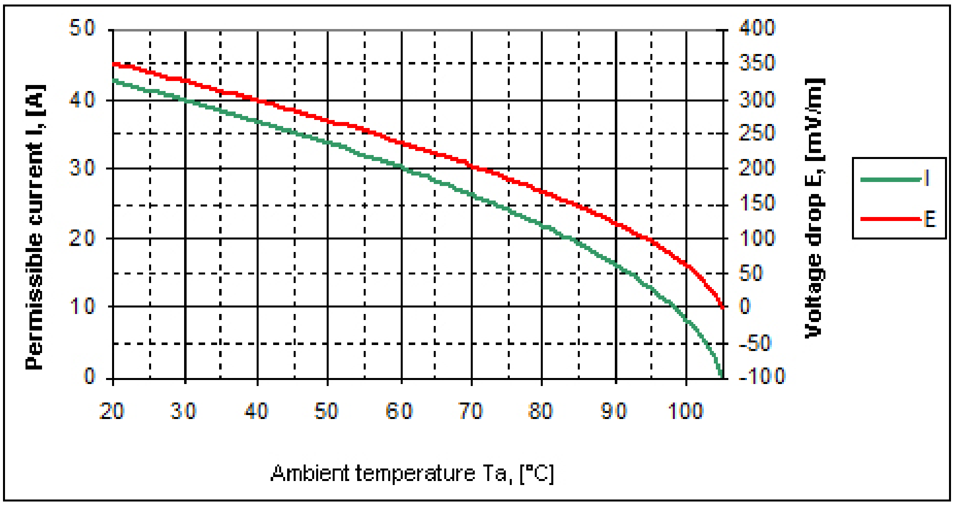


8.1.2.2. Permissible current with specified ambient temperature

$$I(T_a,T_O) = \frac{1}{2 \cdot b} \cdot \left[-a + \sqrt{a^2 + 4 \cdot b \cdot (T_O - T_a)}\right] \qquad \text{(eq. 25)}$$

Note: By solving the quadratic equation, the "+" before the root expression must be used.

Example: FLRY 2,5-B, a = 0,25, b = 0,041, T_O = 105 °C,
R_{20} = 7,6 mΩ/m, $\alpha_\rho = 3{,}81 \cdot 10^{-3}$ 1/K, $\beta_\rho = 6 \cdot 10^{-7}$ 1/K²



8.2. Calculating the heating time – unsteady behavior

The size of the time constant τ is very highly dependent on the ambient temperature Ta, where τ is lower with a higher ambient temperature. If conductor temperature are estimated taking the dynamic transition behavior as a basis, lower values for τ must be selected to ensure additional certainty.

8.2.1 Calculating the heating time with specified current

With specified ambient temperature and permissible conductor temperature, the permissible continuous load current I (T_a, T_O) arises from (eq. 25), at which the long-term service temperature of the cable T_O is not exceeded. This equation can also be used for calculating any limit currents I_{Gr}, if a different limit temperature T_{Gr} is used instead of T_O.

From (eq. 26), taking into account the time constant τ for currents that are higher than the limit current I_{Gr}, the heating time t_E can be calculated, which is required after an abrupt switching-on of the current I. This is so that at the ambient temperature T_a, starting from the no-current status, the conductor temperature T_{Gr} can be reached.

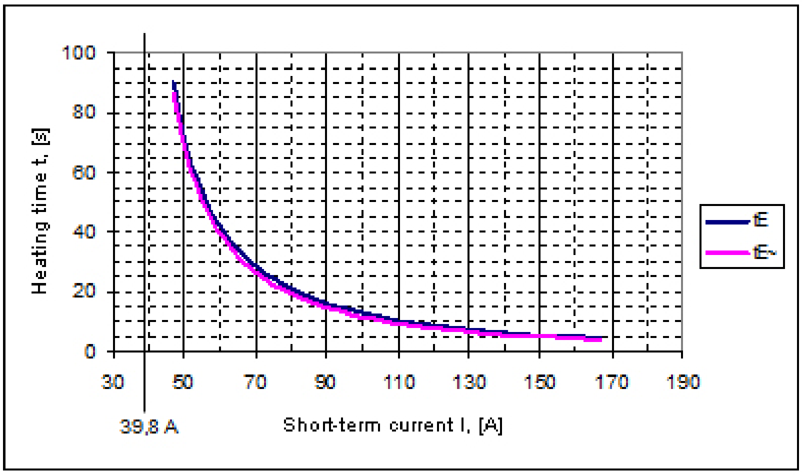
$$t_E = \tau \cdot \ln \frac{a \cdot I + b \cdot I^2}{a \cdot I + b \cdot I^2 - (T_{Gr} - T_a)} \qquad \text{(eq. 26)}$$

As an alternative, one can determine the limit current I_{Gr} with (eq. 25) and calculate it with the simplified equation (eq. 27).

$$t \approx \tau \cdot \ln \frac{I^2}{I^2 - I_{Gr}^2} \qquad \text{(eq. 27)}$$

In the following example, the heating times for various load currents are presented in a diagram, where the short-term current I_{KU} defined in section 5 is used as the limit current I_{Gr}.

Example: FLRY 2,5-B, τ = 68 s, heating of T_a = 65 °C to T_L = 130 °C,
$I_{Gr} = I_{KU}$ = 39,8 A, Compare t_E as per (eq. 26) or t as per. (eq. 27)



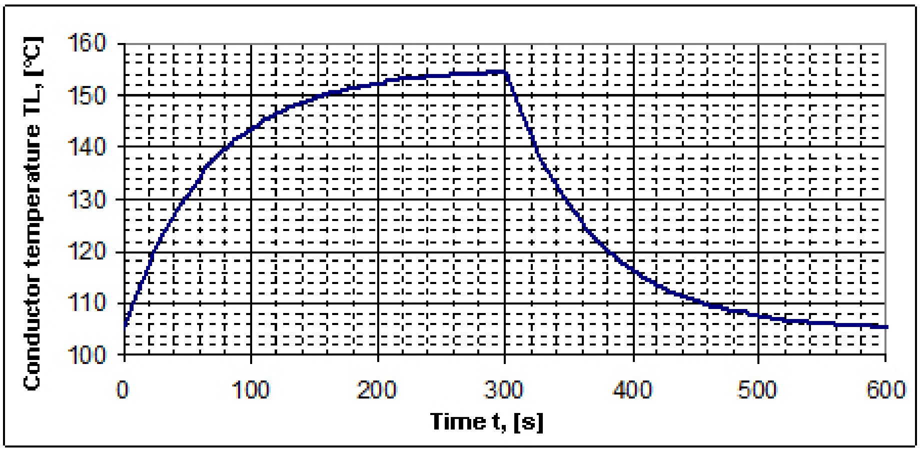
The peak current I_{Ku} is the current at which exactly the short-term temperature T_{Ku} is reached at the conductor, with specified ambient temperature T_a in the steady borderline case. The curve in the diagram thus approaches the steady current I_{Ku} asymptotically.

One can recognize well in the example, that the error when using the simplified (eq. 27) is only very low.

8.2.2 Short-term behavior with load changes

The chronological sequence in load changes can be calculated with the equations (eq. 3) , (eq. 4) , and (eq. 5).

Example: FLRY 2,5-B, τ = 68 s, Ta = To-50 K = 55 °C,
T_{Lmin} = 105 °C, T_{Lmax} = 155 °C, I_D = 32,0 A, I_{Ku} = 46,4 A



This example demonstrates the time behavior during short-term overload. Initially, the conductor has the permissible class temperature of $T_{Lmin} = T_O$ = 105 °C. This is reached at the selected ambient temperature $T_a = T_O$ –50 K = 55 °C by the derating current I_D = 32,0 A. With increase to the overload current $I_{ÜL}$ = 46,4 A, the conductor temperature approaches the short-term temperature $T_{ÜL} = T_O$ +50 K = 155 °C with the time constant τ = 68 s. However, the conductor temperature does not quite reach the short-term temperature, since the lower current is again supplied after 300 s, whereby cooling to T_O takes place with the same time constant.

Note: Both currents I_D and $I_{ÜL}$ can be calculated with (eq. 25) (see section 8.1.2.2).

8.2.3 Short-circuit derating

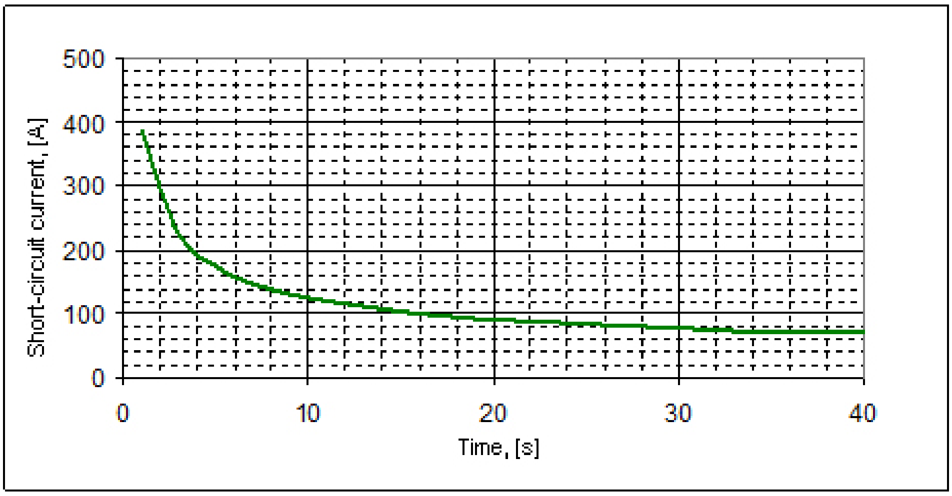
(eq. 27) (see section 8.2.1) can be rewritten as follows, where also I_{Gr} is replaced by $I_{ÜL}$:

$$I(t) \approx I_{ÜL} \cdot \sqrt{\frac{1}{1-e^{-\frac{t}{\tau}}}} \qquad \text{(eq. 28)}$$

The overload current $I_{ÜL}$ has been defined in the preceding example, at which the temperature for the thermal overload test $T_{ÜL} = T_O$ +50 K, defined in LV 213-1, is not exceeded in the steady case. All cables must withstand this temperature for 6 h without incurring damage.

Starting with this overload current $I_{ÜL}$, it can be calculated using (eq. 28), how long short-circuit currents must be present at maximum at the initially current-free conductor, to ensure that the thermal overload temperature $T_{ÜL}$ is not exceeded.

Example: FLRY 2,5-B, τ = 68 s, $T_a = T_O$ –50 K = 55 °C,
$T_{ÜL} = T_O$ +50 K = 155 °C, $I_{ÜL}$ = 46,4 A



8.2.4 Selection of fuses

The guaranteed triggering time of the fuse to be used at the specified short-circuit current strength must be less than or equal to the times calculated in section 8.2.3, to ensure that the conductor temperature remains less than $T_{ÜL.}$

In practice, low short-circuit currents are problematic above all, such as those occurring in creeping short circuits, because many fuses then require a very long time to trigger. This means that the guaranteed triggering times are generally far longer than the time constant τ of the cables. When selecting the fuse, therefore, the thermal overload current $I_{ÜL}$ of the cable must be observed above all.

9. Outlook

In addition to the single-wire cables described in this Standard, the following components are also used for supplying current to the electrical components in vehicles:

1. Multi-wire cables
2. Harnesses
3. Fuses
4. Current distributor boxes

By using and further developing the simplified mathematical approach described in this document, standardized computation procedures are planned to be prepared in the future for these areas.

As described in the references (see section 0), it is also possible to arrive at the characteristic parameters by computation using a few practical control measurements, if the physical material constants of the materials used are known. There is a computational tool (software package) [6] for this purpose, which is offered for sale.

10. Appendix

10.1. List of required measuring equipment (example)

1. Test chamber with approx. 1,8 m^3 space volume (see Figure 1)
2. Power supply unit for current injection, manufactured by Fug, Type "Low Voltage Power Supply NTN 700M – 65"

Input	
Mains connection, single-phase	230 V ±10%
	47 to 63 Hz
	max. 6 A
or	115 V ±10%
	47 to 63 Hz
	max. 12 A
Output	
Output current	0 to 10 A
Output voltage	0 to 65 V
Accuracy	
All data related to maximum value	
Residual ripple	<1 x 10^{-4} ss + 10 mVss
Normal deviation of current or voltage	
At ±10% mains power deviation at idle state	<1 x 10^{-5}
At ±10% mains power deviation at full throttle	<2 x 10^{-4}
Over 8 h constant conditions	<±1 x 10^{-4}
With temperature change	<±1 x 10^{-4}/K
Absolute precision	
For all rated voltages	<±0,2% of nominal value
For all rated currents >5 mA to <10 A	<±0,2% of nominal value

3. High-current device, manufactured by Jovyatlas, custom build without type designation

Input	
Mains connection, three-phase	230 V ±10%
	47 to 63 Hz
	Max. 7 A
Output	
Output current	0 to 1 200 A
Output voltage	0 to 5,1 V
Limits	
Current ripple	0,3% max.
Leap in desired value, current	
Readjustment time 0 to 1 200 A	635 ms typ.

4. Multimeter for current measurement, manufactured by HP, type HP 34401A

	24 h (23 ±1) °C	24 h (23 ±1) °C
	Accuracy of reading	Measuring range accuracy
DC V	%	%
100 mV	±0,0030	±0,0030
1 V	±0,0020	±0,0006
10 V	±0,0015	±0,0004
DC I		
10 mA	±0,005	±0,01
100 mA	±0,010	±0,004
1 A	±0,050	±0,006
3 A	±0,100	±0,020

5. Multimeter for current measurement, manufactured by Keithley, type 2700, with data recording by LabView programming

	24 h (23 ±1) °C	24 h (23 ±1) °C
	Accuracy of reading	Measuring range accuracy
DC V	%	%
100 mV	±0,0015	±0,0030
1 V	±0,0015	±0,0006
10 V	±0,0010	±0,0004
DC I		
20 mA	±0,0060	±0,0030
100 mA	±0,0100	±0,0300
1 A	±0,0200	±0,0030
3 A	±0,1000	±0,0015

6. Temperature measurement with thermopair TE type K, Testo data logger T4 for recording room temperature in derating box and conductor temperature

	24 h (23 ±1) °C	
	Measuring range accuracy	
	%	
Measuring instrument (-100 to 70) °C	±0,3 °C	
Thermopair with TE plug, flexible, length 1 500 mm, filament glass yarn, TE type K	±2,5 °C	±0,0075•δ (referenced to temperature in °C)
Sensor deviation measured at +80 °C	±0,2 °C	

11. Normative references

The following cited documents are required for application of this document. For dated references, only the referenced issue is valid. For undated references, the most recent issue of the referenced document (including all changes) is valid.

LV 112-1	Electric wiring in motor vehicles, copper cable; single-wire, unscreened
LV 112-2	Electric wiring in motor vehicles, aluminum cables; single-wire, unscreened

12. Literature

[1] VDI Heat Atlas, issuing body: Association of German Engineers (VDI), Berlin (Springer Verlag), 10th edited and expanded edition, 2006, ISBN 3-540-25504-4

[2] Kabel und Leitungen für Starkstrom (Cables and lines for heavy current – only available in German), part 1, issuing body Lothar Heinhold, Berlin, Munich (Siemens AG), 4th revised edition 1987, ISBN 3-8009-1472-7

[3] Bestimmung der Strombelastbarkeit von Fahrzeugleitungen (Determining the current-loading capacity of vehicle cables – only available in German), H.-D. Ließ, Universität der Bundeswehr, Munich, 2010

[4] Berechnungswerkzeug (Softwaretool) (Calculation tool (Software tool) – only available in German), H.-D. Ließ, Universität der Bundeswehr, Munich