

INTERNATIONAL STANDARD

IEC
60287-3-2

First edition
1995-06

**Electric cables –
Calculation of the current rating –
Part 3-2:
Sections on operating conditions –
Economic optimization of power cable size**

*This **English-language** version is derived from the original **bilingual** publication by leaving out all French-language pages. Missing page numbers correspond to the French-language pages.*



Reference number
IEC 60287-3-2:1995(E)

Publication numbering

As from 1 January 1997 all IEC publications are issued with a designation in the 60000 series. For example, IEC 34-1 is now referred to as IEC 60034-1.

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Commission Electrotechnique Internationale
International Electrotechnical Commission
Международная Электротехническая Комиссия

PRICE CODE

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For price, see current catalogue

CONTENTS

	Page
FOREWORD	5
Clause	
0 Introduction	7
1 Scope	13
2 Normative references	13
3 Symbols	15
4 Calculation of total costs	17
5 Determination of economic conductor sizes	23
5.1 First approach: economic current range for each conductor in a series of sizes	23
5.2 Second approach: economic conductor size for a given load	25
Annexes	
A Examples of calculation of economic conductor sizes	29
B Mean conductor temperature and resistance	51

INTERNATIONAL ELECTROTECHNICAL COMMISSION

**ELECTRIC CABLES –
CALCULATION OF THE CURRENT RATING –****Part 3: Sections on operating conditions –
Section 2: Economic optimization of power cable size**

FOREWORD

- 1) The IEC (International Electrotechnical Commission) is a worldwide organization for standardization comprising all national electrotechnical committees (IEC National Committees). The object of the IEC is to promote international cooperation on all questions concerning standardization in the electrical and electronic fields. To this end and in addition to other activities, the IEC publishes International Standards. Their preparation is entrusted to technical committees; any IEC National Committee interested in the subject dealt with may participate in this preparatory work. International, governmental and non-governmental organizations liaising with the IEC also participate in this preparation. The IEC collaborates closely with the International Organization for Standardization (ISO) in accordance with conditions determined by agreement between the two organizations.
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International Standard IEC 287-3-2 has been prepared by sub-committee 20A: High-voltage cables, of IEC technical committee 20: Electric cables.

This first edition of 287-3-2 cancels and replaces the first edition of IEC 1059 published in 1991 without technical changes.

IEC 287-1-1 replaces sections one and two of the second edition of IEC 287; IEC 287-2-1 replaces section three and annexes C and D of the second edition of IEC 287; IEC 287-3-1 replaces annexes A and B of the second edition of IEC 287.

The text of this standard is based on the following documents:

DIS	Report on voting
20A(CO)131	20A(CO)139

Full information on the voting for the approval of this standard can be found in the report on voting indicated in the above table.

Annexes A and B are for information only.

0 Introduction

IEC 287 has been divided into three parts and sections so that revisions of, and additions to, the document can be carried out more conveniently.

Each part is divided into sections which are published as separate standards.

Part 1: Current rating equations (100 % load factor) and calculation of losses

Part 2: Thermal resistance

Part 3: Sections on operating conditions

This section was previously IEC 1059.

0.1 General part

The procedure generally used for the selection of a cable size leads to the minimum admissible cross-sectional area, which also minimizes the initial investment cost of the cable. It does not take into account the cost of the losses that will occur during the life of the cable.

The increasing cost of energy, together with the high energy losses which follow from the operating temperatures possible with the newer insulating materials (e.g. 90 °C for XLPE and EPR), now requires that cable size selection be considered on wider economic grounds. Rather than minimizing the initial cost only, the sum of the initial cost and the cost of the losses over the economic life of the cable should also be minimized. For this latter condition a larger size of conductor than would be chosen based on minimum initial cost will lead to a lower power loss for the same current and will, when considered over its economic life, be much less expensive.

The future costs of energy losses during the economic life of the cable can be calculated by making suitable estimates of load growth and cost of energy. The most economical size of conductor is achieved when the sum of the future costs of energy losses and the initial cost of purchase and installation are minimized.

The saving in overall cost, when a conductor size larger than that determined by thermal constraints is chosen, is due to the considerable reduction in the cost of the joule losses compared with the increase in cost of purchase. For the values of the financial and electrical parameters used in this standard, which are not exceptional, the saving in the combined cost of purchase and operation is of the order of 50 % (see clause A.6 in annex A). Calculations for much shorter financial periods can show a similar pattern.

A further important feature, which is demonstrated by examples, is that the savings possible are not critically dependent on the conductor size when it is in the region of the economic value, see figure A.3. This has two implications:

- a) The impact of errors in financial data, particularly those which determine future costs, is small. While it is advantageous to seek data having the best practicable accuracy, considerable savings can be achieved using data based on reasonable estimates.
- b) Other considerations with regard to the choice of conductor size which feature in the overall economics of an installation, such as fault currents, voltage drop and size rationalization, can all be given appropriate emphasis without losing too many of the benefits arising from the choice of an economic size.

0.2 Economic aspects

In order to combine the purchase and installation costs with costs of energy losses arising during the economic life of a cable, it is necessary to express them in comparable economic values, that is values which relate to the same point in time. It is convenient to use the date of purchase of the installation as this point and to refer to it as the "present". The "future" costs of the energy losses are then converted to their equivalent "present values". This is done by the process of discounting, the discounting rate being linked to the cost of borrowing money.

In the procedure given here inflation has been omitted on the grounds that it will affect both the cost of borrowing money and the cost of energy. If these items are considered over the same period of time and the effect of inflation is approximately the same for both, the choice of an economic size can be made satisfactorily without introducing the added complication of inflation.

To calculate the present value of the costs of the losses it is necessary to choose appropriate values for the future development of the load, annual increases in kWh price and annual discounting rates over the economic life of the cable, which could be 25 years or more. It is not possible to give guidance on these aspects in this standard because they are dependent on the conditions and financial constraints of individual installations. Only the appropriate formulae are given: it is the responsibility of the designer and the user to agree on the economic factors to be used.

The formulae proposed in this standard are straightforward, but in their application due regard should be taken of the assumption that the financial parameters are assumed to remain unchanged during the economic life of the cable. Nevertheless, the above comments on the effect of the accuracy of these parameters is relevant here also.

There are two approaches to the calculation of the economic size, based on the same financial concepts. The first, where a series of conductor sizes is being considered, is to calculate a range of economic currents for each of the conductor sizes envisaged for particular installation conditions and then to select that size whose economic range contains the required value of the load. This approach is appropriate where several similar installations are under consideration. The second method, which may be more suitable where only one installation is involved, is to calculate the optimum cross-sectional area for the required load and then to select the closest standard conductor size.

0.3 Other criteria

Other criteria, for example short-circuit current and its duration, voltage drop and cable size rationalization, must be considered also. However, a cable chosen to have an economical size of conductor may well be satisfactory also from these other points of view, so that when sizing a cable the following sequence may be advantageous:

- a) calculate the economic cross-sectional area;
- b) check by the methods given in IEC 287-1, in IEC 287-2 and in IEC 853 that the size indicated by a) is adequate to carry the maximum load expected to occur at the end of the economic period without its conductor temperature exceeding the maximum permitted value;
- c) check that the size of cable selected can safely withstand the prospective short-circuit and earth fault currents for the corresponding durations;
- d) check that the voltage drop at the end of the cable remains within acceptable limits;
- e) check against other criteria appropriate to the installation.

To complete the field of economic selection, proper weight should be given to the consequences of interruption of supply. It may be necessary to use a larger cross-section of conductor than the normal load conditions require and/or the economic choice would suggest, or to adapt the network accordingly.

A further cost component may be recognized in the financial consequence of making a faulty decision weighted by its probability. However, in doing so one enters the field of decision theory which is outside the scope of this standard.

Thus, economic cable sizing is only a part of the total economic consideration of a system and may give way to other important economic factors.

ELECTRIC CABLES – CALCULATION OF THE CURRENT RATING –

Part 3: Sections on operating conditions – Section 2: Economic optimization of power cable size

1 Scope

This International Standard deals solely with the economic choice of conductor size based on joule losses. Voltage dependent losses have not been considered.

NOTES

- 1 It is recommended that the method given in this standard should not be used for cables operating on system voltages equal to or greater than the following (see IEC 287-1-1):

Type of cable	System voltage U_0 kV
Cables insulated with impregnated paper:	
solid type	38
oil-filled and gas pressure	63,5
Cables with other types of insulation:	
butyl rubber	18
EPR	63,5
PVC	6
PE (HD and LD)	127
XLPE (unfilled)	127
XLPE (filled)	63,5

- 2 Modifications to the method given in this standard in order to take dielectric losses into account are under consideration.

Likewise, matters such as maintenance, energy losses in forced cooling systems and time of day energy costs have not been included in this standard.

An example of the application of the method to a hypothetical supply system is given in annex A.

2 Normative references

The following normative documents contain provisions which, through reference in this text, constitute provisions of this section of IEC 287-3. At the time of publication, the editions indicated were valid. All normative documents are subject to revision, and parties to agreements based on this section of IEC 287-3 are encouraged to investigate the possibility of applying the most recent editions of the normative documents indicated below. Members of IEC and ISO maintain registers of currently valid International Standards.

IEC 228: 1978, *Conductors of insulated cables*

IEC 287-1-1: 1994, *Electric cables – Calculation of the current rating – Part 1: Current rating equations (100 % load factor) and calculation of losses – Section 1: General*

IEC 287-2-1: 1994, *Electric cables – Calculation of the current rating – Part 2: Thermal resistance – Section 1: Calculation of thermal resistance*

IEC 853, *Calculation of the cyclic and emergency current rating of cables*

3 Symbols

The symbols used in this standard and the quantities which they represent are given in the following list:

A	variable component of cost per unit length related to conductor size	cu/m.mm ²
B	auxiliary quantity defined by equation (16)	–
C	constant component of cost per unit length related to laying conditions, etc.	cu/m
CT	total cost of a system	cu
D	demand charge each year	cu/W.year
F	auxiliary quantity defined by equation (10)	cu/W
$I_{\max}$	maximum load in first year i.e. the highest hourly mean value	A
$I(t)$	load as a function of time	A
l	cable length	m
CJ	present value of the cost of joule losses during N years	cu
N	period covered by financial calculations, also referred to as "economic life"	year
N_p	number of phase conductors per circuit	–
N_c	number of circuits carrying the same type and value of load	–
P	cost of one watt-hour at relevant voltage level	cu/W.h
CI	installed cost of the length of cable being considered	cu
CI_2	installed cost of the next larger standard size of conductor	cu
CI_1	installed cost of the next smaller standard size of conductor	cu
$CI(S)$	installed cost of a cable as a function of its cross-sectional area	cu
Q	auxiliary quantity defined by equation (8)	–
R	cable a.c. resistance per unit length, including the effect of $\gamma_p, \gamma_s, \lambda_1, \lambda_2$ (considered to be a constant value at an average operating temperature, see clause 4)	Ω/m
R_2	a.c. resistance per unit length of next larger standard conductor size	Ω/m

R_1	a.c. resistance per unit length of next smaller standard conductor size	Ω/m
$R(S)$	a.c. resistance per unit length of a conductor as a function of its area	Ω/m
S	cross-sectional area of a cable conductor	mm^2
S_{ec}	economic conductor size	mm^2
T	operating time at maximum joule loss	h/year
a	annual increase in I_{max}	%
b	annual increase in P , not covered by inflation	%
i	discounting rate used to compute present values	%
r	auxiliary quantity defined by equation (9)	—
t	time	h
γ_p	proximity effect factor, see IEC 287-1-1	—
γ_s	skin effect factor, see IEC 287 1-1	—
α_{20}	temperature coefficient of conductor resistance at 20°C	$1/\text{K}$
θ	maximum rated conductor operating temperature	$^\circ\text{C}$
θ_a	ambient average temperature	$^\circ\text{C}$
θ_m	mean operating conductor temperature	$^\circ\text{C}$
λ_1, λ_2	sheath and armour loss factors, see IEC 287-1-1	—
μ	loss load factor, see IEC 853	—
ρ_{20}	conductor resistivity at 20°C , see 5.2	$\Omega\cdot\text{m}$

4 Calculation of total costs

The total cost of installing and operating a cable during its economic life, expressed in present values, is calculated as follows. Note that all financial quantities are expressed in arbitrary currency units, (cu).

$$\text{The total cost} = CT = CI + CJ \text{ (cu)} \quad (1)$$

where

CI is the cost of the installed length of cable, cu;

CJ is the equivalent cost at the date the installation was purchased, i.e. the present value, of the joule losses during an economic life of N years, cu.

Evaluation of CJ

The total cost due to the losses is composed of two parts: a) the energy charge and b) the charge for the additional supply capacity to provide the losses.