

Method for

Determination of economic optimization of power cable size —

(Implementation of
CENELEC HD 558 S1)

Committees responsible for this British Standard

The preparation of this British Standard was entrusted by the Cables and Insulation Standards Policy Committee (CIL/-) to Technical Committee CIL/20, upon which the following bodies were represented:

- Aluminium Federation
- Association of Consulting Engineers
- Association of Manufacturers of Domestic Electrical Appliances
- British Approvals Service for Cables
- British Cable Makers' Confederation
- British Plastics Federation
- British Steel plc
- British Telecommunications plc
- Department of the Environment (Property Services Agency)
- Department of Trade and Industry (Consumer Safety United, CA Division)
- ERA Technology Ltd.
- Electricity Supply Industry in United Kingdom
- Engineering Equipment and Materials Users' Association
- Institution of Electrical Engineers
- London Regional Transport

The following bodies were also represented in the drafting of the standard, through subcommittees and panels:

- Electrical Contractors' Association
- Institution of Incorporated Executive Engineers
- London Underground Ltd.

This British Standard, having been prepared under the direction of the Cables and Insulation Standards Policy Committee, was published under the authority of the Standards Board and comes into effect on 28 June 1991

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The following BSI references relate to the work on this standard:
Committee reference CIL/20
Draft for comment 89/31146 DC

ISBN 0 580 19757 3

Amendments issued since publication

Amd. No.	Date	Comments

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National foreword

This British Standard has been prepared under the direction of the Cables and Insulation Standards Policy Committee. It is identical with IEC 1059:1991 “*Economic optimization of power cable size*” published by the International Electrotechnical Commission (IEC), which has been endorsed by CENELEC as HD 558 S1.

The Technical Committee has reviewed the provisions of IEC 228:1978, IEC 287:1982 and IEC 853, to which reference is made in the text, and has decided that they are acceptable for use in conjunction with this standard. A related British Standard to IEC 228:1978 is BS 6360:1981.

A British Standard does not purport to include all the necessary provisions of a contract. Users of British Standards are responsible for their correct application.

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Summary of pages

This document comprises a front cover, an inside front cover, pages i and ii, pages 1 to 20, an inside back cover and a back cover.

This standard has been updated (see copyright date) and may have had amendments incorporated. This will be indicated in the amendment table on the inside front cover.

Introduction

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.

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.

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 and 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.

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.

NOTE 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):

<i>Type of cable</i>	<i>System voltage U_0</i>
	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

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

IEC 228:1978, *Conductors of insulated cables*.

IEC 287:1982, *Calculation of the continuous current rating of cables (100 % load factor)*.

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

3 Symbols

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 y_p , y_s , λ_1 , λ_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
y_p	= proximity effect factor, see IEC 287	—
y_s	= skin effect factor, see IEC 287	—
α_{20}	= temperature coefficient of conductor resistance at 20 °C	1/K
θ	= maximum rated conductor operating temperature	°C
θ_a	= ambient average temperature	°C
θ_m	= mean operating conductor temperature	°C
λ_1, λ_2	= sheath and armour loss factors, see IEC 287	—
μ	= loss load factor, see IEC 853	—
ρ_{20}	= conductor resistivity at 20 °C, see 5.2	$\Omega \cdot m$

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 = the cost of the installed length of cable, cu;

CJ = 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.

a) Cost due to energy charge

$$\text{Energy loss during the first year} = (I_{\max}^2 \cdot R \cdot l \cdot N_p \cdot N_c) T \text{ (W.h)} \quad (2)$$

where

$I_{\max}$ = maximum load on the cable during the first year, A;

l = length of cable, m;

R = apparent a.c. resistance of a conductor per unit length, taking into account both skin and proximity effects (y_p, y_s) and losses in metal screens and armour (λ_1, λ_2), Ω/m .

As the economic conductor size is usually larger than the size based on thermal considerations (i.e. the size determined by the use of IEC 287 and/or IEC 853), its temperature will be lower than the maximum permissible value. It is convenient to assume, in the absence of more precise information, that R is constant and has a value corresponding to a temperature of $(\theta - \theta_a)/3 + \theta_a$.

Here θ is the maximum rated conductor temperature for the type of cable concerned and θ_a is the ambient average temperature. Factor 3 is empirical, see Annex B.

NOTE If greater precision is required (for example where the calculations do not indicate clearly which nominal conductor size should be chosen or the growth in load is such that its value during the final years is significantly higher than that of the first year) a better estimate of conductor temperature can be made using as a starting point the conductor size obtained from the approximate temperature given above.

Methods for making a more refined estimate of conductor temperature and resistance are given in Annex B. The economical size is then redetermined using the revised value of conductor resistance.

The effect of conductor resistance on the value of the economical size is small and it is seldom worthwhile to perform the iteration more than once.