Economic optimisation of electric conductors in commercial and public buildings using methodology proposed by IEC 287-3-2

Carlos G. Tanides(1), María J. Cánepa(1), Osvaldo D. Petroni (2) & (1),
Juliana Rizzone(1), and Héctor L. Soibelzon(1)

(1) Electrical Engineering Department, School of Engineering, University of Buenos Aires
Av. Paseo Colón 850, (1063) Capital Federal, ARGENTINA
ctanide@fi.uba.ar

(2) Instituto Argentino de Normalización (IRAM)
Perú 556, (C1068AAB) Buenos Aires
opetroni@iram.org.ar

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Abstract

The main goal of this work is to study the impact of optimising the size of electric conductors within commercial and public buildings in order to minimise electric losses and, at the same time, to reduce electric billing. Norm IEC 287-3-2 establishes a methodology for doing so by considering total cost of installing and operating a cable during its economic life. As a consequence, the electric conductor selected, generally, results with a larger cross-sectional area. In this analysis for the computation of total costs it was considered the influence of taking into account the voltage drop and the replacement of electrical overcurrent protections, when necessary, due to the increased short-circuit current resulting from the diminished circuit impedance for larger cables.

Finally, the methodology was specifically applied to the Paseo Colón building of the School of Engineering of the University of Buenos Aires, analysing a representative sample of 78 electric sectional switchboards where there were measured the electrical load curves and calculated the specific loss load factor of each sector. From the study it was determined the convenience of selecting the cable size resulting from the method proposed by IEC. The total costs savings between “conventional” and “efficient” conductors considering the whole building is around 40%, with a maximum of 55% in the best case, and considering overall energy utilisation of the building, reductions obtained are of 4.9% of the electric power demand and 1.1% on energy consumption.

Introduction

In electric HV and MV transmission and distribution networks, the conductor selection is done using a set of calculus that establishes the cross-sectional area of the conductor. Synthetically, some technical factors are considered: thermal limit due to nominal current circulation, thermal limit due to short-circuit current, voltage drop, cross-sectional area limit due to mechanical reasons, dynamic effects due to short-circuit currents, and the last, but not the least important, the economic cross-sectional area that minimises the total costs of the electrical installation overall its economic life considering installation costs and electrical losses due to the Joule Effect (JE).

Many of this considerations are made in LV installations, although it is not usual to evaluate the economical cross-sectional area that is commonly selected choosing a minimum value, taking into account the given technical factors but minimising first installation costs.

The purpose of this work is to do a preliminary analysis introducing the concept of economical cross-sectional area of a conductor in electrical installations within commercial buildings. Using as a starting point (given there is no specific standard) the IEC 287-3-2 standard that establishes a methodology to obtain the cross-sectional area in power cables. Also, as a case study, the standard was applied to part of an electrical installation of a building.

Methodology proposed by International Standard IEC 287-3-2

In the economical cross-sectional area evaluation of an electric power cable the IEC 287-3-2 standard uses the total cost (*CT*) of a system that includes the evaluation of the installed cost (*CI*) of the cable length being considered and the present value of the cost of Joule losses (*CJ*) during the lifetime of the installation (*N* years).

In this calculation the standard does not include: dielectric losses; maintenance costs; removal of the heat produced by cables by means of A/C system; or the time-of-the-day prices of energy and power demand used in some tariffs.

TOTAL COSTS EVALUATION

Given this situation the total cost of installing and operating a cable during its economic lifetime is expressed in its present value by Equation (1).

$$CT = CI + CJ \quad \text{[cu]} \tag{1}$$

where: *CI* is the installed cost of the length of cable being considered and; *CJ* is the present value of the cost of Joule losses during *N* years.

The installed cost (*CI*) is formed by material cost and installation cost, while joule losses cost (*CJ*) is formed by energy cost and power demand cost due to JE. Considering that *CI* is paid at the end of first year and that *CJ* must be evaluated during economic lifetime *N* years, using the present value concept, the *CT* of installing and operating the cable is defined as shown in Equation (2).

$$CT = CI + (Imax)^2 \times R \times l \times Np \times Nc) \times ((T \times P) + D) \times \frac{Q}{(1 + i/100)} \quad \text{[cu]} \tag{2}$$

where $I_{\max}$ is maximum load in first year [A]; *R* is the cable a.c. resistance per unit length considering other factors (proximity, skin effect, sheath and armour losses) [Ω/m]; *l* is the cable length [m]; *Np* is the number of phase conductors per circuit; *Nc* is the number of circuits carrying the same type and value of load; *T* is the operating time at maximum Joule loss [h/year]; *P* is the cost of one kilowatt-hour at relevant voltage level [cu/W.h]; *D* is the demand charge each year [cu/W.year] and; *Q*, is an auxiliary quantity defined by Equation (4), which depends on a new discount rate index called *r* that is calculated through the increase in load per year, (*a*), the increase in cost of energy per year, not including the effect of inflation, (*b*), and the discount rate (*i*) (see Equation (5)).

A time concept may be defined as "*operating time at maximum joule loss*", which is the number of hours per year that the maximum current $I_{\max}$ would need to flow in order to produce the same total yearly energy losses as the actual, variable, load current. [IEC, 1995, p.19]. IEC 853 defines it mathematically as shown in Equation (3):

$$T = \int_0^{8760} \left(\frac{I(t)}{Imax} \right)^2 .dt \tag{3}$$

where: *t* is time [h]; *I(t)* is the load current as a function of time [A] and $I_{\max}$ is the maximum load in first year [A].

$$Q = \sum_{n=1}^{n=N} \left(r^{n-1} \right) = \frac{(1 - r^N)}{(1 - r)} \tag{4}$$

Considering that *CJ* (see Equation (2)) depends on the square of $I_{\max}$, the cost of energy (*P*) and the discount rate i, the auxiliary quantity *r* is given as follows:

$$r = \frac{(1 + a/100)^2 \times (1 + b/100)}{(1 + i/100)} \tag{5}$$

CONVENTIONAL METHOD (CM)

Starting with $I_{\max}$ value, using this method, we choose the minimum cross-sectional area that takes into account the technical conditions already mentioned. Total costs of the cable length to be installed are calculated using this value and Equation (2) above.

ECONOMIC CURRENT RANGE (ECR)

The *Economic Current Range* (ECR) for each conductor in a series of sizes is one of the procedures suggested by IEC 287-3-2 to minimize *CT* of an electric installation, and it establishes a current range, for each cross-sectional area of conductor, generally larger than those determined by the *CM*. The method uses *upper* and *lower limits* of $I_{\max}$ within *CT* is minimum. Both limits of $I_{\max}$ define the ECR as it is expressed in Equation (6):

$$upper\,limit\, I_{\max} = \sqrt{\frac{CI_2 - CI}{F \times l \times (R - R_2)}} \quad \text{[A]} \tag{6a}$$

$$lower\ limit\, I_{\max} = \sqrt{\frac{CI - CI_1}{F \times l \times (R_1 - R)}} \quad \text{[A]} \tag{6b}$$

where: CI_2 and CI_1: are the installed cost of the next larger and smaller standard conductor respectively [cu]; *CI*: is the installed cost of the length of cable whose conductor size is being considered [cu]; *F:* auxiliary quantity that includes non-variable values in the calculus; R_2 and R_1: is the a.c. resistance per unit length of the next larger and smaller standard conductor respectively [Ω/m] and; *R:* is the a.c. resistance per unit length of the conductor size being considered [Ω/m].

Using this method the upper and lower limits of the ECR, for a particular given load, must be tabulated for each cross-sectional area of conductor in the marketplace. The upper limit for the ECR of a cross-sectional area is the lower limit of the ECR for the next larger conductor size, and vice versa. It is also important to observe that the ECR established for each cross-sectional area is valid only for the given conditions of installation costs, load curve, energy and power demand prices, and discount, increase in demand and in prices rates. Any change in one, or several, of these conditions can vary the values of the ECR. Then for dimensioning a power cable under ECR method it is necessary to know I_{max} to be transported and select a conductor size that includes it within its ECR.

Other considerations in the cross-sectional area of the conductor selection such as fault currents, voltage drop, etc., are taken into account in dimensioning the conductor.

Preliminary considerations: IEC 287-3-2 in commercial buildings

In the implementation of IEC 287-3-2 to commercial and public buildings emerge some questions that we will try to evaluate: a) what is the economic impact in electrical protections due to the lower impedance of cables having larger cross-sectional areas? and b) what and how great is the impact of taking into account time-of-the-day prices of energy and power demand that are used in some tariffs particularly in large buildings?

As regards the first question, as impedance resulting from cables selected with ECR method are lower as a result of using larger cross-sectional areas, the short-circuit current is larger than its equivalent obtained under CM so it is necessary to use, generally, interrupters with greater interrupting capacity and, for this reason, more expensive.

As regards the tariffs, large users (power demand >50 kW), have two different prices for power demand: peak (18 to 23 h) and off-peak; and three prices for energy: peak (18 to 23h), off-peak (5 to 18 h) and valley (23 to 5 h). Therefore evaluation of the term: $TxP + D$ in Eq. (2) should take account of this situation. Given the actual prices of energy and power demand, and for usual values of T found in this kind of buildings ($400 < T < 4\ 000$ h/yr)[1], D term stands out and should be taken into account with greater attention. For this reason, acting on peak-coincidence factor is the best course of action.

In Table 1 we calculate the minimum value of T for different values of I_{max} and cable length that determines, by ECR method, the use of the next larger cable size than that obtained via CM. In other words, there exists an economic cross-sectional area. The calculations done represent the worst hypothesis for the ECR method because I_{max} values were selected at the minimum value within the load current range established by the CM for a given cross-sectional area. In the same table, it can be appreciated that for typical values of cable length (50 to 100 m) and load current (25 to 60 A) found in these buildings the T values obtained are similar than those commonly encountered (see Table 2). Therefore these points are potentially proper to apply ECR and make an economy in cables. Also it can be seen that due to voltage drop effect, as we go to larger cable lengths, minimum T necessary to justify a change to the next cable size, grows, due to the increment in cable sizes obtained by the CM.

Table 1. Minimum T required to justify change from CM cross-sectional area to that obtained by ECR method. Cross-sectional area (by CM / by ECR) in mm^2.

	Cable length [m]				
I_{max} [A]	**10**	**50**	**75**	**100**	**150**
18	650	1 200	1 200	1 500	2 450
	(2.5/4)	(4 / 6)	(4 / 6)	(6 / 10)	(10 / 16)
25	600	600	800	1 250	4 850
	(4 / 6)	(4 / 6)	(6 / 10)	(10 / 16)	(16 / 25)
33	440	440	750	2 750	2 950
	(6 / 10)	(6 / 10)	(10 / 16)	(16 / 25)	(25 / 35)
44	400	400	1 550	1 550	1 700
	(10 / 16)	(10 / 16)	(16 / 25)	(16 / 25)	(25 / 35)
58	890	890	890	1 000	3 100
	(16 / 25)	(16 / 25)	(16 / 25)	(25 / 35)	(35 / 50)
89	400	400	400	1 300	4 500
	(25 / 35)	(25 / 35)	(25 / 35)	(35 / 50)	(70 / 95)

CASE STUDY: SCHOOL OF ENGINEERING (UBA)

In order to evaluate these aspects IEC 287-3-2 procedure was implemented in the Paseo Colon building of the School of Engineering of the University of Buenos Aires (UBA). This building occupies an entire block, and has 8 floors with a covered area of about 41 400 m^2.

Cables analysed were those that connect the general LV switchboard with sectional switchboards located in each floor. There are a total of 78 sectional switchboards that were classified in 11 categories, each one representative of a different function. In each of these categories the load curve was obtained measuring the load current during one week with a frequency interval of 3 seconds for elevators and 3 minutes for the others. Yearly load curve was estimated through this information, energy audits, surveys and billing analysis, and thus, obtained the I_{max} value needed for the calculus.

For the evaluation there were also employed time-of-the-day prices for power demand and energy used and it was considered, when necessary, the replacement of over current protections with greater interruption capacity. The analysis was realised using discount rate $i = 11\%$ and an economic life of the installation $N = 30$ years.

Results obtained

The operating time at maximum joule loss range, T, obtained for this building was between 400 h/year for *elevators* and 3 000 in the case of sectional switchboards that feed *offices* and *corridors*. Figure 1 shows the daily load curve for these limit cases and, Table 2 shows T values for all the switchboards monitored.

In Table 3 we summarise the most important results obtained by the application of CM and ECR method: installation costs (*CI*), energy loss costs (*CJ*), and total costs (*CT*) in absolute and relative values. We can appreciate that economic savings in total cost is 39.60% when choosing cross-sectional areas given by ECR method. This magnitude is similar to that established by [IEC, 1995, p.7] that states *"For the values of the financial and electrical parameters used in this standard, which are not exceptional, the saving in the combined*

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[1] Maximum value of T=4000 h/year was found for a central A/C equipment that worked during the whole year.

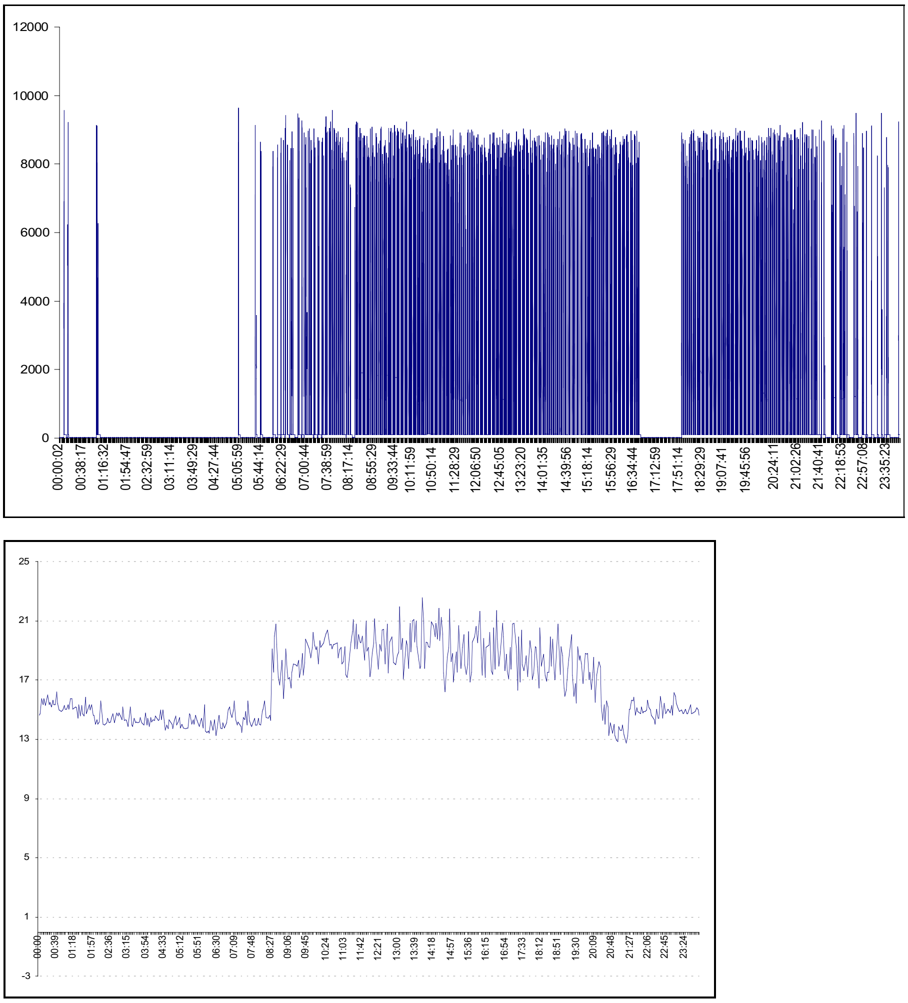

Figure 1. *Daily load curve obtained through measurement in elevator switchboard (T = 400 h/year) (left) and offices and corridors (T = 3 000 h/year) (right).[Cánepa and Rizzone, 2002].*

Table 2. *T* values obtained in different switchboards monitored in the Paseo Colon building and relation between energy and power demand.

Switchboards	*T* [h/year]	*T*P*	*D*	*D/(T*P)*
Elevators	396	12.5	185	14.8
Classrooms, offices and corridors	513	16.2	185	11.4
Offices	596	18.8	185	9.8
Classrooms, and offices	625	19.8	185	9.4
Laboratories	747	23.6	185	7.8
Central Hall	1 396	44.1	185	4.2
Library 1	2 113	66.7	185	2.8
Offices and corridors	2 992	94.5	185	2.0

cost of purchase and operation is of the order of 50% (see clause A.6 in annex A).

Using ECR method installation costs would be 43% larger, but this increment would be compensated with the diminished cost of losses (71%). The increment in the cost of over-current protection was not significant when compared with total cost (3%). Particularly, the greatest savings were obtained for switchboards in *offices* and *corridors* with cable lengths around 50 m and for T = 3 000 h/year where total costs savings were around 55%.

Finally, power demand losses by CM were 36.18 kW representing 6.5% of total power demand and using ECR method this value descend to 10.73 kW representing 1.9%. As regards to energy losses, CM gave a value of 33.3 MWh/year representing 1.4% of total energy consumption and using ECR method value obtained was 8 MWh/year representing 0.3%. Table 4 summarises these values.

Table 3. Comparison between CM and ECR method.

	Costs	CM	% CT_{CM}	ECR	% CT_{ECR}	Variation %
CI	Material and installation	US$ 22 747	22.8%	US$ 33 536	55.7%	47.4%
	Over current protections	US$ 4 539	4.6%	US$ 5 377	8.9%	18.5%
CJ	Power demand losses	US$ 66 026	66.2%	US$ 19 678	32.7%	-70.2%
	Energy losses	US$ 6 372	6.4%	US$ 1 614	2.7%	-74.7%
CT	Total	US$ 99 685	100.0%	US$ 60 205	100.0%	-39.6%
Δ	Δ CI	**43%**				
	Δ CJ	**- 71%**				

Table 4. Power and energy losses by employing CM and ECR method in Paseo Colon building.

Losses	CM	% of total	ECR	% of total	Δ %
Power demand [kW]	36.2	6.5%	10.7	1.9%	-4.9%
Energy [MWh/year]	33.3	1.4%	8.0	0.3%	-1.1%

Conclusions

Savings were significant, even though hypothesis used were very conservative as it was analysed only the part of the electrical installation between general LV to sectional switchboards, not considering cables neither from MV-LV transformer to general switchboard nor from sectional switchboards to end-uses.

The most interesting savings in economic terms and for the electric system as a whole is the decrease in power demand that is around 5%.

The increment in over current protections costs is not relevant compared with total costs and represents only a 3% of increment in installation costs.

Finally, evaluating these results and towards a better understanding of these analysis it is necessary to continue working in a better characterisation of electric installations: cross-sectional areas employed, cable lengths, load curve shapes by function, and sub sector characteristics, in order to extrapolate the results achieved to the overall commercial and public sector and to evaluate incorporation of these standard (or similar) as a common practice.

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