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Effective Cable Sizing model for Building Electrical Services

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Abstract

This paper mainly focuses on the sizing of electrical cables (i.e.cross-sectional area) and its accomplishment in various international standards. Cable sizing methods are at variance across international standards. For example, International Electrotechnical Commission (IEC), National Electrical Code (NEC), British Standard (BS) and Institute of Electrical and Electronics Engineers (IEEE). The basic philosophy underlying any cable sizing calculation is to develop a procedure model on cable sizing. The main objective of this research work is to develop effective cable sizing model for building services.

***Keywords**: Conductor, Cable sizing, Ampacity, Current carrying capacity, Bunch, Voltage drop*

1. Introduction

There are four primary reasons that the cable sizing is very important at design stage. First and foremost, cable sizing is important to operate continuously under full load condition without being damaged. Moreover, it is necessary to withstand the worst short circuit currents flowing through the cable. Ensure that the protective devices are effective during an earth fault. Ensure that, the supply to the load with a suitable voltage and avoid excessive voltage drops.

2. Cable Selection, Sizing and Other Parameters

Sizing Cable sizing methods follow the unchanged basic step process. Firstly, it's vital to gather data about the cables, installation surroundings, and the load that it will carry. In addition, it's crucial to find the current carrying capacity (A, ampere) and voltage drop per ampere meter (MV/A/m) of the cable. The current carrying capacity of a cable is the maximum current that can flow continuously through a cable without damaging the cable's insulation and other components. Short circuit temperature rise and earth fault loop impedance are significant factors to verify the cable size [1].

Every conductors and cables except superconductor have some amount of resistance. This resistance is directly proportional to the length and inversely proportional to the diameter of the conductor.

$$R \propto L/a \qquad \text{[Laws of resistance } R = \rho\,(L/a)\text{]} \qquad (1)$$

Voltage drop occurs in every conductor as the current flows through it. According to Institute of Electrical and Electronics Engineers (IEEE) rule B-23, at any point between a power supply terminal and installation, voltage drop should not increase above 2.5% of provided (supply) voltage.

The component parts that make up of the cable for instance conductors, insulation, and bedding, must be capable of withstanding the temperature rise and heat emanating by the cable. Table 1 shows the current carried by any conductor for continuous periods during normal operation shall be such that the suitable temperature limits.

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Table 1. Maximum operating temperatures for types of cable insulation [3]

Type of insulation	Temperature limit
Thermoplastic	70°C at the conductor
Thermosetting	90°C at the conductor
Mineral (Thermoplastic covered or bare, exposed to touch)	70°C at the sheath
Mineral (Bare not exposed to touch and not in contact with combustible material)	105° at the sheath

Cables with larger cross-sectional areas have minor resistive losses and the ability to dissipate the heat better than smaller cables. Therefore a 25 mm^2 cable will have a higher current carrying capacity than a 16 mm^2 cable [5]. Table 2 explains the difference between current carrying capacity of 16 mm^2 and 25mm^2 and figure 1 explains the basic procedures to determine the cable sizing.

Table 2. Current carrying capacity and voltage drop of different types of cable size [4]

Cable size	Current-carrying capacity	Voltage drop
≤16mm^2	0.95	1.10
≥25mm^2	0.97	1.06

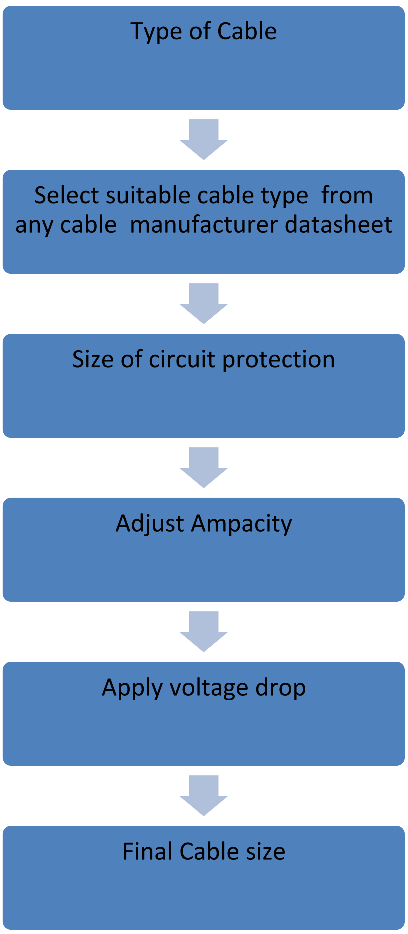


Figure 1. Flow chart shows the steps to determine the cable sizing and voltage drop

3. Cable Sizing Model & Formulation [2]

International standards and cable manufacturers will provide derating factors for a range of installation conditions, for example, ambient or soil temperature, grouping or bunching of cables, and soil thermal resistivity [6]. The installed current rating is calculated by multiplying the base current rating with each of the derating factors.

$$I_c = I_b \times k_d \quad (2)$$

Where I_c is the installed current rating (A), I_b is the base current rating (A) and K_d are the product of all the derating factors.

Motors are normally protected by a separate thermal overload (TOL) relay. Consequently the upstream protective device circuit breaker is not required to protect the cable against overloads. As a result, the cables need only to be sized to cater for the full load current of the motor.

$$I_l \leq I_c \quad (3)$$

Where I_l is the full load current (A), I_p is the protective device rating (A) I_c is the installed cable current rating (A).

Cable Impedances are a function of the cable size (cross-sectional area) and the length of the cable. Most cable manufacturers will quote a cable's resistance and reactance in Ω/km. The following typical cable impedances for low voltage AC single core and multicore cables can be used in the absence of any other data.

For single circuit:

$$I_t \geq \frac{I_n}{C_a\,C_s\,C_d\,C_i\,C_f\,C_c} \quad (4)$$

Where the protective device is is a semi enclosed fuse to BS 3036, C_f=0.725 otherwise C_f=1. The cable installation method is 'in a duct in the ground' or 'buried direct', C_c=0.9. For cables installed above ground C_c=1. C_a=Ambient temperature, C_s=Soil resistivity, C_d=dept of burial, Ci=Thermal Insulation, I_b=the design of current of the circuit, I_t=the value of current for ingle circuit at ambient temperature. For cables installed above ground C_s and C_d =1.

For group:

$$I_t \geq \frac{1}{C_a C_s C_d C_i}\sqrt{\left(\frac{I_n}{C_f C_c}\right)^2 + 0.48\, I_b^{\,2}\left(\frac{1-C_g^{\,2}}{C_g^{\,2}}\right)} \quad (5)$$

For cables having cross sectional area 16mm^2 or less, the design value of mV/A/m is obtained by multiplying the tabulated value by factor C_t given by:

$$C_t = \frac{230 + t_p - \left(C_a^{\,2} C_g^{\,2} C_s^{\,2} C_d^{\,2} - \frac{I_b^{\,2}}{I_t^{\,2}}\right)(t_p - 30)}{230 + t_p} \quad (6)$$

For AC three phase system:

$$V_{3\phi} = \frac{\sqrt{3}I(R_c\cos\phi + X_c\sin\phi)L}{1000} \quad (7)$$

Where $V_{3ø}$ is the three phase voltage drop (V), I is the nominal full load or starting current as applicable (A), R_c is the AC resistance of the cable (Ω/km), X_c is the AC resistance of the cable (Ω/km) cos ø is the load power factor (pu) L is the length of the cable (m).

For AC single phase system:

$$V_{1\phi} = \frac{2I(R_c \cos\phi + X_c \sin\phi)L}{1000} \tag{8}$$

It is standards to indicate maximum permissible voltage drops, which is the maximum voltage drop that is permissible across a cable. If the cable exceeds this voltage drop, then a bigger cable size should be preferred.

Greatest voltage drops across a cable are specified because load consumers will have an input voltage tolerance range. If the voltage of the electrical device is lower than, its rated minimum voltage, then the appliance may not work appropriately.

It may be more precise to calculate the maximum length of a cable for a particular conductor size given a maximum permissible voltage drop 5% of nominal voltage at full load rather than the voltage drop itself. To construct tables showing the maximum lengths corresponding to different cable sizes in order to speed up the selection of similar type cables. [2]

For a three phase system:

$$L_{max} = \frac{1000V_{3\phi}}{\sqrt{3}I(R_c \cos\phi + X_c \sin\phi)} \tag{9}$$

For a single phase system:

$$L_{max} = \frac{1000V_{1\phi}}{2I(R_c \cos\phi + X_c \sin\phi)} \tag{10}$$

A high amount of current will flow through a cable for a short time when there is short circuit happens in the circuit. This surge in current flow causes a temperature rise within the cable.

High temperatures can trigger unnecessary reactions in the cable insulation, sheath materials and other components, which can degrade the condition of the cable. Bigger cable cross-sectional area can dissipate higher fault currents. Therefore, cables should be sized to withstand the largest short circuit.

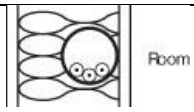
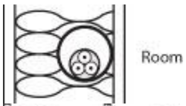
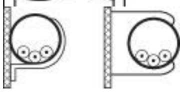
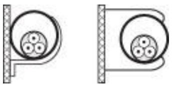
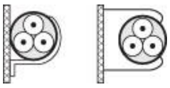
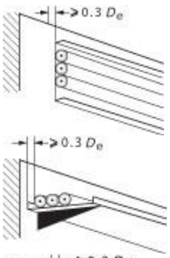
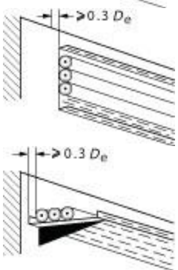
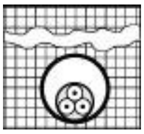
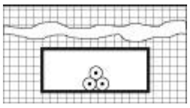
The minimum cable size due to short circuit temperature rise is typically calculated with an equation of the form:

$$A = \frac{\sqrt{i^2 t}}{k} \tag{11}$$

The temperature rise constant is calculated based on the material properties of the conductor and the initial and final conductor temperatures as per equation 12.

$$k = 226\sqrt{\ln\left(1 + \frac{\theta_f - \theta i}{234.5 + \theta_i}\right)} \tag{12}$$

Table 3. Examples of methods of installation [4]

No	Methods of installation	Description	Method of installation
1		Insulated conductors or single-core cables in conduit in a thermally insulated wall	The wall consists of outer weatherproof skin, thermal insulation and an inner skin. Heat from the cables is assumed to escape through the inner skin only.
2		Multi-core cables in conduit in a thermally insulated wall	The wall consists of outer weatherproof skin, thermal insulation and an inner skin. Heat from the cables is assumed to escape through the inner skin only.
4		Insulated conductors or single-core cables in conduit on a wooden, or masonry wall or spaced less than 0,3 x conduit diameter from it	The conduit is mounted on a wooden wall. Conduit is fixed to a masonry wall the current carrying capacity of the non sheated or sheathed cable may be higher.
5		Multi-core cable in conduit on a wooden, or masonry wall or spaced less than 0,3 x conduit diameter from it	The conduit is mounted on a wooden wall. Conduit is fixed to a masonry wall the current carrying capacity of the non sheated or sheathed cable may be higher.
20		Single-core or multi-core cables: - fixed on, or spaced less than 0.3 x cable diameter from a wooden wall	Cable mounted on a wooden wall so that the gap between the cable and the surface is less than 0.3 times the cable diameter. Where the cable is fixed to a embedded in a masonry wall the current-carrying capacity may be higher.
30		On unperforated tray	Cable mounted on a wooden wall so that the gap between the cable and the surface is less than 0.3 times the cable diameter. Where the cable is fixed to a embedded in a masonry wall the current-carrying capacity may be higher.
31		On perforated tray	The cable is supported such that the total heat dissipation is not impeded. A clearance between a cable and any adjacent surface of at least 0.3 times the cable, external diameter for multicore cables 1.0 times the cable diameter for single-core cables
36		Bare or insulated conductors on insulators	The cable is supported such that the total heat dissipation is not impeded. A clearance between a cable and any adjacent surface of at least 0.3 times the cable, external diameter for multicore cables 1.0 times the cable diameter for single-core cables
70		Multi-core cables in conduit or in cable ducting in the ground	The cable is supported such that the total heat dissipation is not impeded. A clearance between a cable and any adjacent surface of at least 0.3 times the cable, external diameter for multicore cables 1.0 times the cable diameter for single-core cables
71		Single-core cable in conduit or in cable ducting in the ground	The cable is supported such that the total heat dissipation is not impeded. A clearance between a cable and any adjacent surface of at least 0.3 times the cable, external diameter for multicore cables 1.0 times the cable diameter for single-core cables

An illustration of some of the many different wiring systems and methods of installation is provided in Table 3 where grouping installation methods having the same characteristics relative to the current-carrying capacities of the wiring systems. Table 4 shows the correction factor k4 for different configuration of cables which has been laid directly.

Table 4. The values of correction factor k4 for different configurations of cables or conductors laid directly in the ground [2].

Number of circuits	**Cable to cable clearance (a)[a]**				
	Nil (cables touching)	**One cable diameter**	**0.125 m**	**0.25 m**	**0.5 m**
2	0.75	0.80	0.85	0.90	0.90
3	0.65	0.70	0.75	0.80	0.85
4	0.60	0.60	0.70	0.75	0.80
5	0.55	0.55	0.65	0.70	0.80
6	0.50	0.55	0.60	0.70	0.80

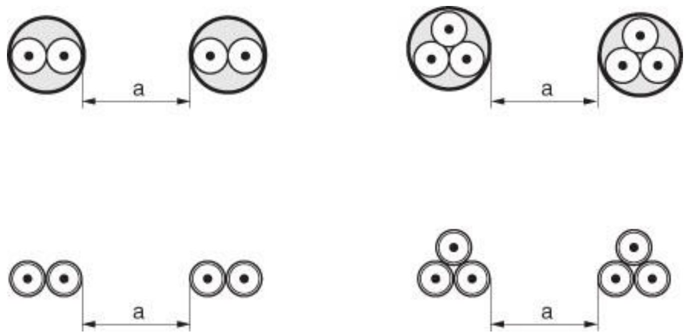


Figure 2. Reduction factors for more than one circuit, single-core or multi-core cables laid directly in the ground. [2]

4. Results

Table 5. Voltage drop for different Electrical Components [1]

	Lighting	Other Uses
Low voltage installation supplied directly from a public low voltage distribution system	3%	5%
Low voltage installation supplied from the private LV supply (*)	6%	8%

Table 5 explains the voltage drop between the origin of an installation and any load point should be greater than the values in the table below expressed with respect to the value of the nominal voltage of installation. [1]

Table 6. Sample of calculation of voltage drop using V=IR

NO	DESCRIPTION		MAX DIST	POWER	LOAD	VOLT	CURRENT	CSA	mV/A/m	DROP		REMAIN VOLT
	FROM	TO	(m)	(W)	(W)	(V)	(A)	(mm2)		(%)	(v)	
1	DB	Light	10	42	84	240	0.35	2.5	18	0.2	0.38	239.63

5. Conclusion

Selecting power cable and types of cables with the sizing of the conductors for specific applications is a very essential part of the plan of any electrical system. That this task is often performed with a least amount of effort and with minimum reflection for all of the applicable design issues. The consequential catastrophe is that inappropriate selection and sizing can easily amplify the installed cost of a facility while also dropping the reliability of the complete system.

This paper highlights on some of the considerations that should be practice for cable selection each and every time. It then suggests the right design tool to calculate and facilitate the selection process without resorting to simplifications.

References

[1] IEC 60364-5-52. "Electrical installations in buildings - Part 5-52: Selection and erection of electrical equipment - Wiring systems" is the IEC standard governing cable sizing. 2009.

[2] National Electricity Code (NEC), 2011.

[3] NFPA 70. "National Electricity Code" is the equivalent standard for IEC 60364 in North America and includes a section covering cable sizing in Article 300. 2011.

[4] BS 7671. "Requirements for Electrical Installations - IEE Wiring Regulations" is the equivalent standard for IEC 60364 in the United Kingdom. 2008.

[5] Adetoro, K. Adebayo. 'Assessment of the Quality of Cables produced in Nigeria'. *Global Advanced Research Journal of Engineering, Technology and Innovation*. 2012; 1(4): 097-102.

[6] Coker AJ, Turner WO, Josephs ZT. *Electrical Wiring*. Redwood Press Limited. 1991: 12 – 28.