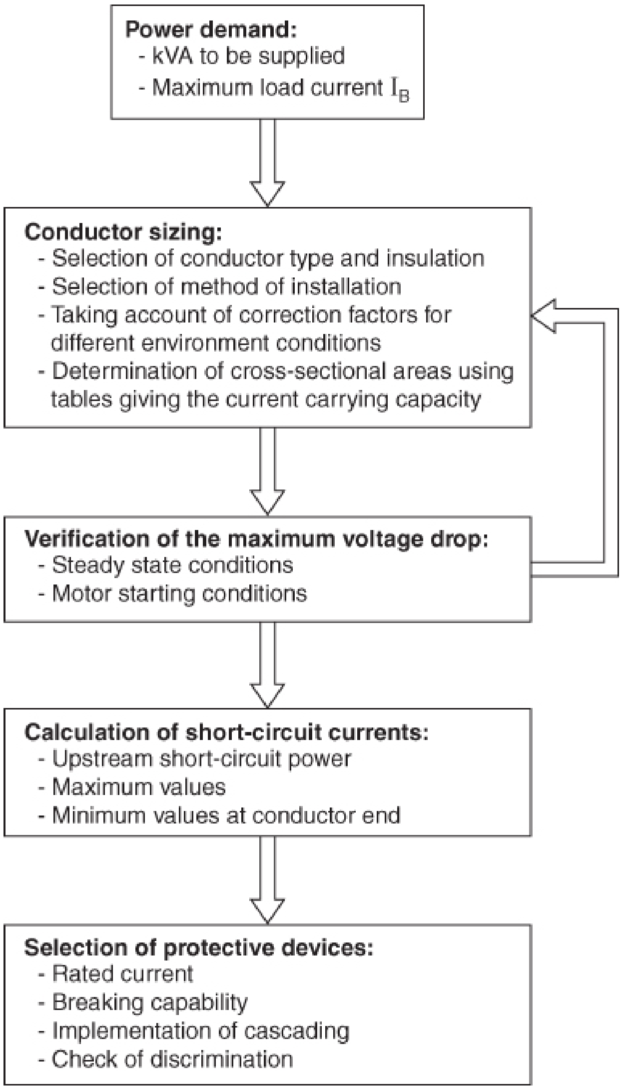
COURSE 9+10

SIZING THE SUPPLY CABLES

Conductors' section is chosen so that, under long-term operating, the temperature of conductor not to exceed certain allowable values over the physical and chemical properties of materials and components which can affect or change the proper functioning of LV networks (conductor's degradation, oxidation, premature aging and degradation of contacts). The cross-sectional areas of conductors are determined by the general method described in next section. Apart from this method some national standards may prescribe a minimum cross-sectional area to be observed for reasons of mechanical endurance. Particular loads require that the cable supplying them be oversized, and that the protection of the circuit be likewise modified.

The flow-chart for the selection of cable size and protective device rating for a given circuit is:



There will be defined:

- <u>Maximum load current:</u>

At the final circuits level, this design current (according to IEV "International Electrotechnical Vocabulary" ref 826-11-10) corresponds to the rated kVA of the load. In the case of motor-starting, or other loads which take a high in-rush current, particularly where frequent starting is concerned (e.g. lift motors, resistance-type spot welding, and so on) the cumulative thermal effects of the overcurrents must be taken into account. Both cables and thermal type relays are affected.

At all upstream circuit levels this current corresponds to the kVA to be supplied, which takes account of the diversity and utilization factors, k_s and k_u respectively.

➢ Maximum allowable current:

Current carrying capacity is the maximum allowable that the cabling for the circuit can carry indefinitely, without reducing its normal life expectancy. The current depends, for a given cross sectional area of conductors, on several parameters:

- Constitution of the cable and cable-way (Cu or Al conductors; PVC or EPR etc. insulation; number of active conductors)
- Ambient temperature
- Method of installation

➢ Overcurrents

An overcurrent occurs each time the value of current exceeds the maximum load current for the load concerned. This current must be cut off with a rapidity that depends upon its magnitude, if permanent damage to the cabling (and appliance if the overcurrent is due to a defective load component) is to be avoided.

Overcurrents of relatively short duration can however, occur in normal operation; two types of overcurrent are distinguished:

- Overloads

These overcurrents can occur in healthy electric circuits, for example, due to a number of small short-duration loads which occasionally occur co-incidentally: motor starting loads, and so on. If either of these conditions persists however beyond a given period (depending on protective-relay settings or fuse ratings) the circuit will be automatically cut off.

- Short-circuit currents

These currents result from the failure of insulation between live conductors or/and between live conductors and earth (on systems having low-impedance-earthed neutrals) in any combination:

  - 3 phases short-circuited (and to neutral and/or earth, or not)
  - 2 phases short-circuited (and to neutral and/or earth, or not)
  - 1 phase short-circuited to neutral (and/or to earth) Influence of neighbouring circuits

1. Choosing the proper section of supply cables from thermal stability condition for permanently or intermittently regime

The maximum allowable intensities I_{ad} for steady currents according to cables’ or bus bars’ section are given spreadsheet, taking into account several parameters such as ambient temperature laying conditions, type of insulation, conductor material type, number of loaded conductors.

When laying circuit elements, in other conditions than those normalized, it is necessary to amend the maximum allowable intensity by applying weightings. Thus, for a phase conductor or cable, one can select a normalized (standardized) section s_F, when:

$$I_{ad1} \geq \frac{I_c}{a \cdot k}$$

- I_c is the load current
- a is a correction coefficient of working regime:

$$\begin{cases} = 1 \; in\ permanent\ regime \\ = \frac{0.875}{\sqrt{DC}} \; for\ intermittent\ regime\ with\ relative\ duration\ actuation\ DC = \frac{t_p}{t_f + t_p} \end{cases}$$

For intermittent operating regimes, a>1 and this correction is applyed only for sections s>10mm^2 for Cu and s>16mm^2 for Al.

- t_f – operating time, t_p – pausing time
- $k = k_1 * k_2 * k_3$……… - overall correction coefficient corresponding to the cooling conditions, it is the product of the partial coefficients k_1, k_2, k_3....
    - The current-carrying capacities of cables in the air are based on an average air temperature equal to 30°C. For other temperatures, the correction factor is given in annex. The related correction factor is here noted k1.
    - The current-carrying capacities of cables in the ground are based on an average ground temperature equal to 20°C. For other temperatures, the correction factor is given in annex. The related correction factor is here noted k2.
    - The current-carrying capacities of cables in the ground are based on a ground resistivity equal to 2.5 K•m/W. For other values, the correction factor is given in annexes. The related correction factor is here noted k3.
    - The current-carrying capacities given in specific tables relate to single circuits consisting of the following numbers of loaded conductors:
        - Two insulated conductors or two single-core cables, or one twin-core cable (applicable to single-phase circuits);
        - Three insulated conductors or three single-core cables, or one three-core cable (applicable to three-phase circuits).

      Where more insulated conductors or cables are installed in the same group, a group reduction factor (here noted k4) shall be applied.
    - The current-carrying capacity of three-phase, 4-core or 5-core cables is based on the assumption that only 3 conductors are fully loaded. However, when harmonic currents are circulating, the neutral current can be significant, and even higher than the phase currents. This is due to the fact that the 3rd harmonic currents of the three phases do not cancel each other, and sum up in the neutral conductor.

      This of course affects the current-carrying capacity of the cable, and a correction factor noted here k5 shall be applied.

      In addition, **if the 3rd harmonic percentage h3 is greater than 33%, the neutral current is greater than the phase current and the cable size selection is based on the neutral current.** The heating effect of harmonic currents in the phase conductors has also to be taken into account.

Obs.:

1. The overall accuracy of correction factors is within ±5 %.

2: The correction factors are applicable to cables drawn into buried ducts; for cables laid direct in the ground the correction factors for thermal resistivities less than 2.5 K•m/W will be higher. Where more precise values are required they may be calculated by methods given in the IEC 60287 series or I7/2011.

3: The correction factors are applicable to ducts buried at depths of up to 0.8 m.

4: It is assumed that the soil properties are uniform. No allowance had been made for the possibility of moisture migration which can lead to a region of high thermal resistivity around the cable. If partial drying out of the soil is foreseen, the permissible current rating should be derived by the methods specified in the IEC 60287 series or I7/2011.

5. If the neutral current is more than 15 % of the phase current and the cable size is selected on the basis of the neutral current then the three phase conductors will not be fully loaded. The reduction in heat generated by the phase conductors offsets the heat generated by the neutral conductor to the extent that it is not necessary to apply any reduction factor to the current carrying capacity for three loaded conductors.

In case of bus bars or conductors equipped with circuits and overload protection is necessary that:

$$I_{ad_2} \geq \frac{I_{rtN}}{1{,}5k},$$

and in case of short-circuit protection devices is necessary that:

$$I_{ad_3} \geq \frac{\psi I_{nfN}}{k} \text{ for protection by fuses}$$

$$I_{ad_4} \geq \frac{I_{reN}}{4{,}5k} \text{ for protection by electromagnetic devices}$$

ψ is a correction coefficient based on the network type and execution, and takes the values:

- ψ = 0,33 – for the receiver circuit (a = 1), executed with conductors in pipe or with cables, in rooms without fire or explosion;
- ψ = 0,66 – for bus bars, in the same condition as above;
- ψ = 1 - for cable soket-outlet circuits and bus bars, executed in rooms cat. A, B, C or industrial lighting;
- ψ = 1,25 - for cable soket-outlet circuits and bus bars, executed in public places, administrative buildings.

There will be adopted a standardized cross-section to which corresponds a maximum allowable intensity of:

$$I_{adN} = \max(I_{ad}; I_{ad2}; I_{ad3}; I_{ad4})$$

2. Verification of chosen cable cross-section

Is made at:

2.1. Mechanical strength and operating performance, which is expressed by the minimum allowable standardized sections (in tables).

2.2. Heating under short term startup:

Starting current density j_p must satisfy the condition:

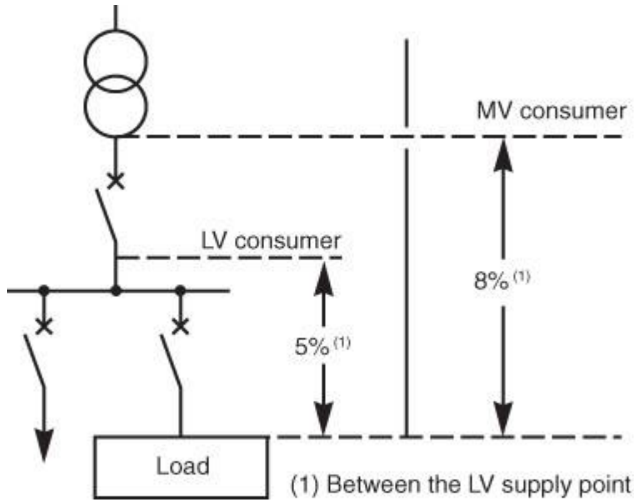
$$j_p = \frac{I_p}{s_F} \leq j_{p\_ad}$$

$j_{p\ ad} = 20\ A/mm^2$ - if the conductor material is Al;

$j_{p\ ad} = 35\ A/mm^2$ - if the conductor material is Cu;

2.3. Maximum allowable voltage-drop:

Type of installations	Lighting circuits	Other uses (heating and power)
A low-voltage service connection from a LV public power distribution network	3%	5%
Consumers MV/LV substation supplied from a public distribution MV system	6%	8%



The voltage-drop limits refer to normal steady-state operating conditions and do not apply at times of motor starting, simultaneous switching (by chance) of several loads, etc. When voltage drops exceed the values shown in Figure, larger cables (wires) must be used to correct the condition.
The value of 8%, while permitted, can lead to problems for motor loads; for example:

- In general, satisfactory motor performance requires a voltage within ± 5% of its rated nominal value in steady-state operation,
- Starting current of a motor can be 5 to 7 times its full-load value (or even higher). If an 8% voltage drop occurs at full-load current, then a drop of 40% or more will occur during start-up. In such conditions the motor will either:

- Stall (i.e. remain stationary due to insufficient torque to overcome the load torque) with consequent over-heating and eventual trip-out
- Or accelerate very slowly, so that the heavy current loading (with possibly undesirable low-voltage effects on other equipment) will continue beyond the normal start-up period

- Finally an 8% voltage drop represents a continuous power loss, which, for continuous loads will be a significant waste of (metered) energy. For these reasons it is recommended that the maximum value of 8% in steady operating conditions should not be reached on circuits which are sensitive to under-voltage problems.

$$\Delta U_s\% = \frac{\sqrt{3} \cdot I_c \cdot l \cdot \cos\varphi_m}{\gamma \cdot s_{SR} \cdot U_n} 100 \leq \Delta U_{s\_ad}\%$$

$$\Delta U_p\% = \frac{\sqrt{3} \cdot I_p \cdot l \cdot \cos\varphi_p}{\gamma \cdot s_{SR} \cdot U_n} 100 \leq \Delta U_{p\_ad}\% = 12\%$$

The minimum allowable section:

- For socket-outlet circuits it is 1,5 mm^2 Cu or 4 mm^2 Al;
- For lighting circuits it is 1,5 mm^2 Cu;
- For single-phased socket-outlets is 2,5 mm^2 Cu;
- For single-phased individual bus-bars in residential buildings is 4mm^2 Cu or 6 mm^2 Al;
- For collective bus-bars it is 10 mm^2 Cu or 16mm^2 Al.

3. Sizing neutral and protective conductors

Neutral conductor is from the same material as the phase conductors. They have the same section:

- For single-phased circuits with 2 conductors
- For three-phased circuits with s_F < 16mm^{2}Cu / 25mm^{2}Al
- For three-phased circuits that could be followed by the 3rd harmonic current and a multiple of 3 in the range of 15% to 33% (e.g. Fluorescent lighting)
- If in normal operation is not assured a balance between phase and neutral.

***Obs.:* a neutral conductor CAN NOT be common to many circuits.**

If the harmonics level is higher than the mentioned one, the neutral's section has to be greater than the phase conductor's.

In three-phased circuits with $s_F \geq$16mm^{2}Cu/25mm^{2}Al, the neutral can have a lower section than the phase conductor, only if its maximum operating conditions correspond to its current carrying capacity.

The allowable section and protection of the neutral conductor depends on:

- Neutral grounding scheme;
- Existence of deforming regime (massive presence of harmonics of order 3 and multiples of 3 determines the selection of a raised section for the neutral and sometimes for all conductors of a cable)
- Indirect protection against accidental contact.

If the neutral has the same section as the phase conductor, there is imposed no special protection.

If the neutral section is smaller than the phase conductors, it shall be protected against overcurrent (overload or short circuit). The neutral conductor may be discontinued by protective devices only if these devices interrupt conductors simultaneously. Interrupting the neutral conductor is done for reasons of protection against indirect contact. PE and PEN should not be interrupted under any circumstances.

Choosing the cross-section for neutral and protective conductors

<table>
<tr><td rowspan="2">No</td><td>Literary</td><td></td><td colspan="3">Characteristics</td><td colspan="2">Observations</td></tr>
<tr><td>Symbol</td><td>Name</td><td>Material</td><td>Active conductor’s section [mm^2]</td><td>Minimum section [mm^2]</td><td colspan="2"></td></tr>
<tr><td rowspan="4">1</td><td rowspan="4">PE</td><td rowspan="4">Protective conductor</td><td rowspan="4">Cu
Al
(OL echivalent)</td><td>$s \le 16$</td><td>$s_{PE} \ge s_F$</td><td>Cu ≥ 4 mm^2
Al ≥ 4 mm^2</td><td>houses
Cu ≥ 2,5mm^2
Al ---</td></tr>
<tr><td>$16 < s \le 35$</td><td>$s_{PE} = 16$</td><td colspan="2"></td></tr>
<tr><td>$s_F \ge 35$</td><td>$s_{PE} \ge s_F/2$</td><td colspan="2"></td></tr>
<tr><td>$s \le 16$ Cu</td><td>$s_P \ge 10$ Cu*</td><td colspan="2">IT equipment</td></tr>
<tr><td rowspan="3">2</td><td rowspan="3">N</td><td rowspan="3">Neutral conductor (nul de lucru)</td><td rowspan="3">Cu
Al</td><td>$s_F \le 16$</td><td>$s_N = s_F$</td><td colspan="2"></td></tr>
<tr><td>$16 < s \le 35$</td><td>$s_N \ge 16$ Cu</td><td colspan="2"></td></tr>
<tr><td>$s_F > 35$</td><td>$s_N \ge 25$Al</td><td colspan="2"></td></tr>
<tr><td>3</td><td>PEN</td><td>Common protective and neutral conductor</td><td>Cu
Al</td><td>$s_F \le 16$</td><td>$s_{PEN} \ge 10$ Cu
$s_{PEN} \ge 16$ Al</td><td colspan="2"></td></tr>
</table>

Section of protective conductor takes the same value with the neutral conductor when both are made of copper. If phase and neutral are made of aluminum, the protective conductor is copper having a section s_{PE} with a lower level (on the range section) than the neutral conductor s_N.

Section of common protective and neutral conductor s_{PEN} is chosen with the same value as s_{PE}. If the protective conductor is not part of the power supply circuit (from a cable or conductor tubes), or is made from Al, his section must be at least 4 mm^2.

A protective conductor shared among more lines should be sized according to section of the largest phase.

To ensure the lowest possible value for the current loop reactance in case of failure, in IT and TN schemes is recommended to locate the protective conductor right next to the circuit conductors (in the same tube or on the same cable ducts).

The type of earthing scheme influences the selection of cable’s section:

- In TT and TN-S schemes:
  - Single-phase circuits or those of c.s.a.[1] ≤ 16 mm^2 (copper), 25 mm^2 (aluminium): the c.s.a. of the neutral conductor must be equal to that of the phases;
  - Three-phase circuits of c.s.a. > 16 mm^2 copper or 25 mm^2 aluminium: the c.s.a. of the neutral may be chosen to be equal to that of the phase conductors, or smaller, on condition that:
    - The current likely to flow through the neutral in normal conditions is less than the permitted value Iz. The influence of triplen[2] harmonics must be given particular consideration, or
    - The neutral conductor is protected against short-circuit,
    - The size of the neutral conductor is at least equal to 16 mm^2 Cu or 25 mm^2 Al.
- In TN-C scheme – are applied the same conditions as above, but in practice, the neutral conductor must not be open-circuited under any circumstances since it constitutes a PE as well as a neutral conductor.

[1] Cross-section area
[2] Harmonics of order 3 and multiple of 3

- In IT scheme is not recommended to distribute the neutral conductor, i.e. a 3-phase 3-wire scheme is preferred. When a 3-phase 4-wire installation is necessary, however, the conditions described above for TT and TN-S schemes are applicable.

4. Conductors' identification

Is made by color and by numbering (if there are more than 5 conductors):

- For protective and neutral conductors:
  - Yellow/green for protective conductors/bus-bars (PE);
  - Yellow/green along the length and additionally marked blue assemblies, for protective and neutral conductor (PEN);
  - Light blue for neutral conductors/busbars (N);

It is not allowed to use green or yellow insulation for phase conductors in circuits with PE or PEN.

- For phase conductors in alternative current it's recommended brown, black, gray, red, yellow, blue, orange, purple, white, pink, turquoise.
- For non-insulated conductors/bus-bars, it is recommended at the ends: red for L1, yellow for L2, blue for L3, black for PEN or PE and white striped black for N.
- For conductors and bus-bars in direct current:
  - Red for positive conductor (+)
  - Blue for negative conductor (-)
  - Light gray for median conductor (0)

The identification is not necessary for: concentrically conductors, for metal sheaths of armored cables used as protective conductors or for cables which insulation prevents marking (eg. Mineral insulated).
It is allowed to use one single color for all the phase conductors of a circuit if the ends are marked accordingly.

Conductors' identification after symbols (FY, CYY, MYYMr, ABYY):

F= fixed installation and copper conductor, if is not preceded by a different letter;
A= on the beginning of code - Al;
 = in the middle of code - wire armature;
B= strip;
Y= PVC insulation;
P= bridge execution (like SATA cable for PC);
C= rubber insulation;
M= on the beginning of code – mobile insulation;
 = in the middle of the code – median execution;
r= round conductor;
p= plate conductor;

The numbers inside the code show which working voltage is suitable for the conductor and the digit represents the cross-section.

For example: FA 1000-6 is a copper bus-bar with robber insulation, for voltages up to 1000 V, having a cross-section of 6 mm^2.