Contents

1. Introduction

When circuit conductors carry load current, a voltage drop is produced in them due to their impedance. This means that the voltage at the load end of the circuit should be expected to be less than that at the supply end, as illustrated in Fig 1.

Voltage drop in conductors carrying load current

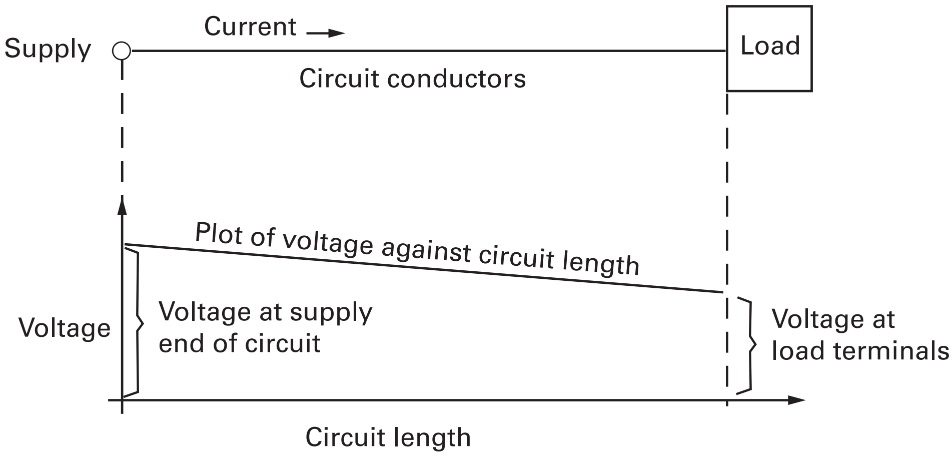

Fig 1

Clearly, it is necessary to limit the voltage drop in a circuit so that the safe and satisfactory operation of current-using equipment supplied through the circuit is not impaired. In order to limit the voltage drop, circuit conductors larger than would otherwise be required may have to be used, depending on the load and the circuit length.

This topic explains the requirements of *BS 7671* relating to maximum permitted voltage drop. Basic methods of calculating the voltage drop produced in the conductors of a circuit are also explained, with the aid of worked examples.

2. Requirements relating to maximum permitted voltage drop

The general requirement of *BS 7671* relating to maximum permitted voltage drop is given in Section 525 of *BS 7671*. Under normal operating conditions, the voltage at the terminals of the fixed current-using equipment is required to be greater than the lower limit given in the product standard for the equipment (Regulation 525.1 refers). Where the fixed current-using equipment is not subject to a product standard, the voltage at the terminals has to be such as not to impair the safe functioning of the equipment (Regulation 525.2 refers).

Unfortunately, product standards or other sources of information about the lowest acceptable voltage at the terminals of fixed current-using equipment may not be readily available. However, a way of proceeding without such information is given in Regulation 525.3. Where the supply to the installation is given in accordance with the *Electricity Safety, Quality and Continuity Regulations 2002* (*ESQCR*), the requirement of Regulation 525.3 is deemed to be met if the voltage drop between the origin of the installation (usually the supply terminals) and a socket-outlet or the terminals of fixed current-using equipment does not exceed the values given in Appendix 12 of *BS 7671*, that is, 3% for lighting installations and 5% for other uses.

A maximum voltage drop in accordance with the values given in Appendix 12 of *BS 7671* is accepted by Regulation 525.3 because the *ESQCR* generally allows an electricity distributer to reduce the voltage of a low voltage supply by no more than 6% of the nominal value. Thus, for example, the voltage at the terminals of an item of fixed current-using equipment (other than a luminaire) or a socket-outlet in an installation should never be less than 89% of the nominal supply voltage (that is 100% - 6% - 5%). This voltage is usually adequate for the safe and satisfactory operation of current-using equipment having a rated voltage corresponding to the nominal voltage of the supply.

A maximum voltage drop of 6% for lighting and 8% for other circuits is normally acceptable in a large installation where the low voltage supply is derived from a privately-owned distribution transformer supplied at high voltage. This is explained in Topic ***V33-17***.

A voltage drop greater than the values given in Appendix 12 of *BS 7671* is also normally acceptable in any installation during motor starting periods and for other equipment with high inrush currents, such as capacitors, transformers and certain types of lighting equipment (Regulation 525.4 refers). However, it has to be verified that the voltage variations during such periods are within the limits specified in the relevant product standards for the equipment. In the absence of a product standard, the voltage variations have to be in accordance with the manufacturer's recommendations.

3. Tables of voltage drop per ampere per metre

Appendix 4 of *BS 7671* includes tables giving values of voltage drop in mV/A/m (millivolts per ampere per metre). The values are for a current of one ampere for a one metre run along the route taken by the cables, and represent the total of all the voltage drops of all the circuit conductors. For three-phase circuits, the tabulated values of voltage drop relate to the line-to-line voltage and balanced three-phase conditions are assumed.

The values assume that all the conductors are at their maximum permitted normal operating temperature.

For cables having conductor sizes up to and including 16 mm^2, inductance may be ignored and the tabulated voltage drop values take account of resistance only. For cables having conductor sizes greater than 16 mm^2, tabulated voltage drop values taking account of conductor resistance, inductance and impedance are given separately. These are identified in the tables by the symbols r, x and z, respectively.

The voltage drop values in the tables are for a.c. or d.c. as indicated. The values for a.c. circuits apply only to frequencies in the range 49 Hz to 61 Hz. The values for cables operating at higher frequencies may be substantially greater.

For single-core armoured cables, the voltage drop values apply where the armour is connected to Earth at both ends. (It should be noted that single-core cables armoured with steel wire or steel tape must not be used for a.c. circuits; Regulation 521.5.2 refers.)

Item 4 explains how to calculate the voltage drop for a given run of cable(s).

4. Basic voltage drop calculations

Items 4.1 to 4.3 explain basic voltage drop calculations.

The calculation method in items 4.1 and 4.2 is for determining the voltage drop in a given run of cable. Where used, this method is usually applied after the intended conductor cross-sectional area for the cable has been chosen on the basis of current-carrying capacity. If the calculated voltage drop is too great to meet the requirements of *BS 7671*, it is necessary to select an increased conductor cross-sectional area and recalculate the voltage drop to confirm that this then meets the requirements of *BS 7671*.

The calculation method in item 4.3 is for determining the minimum conductor cross-sectional area needed to restrict the voltage drop in a given run of cable to within a certain value (such as 5% of the nominal supply voltage). It is subsequently necessary to check that the cross-sectional area determined by this method affords adequate current-carrying capacity for the needs of the circuit.

The calculations in items 4.1 to 4.3 make direct use of the tabulated values of mV/A/m (or, for the larger cable sizes, $(\text{mV/A/m})_z$) given in Appendix 4 of *BS 7671*. There are situations where it can be advantageous to correct the tabulated values of voltage drop in order to improve the accuracy of voltage drop calculations. Item 6 gives further details.

4.1 Calculating the voltage drop for a given run of cable

The voltage drop (V_D) for a given run of cable(s) is calculated by the procedure in (i) to (iii):

(i) Obtain the tabulated mV/A/m value (or, for the larger cable sizes, the tabulated $(\text{mV/A/m})_z$ value) for the cable(s) concerned, from Appendix 4 of *BS 7671*.

(ii) Multiply the mV/A/m value or $(\text{mV/A/m})_z$ value, as applicable, by the length of run of the cable(s) (L) in metres and by the current the cable(s) is intended to carry, namely the design current (I_b), in amperes

(iii) Divide the result of the calculation in (ii) by 1 000, to give the voltage drop for the run of cable(s) in volts (rather than millivolts)

The procedure in (i) to (iii) can be expressed mathematically as given in equation (1):

$$V_D = \frac{\text{mV/A/m} \times L \times I_b}{1\,000} \text{ V} \qquad (1)$$

Where:

V_D is the voltage drop for the given run of cable(s) in volts

mV/A/m is the tabulated mV/A/m value (or, for the larger cable sizes, the tabulated $(\text{mV/A/m})_z$ value) obtained from Appendix 4 of *BS 7671*

L is the length of run of the cable(s) in metres

I_b is the current the cable(s) is intended to carry, namely the design current, in amperes

The procedure is demonstrated in worked example 1.

Worked example 1

Problem

A 6 mm^2 70 °C thermoplastic (pvc) insulated and sheathed flat 2-core cable with protective conductor is used to supply a 230 V 8 kW instantaneous electric shower from a distribution board at the origin of an installation, as shown in Fig 2. The nominal voltage of the public supply is 230 V.

Given that the length of run of the cable is 28 m, determine: (a) the voltage drop and (b) whether or not this falls within the 5% deemed-to-comply limit referred to in Appendix 12 of *BS 7671*.

Shower circuit

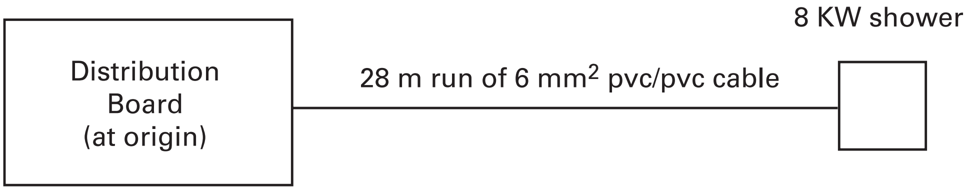

Fig 2

Solution

From Table 4D5 in Appendix 4 of *BS 7671*, the tabulated mV/A/m for a 6 mm^2 70 °C thermoplastic (pvc) insulated and sheathed flat 2-core cable with protective conductor is 7.3 mV/A/m.

The design current for the circuit (I_b) is calculated by dividing the rated power of the instantaneous shower (8 000 watts) by the rated voltage (230 V), giving 34.8 A.

The length of run (L) is 28 m, as given in the problem.

The voltage drop (V_D) is calculated using equation (1), which is:

$$V_D = \frac{\text{mV/A/m} \times L \times I_b}{1\,000} \text{ V} \qquad (2)$$

Substituting the values of mV/A/m, L and I_b into the equation gives:

$$V_D = \frac{7.3 \times 28 \times 34.8}{1\,000} \quad 7.11 \text{ volts}$$ **(Answer (a))**

The calculated voltage drop of 7.11 volts is equivalent to 3.09% of the nominal voltage of the supply (given by 100% x (7.11 V) ÷ (230 V) = 3.09%). Thus, the voltage drop is within the 5% deemed-to-comply limit referred to in Appendix 12 of *BS 7671*, and is therefore acceptable. **(Answer (b))**

4.2 Calculating the total voltage drop where a circuit is NOT directly supplied from the origin

In some cases a circuit is supplied from a distribution board which is not at the origin of the installation, as shown in Fig 3. Where this is the case, the total voltage drop between the origin of the installation and the load end of the circuit is equal to the sum of the voltage drops in the distribution circuit and the circuit concerned (normally a final circuit).

Circuit supplied from a distribution board not at the origin

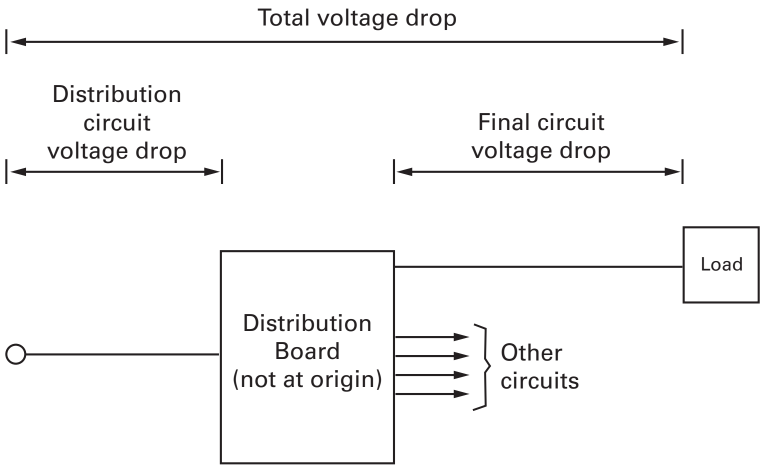

Fig 3

Care is needed when adding together the voltage drop of a three-phase distribution circuit and a single-phase final circuit, as the former voltage drop relates to the line-to-line voltage and the latter relates to the line-to-Earth voltage. The likelihood of errors can be reduced by expressing the voltage drops that are to be added together as percentages (of the nominal line-to-line voltage or line-to-Earth voltage, as applicable). This technique is demonstrated in worked example 2.

Worked example 2

Problem

A three-phase and neutral distribution board is supplied from the origin of an installation by a 75 m run of 4-core 25 mm^2 thermosetting insulated armoured cable to *BS 5467*, having copper conductors. Supplied from the distribution board is a single-phase circuit consisting of a 20 m run of 2-core 2.5 mm^2 thermoplastic (pvc) insulated armoured cable to *BS 5467*, having copper conductors, supplying a machine with a load current of 22 A.

Given that the nominal voltage of the public supply is 400/230 V and the current in the distribution circuit is 80 A per phase, assumed to be balanced, determine:

(a) the total voltage drop between the origin of the installation and the machine under normal operating conditions, expressed as a percentage of the nominal supply voltage, and

(b) whether or not the total voltage drop falls within the 5% deemed-to-comply limit referred to in Appendix 12 of *BS 7671*, and

(c) the total line-to-neutral voltage drop in volts.

Solution

The voltage drop (V_D) in the **distribution** circuit cable is calculated using equation (1), which is:

$$V_D = \frac{\text{mV/A/m} \times L \times I_b}{1\,000} \text{ V} \qquad (3)$$

Where:

the tabulated $(\text{mV/A/m})_z$ value for the 4-core 25 mm^2 cable is 1.65 mV/A/m, as listed under 'z' in column 4 of Table 4E2B in Appendix 4 of *BS 7671*,

L (the length of the cable) is 75 m, as given in the problem, and

I_b (the current carried by the cable) is 80 A, as given in the problem.

Substituting these values into equation (1) gives the voltage drop as:

$$V_D \text{ for distribution circuit } = \frac{1.65 \times 75 \times 80}{1\,000} = 9.9 \text{ volts}$$

The voltage drop of 9 V is equivalent to 2.48% of the nominal line-to-line voltage of the supply (given by 100% x 9.9 V ÷ 400 V) = 2.48%).

The voltage drop (V_D) in the **final** circuit cable supplying the machine is calculated using equation (1), where:

the tabulated mV/A/m value for the 2-core 2.5 mm^2 cable is 19 mV/A/m, obtained from column 2 of Table 4E2B in Appendix 4 of *BS 7671*,

L (the length of the cable) is 20 m, as given in the problem, and

I_b (the current carried by the cable) is 22 A, as given in the problem

Substituting these values into equation (1) gives the voltage drop as:

$$V_D \text{ for final circuit } = \frac{19 \times 20 \times 22}{1\,000} = 8.36 \text{ volts}$$

The voltage drop of 8.36 V is equivalent to 3.63% of the nominal line-to-Earth voltage of the supply (given by 100% x 8.36 V ÷ 230 V = 3.63%).

Now, the total percentage voltage drop between the origin of the installation and the machine is equal to the sum of the voltage drop in the distribution circuit (2.48%) and the voltage drop in the final circuit (3.63%), which is 6.11%. **(Answer (a))**

The total voltage drop of 6.11% does not fall within the 5% deemed-to-comply limit referred to in Appendix 12 of *BS 7671*. **(Answer (b))**

The total voltage drop expressed in volts, line-to-neutral, is 14.01 V (given by 6.1% x 230 V ÷ 100% = 14.01 V). **(Answer (c))**

Note: It is **not** acceptable for the voltage drop within an installation to exceed 5% of the nominal voltage of the supply, unless it is established that the voltage at the terminals of any fixed current-using equipment will be greater than the lower limit corresponding to the product standard relevant to the equipment. Where the equipment is not covered by a product standard, the voltage at the equipment terminals has to be such as not to impair the safe functioning of the equipment. (Regulations 525.1 and 525.2 refer.)

4.3 Determination of minimum conductor size based on voltage drop

It is often desired to determine the minimum conductor cross-sectional area necessary to restrict the voltage drop in a given run of cable to within a certain value (such as 3% or 5% of the nominal supply voltage, depending on the type of installation).

Although this can be done with the aid of equation (1) in item 4.1, this usually involves trial and error. A simpler approach is to use the equation in a rearranged form, as shown in equation (4), such that the subject of the equation is the mV/A/m value.

$$\text{mV/A/m value} = \frac{1\,000 \times V_D}{L \times I_b} \text{ mV/A/m} \qquad (4)$$

The mV/A/m value calculated by means of equation (4) is used to determine the required minimum conductor cross-sectional area with the aid of the relevant voltage drop table in Appendix 4 of *BS 7671*. This is done by selecting the cable size which has the highest tabulated value of mV/A/m (or, for the larger cable sizes, the tabulated $(\text{mV/A/m})_z$ value) not exceeding the calculated mV/A/m value.

Worked example 3

Problem

A 50 m long circuit of two single-core 70 °C thermoplastic (pvc) insulated cables enclosed in conduit or trunking supplies a single-phase load of 75 A from a distribution board at the origin of an installation.

Given that the nominal voltage of the supply is 230 V, determine the minimum conductor cross-sectional area that would result in a voltage drop (V_D) in the circuit of not more than 11.5 V (that is, 5% of the nominal voltage of the supply).

Solution

The maximum tabulated mV/A/m value (or, for the larger cable sizes, the maximum tabulated $(\text{mV/A/m})_z$ value) that would be required in order to result in a voltage drop not exceeding 11.5 V is calculated using equation (4), which is:

$$\text{mV/A/m value} = \frac{1\,000 \times V_D}{L \times I_b} \ \text{mV/A/m}$$

Substituting the values of voltage drop (V_D), length (L) and current (I_b) into the equation gives:

$$\text{mV/A/m value} = \frac{1\,000 \times 11.5}{50 \times 75} = 3.067 \ \text{mV/A/m}$$

It can be seen from Table 4D1B (column 3), in Appendix 4 of *BS 7671*, that the cable size which has the highest tabulated (mV/A/m) value not exceeding 3.067 mV/A/m is 16 mm^2 (tabulated (mV/A/m) value of 2.8 mV/A/m). **(Answer)**

5. Voltage drop calculations for circuits supplying distributed loads

When carrying out voltage drop calculations for a circuit supplying distributed loads (that is, a number of loads connected at different points along the run of the circuit cable(s)), account needs to be taken of the fact that each section of the circuit is carrying a different value of current. This is explained in Topics ***V33-9*** and ***V33-13***, which deal with voltage drop calculations for radial circuits and ring circuits, respectively, supplying distributed loads.

6. Situations where correction of tabulated mV/A/m values may be advantageous

In two situations, direct use of the tabulated mV/A/m values (or, for the larger cable sizes, the tabulated $(\text{mV/A/m})_z$ values) given in Appendix 4 of *BS 7671* can lead to pessimistically high calculated values of voltage drop or, in other words, unnecessarily low values of permitted circuits length. The two situations are:

- Where the conductor operating temperature (and hence its resistance) is less than that on which the tabulated value of mV/A/m was based. This occurs where the design current of the circuit is significantly less than the effective current-carrying capacity of the chosen cable
- Where the power factor of the load is significantly different to the internal power factor of the cable.

Corrections can be made to the tabulated mV/A/m or $(mV/A/m)_z$ values, as applicable, to improve the accuracy of voltage drop calculations in the above situations. Topic ***V33-5*** explains how the corrections are made. It is only worthwhile making such corrections where the tabulated mV/A/m or $(mV/A/m)_z$ value for a cable is marginally too high to give an acceptably low calculated voltage drop.

The voltage drop calculations in item 4 do **not** take account of such corrections.

Topics referred to in this text:

V33-5	VOLTAGE DROP: Taking account of conductor temperature and load power factor
V33-9	VOLTAGE DROP: In radial circuits with distributed loads
V33-13	VOLTAGE DROP: In ring circuits with distributed loads
V33-17	VOLTAGE DROP: Installations supplied from a privately-owned distribution transformer

Topics not referred to in this text, which are related and may be of interest:

V29-13	VOLTAGE: Range

BS 7671 **(Requirements for electrical installations)**

Some of the most important requirements are found in:

Voltage drop in consumers' installations	Section 525