# Calculating temperature-adjusted maximum $Z_S$ values

Following calls to the NAPIT Helpline on the subject, *Bill Allan*, editor of IEE Guidance Note 3, Inspection and Testing, explains adjusting maximum $Z_S$ values for temperature

The note at the bottom of Table 41B1, 41B2 and 41D of BS 7671, as well as Regulation 413-02-05, requires that account be taken of the temperature of circuit conductors.

The temperature of cables affects their resistance. For example, the resistance of a copper conductor increases by some 20 per cent if its temperature rises from 20°C to 70°C. Conductor temperature is influenced by load current and by the ability of the cable to dissipate its heat to its surroundings.

As the temperature of circuit conductors affects the value of the earth fault loop impedance ($Z_S$), we'll consider in this article how to adjust the tabulated maximum $Z_S$ values in BS 7671, taking temperature into account.

## Maximum $Z_S$ tables in BS 7671

The maximum earth fault loop impedance ($Z_S$) values given in Table 41B1, Table 41B2 and Table 41D of BS 7671 have been calculated at the maximum temperature at which cables can operate safely; i.e. the normal conductor operating temperature (usually taken as 70°C for circuits wired in copper/pvc cables). The note below these tables explains that if the conductors are at a different temperature when tested, the reading should be adjusted accordingly.

When testing, conductors are unlikely to be at their normal operating temperature and are more likely to be at around the normal ambient temperature of say, 20°C.

## Adjusting Zs values to take account of temperature

Maximum values of earth fault loop impedance are given in Appendix 2 of IEE Guidance Note 3, Inspection and Testing (GN3) and Appendix 2 of the IEE On-Site Guide (OSG). These values are lower than those in Table 41B1, Table 41B2 and Table 41D of BS 7671 as these are measured values at an assumed conductor temperature of 10°C, while, as mentioned above, those in BS 7671 have been calculated at the conductor normal operating temperature of 70 C. **The ambient temperature during the testing period is assumed to be between 10°C and 20°C.**

When the ambient temperature is at a different value during the test, Table 1B of GN3 and Table 2E of the OSG give ambient temperature multipliers to convert the resistance to a 20°C value.

The 1.2 multiplier in Table 1C of GN3 allows for the 70°C cable to reach its maximum permitted operating temperature (70°C).

## Using GN3

GN3 gives four methods of verifying values of $Z_S$. The test results obtained should be compared with one of the following:

1 for standard pvc circuits, the values in Appendix 2 of GN3
2 earth fault loop impedance figures provided by the designer
3 Table 41B1, Table 41B2 or Table 41D of BS 7671, after correction of temperature
4 rule of thumb figures.

Let's briefly consider each of them in turn. The values given in Appendix 2 of GN3 must not be exceeded when testing in an ambient temperature of 10°C to 20°C. As this is the normal temperature range to be expected, then correction for temperature is not required.

GN3 gives a formula which designers may use to give maximum Zs values.

$$Z \text{ test (max.)} \leq \frac{1}{F} Z_S$$

where:
z test (max) is the maximum acceptable earth fault loop impedance obtained when testing an installation at an ambient temperature of 20°C
$\leq$ means less than or equal to
$Z_S$ is the loop impedance given by Tables 41B1, 41B2 or 41D of BS 7671
F is the conductor temperature resistance factor from Table 1C or Table 1D in Appendix 1 of GN3.

An example of how this formula may be used is given above right:

## Example

A circuit wired in 2 core, flat twin and cpc 70°C pvc cable and protected by a 6 amp BS 88 fuse, has a maximum disconnection time of 0.4 seconds. It is tested at an ambient temperature of 5°C. Calculate the maximum acceptable $Z_S$ value of the circuit, having adjusted it to take account of temperature.

### Solution

$$Z \text{ test (max.)} \leq \frac{1}{F} Z_S$$

From Table 41B1, the maximum permitted value of $Z_S$ = 8.89 ohms
From Table 1C of GN3, F = 1.20

$$Z \text{ test (max.)} \leq \frac{1}{1.20} \times 8.89$$

$$\leq 7.4 \text{ ohms}$$

Another way of expressing this formula is that values taken at 20°C ambient temperature for 70°C cables can be corrected to 70°C by simply dividing the appropriate maximum $Z_S$ value by 1.20 (or multiplying it by 0.83). As pointed out above, the 1.20 multiplier in Table 1C of GN3 allows for the 70°C cable to reach its maximum permitted operating temperature (70°C).

A more accurate reading can be obtained if the external earth fault loop impedance $Z_e$ is known. Let's assume it is 0.35 ohms. In this case, the following formula may be used:

$$Z \text{ test (max.)} \leq \frac{1}{F} Z_S \{ Z_S + Z_e (F - 1) \}$$

$$\leq \frac{1}{1.20} \{8.89 + 0.35 (1.20 - 1)\}$$

$$\leq 7.46 \text{ ohms}$$

## If the ambient temperature is different to 20°C

$\alpha$

If the ambient temperature is expected to be different to 20°C, a further correction can be made to convert the reading to a 20°C value. Let's say it is 5°C. In this case, the following formula may be used:

$$Z \text{ test (max.)} \leq \frac{1}{F + 1 - \alpha} \{ Z_S + Z_e (F - \alpha) \}$$

Note: $\acute{\alpha}$ is the ambient temperature multiplier and is given by Table 1B in Appendix 1 of GN3.

From Table 1B of GN3, $\alpha$ = 0.94

$$Z \text{ test (max.)} \leq \frac{1}{1.20 + 1 - 0.94} \{ 8.89 + 0.35 (1.20 - 0.94) \}$$

$$\leq 0.79 \{ 8.89 + 0.091\}$$

$$\leq 7 \text{ ohms}$$

As mentioned previously, the note below Tables 41B and 41D in BS 7671 says that if the conductors are tested at a temperature which is different to their maximum permitted operating temperature (70°C), which they usually will be, then the reading must be adjusted accordingly. This adjustment can be made by using the formulae given above. It can also be made by using the rule of thumb method discussed next.

## Calculating from 70°C to 20°C

The formulae above involves taking measurements at 20°C and converting them to 70°C values. Alternatively, the 70° C values can be converted to the values at the expected ambient temperature, e.g. 20°C, when the measurement is carried out. The following formula may be used for this calculation:

$$Rx = R70° \text{ C} \times \frac{230 + tx}{(230 + t70°)}$$

where:
Rx = the conductor resistance at the ambient temperature
R70°C = the conductor resistance at 70°C
t70°C = the conductor temperature at 70°C
tx = the expected ambient temperature

Using the previous example, it works out as follows:

$$Rx = R70° \text{ C} \times \frac{230 + tx}{(230 + t70°)}$$

$$= 8.89 \times \frac{230 + 20}{(230 + 70)}$$

$$= 7.74 \text{ ohms}$$

The rule of thumb method in GN3 says that in order to allow for conductors reaching their maximum permitted operating temperature, the measured value of earth fault loop impedance of each circuit at the most remote outlet should not exceed three-quarters of the relevant value in Table 41B1, Table 41B2 or Table 41D. The three-quarters figure allows for a reduced cross-section protective conductor.

NAPIT has produced a prelaminated sheet giving values precalculated for easy reference. These are freely available from the NAPIT office or downloadable from the NAPIT website.

## Conclusion

It is expected that the first and last method will be used more frequently by the smaller contractor. The other two may be used where greater accuracy is required.