Determination of Z_s and the "80% rule

A look at a subject that can be misinterpreted leading to confusion as what exactly is the maximum amount of resistance is allowed in a circuit to ensure disconnection of the fuse or breaker within the time required in BS 7671.

Terminology

There is often more than one name for the same conductor which can cause confusion to those new to the subject.

The *"Line"* conductor. Also known as the *"phase"* conductor is given the symbol is R_1. If it is a ring-circuit, it is given a lower-case symbol r_1.

The Neutral conductor. Also known as R_n. If it is a ring-circuit, it is given a lower-case symbol r_n.

The *"Circuit-protective-conductor",* or *"Cpc"* It is also known as R_2, again if we are talking about a ring-circuit, it is giver a lower-case symbol r_2.

It is important to understand that both Line and Neutral are *"live"* conductors.

Placing a limit on the resistance in the circuit concerned, will ensure there is sufficient current in the event of a fault, to disconnect the overcurrent protective device in the required time in the event of a fault between the line conductor and R_2 or *CPC!*

- Z_s: The symbol given to the resistance or "impedance"; hence the *"Z".* This value starts at the substation transformer and finishes at the fitting in the building, or the overall *"system"* impedance. Also known as "Earth fault loop impedance" *(EFLI)*
- Z_e: The impedance of the external part of the installation, so the actual conductors coming from the supply transformer to the supplier's cutout.
- R_1 + R_2 is the resistance or "impedance" of the *"Line"* or *"phase"* conductor and the circuit protective conductor added together.
- *Design* Z_s: This is the actual impedance of the circuit which must be equal to or less than the maximum permitted value in BS 7671 at the design stage. (70^0C).
- *Measured* Z_s: The actual "measured" value corrected for ambient temperature.
- I_a: The value of current required to trip our breaker or fuse in the required time.
- U_0: The symbol which refers to phase/line earth voltage. In the UK it is 230V
- C_{min}: This is a multiplication factor of 0.95
- I_n: The continuous rating of the breaker or fuse.

We then have the familiar equation: $Z_s = Z_e + (R_1 + R_2)$

It is important to include that if there is a distribution board downstream of the origin it would then be written: $Z_s = Z_{db} + (R_1 + R_2)$ where $Z_{db} = (R_1 + R_2)\ of\ the\ distribution\ circuit.$

The I_a value for a breaker to BS EN 60898 is simple to determine. The continuous rating I_n refers to the "thermal" trip or the bi-metallic strip; whereas. The I_a refers to the "magnetic" trip, or "solenoid" trip current.

- B-curve or type B breaker $I_a = 5\ x\ I_n$
- B-curve or type C breaker $I_a = 10\ x\ I_n$
- B-curve or type D breaker $I_a = 20\ x\ I_n$

Now that we know what Z_s is, it is important to understand how it is calculated.

$$Z_s = \frac{U_0 C_{min}}{I_a}$$

This is how Table 41.3 is produced and it is very important to appreciate that the equation will give you the ***"Maximum Tabulated"*** or ***"Maximum Permitted"*** value of Z_s. and that this value of impedance is valid when the conductors have reached a temperature of 70^0C!

As the temperature of a copper conductor increases, the resistance increases by a known amount: Approximately 2% per 5^0C.

Thermoplastic insulation starts to fail at temperatures above 70^0C, so that becomes our design limit, and it is that limit which is reflected in Table 41.3 in BS 7671. or by calculation using the above equation.

Let's take an example with a B32 breaker:

The I_a value = 5 x 32 = 160 A.

This means that it takes this value of current as a minimum to operate the magnetic trip or solenoid in the breaker. When this occurs, we achieve disconnection in 0.1 seconds, well below the 0.4 seconds required by the regs for a final circuit in a TN system.

$$Z_s = \frac{230\ x\ 0.95}{5\ x\ 32} = \frac{218.5\ V}{160\ A} = 1.366\ (1.37\Omega)$$

We will find the same value if we look it up in Table 41.3 in BS 7671

When it comes to testing the circuit concerned, we cannot use the above value because the conductors are not at 70^0C. Now we employ the 80% rule and multiply the 1.37 x 0.8 = 1.1Ω.

By doing this, we have effectively dropped the resistance to what it would be at 10^0C, which is more representative as a "test" or "measured" value. It is this value that we find in the On-Site Guide in Table B6, or Guidance note 3 Table A5. Both tables have accounted for the 80% rule and so can be used directly to determine the Z_s for the circuit concerned.

Going back to our example with the B32 breaker, the maximum permitted Z_s (70^0C) in BS 7671= 1.37Ω.

The maximum "measured" Z_s for our B 32 breaker in the On-site Guide Table B6/GN3 Table A5 = 1.1Ω.

The difference between the two figures is temperature and it means that if you measure 1.1Ω at 10^0C, the conductors will reach 1.37Ω if they reach 70^0C!

To calculate the measured value for a B 32 breaker:

$$Z_s\ (M) = 0.8\ x \frac{U_0 C_{min}}{I_a} = 0.8\ x\ \frac{218.5}{160} = 1.09\ (1.1\Omega)$$

A further correction can be made if the temperature is other than 10^0C. The On-Site Guide and GN3 both have a table with correction factors.

Table A7 in GN3 or Table B8 in the On-Site Guide.

Ambient temperature (^{0}C)	Correction factor (from 10^0C)
0	0.96
5	0.98
10	1.00
20	1.04
25	1.06
30	1.08

For a B32 breaker, the 80% value = 1.1Ω. This is at 10^0C

If the ambient temperature is 25^0C, the corrected Z_s value should not exceed 1.1 x 1.06 = 1.17Ω.

When measuring the Z_s for the circuit, the preferred method is to calculate it; that is measure the Z_e "live" and measure the R_1+R_2 "dead", then add them together. This is considered the more accurate method because it does not include any parallel paths as would be the case if it were measured live.

Measuring the whole thing live can also be known as *"direct Z_s"*. Any parallel paths will lower the resistance because it offers another pathway for the test current, so the reading will be slightly lower.

This can be used as a method to confirm the calculated figures, but care must be taken of it is a ring circuit: the so-called figure-of-eight cross-connection is not in place, so the readings will increase towards the half-way point of the ring and decrease from the half-way point to the final socket near the consumer unit.