EFFECT OF HARMONICS ON CURRENT RATINGS AND VOLTAGE DROP

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It is well know that when a 3-phase load current includes third or other triple harmonic currents these currents are additive in the neutral. This neutral current will give rise to additional heating of the cables and other equipment in the circuit. Hence appropriate cable sizes and equipment ratings have to be selected to take account of this additional heating.

When the load current includes other harmonics, that are not additive in the neutral, they will have a heating effect on the line conductors. This heating effect has to be taken into account, in addition to the effect of the triplen harmonics, when selecting cables and other equipment.

The heating effect of the non triplen harmonic currents can be taken into account by calculating a correction factor, C_f, to be applied to the fundamental design current. For cable sizes less than 50 mm² this factor can be calculated from the following equation:

$$C_f = \sqrt{\frac{I_f^2 + I_{h5}^2 + \cdots + I_{hn}^2}{I_f^2}} \qquad (1)$$

Where:
I_f = fundamental current
I_{h5} = 5th harmonic content
I_{hn} = nth harmonic content

This factor is applied to the fundamental design current to determine the actual design current, taking account of the effect of harmonics.

For larger cable sizes the a.c. conductor resistance

Nominal conductor size, mm²	a.c. resistance ratio (C_f) Harmonic				
	1	5	7	11	13
	(50 Hz)	(250 Hz)	(350 Hz)	(550 Hz)	(650 Hz)
16	1	1.00	1.01	1.02	1.02
25	1	1.01	1.02	1.04	1.05
35	1	1.02	1.03	1.08	1.10
50	1	1.03	1.06	1.13	1.18
70	1	1.06	1.12	1.25	1.33
95	1	1.12	1.21	1.43	1.54
120	1	1.18	1.31	1.59	1.72
150	1	1.24	1.41	1.73	1.87
185	1	1.34	1.55	1.90	2.05
240	1	1.49	1.74	2.13	2.27
300	1	1.63	1.91	2.29	2.42

Table 1: a.c. resistance ratios (C_f) for 3-core thermosetting unarmoured cables having copper conductors

Nominal conductor size, mm²	Voltage drop ratio (F_h) Harmonic				
	1	5	7	11	13
	(50 Hz)	(250 Hz)	(350 Hz)	(550 Hz)	(650 Hz)
16	1	1.04	1.08	1.19	1.26
25	1	1.10	1.19	1.43	1.57
35	1	1.18	1.33	1.71	1.92
50	1	1.28	1.51	2.05	2.34
70	1	1.51	1.88	2.70	3.13
95	1	1.80	2.34	3.47	4.05
120	1	2.07	2.75	4.14	4.84
150	1	2.39	3.21	4.89	5.73
185	1	2.76	3.75	5.75	6.74
240	1	3.21	4.39	6.76	7.95
300	1	3.56	4.90	7.56	8.89

Table 2: Impedance ratios for 3-core thermosetting unarmoured cables having copper conductors

Note: Tables 1 & 2 given above apply only to the particular cables indicated, 3-core unarmoured cable with thermosetting insulation and copper conductors. The a.c. resistance ratios and the impedance ratios will be different for the different cable types covered by Appendix 4 of BS 7671. The values for single-core cables, whether unarmoured or armoured, touching, spaced or trefoil, are expected to be significantly different from those given above. It is also expected that the values will be affected by conductor material and maximum operating temperature.

and armour losses, if any, will increase significantly with frequency. These factors should be taken into account when calculating the factor, C_f, for larger sizes. In such cases the following equation is used:

$$C_f = \sqrt{\frac{I_f^2 R_f \left(1+\lambda_f\right) + I_{h5}^2 R_{h5} \left(1+\lambda_{h5}\right) + \cdots + I_{hn}^2 R_{hn} \left(1+\lambda_{hn}\right)}{I^2 R_f \left(1+\lambda_f\right)}} \quad (2)$$

Where:
R_f = Resistance at fundamental frequency
λ_f = Armour loss factor at fundamental frequency
R_h = Resistance at harmonic frequency
λ_h = Armour loss factor at harmonic frequency

Both the a.c. conductor resistance and the armour loss factor, at different frequencies, can be calculated using the equations set out in BS IEC 60287-1-1.

The table presented opposite indicates the effect of frequency on a.c. conductor resistance in 3-core unarmoured cables with thermosetting insulation.

The a.c. resistance ratios given in Table 1 can be used to derive derating factors, C_f, for cables carrying harmonic currents.

Multiplying the 50 Hz conductor resistance by the appropriate factor, C_r, from the above table will give the resistance at that frequency.

If $C_r \times R_f$ is substituted for R_h in equation 2 it is clear that R_f will cancel in the numerator and the denominator. Thus the factors given in Table 1 can be used in place of the resistance values in equation 2.

Effect of voltage drop

As well as the additional heating effect of harmonic currents there will also be an effect on the voltage drop in the circuit. This will be most significant for larger cable sizes where the reactance is significant. The voltage drop ratios, F_h, given in Table 2 include the effect of frequency on reactance as well as resistance. The values given are the impedance ratios relative to the 50 Hz impedance.

Taking a simplistic approach the voltage drop, including the effect of harmonics can be taken as the r.m.s sum of the voltage drop due to the current at each frequency. Thus:

$$\Delta V_h = Z_f \times L \times \sqrt{\left(I_f \times I\right)^2 + \left(I_{h5} \times F_{h5}\right)^2 + \cdots + \left(I_{hn} \times F_{hn}\right)^2} \quad (3)$$

Where:
Z_f = 50 Hz impedance
L = circuit length

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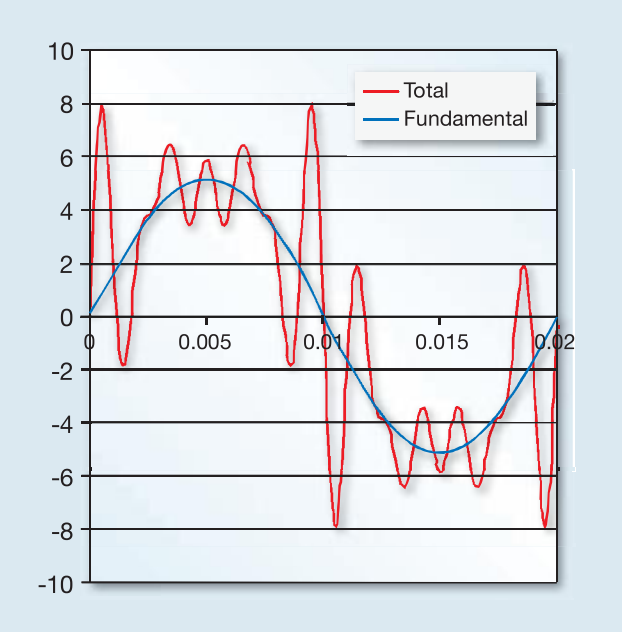


Figure 1: Voltage drop Waveform including harmonics

Nominal conductor size, mm²	Voltage drop ratio Harmonic 1 (50 Hz)	5 (250 Hz)	7 (350 Hz)	11 (550 Hz)	13 (650 Hz)
185	1	2.76	3.75	5.75	6.74

Table 3: Voltage drop ratios for Fig. 1

Frequency	Voltage drop	
Fundamental	0.26 x 1 x 100%	0.260
7th	0.26 x 3.75 x 10%	0.098
9th	0.26 x 4.75 x 10%	0.124
11th	0.26 x 5.75 x 5%	0.075
13th	0.26 x 6.74 x 5%	0.088
r.m.s. value		0.325 x L x I_f
r.m.s/fundamental ratio		1.25

Table 4: Voltage drops in example

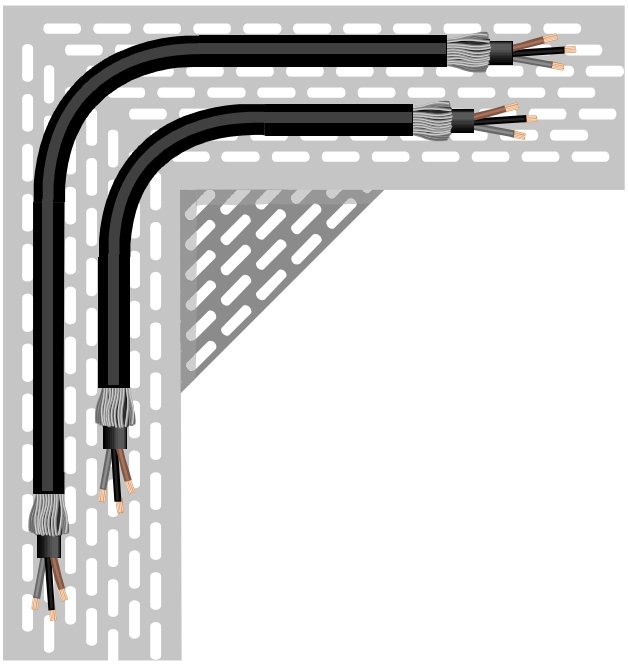
Although the above equation gives an indication of the magnitude of the voltage drop, including the effect of harmonics this may not be the most important factor to consider. Where there is a harmonic content the waveform will be distorted and the effect of that distortion on the operation of other equipment circuit is less clear.

Figure 1 shows the theoretical waveform of the voltage drop in a 185 mm² cable circuit in a 3-phase circuit carrying a current which consists of a fundamental at 50 Hz plus harmonic currents of 10 % of the fundamental at the 7th and 9th harmonic and 5 % at the 11th and 13th harmonic.

This example shows that the peak voltage drop, including the effect of harmonics, is about 1.6 times the peak fundamental voltage drop.

The voltage drop for the impedance (z) of 0.26Ω given in Table 4E2B is only applicable for the fundamental frequency (50 Hz). The overall voltage drop waveform for the cable circuit including the harmonics has been calculated by superposition, that is by adding the instantaneous voltage drops at the various frequencies.

For the example, a value for the 9th harmonic is required as an approximation the value has been taken as 4.75 (Midway between the values for 7th and 11th).

Table 4 below shows that if the r.m.s voltage drop is calculated using equation 3 above then the voltage drop, including the effect of harmonics, is about 1.25 times the fundamental voltage drop.

The question that the installation designer will need to answer is that if a specification calls for the calculation of the voltage drop to include the effect of any harmonic currents should the peak or r.m.s. values be considered. In most cases, the installation designer will consider the r.m.s value. ■