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Short-circuit current calculation in three-phase a.c. systems

**Part 2. Data for electrical equipment for
short-circuit current calculations in
accordance with BS 7639**

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National foreword

This Part of PD 7639 has been prepared under the direction of the Power Electrical Engineering Standards Policy Committee. It is identical with IEC 909-2 : 1992 *Electrical equipment — Data for short-circuit current calculations in accordance with IEC 909*, published by the International Electrotechnical Commission (IEC). The IEC document has been published as a type 3 Technical Report. It is not to be regarded as an international standard. A review of the Technical Report will be carried out by the IEC not later than 3 years after its publication with the options of extension for a further period of 3 years, conversion to an international standard or withdrawal.

Cross-references

International standard	Corresponding British Standard
IEC 50	BS 4727 <i>Glossary of electrotechnical, power, telecommunication, electronics, lighting and colour terms</i>
IEC 781 : 1989	BS 7638 : 1993 <i>Application guide for calculation of short-circuit currents in low-voltage radial systems</i> (Identical)
IEC 909 : 1988	BS 7639 : 1993 <i>Short-circuit current calculation in three-phase a.c. systems</i> (Technically equivalent)

Compliance with a British Standard does not of itself confer immunity from legal obligations.

ELECTRICAL EQUIPMENT – DATA FOR SHORT-CIRCUIT CURRENT CALCULATIONS IN ACCORDANCE WITH IEC 909 (1988)

SECTION 1: GENERAL

1.1 Scope and object

This Technical Report comprises data collected from different countries to be used when necessary for calculating short-circuit currents in accordance with IEC 781 and IEC 909.

Generally, electrical equipment data are given by the manufacturers on the name plate or by the electricity supplier. In some cases, however, the data may not be available. The data presented in this report may be applied for calculating short-circuit currents in low-voltage systems if they are in accordance with typical equipment employed in the user's country. The collected data and their evaluation may be used for medium or high voltage planning purposes and also for comparison with data given by manufacturers. For overhead lines the electrical data may be calculated from the physical dimensions.

1.2 Reference documents

IEC 38: 1983, *IEC standard voltages*.

IEC 50, *International Electrotechnical Vocabulary (IEV)*.

IEC 781: 1989, *Application guide for calculation of short-circuit currents in low-voltage radial systems*.

IEC 909: 1988, *Short-circuit current calculation in three-phase a.c. systems*.

SECTION 2: DATA FOR ELECTRICAL EQUIPMENT

2.1 General

The data presented are necessary for the calculation of short-circuit currents. In general data are presented in the form of curve sheets. For each type of equipment a table is presented, giving data as examples and explanatory notes and additional comments on the supplied data. In all 15 National Committees gave information. Information received is listed in table 1.

In some cases, average values or characteristic trends as function of rated power, rated voltage, etc. are given.

Table 1 – Information received from National Committees

National Committee	Number of answers to questionnaire tables						
	1	2	3	4	5	6	7
Australia	3	3	3	3	3	3	3
Austria	10	11	4	1	8	7	—
Bulgaria	4	15	6	6	14	11	28
China	3	3	3	3	3	3	3
Czechoslovakia	8	5	—	3	9	5	68
Denmark	8	18	1	2	8	15	—
ex-GDR	23	28	9	6	8	—	20
Germany	21	26	2	2	5 ¹⁾	13 ²⁾	19
Hungary	7	16	3	5	9	8	9
Italy	25	16	4	6	26	9	11
Japan	12	10	7	7	7	9	3
Norway	9	10	4	3	9	8	10
UK	—	11	1	5	—	—	—
USA	110	10	1	—	—	10	20
ex-USSR	12	6	3	5	4	— ³⁾	10
	255	188	51	57	113	101	204

1) Additional data for low and medium voltage overhead lines.

2) Additional data for low voltage cables.

3) Data for busbars.

2.2 Data on typical synchronous machines

In figure 1 the subtransient reactance of 50 Hz and 60 Hz synchronous turbogenerators, motors, condensers and salient pole generators is plotted as a function of the rated power.

In figure 2 the rated voltage and power factor of 50 Hz and 60 Hz synchronous turbogenerators, salient pole generators and motors are plotted as a function of the rated power.

In figure 3 the unsaturated and saturated reactances for 50 Hz and 60 Hz turbogenerators are plotted as a function of the rated power.

Data are also given for the zero-sequence reactance. It is recommended that the relationship $X_{(0)}/X''_d = 0,5$ be used.

Characteristic data for synchronous machines are listed in table 2.

Table 2 - Actual data of typical synchronous generators, condensers and motors

No.	Type ¹⁾	Rated voltage and deviation ²⁾		Power factor	Relative values of reactances					DC time constant	Notes	National Committee
		U_{r0}	$\pm p_0$		$x_d^{(3)}$	$x_{dnt}^{(4)}$	x_d''	$x_{(2)}^{(6)}$	$x_{(0)}^{(7)}$			
		S_{r0}		$\cos \varphi_{r0}$						$T_d^{(5)}$		
	-	MVA	kV	%	-	-	-	-	-	s		
1	TG2	100	10,5	± 5	0,80	1,77	1,45	0,134	-	0,246	50 Hz	Germany
2	TG2	125	10,5	± 5	0,80	2,13	1,87	0,16	0,08	0,46	50 Hz	ex-GDR
3	TG2	180	10,5	± 5	0,90	1,83	1,77	0,25	0,14	0,48	50 Hz	Austria
4	TG2	353	18,0	± 5	0,85	2,264	2,17	0,167	0,089	0,194	50 Hz	China
5	TG2	388,9	17,5	± 5	0,90	2,42	2,188	0,203	0,099	0,250	50 Hz	Australia
6	TG2	64	13,8	± 5	0,85	1,865	1,865	0,179	0,104	0,220	60 Hz	USA
7	SG20	290	18	± 5	0,90	1,03	0,96	0,22	0,14	0,36	60 Hz	Japan
8	SG14	48	10	± 5	0,90	0,78	-	0,160	0,170	0,16	50 Hz	Italy
9	SM2	1,45	10	± 5 -10	0,90	1,63	-	0,166	0,166	0,04	50 Hz	ex-USSR
10	SM3	3,4	4,0	± 5	0,80	2,675	2,675	0,249	0,303	0,116	60 Hz	USA
11	SC10	40	13,8	± 5	0	1,33	1,33	0,119	0,129	0,1425	60 Hz	USA
12	SC6	100	10,5	± 5	0	1,78	1,60	0,20	0,25	0,57	50 Hz	Czechoslovakia

1) TG2: Two-pole turbogenerator.

SG: Salient pole generator.

SC: Salient pole synchronous condenser.

SM: Synchronous motor.

2) $U_0 = U_{r0} (1 \pm \frac{p_0}{100})$.

3) Unsaturated synchronous reactance.

4) Saturated synchronous reactance.

5) DC time constant for three-phase terminal short circuit.

6) Negative-sequence reactance.

7) Zero-sequence reactance.

2.3 Data on typical transformers, two-winding, three-winding and auto-transformers

In figure 4 the rated short-circuit voltage is plotted as a function of the rated power for power station generator transformers with or without tap-changer.

An average value for the rated short-circuit voltage is given by

$$u_{kr} = 8 + 0,92 \ln S_{rT}$$

where S_{rT} is the rated power in MVA. (Values of S_{rT} lie between 3 MVA and 1 000 MVA.) From the curve sheet it can be seen that the following average values for u_{kr} may be used:

S_{rT}	1	-	10 MVA:	$u_{kr} \approx 9 \%$
S_{rT}	10	-	100 MVA:	$u_{kr} \approx 11 \%$
S_{rT}	100	-	1 000 MVA:	$u_{kr} \approx 13 \%$

In figure 5 the rated short-circuit voltage of network transformers is plotted as a function of the rated power. For low-voltage transformers 4 % and 6 % are commonly used.

Excluding auto-transformers, the following average values may be used:

S_{rT}	1	-	100 MVA:	$u_{kr} \approx 12 \%$
S_{rT}	100	-	1 000 MVA:	$u_{kr} \approx 14 \%$

In general u_{kr} values for auto-transformers are lower.

The u_{kr} for network transformers in the UK is, on average, twice as large as those reported from other countries.

The relationship $\frac{X_{(0)}}{X_{(1)}}$ for two- and three-winding network transformers is as follows:

For YN d-transformers:	0,8-1,0
For Y zn-transformers:	0,1
For YN yn0 d-transformers:	1,5-3,2

In tables 3A, 3B and 3C, characteristic data for two-winding, three-winding and auto-transformers are listed.

Table 3A - Actual data of typical two-winding transformers (NT-network, PT = power station)

No.	Rated apparent power S_{rT}	Rated voltage		Rated short-circuit voltage		Winding connection symbol	Side of earthing connection	Zero-sequence reactance $X_{(0)}/X_{(1)}$	Tap-changer			Notes	National Committee
		U_{rTHV} kV	U_{rTLV} kV	u_{kr} %	u_{Rr} %				$\pm PT$ %	u_{k+} %	u_{k-} %		
1	0,63	20	0,4	6,0	1,2	Dyn5	LV	≈ 1	± 5	off load		50 Hz, 3 limb, NT	ex-GDR
2	24	33	11	24,2	1,12	YNyn0	HV, LV	0,7	± 10	24,1	25,3	50 Hz, 3 limb, NT	UK
3	31,5	112	22,2	12,8	0,37	YNd5	HV	$\approx 1,0$	± 18	13,9	10,5	50 Hz, NT	Germany
4	80	121	6,3	10,5	-	YNd5	HV	0,71	2x2,5	-	-	50 Hz, 3 limb, NT	Bulgaria
5	500	400	132	26,1	0,30	YNynd5	HV, LV	$\approx 1,6$	± 13			50 Hz, NT	Denmark
6	20	138	13,2	10,58	0,49	Dyn 1	LV	$\approx 0,93$	+2,5 -7,5			60 HZ, 3 limb, PT	USA
7	180	110	10,5	12,0	0,221	Yd11		0,78	± 12			50 Hz, PT	Austria
8	25	132	6,3	10,5		YNd11	HV	1,0				50 Hz, 3 limb, PT	Hungary
9	780	230	21,0	15,3	0,2	YNd5	HV	0,7-0,9	± 15	16,7	14,3	50 Hz, PT	Germany
10	390	350	23,0	15,92	0,554	YNd1	HV	1,0	+10 -15	16,7	15,5	50 Hz, 3 limb, PT	Australia

Table 3B - Actual data of typical three-winding transformers

No.	Rated voltages			Rated apparent powers			Rated short-circuit voltages (related to A)			Connection symbol			Zero-sequence reactances related to side A (HV-side)			Notes	National Committee
	$U_{rTA} = U_{rTHV}$	$U_{rTB} = U_{rTMV}$	$U_{rTC} = U_{rTLV}$	S_{rTAB}	S_{rTAC}	S_{rTBC}	u_{krAB}	u_{krAC}	u_{krBC}	HV	MV	LV	$X_{(0)A}$	$X_{(0)B}$	$X_{(0)C}$		
	kV	kV	kV	MVA	MVA	MVA	%	%	%	-	-	-	Ω	Ω	Ω		
1	34,5	13,8	13,8	7,5	7,5	7,5	3,65	3,58	7,96	YN d1, d1			-	-	-	60 Hz, 3 limb	USA
2	110	38,5	6,3	31,5	31,5	31,5	10,5	17,5	6,5	YN yn0, d11			+6,13	+17,23	+18,24	50 Hz, 3 limb	China
3	120	22	11	25	16	16	11,0	14,5	3,5	YN yn0, d11			+99	-	+3,15	50 Hz, 3 limb	Hungary
4	230	63	20	125	42	42	11,7	10,6	5,9	YN yn0, d11			+124,6	-	+5,74	50 Hz, 5 limb	ex-GDR
5	239	130	13,8	94	94	94	11,79	11,31	12,44	YN yn0, d11			+32,39	+39,23	+36,31	50 Hz, 3 limb	Italy
6	400	230	30	600	150	150	17,5	16,5	11,3	YN yn0, d5			50,5	-3,8	+125,3	50 Hz, 5 limb	Austria

Table 3C - Actual data of typical autotransformers with and without tertiary winding

No.	Rated voltages			Rated apparent powers			Rated short-circuit voltages			Connection symbol			Zero-sequence reactances related to side A (HV-Side)			National Committee
	$U_{rTA} = U_{rTHV}$	$U_{rTB} = U_{rTMV}$	$U_{rTC} = U_{rTLV}$	S_{rTAB}	S_{rTAC}	S_{rTBC}	u_{krAB}	u_{krAC}	u_{krBC}	HV	MV	LV	$X_{(0)A}$	$X_{(0)B}$	$X_{(0)C}$	
	kV	kV	kV	MVA	MVA	MVA	%	%	%	-			Ω	Ω	Ω	
1	132	66	11	60	60	10	11,0	27,5	79,0	Y yn0, d1			+61,6	+4,19	+1049,8	Australia
2	230	121	38,5	200	200	100	11,0	32,0	20,0	Y auto, d11			+30,4	0	+54,2	ex-USSR
3	230	130	-	250	250	-	11,6	-	-	YN yn0			+24,55	-	-	Italy
4	235	165	-	300	300	-	7,0	-	-	YN yn0			+13	-	-	Denmark
5	400	132	18	250	75	75	14,6	12,2	7,1	YN yn0, d11			+10,11	-7,71	+159,1	Hungary
6	400	121	10	250	100	100	12,9	13,1	6,3	YN yn0, d1			+95,7	-13,1	+113,9	Czechoslovakia
7	400	231	30	660	198	198	10,2	13,5	10,6	III, d5 ¹⁾			+24,35	+0,35	+84,65	Germany

1) Three separate poles.

2.4 Data on typical overhead lines, single and double circuits

The positive-sequence impedance may be calculated from conductor data such as cross section and conductor centre-distances (see IEC 909).

The effective resistance per unit length is:

$$R'_L = \frac{\rho}{q}$$

where

q is the cross section

ρ is the resistivity

$$\rho = \frac{1}{54} \frac{\Omega \text{ mm}^2}{\text{m}} \text{ for copper and } \rho = \frac{1}{34} \frac{\Omega \text{ mm}^2}{\text{m}} \text{ for aluminium}$$

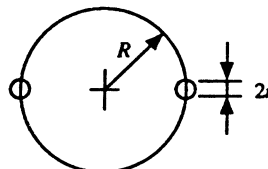
The positive-sequence reactance may be calculated from line data.

For single conductor lines equation (1) is valid (see figure 6):

$$X'_{(1)L} = \frac{\omega \mu_0}{2\pi} (0,25 + \ln \frac{d}{r}) \quad (1)$$

$$d = \sqrt[3]{d_{L1L2} \cdot d_{L1L3} \cdot d_{L2L3}} \quad \text{and } r = \text{conductor radius}$$

For bundle conductor lines equation (2) is valid (see figure 7):



$$X'_{(1)L} = \frac{\omega \mu_0}{2\pi} \left(\frac{0,25}{n} + \ln \frac{d}{r_B} \right) \quad (2)$$

r and d as above, $r_B = \sqrt[n]{nr \cdot R^{n-1}}$ n = number of conductors.

R is the radius in the circle on which the conductors are placed, see figure above.

The zero-sequence impedances are referred to an earth resistivity of $\rho = 100 \Omega\text{m}$ and therefore to an equivalent depth of current return of $\delta = 930 \text{ m}$ (50 Hz) or $\delta = 850 \text{ m}$ (60 Hz).

For single circuit (I) lines without earth wire:

$$\underline{Z}'_{(0)} = \frac{\rho}{nq_n} + 3\omega \frac{\mu_0}{8} + j\omega \frac{\mu_0}{2\pi} \left[\frac{1}{4n} + 3 \ln \frac{\delta}{\sqrt[3]{r_B d^2}} \right] \quad (3)$$

For single circuit (I) lines with one earth wire (D):

$$Z'_{(0)}^{ID} = Z'_{(0)}^I - 3 \frac{Z'_{LD}^2}{Z'_D} \quad (4)$$

$$\text{with } Z'_D = R'_D + \omega \frac{\mu_0}{8} + j\omega \frac{\mu_0}{2\pi} \left[\frac{\mu_D}{4} + \ln \frac{\delta}{r_D} \right]$$

$$Z'_{LD} = \omega \frac{\mu_0}{8} + j\omega \frac{\mu_0}{2\pi} \ln \frac{\delta}{d_{mLD}}$$

$$d_{mLD} = \sqrt[3]{d_{L1D} \cdot d_{L2D} \cdot d_{L3D}}$$

μ_D depends on material and structure of the earth wire.

For single circuit (I) lines with two earth wires (D1, D2):

$$Z'_{(0)}^{ID1D2} = Z'_{(0)}^I - 3 \frac{Z'_{LD1D2}^2}{Z'_{D1D2}} \quad (5)$$

$$\text{with } Z'_{D1D2} = \frac{R'_D}{2} + \omega \frac{\mu_0}{8} + j\omega \frac{\mu_0}{2\pi} \left[\frac{\mu_D}{8} + \ln \frac{\delta}{\sqrt{r_D d_{D1D2}}} \right]$$

$$Z'_{LD1D2} = \omega \frac{\mu_0}{8} + j\omega \frac{\mu_0}{2\pi} \ln \frac{\delta}{d_{mLD1D2}}$$

$$d_{mLD1D2} = \sqrt[6]{d_{L1D1} d_{L2D1} d_{L3D1} d_{L1D2} d_{L2D2} d_{L3D2}}$$

For double circuit (II) lines with one earth wire (D), zero-sequence impedance per circuit (with both circuits in parallel) is:

$$Z'_{(0)}^{IID} = Z'_{(0)}^I + 3Z'_{LM} - 6 \frac{Z'_{LD}^2}{Z'_D} \quad (6)$$

$$\text{with } Z'_{LM} = \omega \frac{\mu_0}{8} + j\omega \frac{\mu_0}{2\pi} \ln \frac{\delta}{d_{LM}}$$

$$d_{mL1M1} = \sqrt[3]{D_{L1M1} \cdot D_{L2M2} \cdot D_{L3M3}}$$

$$d_{mL1M2} = \sqrt[3]{D_{L1M2} \cdot D_{L3M1} \cdot D_{L2M3}}$$

$$d_{LM} = \sqrt[3]{d_{mL1M2}^2 \cdot d_{mL1M1}}$$