

Short-Circuit Calculations

A Handbook to Accompany the Online Short-Circuit
Calculation Program from *www.arcadvisor.com*

August 25, 2006

Introduction

Determining available short circuit fault currents is one of the most important aspects of designing power distribution systems. Short circuits and their effects must be considered in selecting electrical equipment, circuit protection devices, carrying out arc flash analysis. The short circuit calculator presented on www.arcadvisor.com web-site is offered in effort to satisfy the need for a convenient, comprehensive method of calculating fault currents. It is intended for radial and looped low-and medium-voltage circuits. The calculator allows to quickly and easily obtain accurate potential short circuit currents at each node (bus) in a power distribution system.

This program, other programs, or hand calculation can be used to perform short-circuit calculations. Any method used requires specific data on the power distribution system. All this data is converted to short circuit MVA values (SC MVA) for each component in the system. This paper describes the data needed for each type of circuit component and how to obtain the data. It also describes method and advantages of using the online short circuit program to calculate available short-circuit currents.

Utility

The first step in analyzing a power system is to get the data for the power available at the site, the utility data. This data can be obtained from the power company. When calling the power company, explain the type of information you need and ask for the engineering department. It may be helpful to explain why you need the information.

The power company will be able to supply this information for the point in the power system where their responsibility for the power system ends and the customer's responsibility starts. A common location for this point is the secondary of a pole or pad mounted transformer. If the customer is responsible for the transformer, the transition point would be the primary of the transformer. Sometimes a pole mounted disconnect will be the transition point. The power company will specify where in the system their responsibility ends.

The data needed is the line to line voltage (V_{LL}), short-circuit MVA (SC MVA), and X/R. Obtaining the voltage is simple enough. SC MVA is the power available at a bolted three phase fault. Bolted means all three phases connected together with no added impedance. X/R is the ratio of reactance to resistance in the supply. SC MVA and X/R may need to be derived from other data.

Short-circuit current (I_{SC}) is sometimes supplied by the power company rather than SC MVA. This current is the current in one phase of a three phase bolted fault. The SC MVA can be calculated from the short-circuit current using the following equation:

$$SC\ MVA = 1.732 I_{SC} V_{LL}, \text{ where } I_{SC} \text{ is expressed in kA and } V_{LL} \text{ - in kV}$$

Power factor (PF) is sometimes specified instead of X/R. This must be the short circuit power factor. Power factor is defined as the cosine of the angle between voltage and current. X/R is the tangent of this same angle. X/R can be found from power factor by taking the tangent of the inverse cosine of the power factor.

$$X/R = \tan(\cos^{-1} PF)$$

This is all the data needed for the utility.

Transformers

Transformers are specified by output voltage (V), kVA rating, percent impedance (%Z), and X/R ratio. The X/R ratio is the ratio of reactance to resistance. This information, with the exception of X/R, is usually on the transformer nameplate.

If X/R is not specified on the nameplate, the transformer manufacturer may be able to supply this. When contacting the transformer manufacturer, it may be helpful to have the transformer serial number. If X/R cannot be obtained,

check *Appendix A* for a typical value that can be used in the calculations. Transformer short circuit MVA is calculated from kVA and %Z:

$$SC\ MVA = kVA \times 10^{-3} / Z_{p.u.}, \text{ where } Z_{p.u.} \text{ is equal to } \%Z / 100$$

Cables

Data needed for cables is resistance, reactance and length. This data is available in cable standards and manufacturer's specifications. Also, *Appendix B* shows values for resistance and reactance per hundred feet for most commonly used cable types. Lengths may be measured, paced off and estimated. The cable Short Circuit MVA is determined from the equation below:

$$SC\ MVA = n \times kV^2 / Z, \text{ where, } n - \text{number of cables in parallel, } Z = (R^2 + X^2)^{1/2} \text{ Ohm}$$

Motors and Generators

Motors are a source of short-circuit current. They will act like generators when a short-circuit occurs. At a minimum, motors must be specified by horsepower which will be listed on the motor nameplate. Motor specifications are as follows:

kV: Motor rated kV.

HP: Motor Horse Power. Motors may be represented individually or as a lumped group.

FLA: The Full Load Amps.

PF: Motor operating Power Factor. This is used with the Efficiency to determine kVA. Motor groups should use an average value of power factor.

EFF: Motor operating Efficiency. This is used with the Power Factor field to determine kVA. Motor groups should use an average value of efficiency.

kVA/HP: The motor or motor group kVA rating per horsepower. This is a simple way of defining the kVA when full load amperes, or efficiency and power factor are not known. Typical values for standard efficiency motors are listed below:

1.0 kVA/HP - Induction < 100 HP and 0.8 PF Syn Motors

0.95 kVA/HP - Induction 100 < 999 HP

0.90 kVA/HP - Induction > 1000 HP

0.8 kVA/HP - Synchronous 1.0 PF

X''_{dv}: Subtransient reactance in percent on the motor HP base. See *Table A Appendix C* for a typical value that can be used in the calculations if accurate subtransient reactance cannot be obtained.

Table B Appendix C displays ANSI Standard interrupting duty multipliers. Code numbers are chosen according to the motor types, sizes and modeling method. Using the ANSI Code is the recommended method to determine motor impedance $Z_{p.u.}$ used for short circuit calculations:

$$Z_{p.u.} = (X''_{dv})(ANSI\ multiplier)$$

There are three ways to calculate motor kVA. Below the kVA calculation methods are shown in priority order:

1) If the FLA is known, the motor kVA should be determined by the following equation:

$$KVA = (1.73)(FLA)(kV)$$

2) If the FLA is not available and the kVA/HP is known, the motor kVA should be determined from the following equation:

$$KVA = (HP)(kVA/HP)$$

3) If both the FLA and the kVA/HP are not available, the motor kVA should be determined from the following equation:

$$KVA = (HP)(0.746)/(EFF)(PF)$$

Motor and generator short circuit MVA is calculated from kVA rating and subtransient reactance:

$$SC\ MVA = kVA \times 10^{-3} / Z_{p.u.}$$

X/R can be read off from the motor nameplate. If X/R is not specified on the nameplate, the motor manufacturer may be able to supply this. If X/R cannot be obtained, check *Appendix C* tables C and D for a typical value that can be used in the calculations.

About MVA method for short circuit analysis and it's program implementation at www.arcadvisor.com

The MVA method developed by Moon Yuen at Bechtel in the 60's is a modification of the Ohmic method where the impedance of a circuit equals the sum of the impedances of components constituting the circuit. The method uses the admittance of each component expressed as the Short Circuit MVA (SC MVA) that could flow through that component from an infinite bus to a short circuit.

ArcAd's online short circuit calculator performs vector addition of SC MVA contributed by system equipments with arbitrary X/R ratios at every point where they intersect. This provides an extremely accurate analysis of short circuit MVA any node can be subject to.

By performing short circuit MVA analysis for positive, negative and zero sequences, symmetrical three phase and unsymmetrical phase-to-ground, phase-to-phase and double phase-to-ground fault currents can be resolved.

Your online account gives you the advantage of saving the entered system diagram. This is practical for systems with multiple scenarios of interconnections where the system goes through ongoing changes over a period of time. You may continue your analysis without having to re-enter your data from the beginning.

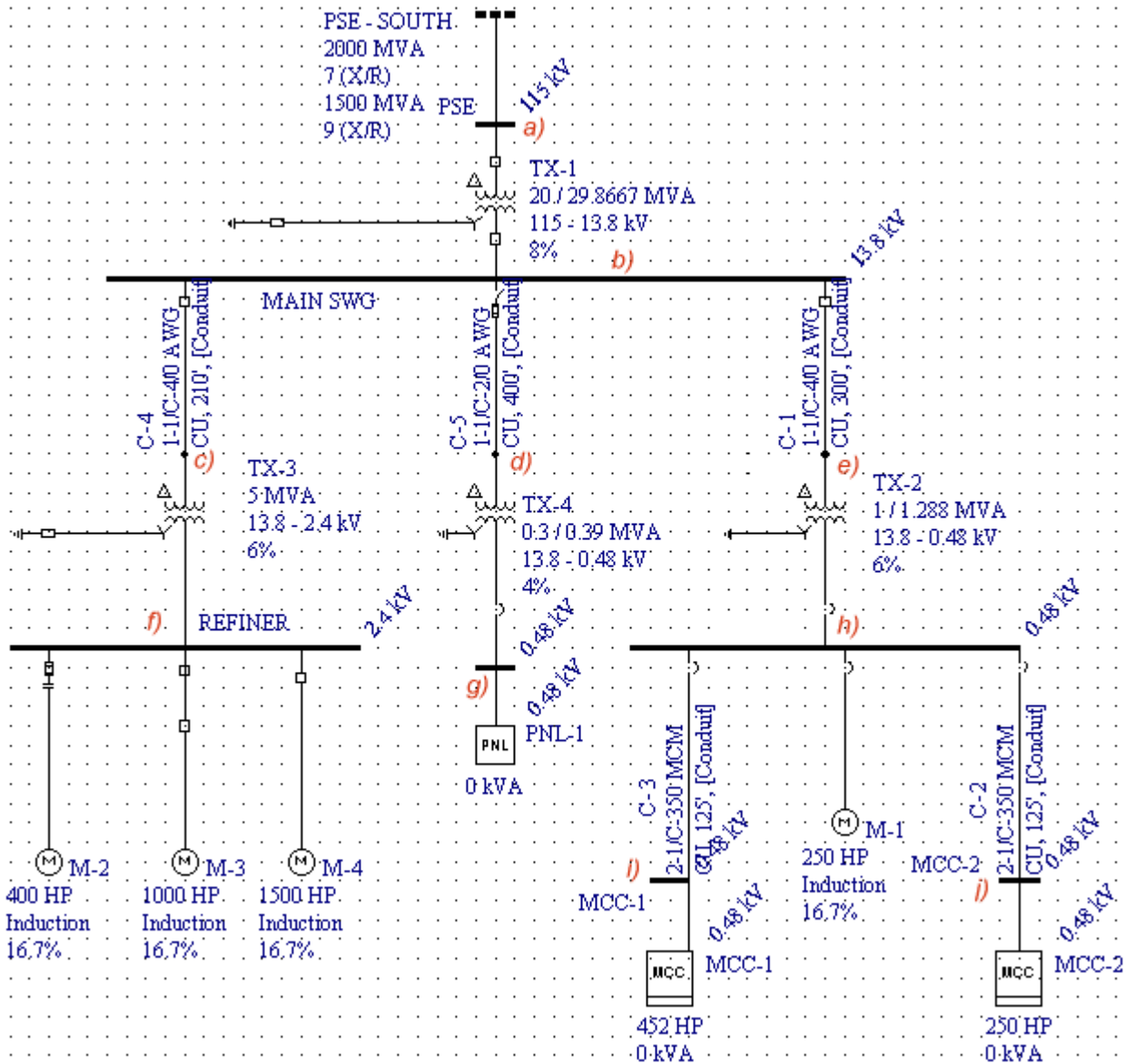
Typical commercial software has more interfaces and graphic content, which make them more appealing and expensive. ArcAd's on-line tool is user friendly, performs error propagation analysis - very important but widely ignored issue, and is offered at a reasonable price. Many other procedures do not take into account room for error, which can distort final values. A lack of understanding of basic error analysis has led some very bright scientists and engineers to make some incredible blunders. ArcAd's short circuit online calculator features input data analysis and hard coded error propagation rules ensuring that the results are not more precise than justified by the accuracy of input data.

We strongly believe that if a resulting fault current margin of error can't be quantified, then it's not engineering, but only a guess. As far as we are aware, none of the available competing products performs proper error analysis. It wouldn't be a problem if most accurate system equipment data were available. Experience shows that by far most real world studies are built upon approximate and therefore more or less accurate input data. The concept of precision is very important indeed and can impact results in surprising ways.

Example:

Step 1

Develop a comprehensive one-line radial diagram of the power system being analyzed. It is recommended that you use a copy of the same one-line diagram which is applied when laying out the distribution system. This approach provides the most complete system.



Step 2

Convert the equipment data to Short Circuit MVA values for each component in the system. Each basic component within the industrial electrical distribution system is pre-assigned a single the SCMVA factor based on the impedance it adds to the system. See sections above on how to do the conversion. For instance, the 5 MVA %Z=6% transformer labeled TX-3 above has a SC MVA = Rated MVA / Z = 5 / 0.06 = 83.3 MVA. For the C-4 conduit with R = 6.09 mOhm and X = 5.49 mOhm per 100 feet taken from manufacturer spec sheet, its short circuit MVA is equal to $(kV)^2 / Z = 13.8^2 / (0.0115^2 + 0.0128^2)^{1/2} = 11050$, where 0.0115 and 0.0128 are resistance and reactance values in Ohms per 210 feet:

LABEL	DESCRIPTION	Voltage, kV	SC MVA	SC MVA error, %	X/R	X/R error, %
PSE	PSE-SOUTH 2000MVA S.E.	115	2000	0	7	0
TX-1	TX-1 20 MVA Z=8% D-YRG	13.8	250	0	22.3	0
C-4	1-1/C-4/0 AWG 210 FEET CU	13.8	11050	0	0.9	0
C-5	1-1/C-2/0 AWG 400 FEET CU	13.8	4205	0	0.6	0
C-1	1-1/C-4/0 AWG 300 FEET CU	13.8	7735	0	0.9	0
TX-3	TX-3 5 MVA Z=6% D-YRG	2.4	83.3	0	12.6	0
TX-4	TX-4 0.3 MVA Z=4% D-YG	0.48	7.5	0	3.7	0
TX-2	TX-2 1 MVA Z=6% D-YG	0.48	16.67	0	5.7	0
M-2	398KVA 16.7%Z 17.62X/R	2.4	2.38	0	17.6	0
M-3	996KVA 16.7%Z 24.97X/R	2.4	5.96	0	25	0
M-4	1494KVA 16.7%Z 28.43X/R	2.4	8.94	0	28.4	0
PNL-1	0 SCMVA 480V PANEL	0.48	0	0	0	0
C-3	2-1/C-350 MCM 125 FEET CU	0.48	66.8	0	1	0
C-2	2-1/C-350 MCM 125 FEET CU	0.48	66.8	0	1	0
MCC-1	446KVA 16.7%Z 4.5X/R	0.48	2.67	0	4.5	0
M-1	247KVA 16.7%Z 14.21X/R	0.48	1.47	0	14.2	0
MCC-2	247KVA 16.7%Z 4.5X/R	0.48	1.48	0	4.5	0

If approximate or typical values are used, SC MVA error and X/R error should be specified. Leave the error equal to 0 when most accurate equipment data is available.

Step 3

Develop a hierarchical tree in terms of database records. The system equipment tree should be broken into levels, with each level being more focused than the last. The tree consists of nodes connected to each other by branches. Please note that a node may have one or more “children”, but can have only one “parent”. Equipment parent *id* equals the id of the upstream device feeding the equipment. In our example, TX-1 is fed from PSE. The TX-1 is assigned parent *id* of "1" which equals the PSE id value. PSE is a root feeding the system, its parent *id* is assigned "0" by default. You will need the reference table such as the one below to input the data for short circuit calculations:

ID	LABEL	DESCRIPTION	Voltage, kV	SC MVA	SC MVA error, %	X/R	X/R error, %	PARENT
1	PSE	PSE-SOUTH 2000MVA S.E.	115	2000	0	7	0	0
2	TX-1	TX-1 20 MVA Z=8% D-YRG	13.8	250	0	22.3	0	1
3	C-4	1-1/C-4/0 AWG 210 FEET CU	13.8	11050	0	0.9	0	2
4	C-5	1-1/C-2/0 AWG 400 FEET CU	13.8	4205	0	0.6	0	2
5	C-1	1-1/C-4/0 AWG 300 FEET CU	13.8	7735	0	0.9	0	2
6	TX-3	TX-3 5 MVA Z=6% D-YRG	2.4	83.3	0	12.6	0	3
7	TX-4	TX-4 0.3 MVA Z=4% D-YG	0.48	7.5	0	3.7	0	4
8	TX-2	TX-2 1 MVA Z=6% D-YG	0.48	16.67	0	5.7	0	5
9	M-2	398KVA 16.7%Z 17.62X/R	2.4	2.38	0	17.6	0	6
10	M-3	996KVA 16.7%Z 24.97X/R	2.4	5.96	0	25	0	6
11	M-4	1494KVA 16.7%Z 28.43X/R	2.4	8.94	0	28.4	0	6
12	PNL-1	0 SCMVA 480V PANEL	0.48	0	0	0	0	7
13	C-3	2-1/C-350 MCM 125 FEET CU	0.48	66.8	0	1	0	8
14	C-2	2-1/C-350 MCM 125 FEET CU	0.48	66.8	0	1	0	8
15	MCC-1	446KVA 16.7%Z 4.5X/R	0.48	2.67	0	4.5	0	13
16	M-1	247KVA 16.7%Z 14.21X/R	0.48	1.47	0	14.2	0	8
17	MCC-2	247KVA 16.7%Z 4.5X/R	0.48	1.48	0	4.5	0	14

Step 4

Create an online account if you don't already have one, and log onto the page where you can add components one by one to build up a radial electrical distribution system. Your account gives you the advantage of saving the entered system diagram. This is practical for systems with multiple scenarios of interconnections where the system goes through ongoing changes over a period of time. *Run the analysis and document the results.* The program will output the hierarchical system equipment tree with short circuit MVA calculated at each node. Short circuits contributed by upstream (red) and downstream (blue) equipment are listed across each node:

- PSE[2000.00(7.00X/R) + 17.14(13.2X/R) = 2017.1 (7.03X/R)]
 - TX-1[222.32(18.0X/R) + 18.40(12.8X/R) = 240.7 (17.4X/R)]
 - C-4[223.14(13.8X/R) + 14.31(21.5X/R) = 237.4 (14.1X/R)]
 - TX-3[60.66(12.9X/R) + 17.28(25.1X/R) = 77.9 (14.5X/R)]
 - M-4[8.94]
 - M-3[5.96]
 - M-2[2.38]
 - C-1[231.5(13.1X/R) + 4.130(5.37X/R) = 236 (12.8X/R)]
 - TX-2[15.55(5.93X/R) + 5.491(5.27X/R) = 21.0 (5.93X/R)]
 - C-2[15.66(3.17X/R) + 1.48(4.50X/R) = 17.1 (3.26X/R)]
 - MCC-2[1.48]
 - C-3[14.95(3.29X/R) + 2.67(4.50X/R) = 17.6 (3.43X/R)]
 - MCC-1[2.67]
 - M-1[1.47]
 - C-5[232.9(9.65X/R) + 0(12.0X/R) = 233 (9.65X/R)]
 - TX-4[7.268(3.78X/R) + 0.00(0.00X/R) = 7.27 (3.78X/R)]
 - PNL-1[0.00]

Since short circuit MVA values are added vectorially, arithmetic addition of upstream and downstream SC MVA does not generally equals the total SC MVA. Upstream and downstream values above contain one more significant digit than required by error analysis rules. This digit is dropped off the final result (in green color). In this manner, phenomenon known as "round-off error" is effectively avoided. Divide total SC MVA values by $1.73 * kV_{LL}$ to get 3 phase short circuit current values in kA. Record the resulting short circuit currents in the reference table:

ID	LABEL	DESCRIPTION	Voltage, kV	SC MVA rating	SC MVA error, %	X/R	X/R error, %	PARENT	Calc. SC MVA	Calc. ISC, kA	Node
1	PSE	PSE-SOUTH 2000MVA S.E.	115	2000	0	7	0	0	2017.1	10.13	a)
2	TX-1	TX-1 20 MVA Z=8% D-YRG	13.8	250	0	22.3	0	1	240.7	10.1	b)
3	C-4	1-1/C-4/0 AWG 210 FEET CU	13.8	11050	0	0.9	0	2	237.4	9.93	c)
4	C-5	1-1/C-2/0 AWG 400 FEET CU	13.8	4205	0	0.6	0	2	233	9.75	d)
5	C-1	1-1/C-4/0 AWG 300 FEET CU	13.8	7735	0	0.9	0	2	236	9.87	e)
6	TX-3	TX-3 5 MVA Z=6% D-YRG	2.4	83.3	0	12.6	0	3	77.9	18.7	f)
7	TX-4	TX-4 0.3 MVA Z=4% D-YG	0.48	7.5	0	3.7	0	4	7.27	8.7	g)
8	TX-2	TX-2 1 MVA Z=6% D-YG	0.48	16.67	0	5.7	0	5	21	25	h)
9	M-2	398KVA 16.7%Z 17.62X/R	2.4	2.38	0	17.6	0	6			
10	M-3	996KVA 16.7%Z 24.97X/R	2.4	5.96	0	25	0	6			
11	M-4	1494KVA 16.7%Z 28.43X/R	2.4	8.94	0	28.4	0	6			
12	PNL-1	0 SC MVA 480V PANEL	0.48	0	0	0	0	7			
13	C-3	2-1/C-350 MCM 125 FEET CU	0.48	66.8	0	1	0	8	17.6	24.2	i)
14	C-2	2-1/C-350 MCM 125 FEET CU	0.48	66.8	0	1	0	8	17.1	20.7	j)
15	MCC-1	446KVA 16.7%Z 4.5X/R	0.48	2.67	0	4.5	0	13			
16	M-1	247KVA 16.7%Z 14.21X/R	0.48	1.47	0	14.2	0	8			
17	MCC-2	247KVA 16.7%Z 4.5X/R	0.48	1.48	0	4.5	0	14			

Appendix A

Primary Substation % Impedance

If specific information is not available use the following as a guide
 For transformers 501 to 10000kVA 3 phase and 501 to 5000kVA 1 phase
 From American Standards Association Standard C57.12.10-1958
 (Included in NEMA Transformer Standard TR-1-1962)

Transformer High Voltage, V	Transformer Low Voltage	
	2400V and above	480V*
2400 to 22900	5.50%	5.75%
26400 to 34400	6%	6.25%
43800	6.50%	6.75%
67000	7%	

* - generally pertains to all voltages 600V and below

Secondary Substation Impedance Data:

High Voltage 15kV Max, Low Voltage 600V Max
 If specific information is not available use the following as a guide

KVA, 3phase	NEMA Std., % Imp.	General Range of Mfgs. % Imp.	Suggested X/R Ratio for S.C. Calcs	Suggested % Imp.
112.5	2 Min.	2.3 - 5.2	5	3 Min
150	2 Min.	2.7 - 5.1	5	3.5 Min
225	2 Min.	4.4 - 5.0	5.5	4.5 Min
300	4.5 Min.	4.5 - 6.0	6	4.5 Min
400	Not Listed	4.5 - 6.0	6	4.5 Min
500	4.5 Min.	4.5 - 6.0	6	5 Min
750	5.75	5.75	7	5.75
1000	5.75	5.75	8	5.75
1500	5.75	5.75	9	5.75
2000	5.75	5.75	12	5.75
2500	5.75	5.75	12	5.75

Note: NEMA industry standards allow a maximum manufacturing tolerance of +/- 7.5% of the specified transformer impedance value.

Appendix B

Copper Conductor Cable Reactance and Resistance Data: Typical Values - Use Exact data if Available. Line-To-Neutral mOhm per 100 feet

Conductor Size AWG or MCM	Three-Single Conductor Cables				One Three Conductor Cable			
	In Magnetic Duct		Not In Magnetic Duct		In Magnetic Duct		Not In Magnetic Duct	
	Reactance "X"	Resistance "R"	React "X"	Resist "R"	React "X"	Resist "R"	React "X"	Resist "R"
14 Solid	7.51	258	5.94	258	5.15	258	4.48	258
12 Solid	6.96	161	5.51	161	5.02	161	4.36	161
10 Solid	6.74	101	5.34	101	4.93	101	4.29	101
8	5.93	67.9	4.74	67.9	4.54	67.9	3.95	67.9
8 Solid	6.06	65.9	4.85	65.9	4.64	65.9	4.04	65.9
6	5.67	42.7	4.54	42.7	4.34	42.7	3.78	42.7
6 Solid	5.88	41.5	4.7	41.5	4.5	41.5	3.92	41.5
4	5.3	26.9	4.24	26.9	4.06	26.9	3.53	26.9
4 Solid	5.55	26.1	4.44	26.1	4.25	26.1	3.7	26.1
2	4.98	17	3.98	16.9	3.81	17	3.32	16.9
1	5.04	13.5	4.03	13.4	3.86	13.5	3.36	13.4
1/0	4.95	10.8	3.96	10.7	3.79	10.8	3.3	10.7
2/0	4.83	8.6	3.86	8.5	3.7	8.6	3.22	8.5
3/0	4.67	6.9	3.73	6.7	3.57	6.9	3.11	6.7
4/0	4.53	5.43	3.62	5.33	3.47	5.43	3.02	5.33
250	4.65	4.72	3.72	4.59	3.56	4.72	3.1	4.59
300	4.52	3.95	3.61	3.8	3.45	3.95	3.01	3.8
350	4.44	3.42	3.55	3.23	3.37	3.42	2.96	3.23
400	4.41	3.05	3.53	2.91	3.33	3.05	2.94	2.91
500	4.32	2.5	3.46	2.35	3.23	2.5	2.88	2.35
600	4.31	2.16	3.44	1.99	3.19	2.16	2.87	1.99
750	4.25	1.81	3.4	1.63	3.1	1.81	2.83	1.63
1000	4.19	1.53	3.35	1.35				

Square D Bus Duct Reactance and Resistance Data

Line-To-Neutral mOhm per 100 feet

Duct Current Rating, A	Square D Feeder Duct				Square D Plug-In Duct			
	Aluminum		Copper		Aluminum		Copper	
	Reactance "X"	Resistance "R"	React "X"	Resist "R"	React "X"	Resist "R"	React "X"	Resist "R"
225					6.88	6.756	6.96	7.544
400					6.95	3.797	7.2	2.464
600	0.243	1.93			3.87	2.221	7.35	1.718
800	0.243	1.93	0.568	1.466	2.82	1.291	4.39	1.425
1000	0.468	1.52	0.243	1.215	2.8	1.081	4.58	0.914
1350	0.516	0.99	0.595	0.847				
1600	0.094	0.87	0.618	0.571				
2000	0.26	0.64	0.12	0.603				
2500	0.147	0.514	0.3	0.415				
3000	0.212	0.436	0.315	0.282				
4000	0.184	0.31	0.212	0.184				

Appendix C

Motors and Generators

(A) Generators	X"d	
	Range	Mean
(1) Turbo Generators (distributed pole)		
2 pole, 625-9375 kVA	6-13	9
2 pole, 12,500 kVA-up	8-12	10
4 pole, 12,500 kVA-up	10-17	14
(2) Salient-pole Generators (without amortisseur)		
12 poles or less	15-35	25
14 poles or more	25-45	35
(3) Salient-pole Generators/ (with amortisseur)		
12 poles or less	10-25	18
14 poles or more	18-40	24
(B) Synchronous Condensers	9-38	24
(C) Synchronous Converters		
600 V dc	17-22	20
250 V dc	28-38	33
(D) Synchronous Motors		
2-6 pole	7-23	15
8-14 pole (incl)	11-29	20

Table A. Percent values on machine KVA rating

Code	Motor	Momentary Duty First Cycle	Interrupting Duty 1.5 - 4 Cycles
Synch	Synchronous	1.0 X"dv	1.5 X"dv
Ind>1000	Induction Motor > 1000 Hp	1.0 X"dv	1.5 X"dv
> 250 @ 3600	Induction Motor > 250 Hp at 3600 RPM	1.0 X"dv	1.5 X"dv
>50	Induction Motor or Motor Group > 50 Hp	1.2 X"dv	3.0 X"dv
<50	Induction Motor Group < 50 Hp	1.67 X"dv	Infinite X"dv
Lumped	Lumped Induction Motor Group	1.0 X"dv (X=25%)	3.0 X"dv

Note: X" for induction motor groups >50 HP and <50 HP are typically assumed equal to 16.7%. Using the impedance multipliers, this corresponds to an equivalent motor contribution of 3.6 to 4.8 times the full load current.

Table B. ANSI Standard impedances and interrupting duty multipliers

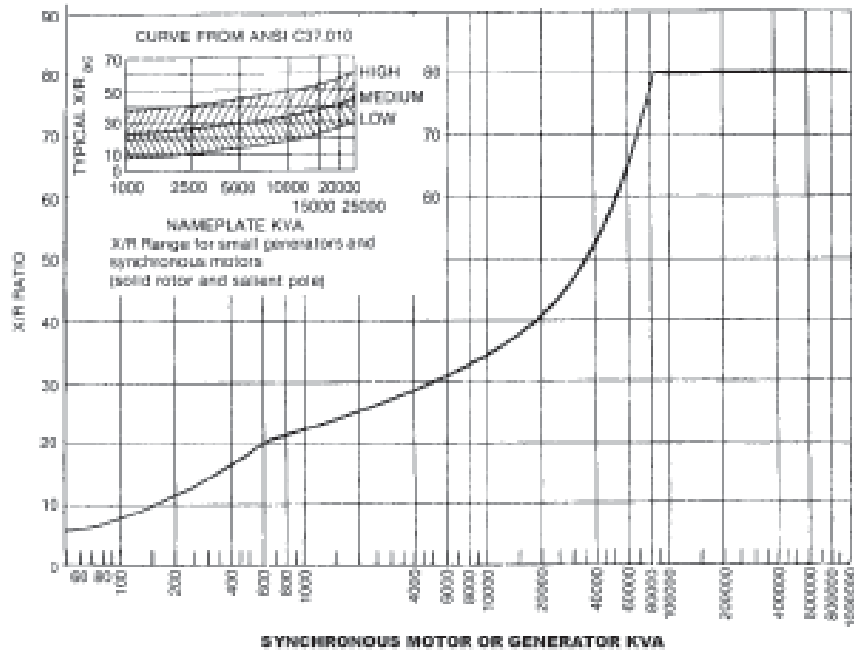


Table C. Typical X/R values for generators and synchronous motors

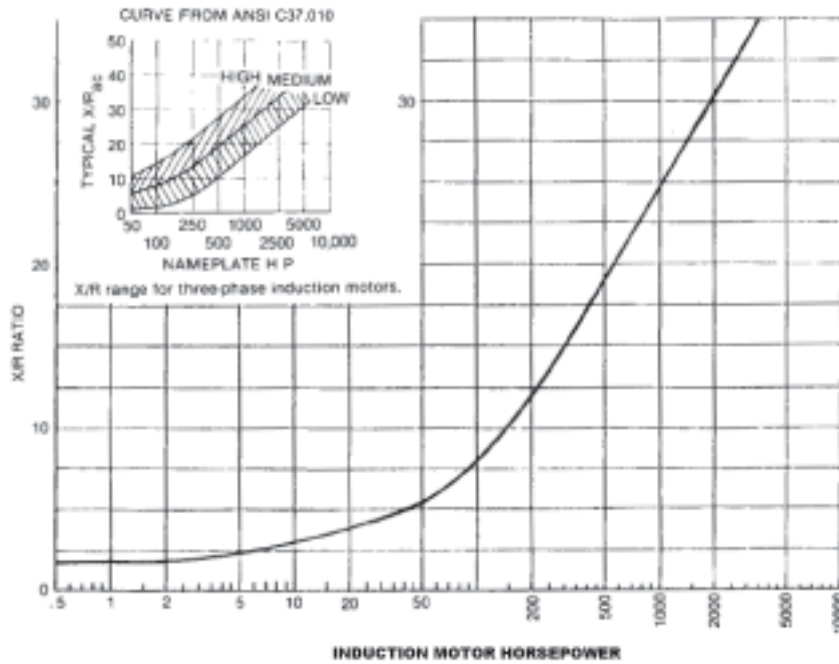


Table D. Typical X/R values for induction motors