11

Formulas and Conversion Factors

Section Outline Page

11.1 FORMULAS

FORMULAS FOR ELECTRIC MACHINES–ALTERNATING AND DIRECT CURRENTS

TO FIND	TYPE OF MACHINE	DIRECT CURRENT	SINGLE PHASE	THREE PHASE
Hp output	For a motor with hp rating	$\frac{E \times I \times Eff}{746}$	$\frac{E \times I \times Eff \times Pf}{746}$	$\frac{1.732 \times E \times I \times Eff \times Pf}{746}$
kW output	For a motor with kW rating	$\frac{E \times I \times Eff}{1000}$	$\frac{E \times I \times Eff \times Pf}{1000}$	$\frac{1.732 \times E \times I \times Eff \times Pf}{1000}$
	For a generator	$\frac{E \times I}{1000}$	$\frac{E \times I \times Pf}{1000}$	$\frac{1.732 \times E \times I \times Pf}{1000}$
kVA output	For a machine with kVA rating	—	$\frac{E \times I}{1000}$	$\frac{1.732 \times E \times I}{1000}$
Current	For a motor with hp rating	$\frac{746 \times hp}{E \times Eff}$	$\frac{746 \times hp}{E \times Eff \times Pf}$	$\frac{746 \times hp}{1.732 \times E \times Eff \times Pf}$
	For a motor with kW rating	$\frac{1000 \times kW}{E \times Eff}$	$\frac{1000 \times kW}{E \times Eff \times Pf}$	$\frac{1000 \times kW}{1.732 \times E \times Eff \times Pf}$
	For a generator	$\frac{1000 \times kW}{E}$	$\frac{1000 \times kW}{E \times Pf}$	$\frac{1000 \times kW}{1.732 \times E \times Pf}$
	For a machine with kVA rating	—	$\frac{1000 \times kVA}{E}$	$\frac{1000 \times kVA}{1.732 \times E}$
Efficiency	For a motor with hp rating	$\frac{746 \times hp}{E \times I}$	$\frac{746 \times hp}{E \times I \times Pf}$	$\frac{746 \times hp}{1.732 \times E \times I \times Pf}$
	For a motor with kW rating	$\frac{1000 \times kW}{E \times I}$	$\frac{1000 \times kW}{E \times I \times Pf}$	$\frac{1000 \times kW}{1.732 \times E \times I \times Pf}$
Power factor	For a motor	—	$\frac{\text{Input watts}}{E \times I}$	$\frac{\text{Input watts}}{1.732 \times E \times I}$
	For a motor	—	$\frac{\text{Output watts}}{E \times I \times Eff}$	$\frac{\text{Output watts}}{1.732 \times E \times I \times Eff}$
	For a generator	—	$\frac{1000 \times kW}{E \times I}$	$\frac{1000 \times kW}{1.732 \times E \times I}$

Rated units

E = Volts
Eff = Efficiency (decimal)
hp = Horsepower
I = Amperes
kVA = Kilovolt-amperes
kW = Kilowatts
Pf = Power factor (decimal)

Note: For motor application formulas, see Page 11-4 and Section 2.7 of this manual.

FORMULAS FOR ELECTRIC CIRCUITS–ALTERNATING AND DIRECT CURRENTS

TO FIND	DIRECT CURRENT	SINGLE PHASE	THREE PHASE
Amperes	$\frac{\text{Watts}}{\text{Volts}}$	$\frac{\text{Watts}}{\text{Volts x Power factor}}$	$\frac{\text{Watts}}{\text{1.732 x Volts x Power factor}}$
Volt-amperes	—	Volts x Amperes	1.732 x Volts x Amperes
Watts	Volts x Amperes	Volts x Amperes x Power factor	1.732 x Volts x Amperes x Power factor
Power factor	—	$\frac{\text{Watts}}{\text{Volts x Amperes}}$	$\frac{\text{Watts}}{\text{1.732 x Volts x Amperes}}$

FORMULAS FOR DIRECT-CURRENT CIRCUITS

E (Volts)	I (Current in amperes)	R (Resistance in ohms)	W (Power in watts)
$I \times R = \frac{W}{I}$	$\frac{E}{R} = \frac{W}{E}$	$\frac{E}{I} = \frac{W}{I^2}$	$I^2 \times R = E \times I$

FORMULAS FOR RESISTANCE, INDUCTANCE AND CAPACITANCE

	Resistance (inductance)	Capacitance
Two in series	$R = R_1 + R_2$	$C = \frac{1}{\frac{1}{C_1} + \frac{1}{C_2}} = \frac{C_1 \times C_2}{C_1 + C_2}$
Three in series	$R = R_1 + R_2 + R_3$	$C = \frac{1}{\frac{1}{C_1} + \frac{1}{C_2} + \frac{1}{C_3}} = \frac{C_1 \times C_2 \times C_3}{C_1 \times C_2 + C_2 \times C_3 + C_3 \times C_1}$
Two in parallel	$R = \frac{1}{\frac{1}{R_1} + \frac{1}{R_2}} = \frac{R_1 \times R_2}{R_1 + R_2}$	$C = C_1 + C_2$
Three in parallel	$R = \frac{1}{\frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3}} = \frac{R_1 \times R_2 \times R_3}{R_1 \times R_2 + R_2 \times R_3 + R_3 \times R_1}$ R = Total resistance	$C = C_1 + C_2 + C_3$ C = Total capacitance
	OHMS LAW Ohms = Volts/Amperes (R = E/I) Amperes = Volts/Ohms (I = E/R) Volts = Amperes x Ohms (E = IR)	**CAPACITANCE IN MICROFARADS AT 60 HZ** $\text{Capacitance} = \frac{\text{2650 x Amperes}}{\text{Volts}}$ $\text{Capacitance} = \frac{\text{2.65 x kVAR}}{(\text{Volts})^2}$

MOTOR APPLICATION FORMULAS–OUTPUT

$$\text{Horsepower} = \frac{\text{Torque (lb•ft) x rpm}}{5252}$$

$$\text{Torque (lb•ft)} = \frac{\text{Horsepower x 5252}}{\text{rpm}}$$

$$\text{Kilowatts} = \frac{\text{Torque (N•m) x rpm}}{9550}$$

$$\text{Torque (N•m)} = \frac{\text{Kilowatts x 9550}}{\text{rpm}}$$

For approximation, use:

Full-load torque = 1.5 lb•ft per hp per pole pair at 60 Hz

Full-load torque = 3.2 N•m per kilowatt per pole pair at 50 Hz

$$\text{Avg. accelerating torque} = \frac{[\text{FLT} + \text{BDT})/2 + \text{BDT} + \text{LRT}}{3}\ ^*$$

Where: FLT = Full-load torque
BDT = Breakdown torque
LRT = Locked-rotor torque

* Note: This formula provides an estimate of the average accelerating torque and is not intended for design purposes.

SPEED–AC MACHINERY

$$\text{Synchronous rpm} = \frac{120 \text{ x Frequency (Hz)}}{\text{Number of poles}}$$

$$\text{Percent slip} = \frac{\text{Synchronous rpm - Full load rpm)}}{\text{Synchronous rpm}} \text{ x } 100$$

SHEAR STRESS

$$\text{Shear stress (psi)} = \frac{\text{hp x } 321{,}000^*}{\text{rpm x } D^3 \text{ (in)}}$$

$$\text{Shear stress (kg/mm}^2) = \frac{\text{kW x } 496 \text{ x } 10^{6\,*}}{\text{rpm x } D^3 \text{ (mm)}}$$

$$\text{Load Wk}^2 \text{ (at motor shaft)} = \frac{\text{Wk}^2 \text{ (load) x Load rpm}^{2\,*}}{\text{Motor rpm}}$$

Where:

D = Shaft diameter (in or mm)
hp = Motor output
kg/mm^2 = Kilograms per square millimeter
psi = Pounds per square inch
rpm = Revolutions per minute
kW = Motor output

* These shear stress equations apply to static cases only and should not be used for design purposes.

AFFINITY LAWS–CENTRIFUGAL APPLICATIONS

$$\frac{\text{Flow}_1}{\text{Flow}_2} = \frac{\text{rpm}_1}{\text{rpm}_2} \qquad \frac{\text{hp}_1}{\text{hp}_2} = \frac{(\text{rpm}_1)^3}{(\text{rpm}_2)^3}$$

$$\frac{\text{Pres}_1}{\text{Pres}_2} = \frac{(\text{rpm}_1)^2}{(\text{rpm}_2)^2}$$

TEMPERATURE CORRECTION OF WINDING RESISTANCE

$$R_C = R_H \text{ x } \frac{(K + T_C)}{(K + T_H)}$$

$$R_H = R_C \text{ x } \frac{(K + T_H)}{(K + T_C)}$$

TEMPERATURE RISE OF WINDING BY RESISTANCE METHOD

$$\text{Temperature rise } (°C) = \left[\frac{(R_H)}{(R_C)} \text{ x } (K + T_C)\right] - (K + T_A)$$

Where:

R_C = Resistance at temperature T_C (Ohms)
R_H = Resistance at temperature T_H (Ohms)
T_A = Ambient temperature when winding is hot (°C)
T_C = Temperature of cold winding (°C)
T_H = Temperature of hot winding (°C)

Value of K: Aluminum = 225
Copper = 234.5

RESISTANCE OF COPPER & ALUMINUM WIRE PER 1000 FT & PER KM AT 20°C (68°F)

Conductivity	OHMS PER 1000 FT	OHMS PER KM
Copper–100% IACS	$\frac{10371}{\text{CM Area}}$	$\frac{17.241}{\text{Sq mm}}$
Aluminum–61.8% IACS	$\frac{16782}{\text{CM Area}}$	$\frac{27.898}{\text{Sq mm}}$

FORMULAS FOR CIRCLES

π (Pi) = 3.1416
Circumference of circle = Diameter x 3.1416
Area of circle = Diameter^2 x 0.7854
Diameter of circle = Circumference x 0.31831

FORMULAS FOR SINE WAVES

rms value	=	0.707	x	peak value
rms value	=	1.11	x	average value
Peak value	=	1.414	x	rms value
Peak value	=	1.57	x	average value
Average value	=	0.637	x	peak value
Average value	=	0.90	x	rms value
Peak-to-peak	=	2.0	x	peak value

11.2 CONVERSION FACTORS AND EQUIVALENCIES

CONVERSION FACTORS

MULTIPLY		BY		TO OBTAIN
LENGTH				
Centimeters	x	0.3937	=	Inches
Feet	x	12.0	=	Inches
Feet	x	0.3048	=	Meters
Inches	x	2.54	=	Centimeters
Inches	x	25.4	=	Millimeters
Kilometers	x	0.6214	=	Miles
Meters	x	3.281	=	Feet
Meters	x	39.37	=	Inches
Meters	x	1.094	=	Yards
Miles	x	5280.0	=	Feet
Miles	x	1.609	=	Kilometers
Millimeters	x	0.03937	=	Inches
Yards	x	0.91442	=	Meters
AREA				
Circular mils	x	7.854×10^{-7}	=	Square inches
Circular mils	x	0.7854	=	Square mils
Square centimeters	x	0.155	=	Square inches
Square feet	x	144.0	=	Square inches
Square feet	x	0.0929	=	Square meters
Square inches	x	6.452	=	Square centimeters
Square meters	x	10.764	=	Square feet
Square meters	x	1.196	=	Square yards
Square millimeters	x	0.00155	=	Square inches
Square mils	x	1.273	=	Circular mils
Square yards	x	0.8361	=	Square meters
VOLUME				
Cubic centimeters	x	0.061	=	Cubic inches
Cubic feet	x	0.0283	=	Cubic meters
Cubic feet	x	7.481	=	Gallons (US)
Cubic inches	x	0.5541	=	Ounces (fluid)
Cubic meters	x	35.31	=	Cubic feet
Cubic meters	x	1.308	=	Cubic yards
Cubic meters	x	264.2	=	Gallons (US)
Cubic yards	x	0.7646	=	Cubic meters
Gallons (Imperial)	x	1.201	=	Gallons (US)
Gallons (US)	x	0.8327	=	Gallons (Imperial)
Gallons (US)	x	0.1337	=	Cubic feet
Gallons (US)	x	3.785	=	Liters
Liters	x	0.2642	=	Gallons (US)
Liters	x	1.057	=	Quarts (liquid)
Ounces (fluid)	x	1.805	=	Cubic inches
Quarts (liquid)	x	0.9463	=	Liters
ENERGY OR WORK				
Btu	x	778.2	=	Foot-pounds
Btu	x	252.0	=	Gram-calories
Btu	x	3.929×10^{-4}	=	Horsepower-hour
Btu	x	1055	=	Joule
Btu	x	2.93×10^{-4}	=	Kilowatt-hour
Joule	x	9.478×10^{-4}	=	Btu
Kilowatt-hour	x	3.6×10^{6}	=	Joule

MULTIPLY		BY		TO OBTAIN
FORCE AND WEIGHT				
Grams	x	0.0353	=	Ounces
Kilograms	x	2.205	=	Pounds
Kilograms	x	0.0011	=	Tons (short)
Newtons	x	0.2248	=	Pounds (force)
Ounces	x	28.35	=	Grams
Pounds	x	453.6	=	Grams
Pounds (force)	x	4.448	=	Newtons
Tons (short)	x	907.2	=	Kilograms
Tons (short)	x	2000.0	=	Pounds
Metric tonnne	x	1000.0	=	Kilograms
PRESSURE				
Atmosphere	x	1.013×10^{5}	=	Newtons per square meter
Atmosphere	x	101325	=	Pascals
Atmosphere	x	14.7	=	Pounds per square inch
Pascal	x	0.102	=	Kilograms per square meter
1 inch of water	x	2.458×10^{-3}	=	Atmospheres
1 inch of water	x	3.613×10^{-2}	=	Pounds per square inch
TORQUE				
Gram-centimeters	x	0.0139	=	Ounce-inches
Kilogram-meters	x	7.233	=	Pound-feet
Newton-meters	x	0.7376	=	Pound-feet
Newton-meters	x	8.851	=	Pound-inches
Ounce-inches	x	72.0	=	Gram-centimeters
Pound-feet	x	1.3558	=	Newton-meters
Pound-inches	x	0.113	=	Newton-meters
ROTARY INERTIA				
Kilogram-cm^2	x	0.341716	=	Pound-$inches^2$
Pounds-$inches^2$	x	2.92641	=	Kilogram-cm^2
Ounce-inches-sec^2	x	72.0079	=	Gram-cm-sec^2
Pound-$feet^2$	x	421.403	=	Kilogram-cm^2
Pound-inches-sec^2	x	1.15213	=	Kilogram-cm-sec^2
POWER				
Btu per hour	x	0.293	=	Watts
Cheval vapeur (CV)	x	736.0	=	Watts
Horsepower (hp)	x	33000.0	=	Foot-pounds per minute
Horsepower (hp)	x	550.0	=	Foot-pounds per second
Horsepower (hp)	x	746.0	=	Watts
Kilowatts	x	1.341	=	Horsepower

CONVERSION FACTORS—CONTINUED

MULTIPLY		BY		TO OBTAIN
PLANE ANGLE				
Degrees	x	0.0175	=	Radians
Minutes	x	0.01667	=	Degrees
Minutes	x	2.9×10^{-4}	=	Radians
Quadrants	x	90.0	=	Degrees
Quadrants	x	1.5708	=	Radians
Radians	x	57.3	=	Degrees
MAGNETIC INDUCTION				
Gauss	x	6.452×10^{-3}	=	Kiloline per square inch
Gauss	x	10^{-4}	=	Webers per square meter
Gauss	x	10^{-4}	=	Tesla
MAGNETIC FIELD STRENGTH				
Ampere turn per cm	x	2.54	=	Ampere turns per inch
Ampere turn per cm	x	1.257	=	Oersted
MAGNETIC FLUX				
Maxwell	x	0.001	=	Kiloline
Maxwell	x	10^{-8}	=	Webers

Pounds are U.S. avoirdupois. Gallons and quarts are U.S., except as noted.

TEMPERATURE CONVERSION CHART

°C	°F	°C	°F	°C	°F	°C	°F	°C	°F	°C	°F
-40	-40	10	50	60	140	110	230	240	464	490	914
	-38.2		51.8		141.8		231.8	245	473	495	923
	-36.4		53.6		143.6		233.6	250	482	500	932
	-34.6		55.4		145.4		235.4	255	491	505	941
	-32.8		57.2		147.2		237.2	260	500	510	950
-35	-31	15	59	65	149	115	239	265	509	515	959
	-29.2		60.8		150.8		240.8	270	518	520	968
	-27.4		62.6		152.6		242.6	275	527	525	977
	-25.6		64.4		154.4		244.4	280	536	530	986
	-23.8		66.2		156.2		246.2	285	545	535	995
-30	-22	20	68	70	158	120	248	290	554	540	1004
	-20.2		69.8		159.8		249.8	295	563	545	1013
	-18.4		71.6		161.6		251.6	300	572	550	1022
	-16.6		73.4		163.4		253.4	305	581	555	1031
	-14.8		75.2		165.2		255.2	310	590	560	1040
-25	-13	25	77	75	167	125	257	315	599	565	1049
	-11.2		78.8		168.8		258.8	320	608	570	1058
	-9.4		80.6		170.6		260.6	325	617	575	1067
	-7.6		82.4		172.4		262.4	330	626	580	1076
	-5.8		84.2		174.2		264.2	335	635	585	1085
-20	-4	30	86	80	176	130	266	340	644	590	1094
	-2.2		87.8		177.8		267.8	345	653	595	1103
	-0.4		89.6		179.6		269.6	350	662	600	1112
	1.4		91.4		181.4		271.4	355	671	605	1121
	3.2		93.2		183.2		273.2	360	680	610	1130
-15	5	35	95	85	185	135	275	365	689	615	1139
	6.8		96.8		186.8		276.8	370	698	620	1148
	8.6		98.6		188.6		278.6	375	707	625	1157
	10.4		100.4		190.4		280.4	380	716	630	1166
	12.2		102.2		192.2		282.2	385	725	635	1175
-10	14	40	104	90	194	140	284	390	734	640	1184
	15.8		105.8		195.8	145	293	395	743	645	1193
	17.6		107.6		197.6	150	302	400	752	650	1202
	19.4		109.4		199.4	155	311	405	761	655	1211
	21.2		111.2		201.2	160	320	410	770	660	1220
-5	23	45	113	95	203	165	329	415	779	665	1229
	24.8		114.8		204.8	170	338	420	788	670	1238
	26.6		116.6		206.6	175	347	425	797	675	1247
	28.4		118.4		208.4	180	356	430	806	680	1256
	30.2		120.2		210.2	185	365	435	815	685	1265
0	32	50	122	100	212	190	374	440	824	690	1274
	33.8		123.8		213.8	195	383	445	833	695	1283
	35.6		125.6		215.6	200	392	450	842	700	1292
	37.4		127.4		217.4	205	401	455	851	705	1301
	39.2		129.2		219.2	210	410	460	860	710	1310
5	41	55	131	105	221	215	419	465	869	715	1319
	42.8		132.8		222.8	220	428	470	878	720	1328
	44.6		134.6		224.6	225	437	475	887	725	1337
	46.4		136.4		226.4	230	446	480	896	730	1346
	48.2		138.2		228.2	235	455	485	905	735	1355

For each additional 1°C, add 1.8°F
For each Additional 1°F, add .556°C

°F = (9/5 x °C) + 32
°C = 5/9 x (°F - 32)

COMMON FRACTIONS OF AN INCH DECIMAL AND METRIC EQUIVALENTS

FRACTION		DECIMAL	mm	FRACTION		DECIMAL	mm
	1/64	0.01562	0.397		33/64	0.51562	13.097
1/32		0.03125	0.794	17/32		0.53125	13.494
	3/64	0.04688	1.191		35/64	0.54688	13.891
1/16		0.06250	1.588	9/16		0.56250	14.288
	5/64	0.07812	1.984		37/64	0.57812	14.684
3/32		0.09375	2.381	19/32		0.59375	15.081
	7/64	0.10938	2.778		39/64	0.60938	15.478
1/8		0.12500	3.175	5/8		0.62500	15.875
	9/64	0.14062	3.572		41/64	0.64062	16.272
5/32		0.15625	3.969	21/32		0.65625	16.669
	11/64	0.17188	4.366		43/64	0.67188	17.066
3/16		0.18750	4.763	11/16		0.68750	17.463
	13/64	0.20312	5.159		45/64	0.70312	17.859
7/32		0.21875	5.556	23/32		0.71875	18.256
	15/64	0.23438	5.953		47/64	0.73438	18.653
1/4		0.25000	6.350	3/4		0.75000	19.050
	17/64	0.26562	6.747		49/64	0.76562	19.447
9/32		0.28125	7.144	25/32		0.78125	19.844
	19/64	0.29688	7.541		51/64	0.79688	20.241
5/16		0.31250	7.938	13/16		0.81250	20.638
	21/64	0.32812	8.334		53/64	0.82812	21.034
11/32		0.34375	8.731	27/32		0.84375	21.431
	23/64	0.35938	9.128		55/64	0.85938	21.828
3/8		0.37500	9.525	7/8		0.87500	22.225
	25/64	0.39062	9.922		57/64	0.89062	22.622
13/32		0.40625	10.319	29/32		0.90625	23.019
	27/64	0.42188	10.716		59/64	0.92188	23.416
7/16		0.43750	11.113	15/16		0.93750	23.813
	29/64	0.45312	11.509		61/64	0.95312	24.209
15/32		0.46875	11.906	31/32		0.96875	24.606
	31/64	0.48438	12.303		63/64	0.98438	25.003
1/2		0.50000	12.700	1/1		1.00000	25.400

PREFIXES–METRIC SYSTEM

FACTOR	PREFIX			SYMBOL
10^{12}	tera	=	a trillion times	T
10^{9}	giga	=	a billion times	G
10^{6}	mega	=	a million times	M
10^{3}	kilo	=	a thousand times	k
10^{2}	hecto	=	a hundred times	h
10	deca	=	ten times	da
1/10	deci	=	a tenth part of	d
$1/10^{2}$	centi	=	a hundredth part of	c
$1/10^{3}$	milli	=	a thousandth part of	m
$1/10^{6}$	micro	=	a millionth part of	µ
$1/10^{9}$	nano	=	a billionth part of	n
$1/10^{12}$	pico	=	a trillionth part of	p