Appendices

Electrical Engineering, National Electrical Code, NFPA 70 E, Electrical Drawings, Introduction to PLC's and Illumination ©

11 PDH

Electrical Engineering for Non-Electrical Engineers Series ©

By

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APPENDICES

Appendix A

This appendix includes the solutions and answers to end of segment self-assessment problems and questions.

Segment 1 – Solutions

1. A given circuit is meant to carry a continuous lighting load of 16 A. In addition, four loads designed for permanent display stands are fastened in place and require 2A each when operating. What is the rating of the over current protective device (OCPD) on the branch circuit?

Solution:
From Article 210.20(a) of the NEC ®, the over current protective device (OCPD) must be rated at 100% of the non-continuous load plus 125% of the continuous load.

∴ The Rating of OCPD = (1.00) (2 A + 2 A + 2 A + 2 A) + (1.25) (16 A)
= 28 A, minimum

A standard fixed-trip circuit breaker or a fuse rated at 30 A can be used (see Sec. 240.6).

2. A three-phase, four-wire feeder with a full-sized neutral carries 14 A continuous and 40 A non-continuous loads. The feeder uses an over current device with a terminal or conductor rating of 60°C. What is the minimum copper conductor size? Assume no derating applies. Use Tables 1.1 and 9.2.

Solution:
Feeder conductor size, before derating, is based on 100% of the non-continuous load and 125% of the continuous load [Art. 215.2(a)].

∴ Amp load = (1.00)(40 A) + (1.25)(14 A)
= 40 A + 17.5 A
= 57.5 A ≈ 58 A

The total of 58 A is used since an ampacity of 0.5 A or greater is rounded up [Sec. 220.2(b)]. Using NEC ® Table 310.15 - as presented in form of Tables 1.1 and 9.2 in this text - TW, UF, **AWG 4 from the 60 °C column should be selected.** The ampacity of AWG 4 is 70 amps.

Note: AWG 6 (the size below AWG 4), with ampacity of 55 amps, would be undersized.

Table 310.15(B)(2)(a) Adjustment Factors for More Than Three Current-Carrying Conductors in a Raceway or Cable							
	Temperature Rating of Conductor						
	60°C (140°F)	75°C (167°F)	90°C (194°F)	60°C (140°F)	75°C (167°F)	90°C (194°F)	
Size AWG or kcmil	Types TW, UF	Types RHW, THHW, THW, THWN, XHHW, USE, ZW	Types TBS, SA, SIS, FEP, FEPB, MI, RHH, RHW-2, THHN, THHW, THW-2, THWN-2, USE-2, XHH, XHHW, XHHW-2, ZW-2	Types TW, UF	Types RHW, THHW, THW, THWN, XHHW, USE	Types TBS, SA, SIS, THHN, THHW, THW-2, THWN-2, RHH, RHW-2, USE-2, XHH, XHHW, XHHW-2, ZW-2	Size AWG or kcmil
	COPPER			ALUMINUM OR COPPER-CLAD ALUMINUM			
18	–	–	14	–	–	–	–
16	–	–	18	–	–	–	–
14*	20	20	25	–	–	–	–
12*	25	25	30	20	20	25	12*
10*	30	35	40	25	30	35	10*
8	40	50	55	30	40	45	8
6	55	65	75	40	50	60	6
4	70	85	95	55	65	75	4
3	5	100	110	65	75	85	3
2	95	115	130	75	90	100	2
1	110	130	150	85	100	115	1
1/0	125	150	170	100	120	135	1/0
2/0	145	175	195	115	135	150	2/0
3/0	165	200	225	130	155	175	3/0
4/0	195	230	260	150	180	205	4/0
250	215	255	290	170	205	230	250
300	240	285	320	190	230	255	300
350	260	310	350	210	250	280	350

Table 1.1: An older version of ampacity table. Included for general format and general content reference only. Contd. Courtesy, NEC, NFPA.

Table 310.15(B)(2)(a) Adjustment Factors for More Than Three Current-Carrying Conductors in a Raceway or Cable							
	Temperature Rating of Conductor						
Size AWG or kcmil	60°C (140°F)	75°C (167°F)	90°C (194°F)	60°C (140°F)	75°C (167°F)	90°C (194°F)	Size AWG or kcmil
	Types TW, UF	Types RHW, THHW, THW, THWN, XHHW, USE, ZW	Types TBS, SA, SIS, FEP, FEPB, MI, RHH, RHW-2, THHN, THHW, THW-2, THWN-2, USE-2, XHH, XHHW, XHHW-2, ZW-2	Types TW, UF	Types RHW, THHW, THW, THWN, XHHW, USE	Types TBS, SA, SIS, THHN, THHW, THW-2, THWN-2, RHH, RHW-2, USE-2, XHH, XHHW, XHHW-2, ZW-2	
	COPPER			ALUMINUM OR COPPER-CLAD ALUMINUM			
CORRECTION FACTORS							
Ambient Temp. (°C)	For ambient temperatures other than 30°C (86°F), multiply the allowable ampacities shown above by the appropriate factor shown below.						Ambient Temp. (°F)
21-25	1.08	1.05	1.04	1.08	1.05	1.04	70-77
26-30	1	1	1	1	1	1	78-86
31-35	0.91	0.94	0.96	0.91	0.94	0.96	87-95
36-40	0.82	0.88	0.91	0.82	0.88	0.91	96-104
41-45	0.71	0.82	0.87	0.71	0.82	0.87	105-113
46-50	0.58	0.75	0.82	0.58	0.75	0.82	114-122
51-55	0.41	0.67	0.76	0.41	0.67	0.76	123-131
56-60	–	0.58	0.71	–	0.58	0.71	132-140
61-70	–	0.33	0.58	–	0.33	0.58	141-158
71-80	–	–	0.41	–	–	0.41	159-176
* Small Condutors. Unless specifically permitted in 240.4(E) through (G), the overcurrent protection shall not exceed 15 amperes for 14 AWG, 20 amperes for 12 AWG, and							
and copper-clad aluminum after any correction factors for ambient temperature and number of conductors have been applied.							

Table 1.2: An older version of ampacity table. Included for general format and general content reference only. Contd. Courtesy, NEC, NFPA.

3. Electrical specifications for a brewery company call for a fusible disconnect switch enclosure that must be able withstand occasional splashing of water during periodic wash downs required

by the local health codes. This design will be applied in breweries in the US as well as Europe. The water flow from the 1-in wash down nozzles is expected to less than 60 GPM from a distance of 11 ft for less than 4 min. (a) Determine the NEMA rating of enclosure for the US installations. (b) Determine the IP rating of enclosure for the European installations.

Solution:
(a) Examination of the NEMA – IP rating table in this segment shows that NEMA 4 enclosure is rated for:

> Watertight (weatherproof). Must exclude at least 65 GPM of water from 1-in. nozzle delivered from a distance not less than 10 ft for 5 min. Used outdoors on ship docks, in dairies, and in breweries.

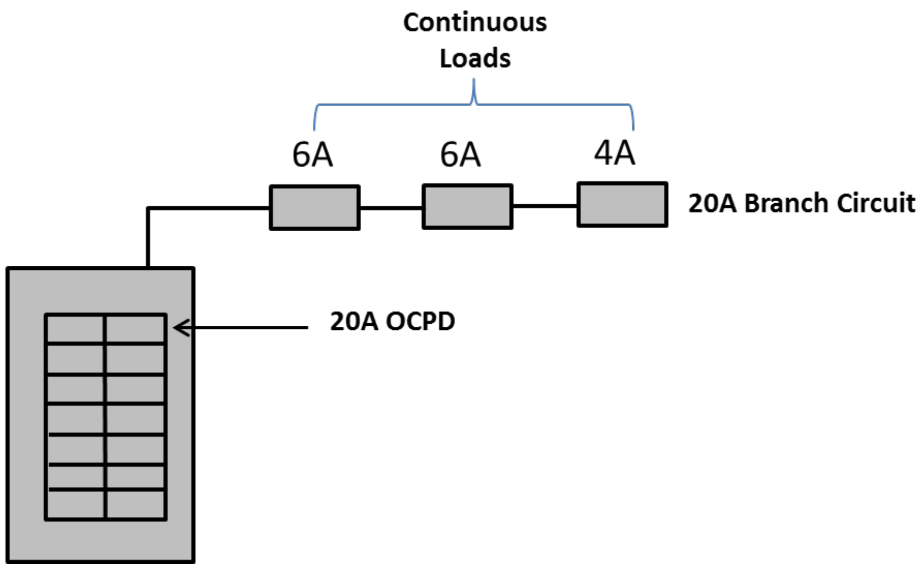
Therefore, a NEMA 4 enclosure would exceed the "1-in wash down nozzle, 60 GPM from a distance of 11 ft for less than 4 min" worst case exposure. Hence, a **NEMA 4 enclosure** should be specified for the US installation.

(b) Since the European installation would be exposed to the same worst case conditions, US NEMA 4's European counterpart, **IP 66 should be specified**.

Note: If the health code, in the US, were to require that chlorine solution be used for the wash down, since chlorine is corrosive, **NEMA 4X** should be specified.

4. Over current Protection & Conductor Ampacity:
Applicable Code/Codes: Articles 210.19 (A) (1), 210.20 (A) and 310.15. Table 310.15(B)(16) as presented in Tables 1.1 and 9.2 of this text (Note: This is not a current table and is only reproduced in this text for exercise and illustration purposes).

The branch circuit in the exhibit below consists of three continuous loads. Over current protection in the branch circuit is provided through a 20 amp circuit breaker. (a) Determine the size of copper conductor based on the ampacities given in Tables 1.1 and 9.2 assuming conductor temperature is at 75°C or less. Assume that 75°C operation and selection is allowed. (b) Verify the size/specifications of the circuit breaker. Assume no derating applies. (c) If the ambient temperature were to rise to 50°C, how would the conductor size be impacted?



Solution:
(a) In accordance with article 210.19 (A) (1): “Branch circuit conductors shall have an ampacity not less than maximum load to be served…..(and) shall have an allowable ampacity not less than the non-continuous load plus 125% of the continuous load.

∴ The conductor ampacity for the given branch circuit
= 1.25 x Continuous Load + 1.00 x Non-Continuous Load
= 1.25 x (16A) + 1.00 x (0) = 20 amps.

According to Table 1.1 (in this text) for 75°C operation, with Types RHW, THHW, THW, THWN, XHHW, USE, ZW insulation, AWG 12 conductor carries an allowable ampacity of 25 amps for conductors that are insulated, rated for 0 – 2000 volt operation, in situations with no more than three (3) current carrying conductors in raceway, cable earth (directly buried); under ambient temperature (not exceeding) 30°C (85°F); with no required/applicable derating. With all conditions remaining the same, an AWG 14 could carry 20 amps. However, the asterisk annotation on both AWG 14 and AWG 12, through the footnotes on Table 1.2, stipulates that if AWG 14 is selected it must be protected at no more than 15 amps. Selection of 15 amp protection for a 16 continuous could result in nuisance tripping or fuse clearing. Therefore, AWG 12, with the stated ampacity of 25 amps, at 75°C operation should be selected. Also, selection of AWG 12 would maintain the existing 20 amp breaker in compliance with the code.

(b) In accordance with article 210.20 (A):

> “Branch-circuit conductors and equipment shall be protected by overcurrent protective devices that have a rating or setting that complies with 210.20(A) through (D).

> (A) Continuous and Non-continuous Loads. Where a branch circuit supplies continuous loads or any combination of continuous and non-continuous loads, the rating of the overcurrent device shall not be less than the non-continuous load plus 125 percent of the continuous load." NEC® 2011.

The over current protection should be rated = 1.25 x Continuous Load
 = 1.25 x (6 + 6 + 4) = 20 amps.

∴ The 20 amp circuit breaker as an over current protection device is adequate for the given branch circuit provided AWG 12 conductor is used.

(c) Ambient Temperature Rise and Conductor size:
According to Article 310, Table 310.15(B)(16), as presented under Tables 1.1 and 9.2 of this text, when ambient deviates from 40°C, the derating/up-rating multipliers, listed at the bottom of Tables 310.15(B)(2)(b) – Table 1.2 in this text - must be applied to adjust the ampacity of the conductor.

As recognized above, the ampacity of an AWG #12, under 75°C operation, is 25 amps. From Table 1.2, the multiplier for 50°C ambient, under 75°C terminal rating, is 0.75.

∴ The adjusted or derated ampacity of AWG #12 conductor, in this case, would be:

= 0.75 x 25 amps = 18,75 amps

Since the derated ampacity of AWG #12, for this application, falls below the 20 amp capacity mandated by 210.19 (A) (1), AWG #12 would no longer be adequate. Therefore, AWG #10, which is the next size above AWG#12, must be considered. According to Table 1.1, for 75°C operation, with Types RHW, THHW, THW, THWN, XHHW, USE, ZW insulation, AWG 10 conductor carries an allowable ampacity of 35 amps. Then, if the 50°C adjustment rating of 0.75 is applied to 35 amp ampacity of an AWG 10, the derated ampacity would be:

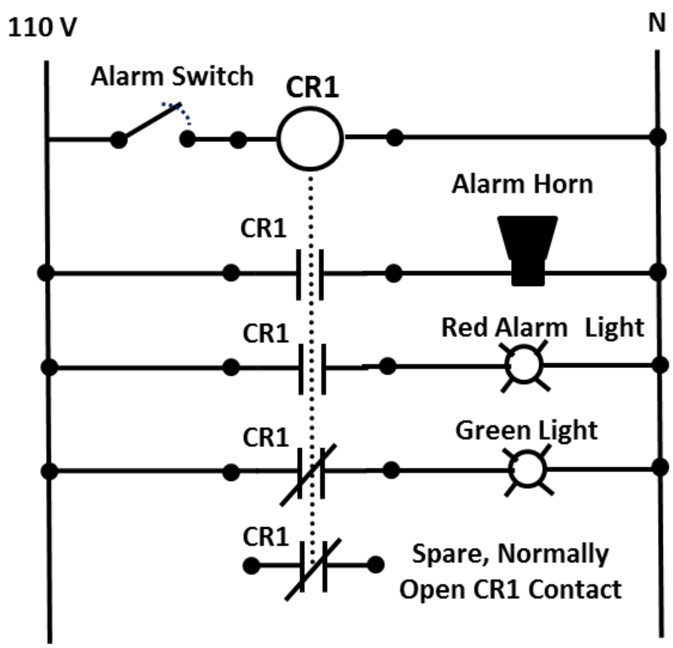
= 0.71 x 35 amps = 26.25 amps

Since the 26.25 amp derated ampacity of AWG #10 exceeds the 20 amp requirement, it would meet the code. AWG #10 should be selected for this application at 50°C ambient temperature.

5. A US appliance manufacturer is planning to market a new appliance in Mexico. The most appropriate safety certification for this appliance would be:

A. UL
B. ULC
C. ETL
D. NOM: NOM Mark: (Norma Official Mexicana) NOM is a mark of product safety approval for virtually any type of product exported into Mexico

6. Assume that the alarm switch in the control circuit depicted below is opened after being closed for a prolonged period of time. Which of the following conditions would best describe the status of the annunciating lights and the horn when the switch is opened?



A. Alarm horn will turn off
B. Red light will turn off
C. Green light will turn on
D. All of the above

Segment 2 – Solutions:

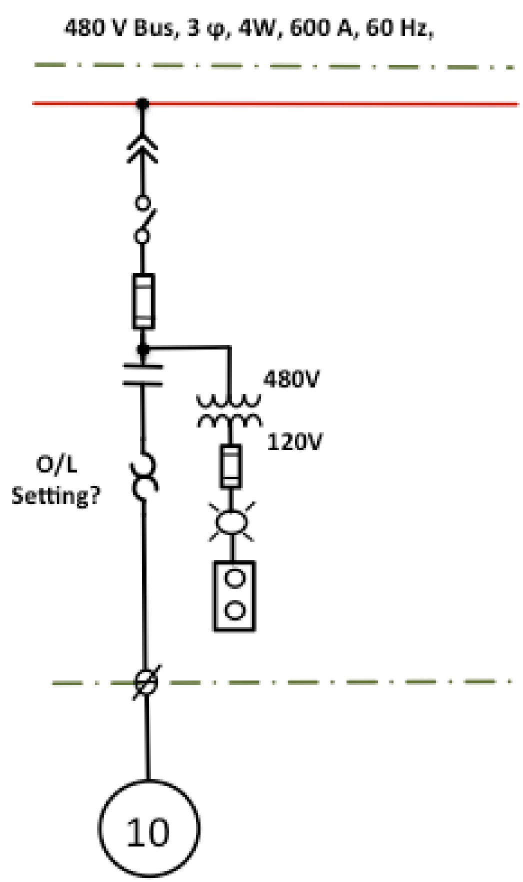
1. Answer the following questions pertaining to the branch circuit shown in the schematic diagram below:

(a) What is the maximum voltage the power distribution system for this branch circuit rated for?

(b) How many wires and phases is the power distribution system for this motor branch circuit rated for?

(c) What would be the proper rating for the branch circuit disconnect switch?

(d) What should the solid-state overload device be set for at commissioning of this branch circuit?



Solution:

(a) The maximum voltage rating of the power distribution system for this branch circuit is included in the specification stated at the very top of the schematic diagram, as 480 V, within the caption:

"**480 V Bus**, 3 ϕ, 4W, 600 A, 60 Hz."

Therefore, the answer is: **480 V.**

(b) The number of wires and phases in this branch circuit can be assessed from the specification stated at the very top of the schematic diagram:

"480 V Bus, **3 ϕ, 4W**, 600 A, 60 Hz."

Therefore, the answer is: **3 ϕ, 4W.**

(c) The proper rating for the branch circuit disconnect switch can be determined by using the NEC ® or through the use of published tables such as the Buss ® table introduced earlier in this segment. As stated in the schematic diagram – in the circled motor symbol – the motor's full load rating is **10 hp**. As specified at the top of schematic diagram, the motor is being powered by a **480 V, 3-phase** source (480 V Bus, 3 ϕ, 4W, 600A, 60 Hz). Therefore, according to the Buss ® table, and as highlighted (circled) below - under the "460 V(480V), 3-ph, section – the fusible disconnect switch size would be **3-ϕ or 3-pole, 30A, 480V.** See the 4th column from the right.

(d) Using the Buss ® table above, for **3 – phase, 10 hp** motor, operating at a **480 V,** the overload device should be set at **17.0 A**.

Note: If NEC ® tables were used here, with the full load current rating of 14A (See the circled segment of the Buss ® table below) the 115% multiplier by NEC ® would result in an overload setting of 16A. It is important to bear in mind that the NEC ® requires that full load amps stated on the nameplate of the motor be used for computations associated with the code. In this text, the Buss ® table is being used for simplicity and illustration purposes.

BUSS® SYSTEM 300 MOTOR PROTECTION GUIDE

"NO-DAMAGE" "TYPE 2" SHORT-CIRCUIT PROTECTION OVERLOAD OR BACK-UP OVERLOAD PROTECTION

Circuit	HP	Motor Full Load Amps	Fuse Size And Type Protection: Over-load: 1.15 S.F. Or Greater Or Rated Not Over 40°C	Over-load: All Other Motors	Back-up: 1.15 S.F. Or Greater Or Rated Not Over 40°C	Back-up: All Other Motors	Switch Or Fuseholder Size	Minimum NEMA Starter Size	Minimum Copper Conductor Size†	Minimum Conduit Size‡
115VAC (120V), 1 ph. (LPN-RK-SP or LPJ-SP)	1/6	4.4	5	5	5.6	5.6	30	00	14	1/2
	1/4	5.8	7	6.25	7.5	7	30	00	14	1/2
	1/3	7.2	9	8	9	9	30	0	14	1/2
	1/2	9.8	12	10	15	12	30	0	14	1/2
	3/4	13.8	15	15	17.5	17.5	30	0	14	1/2
	1	16	20	17.5	20	20	30	0	14	1/2
	1½	20	25	20	25	25	30	1	12	1/2
	2	24	30	25	30	30	30	1	10	1/2
200V (208V), 3 ph. (LPN-RK-SP or LPJ-SP)	1/2	2.3	2.6	2.5	3	2.8	30	00	14	1/2
	3/4	3.22	4	3.5	4.5	4	30	00	14	1/2
	1	4.14	5	4.5	5.6	5	30	00	14	1/2
	1½	5.98	7	6.25	7.5	7	30	00	14	1/2
	2	7.82	9	8	10	9	30	0	14	1/2
	3	11	12	12	15	15	30	0	14	1/2
	5	17.5	20	20	25	25	30	1	12	1/2
	7½	25.3	30*	25*	35	30*	60	1	8	1/2
	10	32.2	40	35	45	40	60	2	6	3/4
	15	48.3	60	50	70**	60	60	3	4	1
	20	62.1	75	70	80	75	100	3	3	1
	25	78.2	90	80	100	90	100	3	1	1¼
	30	92	100	100*	125	110	200	4	1/0	1¼
	40	120	150	125	150	150	200	4	1/0	1¼
	50	150	175	150	200	175	200	5	3/0	1½
	60	177	200*	200*	225	225	400	5	4/0	2
	75	221	250	250	300	300	400	5	300	2
	100	285	350	300	400	350	400	6	500	3
	125	359	400*	400*	450	450	600	6	2-4/0	2-2
	150	414	500	450	600	500	600	6	2-300	2-2

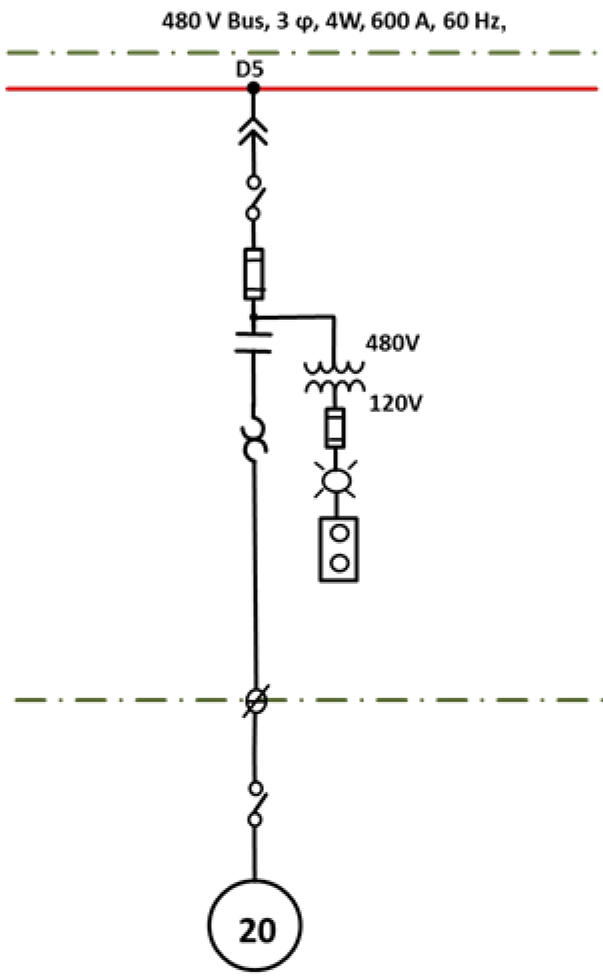
Circuit	HP	Motor Full Load Amps	Fuse Size And Type Protection: Over-load: 1.15 S.F. Or Greater Or Rated Not Over 40°C	Over-load: All Other Motors	Back-up: 1.15 S.F. Or Greater Or Rated Not Over 40°C	Back-up: All Other Motors	Switch Or Fuseholder Size	Minimum NEMA Starter Size	Minimum Copper Conductor Size†	Minimum Conduit Size‡
230V (240V), 1 ph. (LPS-RK-SP or LPJ-SP)	1/6	2.2	2.5	2.5	2.8	2.8	30	00	14	1/2
	1/4	2.9	3.5	3.2	4	3.5	30	00	14	1/2
	1/3	3.6	4.5	4	4.5	4.5	30	00	14	1/2
	1/2	4.9	5.6	5.6	6.25	6	30	00	14	1/2
	3/4	6.9	8	7.5	9	8	30	00	14	1/2
	1	8	10	9	10	10	30	00	14	1/2
	1½	10	12	10	15	12	30	0	14	1/2
	2	12	15	12	15	15	30	0	14	1/2
	3	17	20	17.5	25	20	30	1	12	1/2
	5	28	35	30*	35	35	60	2	8	1/2
	7½	40	50	45	50	50	60	2	6	3/4
	10	50	60	50	70**	60	60	3	4	3/4
460V (480V), 3 ph. (LPS-RK-SP or LPJ-SP)	1/2	1	1.25	1¼	1.25	1.25	30	00	14	1/2
	3/4	1.4	1.6	1.6	1.8	1.8	30	00	14	1/2
	1	1.8	2.25	2	2.25	2.25	30	00	14	1/2
	1½	2.6	3.2	2.6	3.5	3	30	00	14	1/2
	2	3.4	4	3.5	4.5	4	30	00	14	1/2
	3	4.8	5.6	5	6	5.6	30	0	14	1/2
	5	7.6	9	8	10	9	30	0	14	1/2
	7½	11	12	12	15	15	30	1	14	1/2
	10	14	17.5	15	17.5	17.5	30	1	14	1/2
	15	21	25	20	30	25	30	2	10	1/2
	20	27	30*	30*	35	35	60	2	8	1/2
	25	34	40	35	45	40	60	2	6	3/4
	30	40	50	45	50	50	60	3	6	3/4
	40	52	60*	60*	70	60*	100	3	4	1
	50	65	80	70	90	75	100	3	3	1
	60	77	90	80	100	90	100	4	1	1¼
	75	96	110	110	125	125	200	4	1/0	1¼
	100	124	150	125	175	150	200	4	2/0	1½
	125	156	175	175	200	200	200	5	3/0	1½
	150	180	225	200*	225	225	400	5	4/0	2
	200	240	300	250	300	300	400	5	350	2½

* Fuse reducers required. ** 100A switch required.
† THWN connected to 60°C terminations up to #1. AWG to 75°C terminations for 1/0 and larger. Consult equipment manufacturer for listed termination temperature rating. Higher equipment termination temperature ratings may allow smaller conductor and conduit size.
‡ Based on 3 conductors for 3 ph. circuits and 2 conductors for 1 ph. circuits.

MPG

2. Determine the sizes/specifications of the following components in the branch circuit shown below using the Bus ® Table and information included in the questions:

(a) Conductor size.
(b) Conduit size.
(c) Overload setting based on the 115% NEC ® stipulation.
(d) Disconnect switch size, safety and fusible.



Solution:

(a) **Conductor size:** Since the load in the given branch circuit is a 20-hp motor, at 460/480 V, we will focus on the lower right section of the Bus ® table. See the circled 20-hp row on the Bus ® table below. The rightmost columns in the Bus ® table represent NEC ® based switch, starter, conductor and conduit sizes. The second column from the right, for the 20-hp motor load, shows that **AWG # 8 conductor should be specified**.

(b) **Conduit size:** According to the rightmost column in the Bus ® table, a ½" conduit is permitted by the code for housing AWG # 8 conductors associated with the 20-hp motor.

(c) **Overload setting based on the 115% NEC ® stipulation**: First we must identify the FLA, Full Load Amps, for the 20-hp motor, using the Bus ® table. The FLA is listed in the column adjacent to the HP column. So, according to the Bus ® table, FLA for a 3-phase, 20-hp motor, operating at 460/480 V, would be 27 A. Then, as explained in this segment, if the code requires that equipment be protected against overload at 115%, the overload should be set at:

1.15 x (Motor Full Load Amps) = 1.15 x 27 A = **31 A**

(d) **Disconnect switch size, safety and fusible:** In order to specify the sizes of the branch circuit fusible disconnect switch and the safety switch in the field, we will focus on the fourth column from the right in the Bus ® table. In this column we see that **60 A switch is required for a 20-hp motor.** This specification would apply to the branch circuit fusible disconnect switch and the safety switch in the field.

BUSS® SYSTEM 300
MOTOR PROTECTION GUIDE
"NO-DAMAGE" "TYPE 2" SHORT-CIRCUIT PROTECTION
OVERLOAD OR BACK-UP OVERLOAD PROTECTION

	HP	Motor Full Load Amps	Fuse Size And Type Protection: Over-load: 1.15 S.F. Or Greater Or Rated Not Over 40°C	Over-load: All Other Motors	Back-up: 1.15 S.F. Or Greater Or Rated Not Over 40°C	Back-up: All Other Motors	Switch Or Fuseholder Size	Minimum NEMA Starter Size	Minimum Copper Conductor Size†	Minimum Conduit Size‡
115VAC (120V), 1 ph. (LPN-RK-SP or LPJ-SP)	1/6	4.4	5	5	5.6	5.6	30	00	14	1/2
	1/4	5.8	7	6.25	7.5	7	30	00	14	1/2
	1/3	7.2	9	8	9	9	30	0	14	1/2
	1/2	9.8	12	10	15	12	30	0	14	1/2
	3/4	13.8	15	15	17.5	17.5	30	0	14	1/2
	1	16	20	17.5	20	20	30	0	14	1/2
	1½	20	25	20	25	25	30	1	12	1/2
	2	24	30	25	30	30	30	1	10	1/2
200V (208V), 3 ph. (LPN-RK-SP or LPJ-SP)	1/2	2.3	2.6	2.5	3	2.8	30	00	14	1/2
	3/4	3.22	4	3.5	4.5	4	30	00	14	1/2
	1	4.14	5	4.5	5.6	5	30	00	14	1/2
	1½	5.98	7	6.25	7.5	7	30	00	14	1/2
	2	7.82	9	8	10	9	30	0	14	1/2
	3	11	12	12	15	15	30	0	14	1/2
	5	17.5	20	20	25	25	30	1	12	1/2
	7½	25.3	30*	25*	35	30*	60	1	8	1/2
	10	32.2	40	35	45	40	60	2	6	3/4
	15	48.3	60	50	70**	60	60	3	4	1
	20	62.1	75	70	80	75	100	3	3	1
	25	78.2	90	80	100	90	100	3	1	1¼
	30	92	100	100*	125	110	200	4	1/0	1¼
	40	120	150	125	150	150	200	4	1/0	1¼
	50	150	175	150	200	175	200	5	3/0	1½
	60	177	200*	200*	225	225	400	5	4/0	2
	75	221	250	250	300	300	400	5	300	2
	100	285	350	300	400	350	400	6	500	3
	125	359	400*	400*	450	450	600	6	2-4/0	2-2
	150	414	500	450	600	500	600	6	2-300	2-2

	HP	Motor Full Load Amps	Fuse Size And Type Protection: Over-load: 1.15 S.F. Or Greater Or Rated Not Over 40°C	Over-load: All Other Motors	Back-up: 1.15 S.F. Or Greater Or Rated Not Over 40°C	Back-up: All Other Motors	Switch Or Fuseholder Size	Minimum NEMA Starter Size	Minimum Copper Conductor Size†	Minimum Conduit Size‡
230V (240V), 1 ph. (LPS-RK-SP or LPJ-SP)	1/6	2.2	2.5	2.5	2.8	2.8	30	00	14	1/2
	1/4	2.9	3.5	3.2	4	3.5	30	00	14	1/2
	1/3	3.6	4.5	4	4.5	4.5	30	00	14	1/2
	1/2	4.9	5.6	5.6	6.25	6	30	00	14	1/2
	3/4	6.9	8	7.5	9	8	30	00	14	1/2
	1	8	10	9	10	10	30	00	14	1/2
	1½	10	12	10	15	12	30	0	14	1/2
	2	12	15	12	15	15	30	0	14	1/2
	3	17	20	17.5	25	20	30	1	12	1/2
	5	28	35	30*	35	35	60	2	8	1/2
	7½	40	50	45	50	50	60	2	6	3/4
	10	50	60	50	70**	60	60	3	4	3/4
460V (480V), 3 ph. (LPS-RK-SP or LPJ-SP)	1/2	1	1.25	1¼	1.25	1.25	30	00	14	1/2
	3/4	1.4	1.6	1.6	1.8	1.8	30	00	14	1/2
	1	1.8	2.25	2	2.25	2.25	30	00	14	1/2
	1½	2.6	3.2	2.6	3.5	3	30	00	14	1/2
	2	3.4	4	3.5	4.5	4	30	00	14	1/2
	3	4.8	5.6	5	6	5.6	30	0	14	1/2
	5	7.6	9	8	10	9	30	0	14	1/2
	7½	11	12	12	15	15	30	1	14	1/2
	10	14	17.5	15	17.5	17.5	30	1	14	1/2
	15	21	25	20	30	25	30	2	10	1/2
	20	27	30*	30*	35	35	60	2	8	1/2
	25	34	40	35	45	40	60	2	8	3/4
	30	40	50	45	50	50	60	3	6	3/4
	40	52	60*	60*	70	60*	100	3	4	1
	50	65	80	70	90	75	100	3	3	1
	60	77	90	80	100	90	100	4	1	1¼
	75	96	110	110	125	125	200	4	1/0	1¼
	100	124	150	125	175	150	200	4	2/0	1½
	125	156	175	175	200	200	200	5	3/0	1½
	150	180	225	200*	225	225	400	5	4/0	2
	200	240	300	250	300	300	400	5	350	2½

* Fuse reducers required. ** 100A switch required.
† THWN connected to 60°C terminations up to #1. AWG to 75°C terminations for 1/0 and larger. Consult equipment manufacturer for listed termination temperature rating. Higher equipment termination temperature ratings may allow smaller conductor and conduit size.
‡ Based on 3 conductors for 3 ph. circuits and 2 conductors for 1 ph. circuits.

MPG

3. Consider the wiring diagram for the 75-hp motor shown in Figure 2.6 and answer the following questions based on the control logic explained in this segment:

a) What would be the likely outcome if the START switch is depressed while the motor is operating?

Answer: If the START switch is depressed while the motor is operating, the START switch contacts will provide a ***redundant*** 120 V supply to the starter coil and the motor ON light. Therefore, the motor will continue to operate, with no change.

b) What would be the outcome if START and STOP switches are depressed simultaneously?

Answer: If the START and STOP switches are depressed simultaneously, the motor will stop. This is due to the fact that the 120 V supply to the motor starter coil is ***interrupted*** whenever the normally closed contacts of the STOP switch are opened.

c) What would be the likely outcome if the main disconnect switch for the MCC is opened?

Answer: If the main disconnect switch for the MCC is opened, the 480 V supply to the control transformer primary is removed. This de-energizes the secondary, turns off the 120 V supply for motor control circuit and turns off the motor branch circuit.

d) Can the motor be stopped if the motor starter latching contact "welds" shut due to overheating?

Answer: When the spring loaded STOP switch is depressed, the 120 V supply to the motor control circuit is removed and the motor shuts off. However, because the latching contact is sealed shut, the moment the STOP switch is released, the ***motor control coil would re-energize and restart the motor.*** This is due to the fact that with the coil latching contacts sealed closed, the START switch is ***not needed*** to start the motor.

4. Consider the logic associated with Timer P105.TD in Rung # 11 of the PLC relay ladder logic program shown in Figure 2.10 and answer the following questions:

a) What would be status of the timer **Done** bit: "**--| |--**" 105.TD_ CASCADE_ START. DN, if the XIC System E-Stop bit turns "**False,**" 1 second after Timer P105.TD in Rung # 11 is turned on?

Answer: The "**--| |--**" 105.TD_ CASCADE_ START. DN bit is OFF when the timer begins the count. This bit remains OFF until the timer has timed out and Accumulated time becomes equal to the Preset time of 2500 milliseconds, or 2.5 seconds. The XIC System E-Stop bit is representing the state of the System Emergency Stop switch. When this switch is depressed, the E-Stop bit turns "**False**" and the Timer P105.TD_CASCADE_START rung (Rung #11) is "broken," and the timer stops. Since, at 1second, or 1000 milliseconds, the accumulated time is not equal to the present time of 2500 milliseconds, the 105.TD_ CASCADE_ START. DN, **Done** bit will remain **OFF**.

b) Would the "P105 Conveyor _CMD" bit – commanding P105 Conveyor to turn ON - be **True** if and when the system E-Stop switch is engaged/pressed?

Answer: The answer is no. This is because the XIC System E-Stop bit, representing the state of the System Emergency Stop switch, will turn "**False**" and stop the timer before it times out and turns ON the "P105.TD_ CASCADE_ START. DN" bit. From examination of Rung #11we can see that if the P105.TD_CASCADE_START. DN **Done** bit is **not True**, P105 Conveyor _CMD" coil will ***not*** energize and P105 Conveyor will remain **OFF**.

Segment 3 – Solutions

1. HP, or hourly pricing, program is a standard feature in all OPT, or Time of Use, schedules.
A. True
B. False

2. The energy charge rate structure with Electrical OPT schedule is:
A. Flat, year round
B. Tiered
C. Exponential
D. Is a function of time and season.

3. A large industrial electricity consumer set the peak demand in July's billing month at 40 megawatt. The demand rate structure is same as that included in Duke Energy ® OPT-I, Time of Use, rate schedule, as shown in Table 3.2. Determine the demand cost for the month.
A. $367,000
B. $505,000
C. $407,000
D. $476,579

Solution:
As explained earlier in this segment, the demand charges under OPT-I rate schedule are tiered. The tiered levels of demand charges are shown in Duke Energy's OPT-I rate schedule introduced in this segment under Table 3.2.
As apparent from the Table 3.2 excerpt below, July rates, under the OPT-I rate schedule falls under the summer months. Therefore, the shaded section of the excerpted table will be used for the tiered demand calculation.

II. Demand Charge	Summer Months	Winter Months
A. On-Peak Demand Charge	**June 1 – September 30**	**October 1 – May 31**
For the first 2000 kW of Billing Demand per month, per kW	**$14.0767**	**$8.2981**
For the next 3000 kW of Billing Demand per month, per kW	**$12.8972**	**$7.1075**
For all over 5000 kW of Billing Demand per month, per kW	**$11.7067**	**$5.9064**

Charge for the first tier, or 2000 kW = (2000 kW).($14.0767/kW)
= $28,153
Charge for the second tier, or 3000 kW = (3000 kW).($12.8972/kW)
= $38,691
Charge for the remaining demand = (40,000 kW - 5000 kW).($11.7067/kW)
= $409,734
Total demand charge for the month = $28,153 + $38,691 + $409,734
= **$476,579**

4. Calculate the ***energy charge*** for the month of July considered in Problem 3 if all of the energy is consumed during On-Peak hours, for 10 hours per day. Assume that there are 30 days in the billing month and that the load factor is 1, or 100%.

A. $902,000
B. $416,808
C. $2,064,187
D. None of the above

Solution:
As explained earlier in this segment, the energy charges under OPT-I rate schedule are classified into two categories: (a) On-Peak energy charges per month, per kWh, and (b) Off-Peak energy charges per month, per kWh. The energy cost rates for On-Peak and Off-Peak usage are shown in the shaded fields of Table 3.2 excerpt below:

III. Energy Charges	All Months
A. All On-Peak Energy Per Month, Per kWh	**5.7847¢**
B. All Off-Peak Energy, Per Month, Per kWh	**3.4734¢**

Since the total energy consumption is not given, we can derive it based on the parameters identified in the problem statement.

Since the load factor is unity, or “1,” as discussed earlier in this text:

$$\text{Load Factor} = \frac{\text{Average Demand}}{\text{Peak Demand}}$$

Since Load Factor, in this case = 1,

$$1 = \frac{\text{Average Demand}}{\text{Peak Demand}}, \text{ or Average Demand} = \text{Peak Demand} = 40{,}000 \text{ kW}$$

The energy consumed during the billing month

= (number of hours of operation).(Average Demand)

= (30 days/billing month x 10 hours of operation/day).(Average Demand)

= (300 hours of operation/month).(40,000kW)

= 12,000,000kWh per month

Total energy cost for the month:

= (12,000,000kWh).(3.4734¢/kWh).(100¢/$)

= **$416,808**

5. Which of the following statements describes the role of EPC and ESCO most accurately?

A. The terms EPC and ESCO are synonymous

B. EPC is method for implementing energy projects and ESCO’s are entities that offer this alternative.

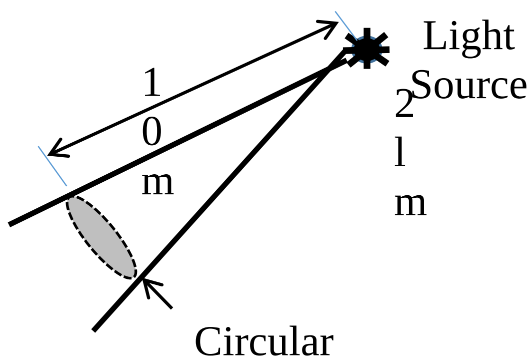
C. EPC is required by Department of Energy, ESCO’s are not.

D. None of the above

Segment 4 - Solutions

1. Consider the lighting scenario described in Example 4.1. Determine the impact on the luminous flux at the 1 m circular target if the distance increased to 10 m. See the diagram below.

Solution



Luminous flux emitted by the source and received by the target at a distance of 10 m is calculated using Eqs. 12.1, 12.2 and 12.3.

$$\Phi = 4.\pi.I \qquad \text{Eq. 4.1}$$

$$I = \frac{\Phi}{\omega} \qquad \text{Eq. 4.2}$$

$$\omega = \frac{A}{r^2} \qquad \text{Eq. 4.3}$$

By applying Eq. 4.3, with A = 0.785 m^2, and r = 10 m:

$$\omega = \frac{A}{r^2} = \frac{0.785\ m^2}{(10\ m)^2} = 0.00785\ sr$$

By applying Eq. 4.2, with ω = 0.00785 sr, and the original source flux of 2 lm:

$$I = \frac{\Phi}{\omega} = \frac{2\ lm}{0.00785\ sr} = 255\ lm/sr$$

By applying Eq. 4.1, with I = 255 lm/sr as calculated before:

$$\Phi = 4.\pi.I = 4.\pi \text{ sr}.(255 \text{ lm/sr}) = 3200 \text{ lm}$$

The **ω, I** and luminous flux **Φ** values calculated above, with the 1 m target at a 10 m distance, can be compared with the **ω, I** and luminous flow **Φ** values calculated for the target distance of 5 m as shown in the table below.

At r = 10 m		**At r = 5 m**	**Ex. 12.1**
0.00785	**sr**	**0.0314**	**sr**
254.78	**lm/sr**	**63.69**	**lm/sr**
3200	**lm**	**800**	**lm**

It is apparent from the table above that, with all other parameters held constant, as the **distance of the 1 m target is doubled**, from 5 m to 10 m, the **luminous flux Φ quadruples**.

2. A180W low pressure sodium vapor lamp is being used to illuminate an exterior space. Determine the luminous flux that would be emitted by this lamp.

Solution:

Given:

P = 180 W

From Table 4.2, efficacy of a low pressure vapor lamp is 180 lm/W

$$\eta = \text{Luminous Efficacy} = K = 180 = \frac{\Phi}{180}$$

$$\Phi = \left(180 \ \frac{\text{lm}}{\text{W}}\right).(180 \text{ W}) = 32{,}400 \text{ lm}$$

$$\therefore \ \text{Luminous Flux, } \Phi = 32{,}400 \text{ lm}$$

3. Consider the scenario depicted in Example 4.2 and assume that the manufacturer's specifications show tested illuminance of the lamp, at 3.0 ft, to be 1000 lx. Determine the amount of illuminance, E, at the floor elevation, directly below the lamp.

Solution:

Apply the single source special case interpretation of the inverse square law in form of Eq. 4.7:

$$E_1 r_1^2 = E_2 r_2^2$$

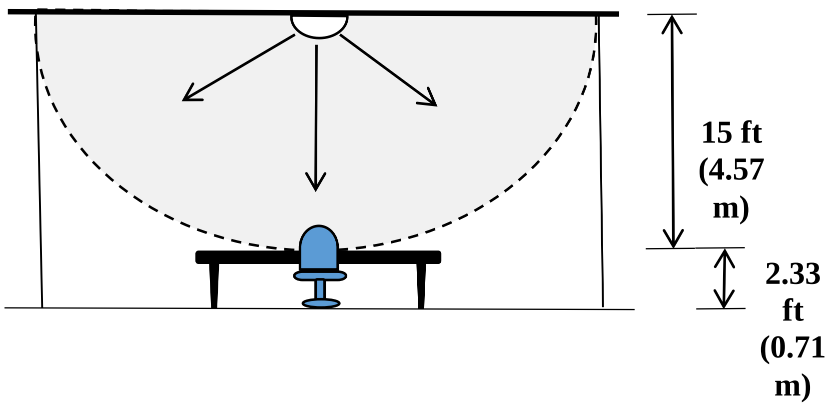
In this case,

E_1 = 1000 lx

r_1 = 3.0 ft

r_2 = 2.33 ft + 15 ft = 17.33 ft

E_2 = ?



Then, by rearranging Eq. 4.7:

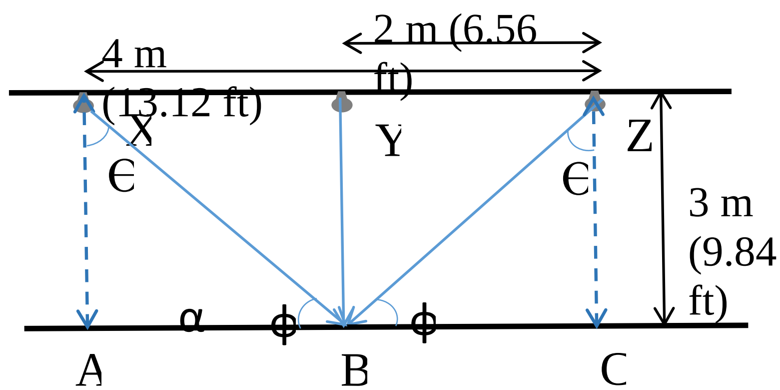
$$E_2 = \frac{E_1 r_1^2}{r_2^2} = \frac{(1000\ \text{lx}).(3\text{ft})^2}{(2.33+15)^2} = 30\ \text{lx}$$

4. Consider the situation stated in Example 4.7. Proposed layout of the lighting system for the work space is shown below. The luminous intensity, I, for lamp **Y** is 700 cd. The luminous intensity for lamps **X** and **Z** is 600 cd. Determine the following:

a) Illuminance $E_{Y\text{-}B}$, at point B, due to light source Y.

b) Total Illuminance, E_B, at point B, due to light sources X, Y and Z.

Solution:
a) Illuminance $E_{Y\text{-}B}$, at point B, due to light source Y.



Geometry of the inclined light path

a) Apply the cosine-cubed law. Since point B lies directly below source Y, angle θ = 0. Apply Eq. 4.9:

$$\text{Illuminance} = E = \frac{I}{h^2}\text{Cos}^3\theta \qquad \text{Eq. 4.9}$$

$$E_{Y-B} = \frac{I}{h^2}\text{Cos}^3\theta = \frac{700\text{ cd}}{(3\text{m})^2}\text{Cos}^3(0)$$

$$= \frac{700\text{ cd}}{(3\text{m})^2}(1) = 77.78\text{ cd/m}^2 \text{ or } 77.8\text{ lx}$$

b) Total Illuminance, E_B, at point B, due the light sources X, Y and Z can be expressed as a sum of illuminance contributions by the three sources, at point B. In other words:

$$E_B = E_{X-B} + E_{Y-B} + E_{Z-B}$$

$E_{Y\text{-}B}$ = 77.8 lx, as calculated in part (a)
$E_{X\text{-}B}$ would be calculated by applying the cosine-cubed law. However, this would require knowledge of value of angle θ portended by the light path X-B with respect to the orthogonal line X-A as shown in the diagram.

Applying Pythagorean theorem to the triangle **XAB**:

$$\theta = \text{Tan}^{-1}\left(\frac{BA}{XA}\right) = \text{Tan}^{-1}\left(\frac{2}{3}\right) = 33.7°$$

Then, by applying the cosine-cubed law, or Eq. 4.9:

$$E_{X-B} = \frac{I}{h^2}\text{Cos}^3\theta = \frac{600\text{ cd}}{3^2}\text{Cos}^3(33.7°)$$

$$= \frac{600\text{ cd}}{(3\text{m})^2}(0.576) = 38.4\text{ cd/m}^2 \text{ or } 38.4\text{ lx}$$

Due to symmetry, by inspection:

$E_{Z\text{-}B} = E_{X\text{-}B} = 38.4$ lx

Therefore,

$$E_B = E_{X-B} + E_{Y-B} + E_{Z-B}$$

$$= 38.4\text{ lx} + 77.8\text{ lx} + 38.4\text{ lx}$$

$$= 154.7\text{ lx}$$

Appendix B
Common Units and Unit Conversion Factors

Power
In the SI or Metric unit system, DC power or “real” **power** is traditionally measured in watts and:

kW = 1,000 Watts
MW = 1,000,000 Watts = 10^{6} W
GW = 1,000,000,000 Watts = 10^{9} W
TW = 10^{12} W

Where k = 1000, M = 1000,000, G = 1 billion, and T = 1 trillion.

Some of the more common **power conversion factors** that are used to convert between SI System and US system of units are listed below:

1.055 kJ/s = 1.055 kW = 1 BTU/s
1–hp = One hp = 746 Watts
= 746 J/s
= 746 N-m/s
= 0.746 kW
= 550 ft-lbf/sec

Energy
In the SI or Metric unit system, DC energy or “**real” energy** is traditionally measured in Wh, kWh, MWh, GWh, TWh (10^{12} Wh).

kWh = 1,000 Watt-hours
MWh = 1,000,000 Watt-hour = 10^{6} Wh
GWh = 1,000,000,000 Watt-hours = 10^{9} Wh
TWh = 10^{12} Wh

Some mainstream conversion factors that can be used to convert electrical energy units within the SI realm or between the SI and US realms are referenced below:

1000 kW x 1h = 1 MWh
1 BTU = 1055 J = 1.055 kJ
1 BTU = 778 ft-lbf

Energy, Work and Heat Conversion Factors:

Energy, Work or Heat		
Btu	1.05435	kJ
Btu	0.251996	kcal
Calories (cal)	4.184	Joules (J)
ft-lbf	1.355818	J
ft-lbf	0.138255	kgf-m
hp-hr	2.6845	MJ
KWH	3.6	MJ
m-kgf	9.80665	J
N-m	1	J

Power Conversion Factors:

Power		
Btu/hr	0.292875	Watt (W)
ft-lbf/s	1.355818	W
Horsepower (hp)	745.6999	W
Horsepower	550.*	ft-lbf/s

Temperature Conversion Factors/Formulas:

Temperature		
Fahrenheit	(°F-32) /1.8	Celsius
Fahrenheit	°F+459.67	Rankine
Celsius	°C+273.16	Kelvin
Rankine	R/1.8	Kelvin

Common Electrical Units, their components and nomenclature:

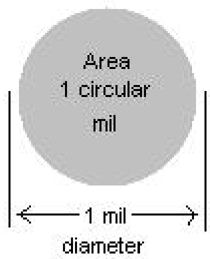
Force	Newton	**N**	**$kg\ m\ s^{-2}$**
Energy	joule	**J**	**$kg\ m^2\ s^{-2}$**
Power	watt	**W**	**$kg\ m^2\ s^{-3}$**
Frequency	hertz	**Hz**	**s^{-1}**
Charge	coulomb	**C**	**A s**
Capacitance	farad	**F**	**$C^2\ s^2\ kg^{-1}\ m^{-2}$**
Magnetic Induction	tesla	**T**	**$kg\ A^{-1}\ s^{-2}$**

Common Unit Prefixes:

1.00E-12	**pico**	**p**
1.00E-09	**nano**	**n**
1.00E-06	**micro**	**µ**
1.00E-03	**milli**	**m**
1.00E+03	**kilo**	**k**
1.00E+06	**mega**	**M**
1.00E+09	**giga**	**G**
1.00E+12	**tera**	**T**

Wire Size Conversions:

A circular mil can be defined as a unit of area, equal to the area of a circle with a diameter of one mil (one thousandth of an inch), depicted as:



1 circular mil is approximately equal to:

- 0.7854 square mils (1 square mil is about 1.273 circular mils)
- 7.854×10^{-7} square inches (1 square inch is about 1.273 million circular mils)
- 5.067×10^{-10} m^2
- 506.7 μm^2

1000 circular mils = 1 MCM or 1 kcmil, and is (approximately) equal to:

- 0.5067 mm^2, so 2 kcmil ≈ 1 mm^2

AWG to Circular Mil Conversion

The formula to calculate the circular mil for any given AWG (American Wire Gage) size is as follows:

.$\boldsymbol{A_n}$ represents the circular mil area for the AWG size $\boldsymbol{n}$.

$$A_n = (5 \times 92^{\frac{36-n}{39}})^2$$

For example, a AWG number 12 gauge wire would use **n = 12**; and the calculated result would be 6529.946789 circular mils

Circular Mil to mm^2 and Dia (mm or in) Conversion:

kcmil or, MCM	mm²	Diameter	
		in.	mm
250	126.7	0.5	12.7
300	152	0.548	13.91
350	177.3	0.592	15.03
400	202.7	0.632	16.06
500	253.4	0.707	17.96
600	304	0.775	19.67
700	354.7	0.837	21.25
750	380	0.866	22
800	405.4	0.894	22.72
900	456	0.949	24.1
1000	506.7	1	25.4
1250	633.4	1.118	28.4
1500	760.1	1.225	31.11
1750	886.7	1.323	33.6
2000	1013.4	1.414	35.92

Appendix C – Greek Symbols Commonly Used in Electrical Engineering

Greek Alphabet			
Αα	Alpha	Νν	Nu
Ββ	Beta	Ξξ	Xi
Γγ	Gamma	Οο	Omicron
Δδ	Delta	Ππ	Pi
Εε	Epsilon	Ρρ	Rho
Ζζ	Zeta	Σσς	Sigma
Ηη	Eta	Τ τ	Tau
Θθ	Theta	Υυ	Upsilon
Ιι	Iota	Φφ	Phi
Κκ	Kappa	Χχ	Chi
Λλ	Lambda	Ψψ	Psi
Μμ	Mu	Ωω	Omega