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High Reliability Power System Design

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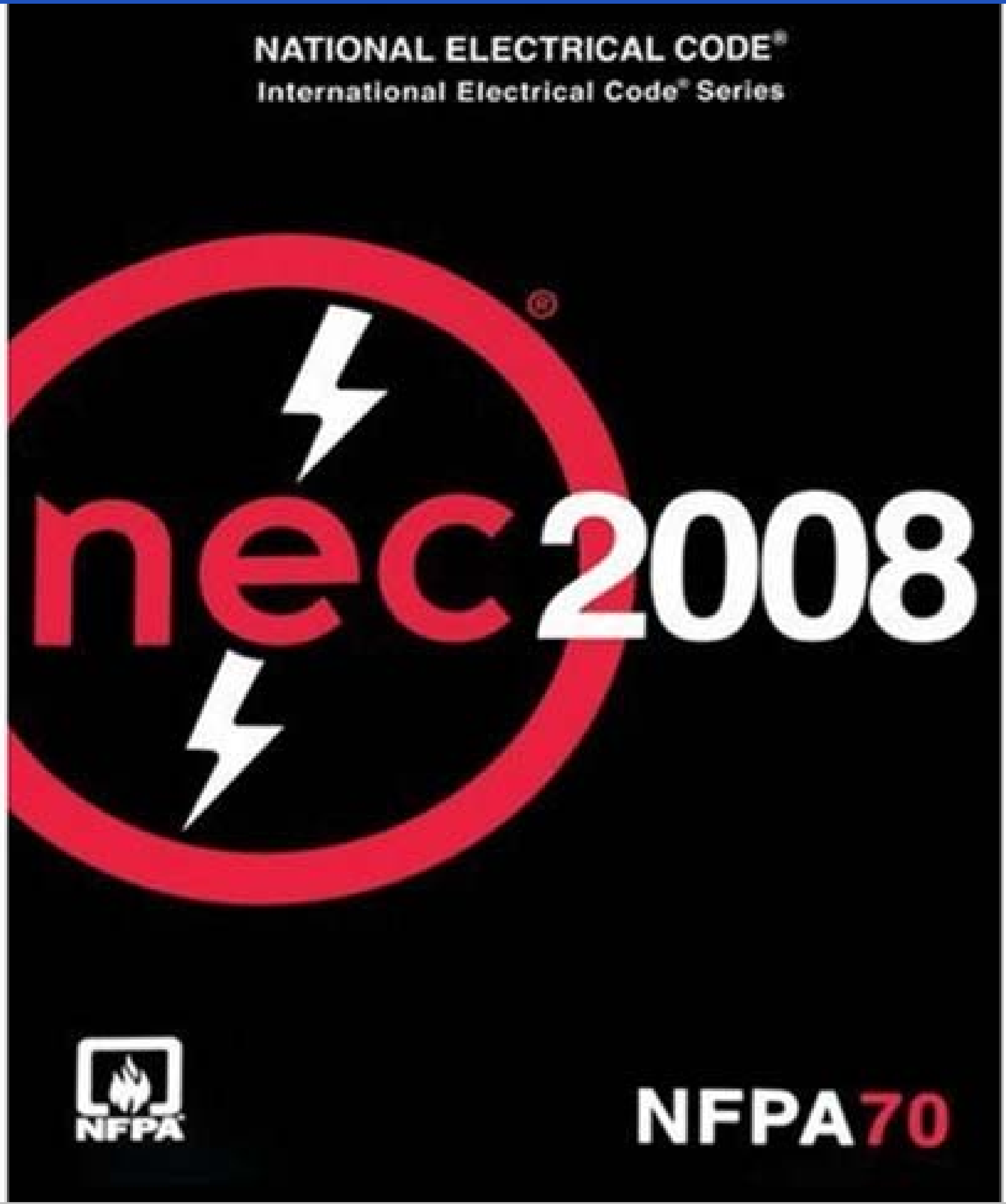
Agenda

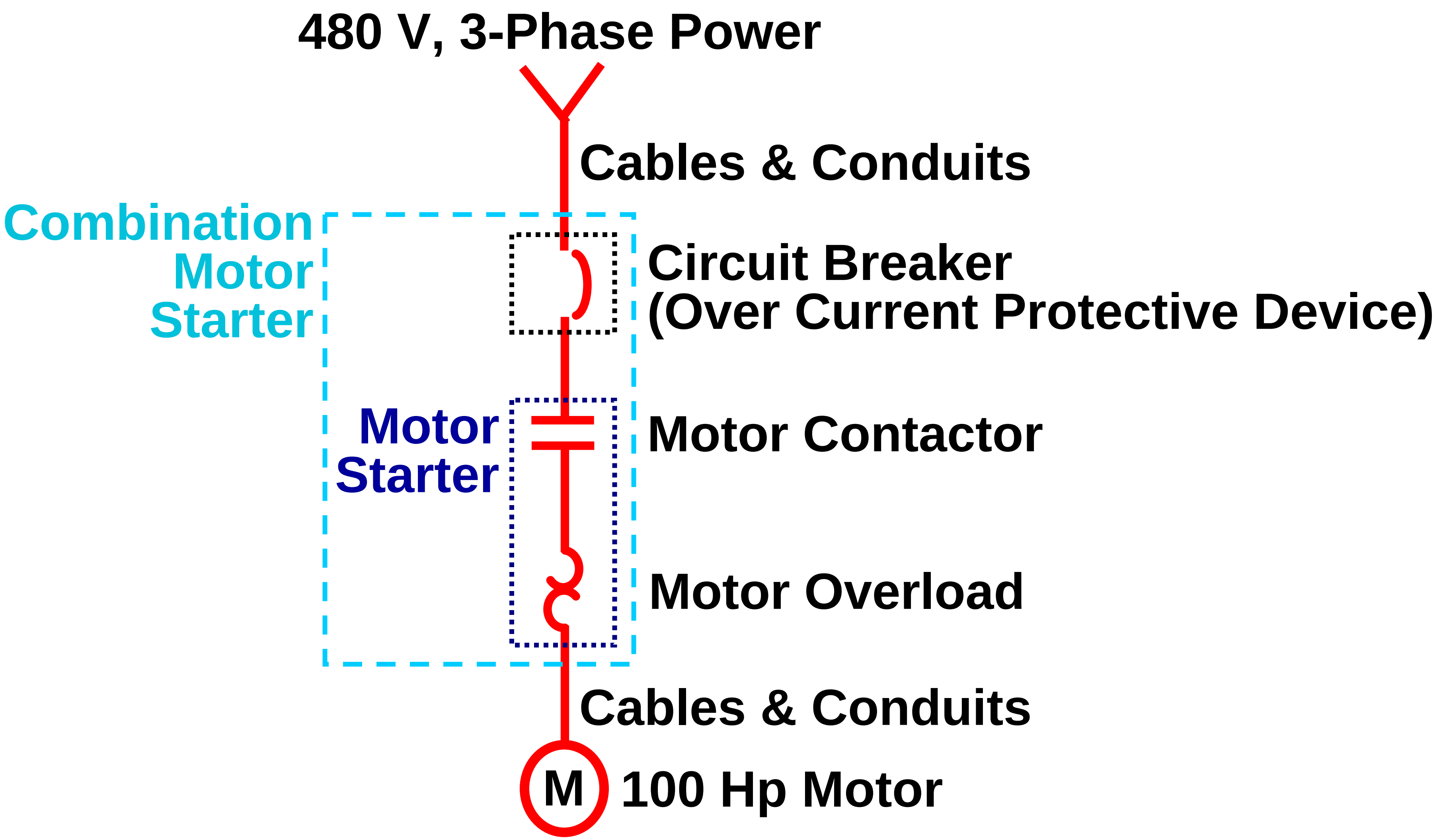
- 3 case studies for high reliability power systems
- Design concepts
- Start with basics for simple circuit design
- Considerations for temperature, safety, etc.
- Build system with transformers, switchgear, etc.
- Overall power system design
- 2008 National Electrical Code (NEC)
- "Bible" for designing electrical systems in USA


NATIONAL ELECTRICAL CODE®
International Electrical Code® Series
nec 2008
NFPA
NFPA 70

U.S. Typical System Voltages

- **120 V, for most small loads like laptops**
- **120/240 V, 1-phase distribution**
- **208Y/120 V, 3-phase distribution**
- **480Y/277 V, 3-phase distribution**
- **4.16Y/2.4 kV, 3-phase distribution**
- **12.47Y/7.2 kV, 3-phase distribution**
- **Utility Distribution: 12 kV, 23 kV, 34.5 kV, etc.**
- **Utility Transmission: 46 kV, 60 kV, 115 kV, etc.**
- **All at 60 Hz**

Simple Circuit Design for 480 V, 100 Hp Pump



Simple Circuit Design for 480 V, 100 Hp Pump

- **BASIC ELEMENTS**
- **Load: 100 Hp pump for moving liquid**
- **Cables & Conduit: Conveys power, safely, from motor starter to pump**
- **Motor Overload: Provides protection to motor from overload conditions (e.g., bimetallic strip, electronic)**
- **Motor Contactor: Allows passage of power to motor from source**
- **Circuit Breaker (OCPD): Provides overload <u>and</u> short circuit protection**

Simple Circuit Design for 480 V, 100 Hp Pump

- **Cables & Conduit: Conveys power, safely, from power source to motor starter**
- **Power Source: 480 V, 3-phase, 60 Hz**
- **Control: Not shown in single line diagram**
- **Control Methods: Level switch, flow sensor, pressure sensor, manual start/stop, automated control system, PLC, DCS, SCADA, etc.**
- **PLC = Programmable Logic Controller**
- **DCS = Distributed Control System**
- **SCADA = Supervisory Control and Data Acquisition**

Simple Circuit Design for 480 V, 100 Hp Pump

Simple Circuit Design for 480 V, 100 Hp Pump

Simple Circuit Design for 480 V, 100 Hp Pump

- **DESIGN CALCULATIONS**
- **A. Determine full-load current, IFL**
- **B. Size motor starter**
- **C. Size overcurrent protection, breaker**
- **D. Size conductors for cables**
- **E. Size grounding conductor**
- **F. Size conduit for cables**

Simple Circuit Design for 480 V, 100 Hp Pump

- **A. <u>Determine Full-Load Current, IFL</u>**
- **Three methods**
- **1) Calculate from power source**
- **2) Directly from motor nameplate**
- **3) From NEC Table 430.250**

Simple Circuit Design for 480 V, 100 Hp Pump

- **1) Calculate IFL from power source:**

$$IFL = \frac{kVA}{\text{Sq Rt (Phases) x Voltage}}$$

- **Where, Phases = 3**
- **Where, Voltage = 480 V, or 0.48 kV**
- **Where, kVA = kW/PF**
- **Where, PF = Power factor, assume typical 0.85**
- **Where, kW = Hp x 0.746 kW/Hp**

Simple Circuit Design for 480 V, 100 Hp Pump

- **Thus, kW = 100 Hp x 0.746 kW/Hp = 74.6 kW**
- **kVA = 74.6 kW/0.85 PF = 87.8 kVA**
- **And,**

$$\mathrm{IFL} = \frac{87.8\ \mathrm{kVA}}{\mathrm{Sq\ Rt}\ (3) \times 0.48\ \mathrm{kV}} = 105.6\ \mathrm{A}$$

Simple Circuit Design for 480 V, 100 Hp Pump

- 2) IFL directly from motor nameplate:
- Depends on whether motor has been purchased to inspect motor nameplate
- Many different motor designs
- Results in different IFLs for exact same Hp
- High efficiency motors will have lower IFL
- Low efficiency and lower cost motors will have higher IFLs

Simple Circuit Design for 480 V, 100 Hp Pump

- **3) IFL from NEC Table 430.250**
- **NEC Table 430.250 = Full-Load Current, Three-Phase Alternating-Current Motors**
- **Most common motor type = Induction-Type Squirrel Cage and Wound Rotor motors**
- **NEC Table 430.250 includes IFLs for various induction motor Hp sizes versus motor voltage**
- **Motor voltages = 115 V, 200 V, 208 V, 230 V, 460 V, and 575 V.**

NEC Table 430.250, Motor Full-Load Currents

Table 430.250 Full-Load Current, Three-Phase Alternating-Current Motors

The following values of full-load currents are typical for motors running at speeds usual for belted motors and motors with normal torque characteristics.

The voltages listed are rated motor voltages. The currents listed shall be permitted for system voltage ranges of 110 to 120, 220 to 240, 440 to 480, and 550 to 600 volts.

	Induction-Type Squirrel Cage and Wound Rotor (Amperes)							Synchronous-Type Unity Power Factor* (Amperes)			
Horsepower	115 Volts	200 Volts	208 Volts	230 Volts	460 Volts	575 Volts	2300 Volts	230 Volts	460 Volts	575 Volts	2300 Volts
½	4.4	2.5	2.4	2.2	1.1	0.9	—	—	—	—	—
¾	6.4	3.7	3.5	3.2	1.6	1.3	—	—	—	—	—
1	8.4	4.8	4.6	4.2	2.1	1.7	—	—	—	—	—
1½	12.0	6.9	6.6	6.0	3.0	2.4	—	—	—	—	—
2	13.6	7.8	7.5	6.8	3.4	2.7	—	—	—	—	—
3	—	11.0	10.6	9.6	4.8	3.9	—	—	—	—	—
5	—	17.5	16.7	15.2	7.6	6.1	—	—	—	—	—
7½	—	25.3	24.2	22	11	9	—	—	—	—	—
10	—	32.2	30.8	28	14	11	—	—	—	—	—
15	—	48.3	46.2	42	21	17	—	—	—	—	—
20	—	62.1	59.4	54	27	22	—	—	—	—	—
25	—	78.2	74.8	68	34	27	—	53	26	21	—
30	—	92	88	80	40	32	—	63	32	26	—
40	—	120	114	104	52	41	—	83	41	33	—
50	—	150	143	130	65	52	—	104	52	42	—
60	—	177	169	154	77	62	16	123	61	49	12
75	—	221	211	192	96	77	20	155	78	62	15
100	—	285	273	248	124	99	26	202	101	81	20
125	—	359	343	312	156	125	31	253	126	101	25
150	—	414	396	360	180	144	37	302	151	121	30
200		552	528	480	240	192	49	400	201	161	40
250	—	—	—	—	302	242	60	—	—	—	—
300	—	—	—	—	361	289	72	—	—	—	—
350	—	—	—	—	414	336	83	—	—	—	—
400	—	—	—	—	477	382	95	—	—	—	—
450	—	—	—	—	515	412	103	—	—	—	—
500	—	—	—	—	590	472	118	—	—	—	—

IFL for 100 Hp, 460 V, Induction Type Motor

Horsepower	115 Volts	200 Volts	208 Volts	230 Volts	460 Volts
½	4.4	2.5	2.4	2.2	1.1
¾	6.4	3.7	3.5	3.2	1.6
1	8.4	4.8	4.6	4.2	2.1
1½	12.0	6.9	6.6	6.0	3.0
2	13.6	7.8	7.5	6.8	3.4
3	—	11.0	10.6	9.6	4.8
5	—	17.5	16.7	15.2	7.6
7½	—	25.3	24.2	22	11
10	—	32.2	30.8	28	14
15	—	48.3	46.2	42	21
20	—	62.1	59.4	54	27
25	—	78.2	74.8	68	34
30	—	92	88	80	40
40	—	120	114	104	52
50	—	150	143	130	65
60	—	177	169	154	77
75	—	221	211	192	96
100	—	285	273	248	124
125	—	359	343	312	156
150	—	414	396	360	180
200		552	528	480	240

Simple Circuit Design for 480 V, 100 Hp Pump

- **Three methods, summary**
- **1) Calculate from power source = 105.6 A**
- **2) Directly from motor nameplate = Depends on motor design and efficiency**
- **3) From NEC Table 430.250 = 124 A**

- **Why is there a difference?**

Simple Circuit Design for 480 V, 100 Hp Pump

- **Three methods, summary**
- **1) Calculate from power source >>>**

  a) Does not account for motor efficiency

  b) Had to assume some typical power factor

  c) Smaller Hp motors will have very low PF

Simple Circuit Design for 480 V, 100 Hp Pump

- Three methods, summary
- 2) Directly from motor nameplate >>>

a) Most accurate

b) Actual motor may not be available to see nameplate

c) Usually the case when design is executed before equipment purchase and installation

d) Even after installation, motor may have to be replaced

e) New motor may be less efficient, or higher IFL

Simple Circuit Design for 480 V, 100 Hp Pump

- **Three methods, summary**
- **3) From NEC Table 430.250 >>>**

a) Most conservative, since IFL is usually higher

b) Avoids installing conductors for high efficiency motor (lower IFL), but may be too small for a replacement low efficiency motor (higher IFL)

c) This is safety consideration to prevent a fire

d) Use of IFL from table is <u>required</u> by NEC for sizing conductors

e) For 100 Hp, 460 V motor, IFL = 124 A

Simple Circuit Design for 480 V, 100 Hp Pump

- **B. Size Motor Starter**
- **U.S. uses standard NEMA class starter sizes**
- **Main difference is in size of motor contactor**
- **Motor contactor must be sized to carry full-load current and starting in-rush current (about 5.5 x IFL)**
- **Allows motor starter manufacturers to build starters with fewer different size contactors**

Simple Circuit Design for 480 V, 100 Hp Pump

- **For 460 V, 3-phase motors:**

NEMA Starter Size	Max Hp
1	10
2	25
3	50
4	100
5	200
6	400
7	600

Simple Circuit Design for 480 V, 100 Hp Pump

Simple Circuit Design for 480 V, 100 Hp Pump

- **For 208 V, 3-phase motors:**

NEMA Starter Size	Max Hp
1	5
2	10
3	25
4	40
5	75

- **For same motor Hp, IFL is higher for 208 V vs. 460 V; thus, max Hp for 208 V is lower**

Simple Circuit Design for 480 V, 100 Hp Pump

- **Size Motor Starter Summary**
- **For 100 Hp, 460 V, 3-phase motor:**
- **Motor starter size = NEMA Size 4**

Simple Circuit Design for 480 V, 100 Hp Pump

- **C. <u>Size Overcurrent Protection, Breaker</u>**
- **Circuit breaker comes with combination motor starter**
- **Size is based on the motor IFL**
- **Minimum breaker size = IFL x 125%**
- **For 100 Hp, 460 V, 3-phase motor,**
- **Minimum breaker size = 124 A x 1.25 = 155 A**
- **Next higher standard available size = 175 A**
- **<u>Maximum</u> breaker size >>> per NEC**

Simple Circuit Design for 480 V, 100 Hp Pump

- **NEC Table 430.52 = Maximum Rating or Setting of Motor Branch-Circuit Short-Circuit and Ground-Fault Protective Devices**
- **Depends on type of motor**
- **Depends on type of OCPD**

NEC Table 430.52, Maximum OCPD for Motors

Table 430.52 Maximum Rating or Setting of Motor Branch-Circuit Short-Circuit and Ground-Fault Protective Devices

	Percentage of Full-Load Current			
Type of Motor	Nontime Delay Fuse[1]	Dual Element (Time-Delay) Fuse[1]	Instantaneous Trip Breaker	Inverse Time Breaker[2]
Single-phase motors	300	175	800	250
AC polyphase motors other than wound-rotor	300	175	800	250
Squirrel cage — other than Design B energy-efficient	300	175	800	250
Design B energy-efficient	300	175	1100	250
Synchronous[3]	300	175	800	250
Wound rotor	150	150	800	150
Direct current (constant voltage)	150	150	250	150

Simple Circuit Design for 480 V, 100 Hp Pump

- Per NEC Table 430.52,
- Maximum OCPD for 100 Hp, 460 V motor = IFL x 250%
- Maximum breaker size = 124 A x 2.5 = 310 A
- Next higher standard available size = 350 A

- Why the difference?

Simple Circuit Design for 480 V, 100 Hp Pump

- **Recall,**
- **Minimum breaker size = 175 A**
- **Maximum breaker size = 350 A**
- **To allow for motor starting in-rush = IFL x 5.5**
- **In-rush current = IFL x 5.5 = 124 A x 5.5 = 682 A**
- **682 A exceeds 175 A and 350 A breaker, but breaker won't trip during normal starting of about 5 seconds**
- **Breaker is inverse time, not instantaneous, and allows <u>short-time</u> overcurrent conditions**

Simple Circuit Design for 480 V, 100 Hp Pump

- **D. <u>Size Conductors for Cables</u>**
- **Conductors must be sized to carry full-load current, continuously**
- **Sizing criteria is based on IFL x 125%, again**
- **For 100 Hp, 460 V, 3-phase motor,**
- **Minimum conductor ampacity = 124 A x 1.25 = 155 A**
- **NEC Table 310.16 governs conductor ampacity**

Simple Circuit Design for 480 V, 100 Hp Pump

- **NEC Table 310.16 = Allowable Ampacities of Insulated Conductors Rated 0 Through 2000 Volts, 60°C (140°F Through 194°F), Not More Than Three Current-Carrying Conductors in Raceway, Cable, or Earth (Directly Buried), Based on Ambient Temperature of 30°C (86°F)**
- **includes ampacities for copper and aluminum conductors**
- **Standard engineering practice = use Cu conductors**
- **Includes temperature ratings of 60°C, 75°C, and 90°C**
- **Use 75°C because of rating of device terminations**

NEC Table 310.16, Conductor Ampacity

Table 310.16 Allowable Ampacities of Insulated Conductors Rated 0 Through 2000 Volts, 60°C Through 90°C (140°F Through 194°F), Not More Than Three Current-Carrying Conductors in Raceway, Cable, or Earth (Directly Buried), Based on Ambient Temperature of 30°C (86°F)

	Temperature Rating of Conductor [See Table 310.13(A).]						
	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			Size AWG or kcmil
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	85	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
400	280	335	380	225	270	305	400
500	320	380	430	260	310	350	500
600	355	420	475	285	340	385	600
700	385	460	520	310	375	420	700
750	400	475	535	320	385	435	750
800	410	490	555	330	395	450	800
900	435	520	585	355	425	480	900
1000	455	545	615	375	445	500	1000
1250	495	590	665	405	485	545	1250
1500	520	625	705	435	520	585	1500
1750	545	650	735	455	545	615	1750
2000	560	665	750	470	560	630	2000

NEC Table 310.16, Conductor Ampacity

Table 310.16 Allowable Ampacities of Insulated Conductors Rated 0 Through 2000 Volts, 60°C Through 90°C (140°F Through 194°F), Not More Than Three Current-Carrying Conductors in Raceway, Cable, or Earth (Directly Buried), Based on Ambient Temperature of 30°C (86°F)

	Temperature Rating of Conductor [See Table 310.13(A).]						
	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			Size AWG or kcmil
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

Simple Circuit Design for 480 V, 100 Hp Pump

- **The U.S. uses a non-universal system for identifying conductor sizes**
- **AWG = American Wire Gage (higher the number, the small the conductor diameter)**
- **kcmil = Thousand circular mils (based on cross-sectional area)**
- **A more universal method is to identify conductor sizes by the cross-sectional area of the conductor, using square millimeters, or mm^2**
- **NEC Chapter 9, Table 8, Conductor Properties, has a translation table**

NEC Chapter 9, Table 8, Conductor Properties

Table 8 Conductor Properties

			Conductors							Direct-Current Resistance at 75°C (167°F)					
			Stranding			Overall				Copper					
	Area			Diameter		Diameter		Area		Uncoated		Coated		Aluminum	
Size (AWG or kcmil)	mm²	Circular mils	Quantity	mm	in.	mm	in.	mm²	in.²	ohm/km	ohm/kFT	ohm/km	ohm/kFT	ohm/km	ohm/kFT
18	0.823	1620	1	—	—	1.02	0.040	0.823	0.001	25.5	7.77	26.5	8.08	42.0	12.8
18	0.823	1620	7	0.39	0.015	1.16	0.046	1.06	0.002	26.1	7.95	27.7	8.45	42.8	13.1
16	1.31	2580	1	—	—	1.29	0.051	1.31	0.002	16.0	4.89	16.7	5.08	26.4	8.05
16	1.31	2580	7	0.49	0.019	1.46	0.058	1.68	0.003	16.4	4.99	17.3	5.29	26.9	8.21
14	2.08	4110	1	—	—	1.63	0.064	2.08	0.003	10.1	3.07	10.4	3.19	16.6	5.06
14	2.08	4110	7	0.62	0.024	1.85	0.073	2.68	0.004	10.3	3.14	10.7	3.26	16.9	5.17
12	3.31	6530	1	—	—	2.05	0.081	3.31	0.005	6.34	1.93	6.57	2.01	10.45	3.18
12	3.31	6530	7	0.78	0.030	2.32	0.092	4.25	0.006	6.50	1.98	6.73	2.05	10.69	3.25
10	5.261	10380	1	—	—	2.588	0.102	5.26	0.008	3.984	1.21	4.148	1.26	6.561	2.00
10	5.261	10380	7	0.98	0.038	2.95	0.116	6.76	0.011	4.070	1.24	4.226	1.29	6.679	2.04
8	8.367	16510	1	—	—	3.264	0.128	8.37	0.013	2.506	0.764	2.579	0.786	4.125	1.26
8	8.367	16510	7	1.23	0.049	3.71	0.146	10.76	0.017	2.551	0.778	2.653	0.809	4.204	1.28
6	13.30	26240	7	1.56	0.061	4.67	0.184	17.09	0.027	1.608	0.491	1.671	0.510	2.652	0.808
4	21.15	41740	7	1.96	0.077	5.89	0.232	27.19	0.042	1.010	0.308	1.053	0.321	1.666	0.508
3	26.67	52620	7	2.20	0.087	6.60	0.260	34.28	0.053	0.802	0.245	0.833	0.254	1.320	0.403
2	33.62	66360	7	2.47	0.097	7.42	0.292	43.23	0.067	0.634	0.194	0.661	0.201	1.045	0.319
1	42.41	83690	19	1.69	0.066	8.43	0.332	55.80	0.087	0.505	0.154	0.524	0.160	0.829	0.253
1/0	53.49	105600	19	1.89	0.074	9.45	0.372	70.41	0.109	0.399	0.122	0.415	0.127	0.660	0.201
2/0	67.43	133100	19	2.13	0.084	10.62	0.418	88.74	0.137	0.3170	0.0967	0.329	0.101	0.523	0.159
3/0	85.01	167800	19	2.39	0.094	11.94	0.470	111.9	0.173	0.2512	0.0766	0.2610	0.0797	0.413	0.126
4/0	107.2	211600	19	2.68	0.106	13.41	0.528	141.1	0.219	0.1996	0.0608	0.2050	0.0626	0.328	0.100
250	127	—	37	2.09	0.082	14.61	0.575	168	0.260	0.1687	0.0515	0.1753	0.0535	0.2778	0.0847
300	152	—	37	2.29	0.090	16.00	0.630	201	0.312	0.1409	0.0429	0.1463	0.0446	0.2318	0.0707
350	177	—	37	2.47	0.097	17.30	0.681	235	0.364	0.1205	0.0367	0.1252	0.0382	0.1984	0.0605
400	203	—	37	2.64	0.104	18.49	0.728	268	0.416	0.1053	0.0321	0.1084	0.0331	0.1737	0.0529
500	253	—	37	2.95	0.116	20.65	0.813	336	0.519	0.0845	0.0258	0.0869	0.0265	0.1391	0.0424
600	304	—	61	2.52	0.099	22.68	0.893	404	0.626	0.0704	0.0214	0.0732	0.0223	0.1159	0.0353
700	355	—	61	2.72	0.107	24.49	0.964	471	0.730	0.0603	0.0184	0.0622	0.0189	0.0994	0.0303
750	380	—	61	2.82	0.111	25.35	0.998	505	0.782	0.0563	0.0171	0.0579	0.0176	0.0927	0.0282
800	405	—	61	2.91	0.114	26.16	1.030	538	0.834	0.0528	0.0161	0.0544	0.0166	0.0868	0.0265
900	456	—	61	3.09	0.122	27.79	1.094	606	0.940	0.0470	0.0143	0.0481	0.0147	0.0770	0.0235
1000	507	—	61	3.25	0.128	29.26	1.152	673	1.042	0.0423	0.0129	0.0434	0.0132	0.0695	0.0212
1250	633	—	91	2.98	0.117	32.74	1.289	842	1.305	0.0338	0.0103	0.0347	0.0106	0.0554	0.0169
1500	760	—	91	3.26	0.128	35.86	1.412	1011	1.566	0.02814	0.00858	0.02814	0.00883	0.0464	0.0141
1750	887	—	127	2.98	0.117	38.76	1.526	1180	1.829	0.02410	0.00735	0.02410	0.00756	0.0397	0.0121
2000	1013	—	127	3.19	0.126	41.45	1.632	1349	2.092	0.02109	0.00643	0.02109	0.00662	0.0348	0.0106

NEC Chapter 9, Table 8, Conductor Properties

Size (AWG or kcmil)	Area mm²	Area Circular mils
18	0.823	1620
18	0.823	1620
16	1.31	2580
16	1.31	2580
14	2.08	4110
14	2.08	4110
12	3.31	6530
12	3.31	6530
10	5.261	10380
10	5.261	10380
8	8.367	16510
8	8.367	16510
6	13.30	26240
4	21.15	41740
3	26.67	52620
2	33.62	66360
1	42.41	83690

Size (AWG or kcmil)	Area mm²	Area Circular mils
1/0	53.49	105600
2/0	67.43	133100
3/0	85.01	167800
4/0	107.2	211600
250	127	—
300	152	—
350	177	—
400	203	—
500	253	—
600	304	—
700	355	—
750	380	—
800	405	—
900	456	—
1000	507	—
1250	633	—
1500	760	—
1750	887	—
2000	1013	—

Simple Circuit Design for 480 V, 100 Hp Pump

- **For 100 Hp, 460 V, 3-phase motor,**
- **Minimum conductor ampacity = 124 A x 1.25 = 155 A**
- **Minimum conductor size = 2/0 AWG (67.43 mm^2)**
- **Ampacity of 2/0 AWG (67.43 mm^2) = 175 A**

Simple Circuit Design for 480 V, 100 Hp Pump

Size AWG or kcmil	Types TW, UF	Types RHW, THHW, THW, THWN, XHHW, USE, ZW
		COPPER
18	—	—
16	—	—
14*	20	20
12*	25	25
10*	30	35
8	40	50
6	55	65
4	70	85
3	85	100
2	95	115
1	110	130
1/0	125	150
2/0	145	175
3/0	165	200
4/0	195	230

Simple Circuit Design for 480 V, 100 Hp Pump

- **Cables for 480 V power circuits are available with standard 600 V class cables**
- **Cables must be suitably rated for dry, damp, or wet conditions**
- **For above ground applications, dry and damp rated cables are acceptable**
- **For underground ductbank applications, dry and wet cables are essential**
- **Many different kinds of 600 V insulation/jacket type cables are available**

Simple Circuit Design for 480 V, 100 Hp Pump

- **The four most common 600 V cables are as follows:**
- **RHW = Flame-retardant, moisture-resistant thermoset**
- **THHN = Flame-retardant, heat-resistant, thermoplastic**
- **THWN = Flame-retardant, moisture- and heat-resistant, thermoplastic**
- **XHHW = Flame-retardant, moisture-resistant, thermoset**

Simple Circuit Design for 480 V, 100 Hp Pump

- **Standard engineering practice is to use heavy duty cables for reliability and fewer chances for failures**
- **For all power circuits, use XHHW-2, 90°C wet and dry (cross-linked thermosetting polyethylene insulation)**
- **For small lighting and receptacle circuits, use THHN/THWN, 90°C dry, 75°C wet**

Simple Circuit Design for 480 V, 100 Hp Pump

- **E. <u>Size Grounding Conductor</u>**
- **Grounding conductor is very, very important**
- **Required for ground fault return path to upstream circuit breaker (or OCPD)**
- **Breaker must sense the fault and trip in order to clear the fault**
- **Or, if a fuse, the fuse element must melt through**
- **NEC Table 250.122 governs the minimum size of grounding conductors**

Simple Circuit Design for 480 V, 100 Hp Pump

- **NEC Table 250.122 = Minimum Size Equipment Grounding Conductors for Grounding Raceway and Equipment**
- **Standard engineering practice is to use Cu conductors for both power and grounding**
- **Size of grounding conductors is based on rating of upstream breaker, fuse (or OCPD)**
- **Why?**
- **If grounding conductor is too small (and therefore higher impedance), the OCPD may not detect the ground fault return**

NEC Table 250.122, Grounding Conductors

Table 250.122 Minimum Size Equipment Grounding Conductors for Grounding Raceway and Equipment

Rating or Setting of Automatic Overcurrent Device in Circuit Ahead of Equipment, Conduit, etc., Not Exceeding (Amperes)	Size (AWG or kcmil)	
	Copper	Aluminum or Copper-Clad Aluminum*
15	14	12
20	12	10
30	10	8
40	10	8
60	10	8
100	8	6
200	6	4
300	4	2
400	3	1
500	2	1/0
600	1	2/0
800	1/0	3/0
1000	2/0	4/0
1200	3/0	250
1600	4/0	350
2000	250	400
2500	350	600
3000	400	600
4000	500	800
5000	700	1200
6000	800	1200

Simple Circuit Design for 480 V, 100 Hp Pump

- **For 100 Hp, 460 V, 3-phase motor:**
- **Minimum size breaker in starter = 175 A**
- **Next higher size breaker in NEC 250.122 = 200 A**
- **Then, grounding conductor = 6 AWG (13.30 mm^2)**

- **Maximum size breaker in starter = 350 A**
- **Next higher size breaker in NEC 250.122 = 400 A**
- **Then, grounding conductor = 3 AWG (26.67 mm^2)**

Simple Circuit Design for 480 V, 100 Hp Pump

Table 250.122 Minimum Size Equipment Grounding Conductors for Grounding Raceway and Equipment

	Rating or Setting of Automatic Overcurrent Device in Circuit Ahead of Equipment, Conduit, etc., Not Exceeding (Amperes)	Size (AWG or kcmil)	
		Copper	Aluminum or Copper-Clad Aluminum*
	15	14	12
	20	12	10
	30	10	8
	40	10	8
	60	10	8
	100	8	6
Min	200	6	4
	300	4	2
Max	400	3	1
	500	2	1/0
	600	1	2/0
	800	1/0	3/0

Simple Circuit Design for 480 V, 100 Hp Pump

- **For most motor applications, the minimum sizing calculation is adequate (using IFL x 125%)**
- **Concern would only be with motor starters that take an excessive amount of time to start**
- **Thus, grounding conductor = 6 AWG (13.30 mm^2)**

Simple Circuit Design for 480 V, 100 Hp Pump

- **F. Size Conduit for Cables**
- **Size of conduit depends on quantity and size of cables inside**
- **First, calculate cross-sectional area of all cables in the conduit**
- **Different cable manufacturers produce cables with slightly different diameters**
- **If actual cable data sheet is available, then those cable diameters can be used**
- **If not, such as during design, the NEC Table is used**

Simple Circuit Design for 480 V, 100 Hp Pump

- **NEC Chapter 9, Table 5 = Dimensions of Insulated Conductors and Fixture Wires, Type XHHW**
- **Table includes cable diameter and cable cross-sectional area**
- **Select cable cross-sectional area since we have to calculate based on cable areas and conduit areas**

NEC Chapter 9, Table 5, Cable Dimensions

Type	Size (AWG or kcmil)	Approximate Diameter		Approximate Area	
		mm	in.	mm^2	$in.^2$
Type: KF-1, KF-2, KFF-1, KFF-2, XHH, XHHW, XHHW-2, ZW					
XHHW, ZW, XHHW-2, XHH	14	3.378	0.133	8.968	0.0139
	12	3.861	0.152	11.68	0.0181
	10	4.470	0.176	15.68	0.0243
	8	5.994	0.236	28.19	0.0437
	6	6.960	0.274	38.06	0.0590
	4	8.179	0.322	52.52	0.0814
	3	8.890	0.350	62.06	0.0962
	2	9.703	0.382	73.94	0.1146
XHHW, XHHW-2, XHH	1	11.23	0.442	98.97	0.1534
	1/0	12.24	0.482	117.7	0.1825
	2/0	13.41	0.528	141.3	0.2190
	3/0	14.73	0.58	170.5	0.2642
	4/0	16.21	0.638	206.3	0.3197
	250	17.91	0.705	251.9	0.3904
	300	19.30	0.76	292.6	0.4536
	350	20.60	0.811	333.3	0.5166
	400	21.79	0.858	373.0	0.5782
	500	23.95	0.943	450.6	0.6984
	600	26.75	1.053	561.9	0.8709
	700	28.55	1.124	640.2	0.9923
	750	29.41	1.158	679.5	1.0532
	800	30.23	1.190	717.5	1.1122
	900	31.85	1.254	796.8	1.2351
	1000	33.32	1.312	872.2	1.3519
	1250	37.57	1.479	1108	1.7180
	1500	40.69	1.602	1300	2.0157
	1750	43.59	1.716	1492	2.3127
	2000	46.28	1.822	1682	2.6073

Simple Circuit Design for 480 V, 100 Hp Pump

- **For 100 Hp, 460 V, 3-phase motor,**
- **Circuit = 3-2/0 AWG (67.43 mm^2), 1-6 AWG (13.30 mm^2) GND**
- **In one conduit**

Simple Circuit Design for 480 V, 100 Hp Pump

Type	Size (AWG or kcmil)	Approximate Diameter		Approximate Area	
		mm	in.	mm^2	$in.^2$
Type: KF-1, KF-2, KFF-1, KFF-2, XHH, XHHW, XHHW-2, ZW					
XHHW, ZW, XHHW-2, XHH	14	3.378	0.133	8.968	0.0139
	12	3.861	0.152	11.68	0.0181
	10	4.470	0.176	15.68	0.0243
	8	5.994	0.236	28.19	0.0437
	6	6.960	0.274	38.06	0.0590
	4	8.179	0.322	52.52	0.0814
	3	8.890	0.350	62.06	0.0962
	2	9.703	0.382	73.94	0.1146
XHHW, XHHW-2, XHH	1	11.23	0.442	98.97	0.1534
	1/0	12.24	0.482	117.7	0.1825
	2/0	13.41	0.528	141.3	0.2190
	3/0	14.73	0.58	170.5	0.2642
	4/0	16.21	0.638	206.3	0.3197
	250	17.91	0.705	251.9	0.3904
	300	19.30	0.76	292.6	0.4536
	350	20.60	0.811	333.3	0.5166
	400	21.79	0.858	373.0	0.5782
	500	23.95	0.943	450.6	0.6984

Simple Circuit Design for 480 V, 100 Hp Pump

- **Per NEC Table:**
- **Area of 2/0 AWG (67.43 mm^2) cable = 141.3 mm^2**
- **Area of 6 AWG (13.30 mm^2) cable = 38.06 mm^2**
- **Total cross-sectional area of all cables =**
  3 x 141.3 mm^2 + 1 x 38.06 mm^2 = 462.0 mm^2

Simple Circuit Design for 480 V, 100 Hp Pump

- **Next, select minimum conduit size for 462.0 mm^2 of total cable cross-sectional area**
- **Criteria of minimum conduit is governed by NEC Chapter 9, Table 1 = Percent of Cross Section of Conduit and Tubing for Conductors**
- **Very rarely does a circuit have only 1 or 2 cables (DC circuits)**
- **Majority of circuits are over 2 cables**
- **Thus, maximum cross section of cables to conduit is 40%, also known as “Fill Factor”**

NEC Chapter 9, Table 1, Maximum Fill Factor

Chapter 9

Table 1 Percent of Cross Section of Conduit and Tubing for Conductors

Number of Conductors	All Conductor Types
1	53
2	31
Over 2	40

Simple Circuit Design for 480 V, 100 Hp Pump

- **Why does the NEC limit the fill factor to 40%?**
- **Two major factors:**
- **1) Cable Damage During Installation – If the conduit has too many cables in the conduit, then the pulling tension increases and the cable could be damaged with broken insulation**
- **2) Thermal Heat Management – Heat emanates from cables when current flows through them (I^2xR), and elevated temperatures increases resistance and reduces ampacity of conductor**

Simple Circuit Design for 480 V, 100 Hp Pump

- **Similar to cables, different conduit manufacturers produce conduits with slightly different diameters**
- **If actual conduit data sheet is available, then those conduit diameters can be used**
- **If not, such as during design, the NEC Table is used**
- **NEC Chapter 9, Table 4 = Dimensions and Percent Area of Conduit and Tubing, Article 344 – Rigid Metal Conduit (RMC) or Article 352 and 353 – Rigid PVC Conduit (PVC), Schedule 40**
- **Standard engineering practice = 21 mm diameter minimum conduit size**

NEC Chapter 9, Table 4, RMC Conduit Dimensions

Article 344 — Rigid Metal Conduit (RMC)

Metric Designator	Trade Size	Nominal Internal Diameter		Total Area 100%		60%		1 Wire 53%		2 Wires 31%		Over 2 Wires 40%	
		mm	in.	mm^2	$in.^2$	mm^2	$in.^2$	mm^2	$in.^2$	mm^2	$in.^2$	mm^2	$in.^2$
12	3⁄8	—	—	—	—	—	—	—	—	—	—	—	—
16	½	16.1	0.632	204	0.314	122	0.188	108	0.166	63	0.097	81	0.125
21	¾	21.2	0.836	353	0.549	212	0.329	187	0.291	109	0.170	141	0.220
27	1	27.0	1.063	573	0.887	344	0.532	303	0.470	177	0.275	229	0.355
35	1¼	35.4	1.394	984	1.526	591	0.916	522	0.809	305	0.473	394	0.610
41	1½	41.2	1.624	1333	2.071	800	1.243	707	1.098	413	0.642	533	0.829
53	2	52.9	2.083	2198	3.408	1319	2.045	1165	1.806	681	1.056	879	1.363
63	2½	63.2	2.489	3137	4.866	1882	2.919	1663	2.579	972	1.508	1255	1.946
78	3	78.5	3.090	4840	7.499	2904	4.499	2565	3.974	1500	2.325	1936	3.000
91	3½	90.7	3.570	6461	10.010	3877	6.006	3424	5.305	2003	3.103	2584	4.004
103	4	102.9	4.050	8316	12.882	4990	7.729	4408	6.828	2578	3.994	3326	5.153
129	5	128.9	5.073	13050	20.212	7830	12.127	6916	10.713	4045	6.266	5220	8.085
155	6	154.8	6.093	18821	29.158	11292	17.495	9975	15.454	5834	9.039	7528	11.663

NEC Chapter 9, Table 4, PVC Conduit Dimensions

Articles 352 and 353 — Rigid PVC Conduit (PVC), Schedule 40, and HDPE Conduit (HDPE)

Metric Designator	Trade Size	Nominal Internal Diameter		Total Area 100%		60%		1 Wire 53%		2 Wires 31%		Over 2 Wires 40%	
		mm	in.	mm^2	$in.^2$	mm^2	$in.^2$	mm^2	$in.^2$	mm^2	$in.^2$	mm^2	$in.^2$
12	⅜	—	—	—	—	—	—	—	—	—	—	—	—
16	½	15.3	0.602	184	0.285	110	0.171	97	0.151	57	0.088	74	0.114
21	¾	20.4	0.804	327	0.508	196	0.305	173	0.269	101	0.157	131	0.203
27	1	26.1	1.029	535	0.832	321	0.499	284	0.441	166	0.258	214	0.333
35	1¼	34.5	1.360	935	1.453	561	0.872	495	0.770	290	0.450	374	0.581
41	1½	40.4	1.590	1282	1.986	769	1.191	679	1.052	397	0.616	513	0.794
53	2	52.0	2.047	2124	3.291	1274	1.975	1126	1.744	658	1.020	849	1.316
63	2½	62.1	2.445	3029	4.695	1817	2.817	1605	2.488	939	1.455	1212	1.878
78	3	77.3	3.042	4693	7.268	2816	4.361	2487	3.852	1455	2.253	1877	2.907
91	3½	89.4	3.521	6277	9.737	3766	5.842	3327	5.161	1946	3.018	2511	3.895
103	4	101.5	3.998	8091	12.554	4855	7.532	4288	6.654	2508	3.892	3237	5.022
129	5	127.4	5.016	12748	19.761	7649	11.856	6756	10.473	3952	6.126	5099	7.904
155	6	153.2	6.031	18433	28.567	11060	17.140	9770	15.141	5714	8.856	7373	11.427

Simple Circuit Design for 480 V, 100 Hp Pump

- **RMC is usually used above ground and where mechanical protection is required to protect the cables from damage**
- **PVC = Poly-Vinyl-Chloride**
- **PVC is usually used in underground ductbanks**
- **PVC Schedule 40 is thinner wall than Schedule 80**
- **Concrete encasement around PVC Schedule 40 provide the mechanical protection, particularly when trenching or digging is being performed later**

Simple Circuit Design for 480 V, 100 Hp Pump

- **For the 100 Hp, 460 V, 3-phase motor,**
- **Total cable area = 462.0 mm^2**
- **For RMC, a conduit diameter of 41 mm has an area of 1333 mm^2**
- **Fill Factor = Total Cable Area/Conduit Area**
- **Fill Factor = 462 mm^2/1333 mm^2 = 34.7%**
- **FF < 40%, and is compliant with the NEC**
- **A larger conduit could be used: 53 mm = 2198 mm^2**
- **Fill Factor = 462 mm^2/2198 mm^2 = 21.0% >>> OK**

Simple Circuit Design for 480 V, 100 Hp Pump

- **For PVC, a conduit diameter of 41 mm has an area of 1282 mm^2**
- **Note the area of 1282 mm^2 for PVC is slightly less than the area of 1333 mm^2 for RMC**
- **Fill Factor = 462 mm^2/1282 mm^2 = 36.0%**
- **FF < 40%, and is compliant with the NEC**
- **A larger conduit could be used: 53 mm = 2124 mm^2**
- **Fill Factor = 462 mm^2/2124 mm^2 = 21.7% >>> Still OK**

Voltage Drop Considerations

- **For short circuit lengths, voltage drop considerations will not apply**
- **But for longer lengths, the increased resistance in cables will affect voltage drop**
- **If so, the conductors should be increased in size to minimize voltage drop**
- **Consider previous example with the 100 Hp, 460 V, 3-phase motor circuit**
- **Consider two circuit lengths: 25 meters, or 500 meters for illustration**

Voltage Drop Considerations

- Very basic formula for Vdrop = (1.732 or 2) x I x L x Z/L
- There are more exact formulas to use, but the goal is to calculate the approximate Vdrop to then determine if or how to compensate
- For 3-phase circuits: use 1.732, Sq Rt (3)
- For 1-phase circuits: use 2, for round trip length
- Where, I = load current (124 A for 100 Hp pump)
- Where, L = circuit length (25 m or 500 m)
- Where Z/L = impedance per unit length

Voltage Drop Considerations

- **For Z/L data, use NEC Chapter 9, Table 9 = Alternating-Current Resistance and Reactance for 600-Volt Cables, 3-Phase, 60 Hz, 75°C (167°F) – Three Single Conductors in Conduit**
- **For most applications, assume a power factor of 0.85**
- **Then, the column heading of “Effective Z at 0.85 PF for Uncoated Copper Wires” can be easily used**
- **Sub-columns include options for PVC conduit, Aluminum conduit, and Steel conduit**

NEC Chapter 9, Table 9, Z for Conductors

Table 9 Alternating-Current Resistance and Reactance for 600-Volt Cables, 3-Phase, 60 Hz, 75°C (167°F) — Three Single Conductors in Conduit

	Ohms to Neutral per Kilometer Ohms to Neutral per 1000 Feet															
	X_L (Reactance) for All Wires		Alternating-Current Resistance for Uncoated Copper Wires			Alternating-Current Resistance for Aluminum Wires			Effective Z at 0.85 *PF* for Uncoated Copper Wires			Effective Z at 0.85 *PF* for Aluminum Wires			
Size (AWG or kcmil)	PVC, Aluminum Conduits	Steel Conduit	PVC Conduit	Aluminum Conduit	Steel Conduit	PVC Conduit	Aluminum Conduit	Steel Conduit	PVC Conduit	Aluminum Conduit	Steel Conduit	PVC Conduit	Aluminum Conduit	Steel Conduit	Size (AWG or kcmil)
14	0.190 0.058	0.240 0.073	10.2 3.1	10.2 3.1	10.2 3.1	— —	— —	— —	8.9 2.7	8.9 2.7	8.9 2.7	— —	— —	— —	14
12	0.177 0.054	0.223 0.068	6.6 2.0	6.6 2.0	6.6 2.0	10.5 3.2	10.5 3.2	10.5 3.2	5.6 1.7	5.6 1.7	5.6 1.7	9.2 2.8	9.2 2.8	9.2 2.8	12
10	0.164 0.050	0.207 0.063	3.9 1.2	3.9 1.2	3.9 1.2	6.6 2.0	6.6 2.0	6.6 2.0	3.6 1.1	3.6 1.1	3.6 1.1	5.9 1.8	5.9 1.8	5.9 1.8	10
8	0.171 0.052	0.213 0.065	2.56 0.78	2.56 0.78	2.56 0.78	4.3 1.3	4.3 1.3	4.3 1.3	2.26 0.69	2.26 0.69	2.30 0.70	3.6 1.1	3.6 1.1	3.6 1.1	8
6	0.167 0.051	0.210 0.064	1.61 0.49	1.61 0.49	1.61 0.49	2.66 0.81	2.66 0.81	2.66 0.81	1.44 0.44	1.48 0.45	1.48 0.45	2.33 0.71	2.36 0.72	2.36 0.72	6
4	0.157 0.048	0.197 0.060	1.02 0.31	1.02 0.31	1.02 0.31	1.67 0.51	1.67 0.51	1.67 0.51	0.95 0.29	0.95 0.29	0.98 0.30	1.51 0.46	1.51 0.46	1.51 0.46	4
3	0.154 0.047	0.194 0.059	0.82 0.25	0.82 0.25	0.82 0.25	1.31 0.40	1.35 0.41	1.31 0.40	0.75 0.23	0.79 0.24	0.79 0.24	1.21 0.37	1.21 0.37	1.21 0.37	3
2	0.148 0.045	0.187 0.057	0.62 0.19	0.66 0.20	0.66 0.20	1.05 0.32	1.05 0.32	1.05 0.32	0.62 0.19	0.62 0.19	0.66 0.20	0.98 0.30	0.98 0.30	0.98 0.30	2
1	0.151 0.046	0.187 0.057	0.49 0.15	0.52 0.16	0.52 0.16	0.82 0.25	0.85 0.26	0.82 0.25	0.52 0.16	0.52 0.16	0.52 0.16	0.79 0.24	0.79 0.24	0.82 0.25	1
1/0	0.144 0.044	0.180 0.055	0.39 0.12	0.43 0.13	0.39 0.12	0.66 0.20	0.69 0.21	0.66 0.20	0.43 0.13	0.43 0.13	0.43 0.13	0.62 0.19	0.66 0.20	0.66 0.20	1/0
2/0	0.141 0.043	0.177 0.054	0.33 0.10	0.33 0.10	0.33 0.10	0.52 0.16	0.52 0.16	0.52 0.16	0.36 0.11	0.36 0.11	0.36 0.11	0.52 0.16	0.52 0.16	0.52 0.16	2/0
3/0	0.138 0.042	0.171 0.052	0.253 0.077	0.269 0.082	0.259 0.079	0.43 0.13	0.43 0.13	0.43 0.13	0.289 0.088	0.302 0.092	0.308 0.094	0.43 0.13	0.43 0.13	0.46 0.14	3/0
4/0	0.135 0.041	0.167 0.051	0.203 0.062	0.220 0.067	0.207 0.063	0.33 0.10	0.36 0.11	0.33 0.10	0.243 0.074	0.256 0.078	0.262 0.080	0.36 0.11	0.36 0.11	0.36 0.11	4/0
250	0.135 0.041	0.171 0.052	0.171 0.052	0.187 0.057	0.177 0.054	0.279 0.085	0.295 0.090	0.282 0.086	0.217 0.066	0.230 0.070	0.240 0.073	0.308 0.094	0.322 0.098	0.33 0.10	250
300	0.135 0.041	0.167 0.051	0.144 0.044	0.161 0.049	0.148 0.045	0.233 0.071	0.249 0.076	0.236 0.072	0.194 0.059	0.207 0.063	0.213 0.065	0.269 0.082	0.282 0.086	0.289 0.088	300
350	0.131 0.040	0.164 0.050	0.125 0.038	0.141 0.043	0.128 0.039	0.200 0.061	0.217 0.066	0.207 0.063	0.174 0.053	0.190 0.058	0.197 0.060	0.240 0.073	0.253 0.077	0.262 0.080	350
400	0.131 0.040	0.161 0.049	0.108 0.033	0.125 0.038	0.115 0.035	0.177 0.054	0.194 0.059	0.180 0.055	0.161 0.049	0.174 0.053	0.184 0.056	0.217 0.066	0.233 0.071	0.240 0.073	400

Voltage Drop Considerations

	X_L (Reactance) for All Wires		Alternating-Current Resistance for Uncoated Copper Wires			Alternating-Current Resistance for Aluminum Wires			Effective Z at 0.85 *PF* for Uncoated Copper Wires			Effective Z at 0.85 *PF* for Aluminum Wires			
Size (AWG or kcmil)	PVC, Aluminum Conduits	Steel Conduit	PVC Conduit	Aluminum Conduit	Steel Conduit	PVC Conduit	Aluminum Conduit	Steel Conduit	PVC Conduit	Aluminum Conduit	Steel Conduit	PVC Conduit	Aluminum Conduit	Steel Conduit	Size (AWG or kcmil)
14	0.190 0.058	0.240 0.073	10.2 3.1	10.2 3.1	10.2 3.1	— —	— —	— —	8.9 2.7	8.9 2.7	8.9 2.7	— —	— —	— —	14
12	0.177 0.054	0.223 0.068	6.6 2.0	6.6 2.0	6.6 2.0	10.5 3.2	10.5 3.2	10.5 3.2	5.6 1.7	5.6 1.7	5.6 1.7	9.2 2.8	9.2 2.8	9.2 2.8	12
10	0.164 0.050	0.207 0.063	3.9 1.2	3.9 1.2	3.9 1.2	6.6 2.0	6.6 2.0	6.6 2.0	3.6 1.1	3.6 1.1	3.6 1.1	5.9 1.8	5.9 1.8	5.9 1.8	10
8	0.171 0.052	0.213 0.065	2.56 0.78	2.56 0.78	2.56 0.78	4.3 1.3	4.3 1.3	4.3 1.3	2.26 0.69	2.26 0.69	2.30 0.70	3.6 1.1	3.6 1.1	3.6 1.1	8
6	0.167 0.051	0.210 0.064	1.61 0.49	1.61 0.49	1.61 0.49	2.66 0.81	2.66 0.81	2.66 0.81	1.44 0.44	1.48 0.45	1.48 0.45	2.33 0.71	2.36 0.72	2.36 0.72	6
4	0.157 0.048	0.197 0.060	1.02 0.31	1.02 0.31	1.02 0.31	1.67 0.51	1.67 0.51	1.67 0.51	0.95 0.29	0.95 0.29	0.98 0.30	1.51 0.46	1.51 0.46	1.51 0.46	4
3	0.154 0.047	0.194 0.059	0.82 0.25	0.82 0.25	0.82 0.25	1.31 0.40	1.35 0.41	1.31 0.40	0.75 0.23	0.79 0.24	0.79 0.24	1.21 0.37	1.21 0.37	1.21 0.37	3
2	0.148 0.045	0.187 0.057	0.62 0.19	0.66 0.20	0.66 0.20	1.05 0.32	1.05 0.32	1.05 0.32	0.62 0.19	0.62 0.19	0.66 0.20	0.98 0.30	0.98 0.30	0.98 0.30	2
1	0.151 0.046	0.187 0.057	0.49 0.15	0.52 0.16	0.52 0.16	0.82 0.25	0.85 0.26	0.82 0.25	0.52 0.16	0.52 0.16	0.52 0.16	0.79 0.24	0.79 0.24	0.82 0.25	1
1/0	0.144 0.044	0.180 0.055	0.39 0.12	0.43 0.13	0.39 0.12	0.66 0.20	0.69 0.21	0.66 0.20	0.43 0.13	0.43 0.13	0.43 0.13	0.62 0.19	0.66 0.20	0.66 0.20	1/0
2/0	0.141 0.043	0.177 0.054	0.33 0.10	0.33 0.10	0.33 0.10	0.52 0.16	0.52 0.16	0.52 0.16	0.36 0.11	0.36 0.11	0.36 0.11	0.52 0.16	0.52 0.16	0.52 0.16	2/0

Voltage Drop Considerations

- For steel conduit, Z/L = 0.36 ohms/kilometer
- For PVC conduit, Z/L = 0.36 ohms/kilometer
- Happens to be same Z/L
- Other table entries are different between steel and PVC for exact same size of conductor
- The difference is due primarily to inductance from interaction with the steel conduit

Voltage Drop Considerations

- For 100 Hp, 460 V, 3-phase motor, with $\boxed{L = 25\ m:}$
- Vdrop = 1.732 x I x L x Z/L
- Vdrop = 1.732 x 124 A x .025 km x 0.36 ohms/km

  = 1.94 V
- Vdrop (%) = Vdrop/System Voltage
- Vdrop (%) = 1.94 V/480 V = 0.4%
- What is criteria for excessive Vdrop?

Voltage Drop Considerations

- The NEC does not dictate Vdrop limitations
- A lower than normal voltage at device is not a safety consideration; only operational functionality of device
- However, NEC has a Fine Print Note (FPN) that recommends a maximum Vdrop of 5%
- An FPN is optional, and not binding per the NEC
- Thus, Vdrop of 0.4% is acceptable
- NEC 210.19(A)(1) = Conductors-Minimum Ampacity and Size, General, FPN No. 4

NEC 210.19(A)(1), FPN No. 4, Voltage Drop, 3%

FPN No. 1: See 310.15 for ampacity ratings of conductors.

FPN No. 2: See Part II of Article 430 for minimum rating of motor branch-circuit conductors.

FPN No. 3: See 310.10 for temperature limitation of conductors.

FPN No. 4: Conductors for branch circuits as defined in Article 100, sized to prevent a voltage drop exceeding 3 percent at the farthest outlet of power, heating, and lighting loads, or combinations of such loads, and where the maximum total voltage drop on both feeders and branch circuits to the farthest outlet does not exceed 5 percent, provide reasonable efficiency of operation. See FPN No. 2 of 215.2(A)(3) for voltage drop on feeder conductors.

Voltage Drop Considerations

- **For 100 Hp, 460 V, 3-phase motor, with L = $\boxed{\text{500 m:}}$**
- **Vdrop = 1.732 x I x L x Z/L**
- **Vdrop = 1.732 x 124 A x .5 km x 0.36 ohms/km**

  = 38.66 V
- **Vdrop (%) = Vdrop/System Voltage**
- **Vdrop (%) = 38.66 V/480 V = 8.1%**
- **This Vdrop far exceeds the 5% limit**
- **How do we compensate for excessive Vdrop?**

Voltage Drop Considerations

- **To compensate for excessive Vdrop, most common method is to increase size of conductors**
- **Must increase size of previous 2/0 AWG (67.43 mm^2) conductors, or lower impedance of conductors**
- **Per NEC Chapter 9, Table 9, for 300 kcmil (152 mm^2):**
- **For steel conduit, Z/L = 0.213 ohms/kilometer**
- **For PVC conduit, Z/L = 0.194 ohms/kilometer**
- **Recalculate Vdrop with 300 kcmil (152 mm^2) conductors**

Voltage Drop Considerations

- For 100 Hp, 460 V, 3-phase motor, with L = $\boxed{\text{500 m,}}$ and with steel conduit:
- Vdrop = 1.732 x 124 A x .5 km x 0.213 ohms/km

  = 22.87 V
- Vdrop (%) = Vdrop/System Voltage
- Vdrop (%) = 22.87 V/480 V = 4.7%
- This Vdrop is now below the 5% limit

Voltage Drop Considerations

- **For 100 Hp, 460 V, 3-phase motor, with L = $\boxed{\text{500 m,}}$ and with PVC conduit:**
- **Vdrop = 1.732 x 124 A x .5 km x 0.194 ohms/km**

  = 20.83. V
- **Vdrop (%) = Vdrop/System Voltage**
- **Vdrop (%) = 20.83 V/480 V = 4.3%**
- **This Vdrop is also below the 5% limit**

Voltage Drop Considerations

- **With increased conductors from 2/0 AWG (67.43 mm^2) to 300 kcmil (152 mm^2), the conduit may now be too small, resulting in a FF exceeding 40%**
- **Per NEC Chapter 9, Table 5:**
- **Area of 300 kcmil (152 mm^2) cable = 292.6 mm^2**
- **What about the previous grounding conductor of 6 AWG (13.30 mm^2) cable?**

Voltage Drop Considerations

- **NEC requires that when increasing size of conductors to compensate for voltage drop, the grounding conductor must be increased in size by the same proportion**
- **NEC 250.122(B) = Size of Equipment Grounding Conductors, Increased in Size**

NEC 250.122(B), Increase Ground for Vdrop

250.122 Size of Equipment Grounding Conductors.

(A) General. Copper, aluminum, or copper-clad aluminum equipment grounding conductors of the wire type shall not be smaller than shown in Table 250.122, but in no case shall they be required to be larger than the circuit conductors supplying the equipment. Where a cable tray, a raceway, or a cable armor or sheath is used as the equipment grounding conductor, as provided in 250.118 and 250.134(A), it shall comply with 250.4(A)(5) or (B)(4).

(B) Increased in Size. Where ungrounded conductors are increased in size, equipment grounding conductors, where installed, shall be increased in size proportionately according to the circular mil area of the ungrounded conductors.

(C) Multiple Circuits. Where a single equipment grounding conductor is run with multiple circuits in the same raceway, cable, or cable tray, it shall be sized for the largest overcurrent device protecting conductors in the raceway, cable, or cable tray. Equipment grounding conductors installed in cable trays shall meet the minimum requirements of 392.3(B)(1)(c).

Voltage Drop Considerations

- **Must calculate % increase in cross-sectional area of phase conductors**
- **Then use that same % increase for the grounding conductor**
- **Increase from 2/0 AWG (67.43 mm^2) to 300 kcmil (152 mm^2) = 152 mm^2/ 67.43 mm^2 = 225%**
- **Increase of grounding conductor of 6 AWG (13.30 mm^2) by 225% = 13.30 mm^2 x 225% = 30.0 mm^2**
- **Use NEC Chapter 9, Table 8, to select a conductor close to 30.0 mm^2**

NEC Chapter 9, Table 8, Conductor Properties

Size (AWG or kcmil)	Area mm^2	Area Circular mils
18	0.823	1620
18	0.823	1620
16	1.31	2580
16	1.31	2580
14	2.08	4110
14	2.08	4110
12	3.31	6530
12	3.31	6530
10	5.261	10380
10	5.261	10380
8	8.367	16510
8	8.367	16510
6	13.30	26240
4	21.15	41740
3	26.67	52620
2	33.62	66360
1	42.41	83690

Size (AWG or kcmil)	Area mm^2	Area Circular mils
1/0	53.49	105600
2/0	67.43	133100
3/0	85.01	167800
4/0	107.2	211600
250	127	—
300	152	—
350	177	—
400	203	—
500	253	—
600	304	—
700	355	—
750	380	—
800	405	—
900	456	—
1000	507	—
1250	633	—
1500	760	—
1750	887	—
2000	1013	—

Voltage Drop Considerations

- NEC Chapter 9, Table 8 shows that 2 AWG (33.62 mm^2) is close to and exceeds the calculated value of 30.0 mm^2
- In some cases, the increase in phase conductor may result in a very large %, especially when starting with small conductors
- May be possible that applying that % increase results in a grounding conductor larger than the phase conductors
- That doesn’t sound very reasonable

NEC 250.122(A), Limit Increase Ground for Vdrop

250.122 Size of Equipment Grounding Conductors.

(A) General. Copper, aluminum, or copper-clad aluminum equipment grounding conductors of the wire type shall not be smaller than shown in Table 250.122, but in no case shall they be required to be larger than the circuit conductors supplying the equipment. Where a cable tray, a raceway, or a cable armor or sheath is used as the equipment grounding conductor, as provided in 250.118 and 250.134(A), it shall comply with 250.4(A)(5) or (B)(4).

(B) Increased in Size. Where ungrounded conductors are increased in size, equipment grounding conductors, where installed, shall be increased in size proportionately according to the circular mil area of the ungrounded conductors.

(C) Multiple Circuits. Where a single equipment grounding conductor is run with multiple circuits in the same raceway, cable, or cable tray, it shall be sized for the largest overcurrent device protecting conductors in the raceway, cable, or cable tray. Equipment grounding conductors installed in cable trays shall meet the minimum requirements of 392.3(B)(1)(c).

Voltage Drop Considerations

- **Thus, final circuit adjusted for voltage drop =**
- **3-300 kcmil (152 mm^2), 1-2 AWG (33.62 mm^2) GND**
- **Now, very unlikely the previous conduit size of 41 mm in diameter, or even the next size of 53 mm will be adequate to keep FF less than 40%**
- **Need to re-calculate the total cable area**

Voltage Drop Considerations

Type	Size (AWG or kcmil)	Approximate Diameter mm	Approximate Diameter in.	Approximate Area mm^2	Approximate Area $in.^2$
Type: KF-1, KF-2, KFF-1, KFF-2, XHH, XHHW, XHHW-2, ZW					
XHHW, ZW, XHHW-2, XHH	14	3.378	0.133	8.968	0.0139
	12	3.861	0.152	11.68	0.0181
	10	4.470	0.176	15.68	0.0243
	8	5.994	0.236	28.19	0.0437
	6	6.960	0.274	38.06	0.0590
	4	8.179	0.322	52.52	0.0814
	3	8.890	0.350	62.06	0.0962
	2	9.703	0.382	73.94	0.1146
XHHW, XHHW-2, XHH	1	11.23	0.442	98.97	0.1534
	1/0	12.24	0.482	117.7	0.1825
	2/0	13.41	0.528	141.3	0.2190
	3/0	14.73	0.58	170.5	0.2642
	4/0	16.21	0.638	206.3	0.3197
	250	17.91	0.705	251.9	0.3904
	300	19.30	0.76	292.6	0.4536
	350	20.60	0.811	333.3	0.5166
	400	21.79	0.858	373.0	0.5782
	500	23.95	0.943	450.6	0.6984

Voltage Drop Considerations

- **Per NEC Chapter 9, Table 5:**
- **Area of 300 kcmil (152 mm^2) cable = 292.6 mm^2**
- **Area of 2 AWG (33.62 mm^2) cable = 73.94 mm^2**
- **Total cross-sectional area of all cables = 3 x 292.6 mm^2 + 1 x 73.94 mm^2 = 951.7 mm^2**
- **Need to re-calculate minimum conduit diameter**

NEC Chapter 9, Table 4, RMC Conduit Dimensions

Article 344 — Rigid Metal Conduit (RMC)

Metric Designator	Trade Size	Nominal Internal Diameter mm	Nominal Internal Diameter in.	Total Area 100% mm^2	Total Area 100% $in.^2$	60% mm^2	60% $in.^2$	1 Wire 53% mm^2	1 Wire 53% $in.^2$
12	⅜	—	—	—	—	—	—	—	—
16	½	16.1	0.632	204	0.314	122	0.188	108	0.166
21	¾	21.2	0.836	353	0.549	212	0.329	187	0.291
27	1	27.0	1.063	573	0.887	344	0.532	303	0.470
35	1¼	35.4	1.394	984	1.526	591	0.916	522	0.809
41	1½	41.2	1.624	1333	2.071	800	1.243	707	1.098
53	2	52.9	2.083	2198	3.408	1319	2.045	1165	1.806
63	2½	63.2	2.489	3137	4.866	1882	2.919	1663	2.579
78	3	78.5	3.090	4840	7.499	2904	4.499	2565	3.974
91	3½	90.7	3.570	6461	10.010	3877	6.006	3424	5.305
103	4	102.9	4.050	8316	12.882	4990	7.729	4408	6.828
129	5	128.9	5.073	13050	20.212	7830	12.127	6916	10.713
155	6	154.8	6.093	18821	29.158	11292	17.495	9975	15.454

Voltage Drop Considerations

- **Per NEC Chapter 9, Table 4:**
- **For RMC, a conduit diameter of 53 mm has an area of 2198 mm^2**
- **Fill Factor = 951.7 mm^2/2198 mm^2 = 43.3%**
- **FF > 40%, and is in violation of the NEC**
- **For RMC, a conduit diameter of 63 mm has an area of 3137 mm^2**
- **Fill Factor = 951.7 mm^2/3137 mm^2 = 30.3% >> OK**

NEC Chapter 9, Table 4, PVC Conduit Dimensions

Articles 352 and 353 — Rigid PVC Conduit (PVC), Schedule 40,

Metric Designator	Trade Size	Nominal Internal Diameter		Total Area 100%		60%		1 Wire 53%	
		mm	in.	mm²	in.²	mm²	in.²	mm²	in.²
12	⅜	—	—	—	—	—	—	—	—
16	½	15.3	0.602	184	0.285	110	0.171	97	0.151
21	¾	20.4	0.804	327	0.508	196	0.305	173	0.269
27	1	26.1	1.029	535	0.832	321	0.499	284	0.441
35	1¼	34.5	1.360	935	1.453	561	0.872	495	0.770
41	1½	40.4	1.590	1282	1.986	769	1.191	679	1.052
53	2	52.0	2.047	2124	3.291	1274	1.975	1126	1.744
63	2½	62.1	2.445	3029	4.695	1817	2.817	1605	2.488
78	3	77.3	3.042	4693	7.268	2816	4.361	2487	3.852
91	3½	89.4	3.521	6277	9.737	3766	5.842	3327	5.161
103	4	101.5	3.998	8091	12.554	4855	7.532	4288	6.654
129	5	127.4	5.016	12748	19.761	7649	11.856	6756	10.473
155	6	153.2	6.031	18433	28.567	11060	17.140	9770	15.141

Voltage Drop Considerations

- **Per NEC Chapter 9, Table 4:**
- **For PVC, a conduit diameter of 53 mm has an area of 2124 mm^2**
- **Fill Factor = 951.7 mm^2/2124 mm^2 = 44.8%**
- **FF > 40%, and is in violation of the NEC**
- **For PVC, a conduit diameter of 63 mm has an area of 3029 mm^2**
- **Fill Factor = 951.7 mm^2/3029 mm^2 = 31.4% >> OK**

Voltage Ratings of Motor/Starter & Utility Supply

- **Recall,**
- **Utility supply = 480 V, nominal**
- **Motors and motor starters rating = 460 V**

- **Why 20 V difference?**

Voltage Ratings of Motor/Starter & Utility Supply

- **To give the motor a chance to start under less than nominal conditions**
- **Utility can't guarantee 480 V at all times**
- **Heavily load utility circuits reduce utility voltage**
- **Sometimes have capacitor banks to boost voltage or auto tap changing transformers or voltage regulators**
- **Unless utility has a history of poor voltage delivery profiles, assume 480 V, or 1.0 per unit (pu)**

Voltage Ratings of Motor/Starter & Utility Supply

- **Assuming utility is 480 V, you have built-in 20 V margin, or 460 V/480 V = 4.3% of voltage margin**

- **Generally, motors require 90% voltage minimum to start**
- **With respect to motor: 460 V x 0.90 = 414 V is minimum voltage at motor terminals to start**
- **With respect to utility supply: 480 V – 414 V = 66 V, or 414 V/480 V = 15.9% of voltage margin**

Voltage Ratings of Motor/Starter & Utility Supply

- **Prefer to avoid getting near 414 V, otherwise risk motor not starting**
- **Account for lower utility voltage by design consideration beyond 20 V margin**
- **Hence, the 5% voltage drop limit is important**
- **Can't control utility supply voltage, but can control design considerations**

Let's Add a Second 100 Hp Pump

- **Identical 100 Hp, 460 V, 3-phase motor**
- **Same cables and conduit, increased in size for Vdrop**
- **3-300 kcmil (152 mm^2), 1-2 AWG (33.62 mm^2) GND**
- **But run in parallel to first circuit**
- **Why not combine all 7 cables into one larger conduit?**
- **Note the grounding conductor can be shared**
- **Possible, but there are consequences**

Let’s Add a Second 100 Hp Pump

- **The major consequence is coincident heating effects on each individual circuit**
- **Recall, heating effects of current through a conductor generates heat in the form of losses = I^2xR**
- **The NEC dictates ampacity derating for multiple circuits in one conduit**
- **NEC Table 310.15(B)(2)(a) = Adjustment Factors for More Than Three Current-Carrying Conductors in a Raceway or Cable**

Let's Add a Second 100 Hp Pump

Table 310.15(B)(2)(a) Adjustment Factors for More Than Three Current-Carrying Conductors in a Raceway or Cable

Number of Current-Carrying Conductors	Percent of Values in Tables 310.16 through 310.19 as Adjusted for Ambient Temperature if Necessary
4–6	80
7–9	70
10–20	50
21–30	45
31–40	40
41 and above	35

Let's Add a Second 100 Hp Pump

- **Thus, for 6 cables in one conduit, the derating of 4-6 cables requires an ampacity derating of 80%**
- **The previous ampacity of 285 A for 300 kcmil (152 mm^2) must be derated as follows:**
- **4-6 cable derating = 285 A x 0.80 = 228 A**
- **Previous load current has not changed:**
  124 A x 125% = 155 A
- **Derated ampacity of 228 A is greater than 155 A**
- **If there are 7 cables in the conduit, why don't we use the 2nd line for 7-9 cables with a derating of 70%?**

Let's Add a Second 100 Hp Pump

- **Because the 7th cable is a grounding conductor, and is therefore not a "current-carrying conductor"**
- **New dual circuit = 3-300 kcmil (152 mm^2), 1-2 AWG (33.62 mm^2) GND**
- **Previous conduit size of 63 mm is now probably too small and will result in a FF < 40% per NEC**

Let's Add a Second 100 Hp Pump

- **Per NEC Chapter 9, Table 5:**
- **Area of 300 kcmil (152 mm^2) cable = 292.6 mm^2**
- **Area of 2 AWG (33.62 mm^2) cable = 73.94 mm^2**
- **Total cross-sectional area of all cables =**
  6 x 292.6 mm^2 + 1 x 73.94 mm^2 = 1829.5 mm^2
- **Need to re-calculate minimum conduit diameter**

NEC Chapter 9, Table 4, RMC Conduit Dimensions

Article 344 — Rigid Metal Conduit (RMC)

Metric Designator	Trade Size	Nominal Internal Diameter		Total Area 100%		60%		1 Wire 53%	
		mm	in.	mm^2	$in.^2$	mm^2	$in.^2$	mm^2	$in.^2$
12	⅜	—	—	—	—	—	—	—	—
16	½	16.1	0.632	204	0.314	122	0.188	108	0.166
21	¾	21.2	0.836	353	0.549	212	0.329	187	0.291
27	1	27.0	1.063	573	0.887	344	0.532	303	0.470
35	1¼	35.4	1.394	984	1.526	591	0.916	522	0.809
41	1½	41.2	1.624	1333	2.071	800	1.243	707	1.098
53	2	52.9	2.083	2198	3.408	1319	2.045	1165	1.806
63	2½	63.2	2.489	3137	4.866	1882	2.919	1663	2.579
78	3	78.5	3.090	4840	7.499	2904	4.499	2565	3.974
91	3½	90.7	3.570	6461	10.010	3877	6.006	3424	5.305
103	4	102.9	4.050	8316	12.882	4990	7.729	4408	6.828
129	5	128.9	5.073	13050	20.212	7830	12.127	6916	10.713
155	6	154.8	6.093	18821	29.158	11292	17.495	9975	15.454

Let’s Add a Second 100 Hp Pump

- **Per NEC Chapter 9, Table 4:**
- **For RMC, the previous conduit diameter of 63 mm has an area of 3137 mm^2**
- **Fill Factor = 1829.5 mm^2/3137 mm^2 = 58.3%**
- **FF > 40%, and is in violation of the NEC**
- **For RMC, a conduit diameter of 78 mm has an area of 4840 mm^2**
- **Fill Factor = 1829.5 mm^2/4840 mm^2 = 37.8% >> OK**

NEC Chapter 9, Table 4, PVC Conduit Dimensions

Articles 352 and 353 — Rigid PVC Conduit (PVC), Schedule 40,

Metric Designator	Trade Size	Nominal Internal Diameter		Total Area 100%		60%		1 Wire 53%	
		mm	in.	mm^2	$in.^2$	mm^2	$in.^2$	mm^2	$in.^2$
12	3/8	—	—	—	—	—	—	—	—
16	½	15.3	0.602	184	0.285	110	0.171	97	0.151
21	¾	20.4	0.804	327	0.508	196	0.305	173	0.269
27	1	26.1	1.029	535	0.832	321	0.499	284	0.441
35	1¼	34.5	1.360	935	1.453	561	0.872	495	0.770
41	1½	40.4	1.590	1282	1.986	769	1.191	679	1.052
53	2	52.0	2.047	2124	3.291	1274	1.975	1126	1.744
63	2½	62.1	2.445	3029	4.695	1817	2.817	1605	2.488
78	3	77.3	3.042	4693	7.268	2816	4.361	2487	3.852
91	3½	89.4	3.521	6277	9.737	3766	5.842	3327	5.161
103	4	101.5	3.998	8091	12.554	4855	7.532	4288	6.654
129	5	127.4	5.016	12748	19.761	7649	11.856	6756	10.473
155	6	153.2	6.031	18433	28.567	11060	17.140	9770	15.141

Let's Add a Second 100 Hp Pump

- **Per NEC Chapter 9, Table 4:**
- **For PVC, the previous conduit diameter of 63 mm has an area of 3029 mm^2**
- **Fill Factor = 1829.5 mm^2/3029 mm^2 = 60.4%**
- **FF > 40%, and is in violation of the NEC**
- **For PVC, a conduit diameter of 78 mm has an area of 4693 mm^2**
- **Fill Factor = 1829.5 mm^2/4693 mm^2 = 39.0% >> OK**

Cable Temperature Considerations

- **Why?**
- **As temperature of copper increases, the resistance increases**
- **Common when conduit is located in boiler room or on roof in direct sunlight**
- **Voltage at load = Voltage at source – Voltage drop in circuit between**
- **Recall, E = I x R, where I is constant for load**
- **R increases with temperature, thereby increasing Vdrop**

Cable Temperature Considerations

- **Higher ambient temperature may dictate larger conductor**
- **NEC Table 310.16 governs derating of conductor ampacity due to elevated temperature**
- **NEC Table 310.16 = Allowable Ampacities of Insulated Conductors Rated 0 Through 2000 Volts, 60°C (140°F Through 194°F), Not More Than Three Current-Carrying Conductors in Raceway, Cable, or Earth (Directly Buried), Based on Ambient Temperature of 30°C (86°F)**
- **This is bottom half of previous ampacity table**

NEC Table 310.16, Conductor Temp Derating

Size AWG or kcmil	Types TW, UF	Types RHW, THHW, THW, THWN, XHHW, USE, ZW	RHW-2, THHN, THHW, THW-2, THWN-2, USE-2, XHH, XHHW, XHHW-2, ZW-2
Ambient Temp. (°C)	For ambient temperatures other than 30°C (86°F), multiply the factor shown b		
21–25	1.08	1.05	1.04
Nominal 26–30	1.00	1.00	1.00
31–35	0.91	0.94	0.96
36–40	0.82	0.88	0.91
41–45	0.71	0.82	0.87
46–50	0.58	0.75	0.82
51–55	0.41	0.67	0.76
56–60	—	0.58	0.71
61–70	—	0.33	0.58
71–80	—	—	0.41

Cable Temperature Considerations

- **For ambient temperature between 36°C and 40°C, previous ampacity must be derated to 0.88 of nominal ampacity**
- **The previous ampacity of 285 A for 300 kcmil (152 mm^2) must be derated as follows:**
- **Temperature derating @ 36-40°C = 285 A x 0.88 = 250.8 A**
- **Previous load current has not changed: 124 A x 125% = 155 A**
- **Derated ampacity of 250.8 A is greater than 155 A**

Cable Temperature Considerations

- **For ambient temperature between 46°C and 50°C, previous ampacity must be derated to 0.75 of nominal ampacity**
- **The previous ampacity of 285 A for 300 kcmil (152 mm^2) must be derated as follows:**
- **Temperature derating @ 46-50°C = 285 A x 0.75 = 213.8 A**
- **Previous load current has not changed:
124 A x 125% = 155 A**
- **Derated ampacity of 213.8 A is greater than 155 A**

Cable Temperature Considerations

- **The two derated ampacities of 250.8 A and 213.8 A, were both greater than the target ampacity of 155 A**
- **We already compensated for Vdrop with larger conductors**
- **If we had the first Vdrop example with 25 m circuit length, the conductors might have to be increased due to elevated temperature**

Cable Temperature Considerations

- **Recall, target ampacity = 155 A**
- **Recall, non-Vdrop conductor was 3-2/0 AWG (67.43 mm^2), 1-6 AWG (13.30 mm^2) GND**
- **Recall, ampacity of 2/0 AWG (67.43 mm^2) = 175 A**
- **For derating at <u>36°C to 40°C</u> = 175 A x 0.88 = 154 A**
- **Close enough to target ampacity of 155 A, OK**
- **But for second temperature range:**
- **For derating at <u>46°C to 50°C</u> = 175 A x 0.75 = 131 A**
- **Ampacity is too low; must go to next size larger**

What if Feeder is Part UG and Part AG?

- Underground ductbank has cooler temperatures
- Aboveground can vary but will be worst case
- What if conduit run is through both types?
- NEC allows selecting lower UG ampacity
- But very restrictive
- NEC 310.15(A)(2), Ampacities for Conductors Rated 0-2000 Volts, General, Selection of Ampacity, Exception
- NEC 10 ft or 10%, whichever is less

What if Feeder is Part UG and Part AG?

What if Feeder is Part UG and Part AG?

NEC 310.15(A)(2), Ampacity in Mixed Conduit

No. 4, for branch circuits and 215.2(A), FPN No. 2, for feeders.

FPN No. 2: For the allowable ampacities of Type MTW wire, see Table 13.5.1 in NFPA 79-2007, *Electrical Standard for Industrial Machinery.*

(2) Selection of Ampacity. Where more than one calculated or tabulated ampacity could apply for a given circuit length, the lowest value shall be used.

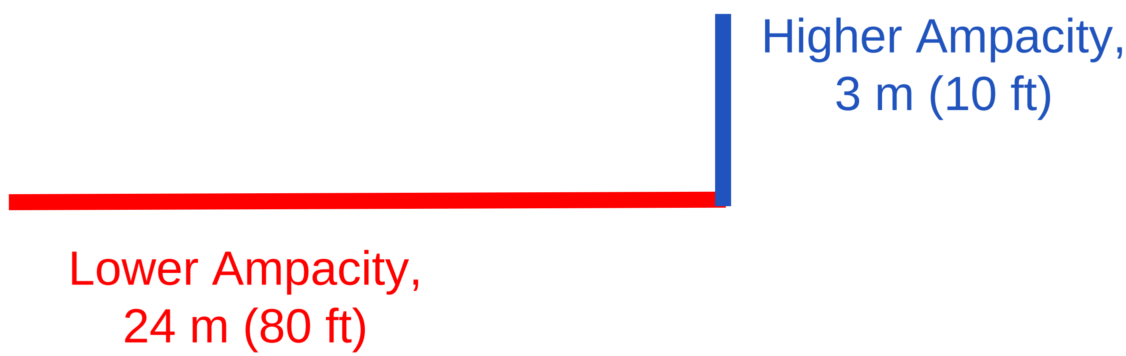
Exception: Where two different ampacities apply to adjacent portions of a circuit, the higher ampacity shall be permitted to be used beyond the point of transition, a distance equal to 3.0 m (10 ft) or 10 percent of the circuit length figured at the higher ampacity, whichever is less.

FPN: See 110.14(C) for conductor temperature limitations due to termination provisions.

(B) Tables. Ampacities for conductors rated 0 to 2000 volts shall be as specified in the Allowable Ampacity Table

What if Feeder is Part UG and Part AG?

- **NEC 310.15(A)(2), Exception, says to use lower ampacity when different ampacities apply**
- **However, can use higher ampacity if second length of conduit after transition is less than 3 meters (10 ft) or the length of the higher ampacity conduit is 10% of entire circuit, whichever is less**



Simple Circuit Design for a 120 V, 1-Phase Load

- **Duplex receptacles are generally convenience receptacles for most any 120 V, 1-phase load**
- **Single loads like a copy machine or refrigerator can be plugged into a receptacle**
- **Estimate refrigerator load demand = 1000 VA**
- **IFL = VA/V = 1000 VA/120 V = 8.33 A**
- **IFL x 125% = 8.33 A x 1.25 = 10.4 A**
- **Use NEC Table 310.16 to select conductor size greater than 10.4 A**

NEC Table 310.16, Conductor Ampacity

Size AWG or kcmil	Temperature Rating of Conductor		
	60°C (140°F)	75°C (167°F)	90°C (194°F)
	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
	COPPER		
18	—	—	14
16	—	—	18
14*	20	20	25
12*	25	25	30
10*	30	35	40
8	40	50	55
6	55	65	75
4	70	85	95
3	85	100	110
2	95	115	130
1	110	130	150

Simple Circuit Design for a 120 V, 1-Phase Load

- **Per NEC Table 310.16,**
- **14 AWG (2.08 mm^2) has an ampacity of 20 A**
- **12 AWG (3.31 mm^2) has an ampacity of 25 A**
- **Both would work**
- **But standard engineering practice is to use 12 AWG (3.31 mm^2) minimum for all power-related circuits**
- **Why?**
- **To neglect ambient temperature by being conservative for simplicity with built-in 25% margin**

Simple Circuit Design for a 120 V, 1-Phase Load

- **Select circuit breaker based on IFL x 125% = 10.4 A**
- **Breaker must always be equal to or greater than load current to protect the conductor**
- **At 120 V, smallest panelboard breaker is 15 A**
- **Next available larger size is 20 A**
- **For small molded case breakers, must derate maximum allowable amperes to 80% of breaker rating**
- **Breaker derating: 15 A x 0.80 = 12 A max allowable**
- **Breaker derating: 20 A x 0.80 = 16 A max allowable**

Simple Circuit Design for a 120 V, 1-Phase Load

- **Why?**
- **Biggest reason is that a continuous load tends to build up heat in the breaker, caused by I^2R**
- **The overload element in a small molded case breaker is a bimetallic strip of dissimilar metals that separate when the current flowing thru them exceeds its rating**
- **The elevated temperature over time can change the resistance of the metals and move closer to the actual trip point**
- **At 15 A or 20 A, the manufacturing tolerances on the trip point is not accurate**

Simple Circuit Design for a 120 V, 1-Phase Load

- **Need to be conservative and prevent nuisance tripping**
- **Select 20 A breaker**
- **Standard engineering practice is to use 20 A breakers regardless of the load demand**
- **That includes a load that requires only 1 A**
- **Why?**

Simple Circuit Design for a 120 V, 1-Phase Load

- **Overcurrent protection indeed may be 5 A extra in selecting a 20 A breaker**
- **This really only affects overload conditions when the demand current exceeds 15 A or 20 A**
- **Under short circuit conditions, say 2000 A of fault current, both breakers will virtually trip at the same time**
- **Refrigerator is very unlikely to draw say, 12 A, because its max demand is 8.33 A**

Simple Circuit Design for a 120 V, 1-Phase Load

- **If the compressor motor were to lock up and freeze, that would not really be a short circuit**
- **But the current flow to the compressor motor would be about 5.5 times the IFL (or the same when the motor starts on in-rush)**
- **Motor locked rotor current is then 5.5 x 8.33 A = 45.8 A**
- **This exceeds both 15 A or 20 A, with or without the 80% derating**

Simple Circuit Design for a 120 V, 1-Phase Load

- **If all breakers in a panelboard were 20 A, then it would be easy to swap out if breaker fails**
- **Or use a 20 A spare breaker instead of worrying about a 15 A breaker being too small in the future**
- **Cost differential is trivial between 15 A and 20 A breakers**

- **Use NEC Table 250.122 to select grounding conductor**

NEC Table 250.122, Grounding Conductors

Table 250.122 Minimum Size Equipment Grounding Conductors for Grounding Raceway and Equipment

Rating or Setting of Automatic Overcurrent Device in Circuit Ahead of Equipment, Conduit, etc., Not Exceeding (Amperes)	Size (AWG or kcmil)	
	Copper	Aluminum or Copper-Clad Aluminum*
15	14	12
20	12	10
30	10	8
40	10	8
60	10	8
100	8	6

Simple Circuit Design for a 120 V, 1-Phase Load

- **Grounding conductor is 12 AWG (3.31 mm^2) based on breaker rating of 20 A**
- **Circuit = 2-12 AWG (3.31 mm^2), 1-12 AWG (3.31 mm^2) GND**
- **Recall, for small lighting and receptacle circuits, use THHN/THWN, 90°C dry, 75°C wet**
- **This time we use NEC Chapter 9, Table 5, for Type THHN/THWN cable**

Simple Circuit Design for a 120 V, 1-Phase Load

Table 5 *Continued*

Type	Size (AWG or kcmil)	Approximate Diameter mm	Approximate Diameter in.	mm²
THHN, THWN, THWN-2	14	2.819	0.111	6.258
	12	3.302	0.130	8.581
	10	4.166	0.164	13.61
	8	5.486	0.216	23.61
	6	6.452	0.254	32.71
	4	8.230	0.324	53.16
	3	8.941	0.352	62.77
	2	9.754	0.384	74.71
	1	11.33	0.446	100.8
	1/0	12.34	0.486	119.7
	2/0	13.51	0.532	143.4
	3/0	14.83	0.584	172.8
	4/0	16.31	0.642	208.8
	250	18.06	0.711	256.1
	300	19.46	0.766	297.3

Simple Circuit Design for a 120 V, 1-Phase Load

- **Per NEC Table:**
- **Area of 12 AWG (3.31 mm^2) cable = 8.581 mm^2**
- **Total cross-sectional area of all cables =**
  2 x 8.581 mm^2 + 1 x 8.581 mm^2 = 25.7 mm^2
- **Use NEC Chapter 9, Table 4 to select conduit size**

NEC Chapter 9, Table 4, RMC Conduit Dimensions

Article 344 — Rigid Metal Conduit (RMC)

Metric Designator	Trade Size	Nominal Internal Diameter		Total Area 100%		60%		1 Wire 53%	
		mm	in.	mm^2	$in.^2$	mm^2	$in.^2$	mm^2	$in.^2$
12	⅜	—	—	—	—	—	—	—	—
16	½	16.1	0.632	204	0.314	122	0.188	108	0.166
21	¾	21.2	0.836	353	0.549	212	0.329	187	0.291
27	1	27.0	1.063	573	0.887	344	0.532	303	0.470
35	1¼	35.4	1.394	984	1.526	591	0.916	522	0.809
41	1½	41.2	1.624	1333	2.071	800	1.243	707	1.098
53	2	52.9	2.083	2198	3.408	1319	2.045	1165	1.806
63	2½	63.2	2.489	3137	4.866	1882	2.919	1663	2.579
78	3	78.5	3.090	4840	7.499	2904	4.499	2565	3.974
91	3½	90.7	3.570	6461	10.010	3877	6.006	3424	5.305
103	4	102.9	4.050	8316	12.882	4990	7.729	4408	6.828
129	5	128.9	5.073	13050	20.212	7830	12.127	6916	10.713
155	6	154.8	6.093	18821	29.158	11292	17.495	9975	15.454

Simple Circuit Design for a 120 V, 1-Phase Load

- Per NEC Chapter 9, Table 4:
- For RMC, a conduit diameter of 16 mm has an area of 204 mm^2
- Fill Factor = 25.7 mm^2/204 mm^2 = 12.6%
- FF < 40%, OK
- For RMC, a conduit diameter of 21 mm has an area of 353 mm^2
- Fill Factor = 25.7 mm^2/353 mm^2 = 7.3%, OK

NEC Chapter 9, Table 4, PVC Conduit Dimensions

Articles 352 and 353 — Rigid PVC Conduit (PVC), Schedule 40,

Metric Designator	Trade Size	Nominal Internal Diameter mm	Nominal Internal Diameter in.	Total Area 100% mm^2	Total Area 100% $in.^2$	60% mm^2	60% $in.^2$	1 Wire 53% mm^2	1 Wire 53% $in.^2$
12	⅜	—	—	—	—	—	—	—	—
16	½	15.3	0.602	184	0.285	110	0.171	97	0.151
21	¾	20.4	0.804	327	0.508	196	0.305	173	0.269
27	1	26.1	1.029	535	0.832	321	0.499	284	0.441
35	1¼	34.5	1.360	935	1.453	561	0.872	495	0.770
41	1½	40.4	1.590	1282	1.986	769	1.191	679	1.052
53	2	52.0	2.047	2124	3.291	1274	1.975	1126	1.744
63	2½	62.1	2.445	3029	4.695	1817	2.817	1605	2.488
78	3	77.3	3.042	4693	7.268	2816	4.361	2487	3.852
91	3½	89.4	3.521	6277	9.737	3766	5.842	3327	5.161
103	4	101.5	3.998	8091	12.554	4855	7.532	4288	6.654
129	5	127.4	5.016	12748	19.761	7649	11.856	6756	10.473
155	6	153.2	6.031	18433	28.567	11060	17.140	9770	15.141

Simple Circuit Design for a 120 V, 1-Phase Load

- **Per NEC Chapter 9, Table 4:**
- **For PVC, a conduit diameter of 16 mm has an area of 184 mm^2**
- **Fill Factor = 25.7 mm^2/184 mm^2 = 14.0%**
- **FF < 40%, OK**
- **For PVC, a conduit diameter of 21 mm has an area of 327 mm^2**
- **Fill Factor = 25.7 mm^2/327 mm^2 = 7.9%, OK**

Simple Circuit Design for a 120 V, 1-Phase Load

- Both conduit diameters of 16 mm and 21 mm, for both RMC and PVC would work
- Standard engineering practice is to use 21 mm conduits for all circuits

- Why?
- Allows future addition of cables
- Cost differential is trivial between 16 mm and 21 mm conduits

Simple Circuit Design for a 120 V, 1-Phase Load

- **Also prevents poor workmanship by installer when bending conduit**
- **Need a conduit bender that produces nice even angled sweep around 90 degrees**
- **Small diameter conduit can easily be bent too sharply and pinch the conduit, thereby reducing the available cross-sectional area of the conduit**

Panelboard Design

- **The 20 A breakers for the duplex receptacles would be contained in a panelboard**
- **There are 3-phase panelboards: 208Y/120 V fed from 3-phase transformers**
- **Where, 208 V is the phase-to-phase voltage, or 120 V x 1.732 = 208 V**

Panelboard Design

Panelboard Design

- There are 1-phase panelboards: 120/240 V fed from 1-phase transformers
- Where, 240 V is the phase-to-phase voltage with a center-tapped neutral
- Phase A to neutral is 120 V
- Phase B to neutral is 120 V
- Phase A to Phase B is 240 V
- Selection of panelboard depends on type of loads to be powered

Panelboard Design

- **If all loads are 120 V, then either panelboard would suffice**
- **If some loads are 240 V, 1-phase, like a small air conditioner, then you need the 120/240 V, 1-phase panelboard**
- **If some loads are 208 V, 3-phase, like a fan or pump, then you need the 208Y/120 V, 3-phase panelboard**
- **Given a choice on load voltage requirements, the 208Y/120 V, 3-phase panelboard allows more flexibility with a smaller continuous bus rating in amperes**

Panelboard Schedule Calculation

PHASE			PANELBOARD: EXIST POWER PANEL A	BUS: COPPER						MAINS: 3P-100 A MAIN BREAKER	PHASE		
"L1"	"L2"	"L3"	SERVICE: 208Y/120 V, 3PH, 4W, S/N	RATING:100 A						LOCATION: BITTERS PUMP STATION	"L1"	"L2"	"L3"
VA	VA	VA	MOUNTING: SURFACE	KAIC: 10,000 A						4.16 KV MCC BUS A	VA	VA	VA
			LOAD	P	BKR	CKT #		BKR	P	LOAD			
840			HSP #1 MOTOR OPERATED VALVE	3	20	1	2	20	3	HSP #2 MOTOR OPERATED VALVE	840		
	840		-	-	-	3	4	-	-	-		840	
		840	-	-	-	5	6	-	-	-			840
0			SPARE	1	20	7	8	20	3	HSP #3 MOTOR OPERATED VALVE	840		
	480		BUS A TEST POWER	1	20	9	10	-	-	-		840	
		480	SOUTH RESERVOIR LIGHTS	1	20	11	12	-	-	-			840
240			CONTROL VALVE, 8" & 12"	1	20	13	14	20	1	CL2 CABINET LIGHTS, PUMP	480		
	120		HSP #1 PANAMETRICS	1	20	15	16	20	1	AREA LIGHTS		480	
		480	HSP #1 PANEL HEATER	1	20	17	18	20	1	HSP #1 PANEL LIGHTS, RECEPTACLES			240
480			CATHODIC PROTECTION PANEL	1	20	19	20	20	3	SPARE	0		
	480		SWGR LIGHTS, RECEPTACLES	1	20	21	22	-	-	-		0	
		480	HSP #10 TEST POWER	1	20	23	24	-	-	-			0
840			HSP #10 MOTOR OPERATED VALVE	3	20	25	26	20	1	HSP #6 POWER	480		
	840		-	-	-	27	28	20	1	HSP #6 PANAMETRICS		120	
		840	-	-	-	29	30	20	1	HSP #6 AREA RECEPTACLES			360
840			HSP #6 MOTOR OPERATED VALVE	3	20	31	32	20	1	HSP #6 AREA RECEPTACLES	360		
	840		-	-	-	33	34	20	1	SPARE		0	
		840	-	-	-	35	36	20	1	SPARE			0
480			HSP #6 HEATER	1	20	37	38	20	1	SWGR SPACE HEATERS	480		
	360		TANK A, LIGHTS, RECEPTACLES	1	20	39	40	20	1	HSP #3 TEST POWER		480	
		480	TANK A, HEATER	1	20	41	42	20	1	COMPRESSOR			600
3720			TOTAL "L1"			7200				TOTAL "L1"	3480		
	3960		TOTAL "L2"			6720				TOTAL "L2"		2760	
		4440	TOTAL "L3"			7320				TOTAL "L3"			2880
			TOTAL LOAD (VA) =			21240							
			PHASES =			3							
			VOLTAGE (V) =			208							
			TOTAL CURRENT (A) =			59.0							
			DERATING =			1.25							
			MINIMUM BUS RATING (A) =			73.7							
			SELECTED BUS RATING (A) =			100							

1 of 3

2 of 3

3 of 3

Panelboard Design

- **View 1 of 3:**
- **Each load is entered in the spreadsheet**
- **Each load's demand VA is entered into the spreadsheet**
- **Each load's breaker is entered with trip rating and 1, 2, or 3 poles (120 V or 208 V)**

Panelboard Schedule Calculation

PHASE			PANELBOARD: EXIST POWER PANEL A	BUS: COPPER		
"L1"	"L2"	"L3"	SERVICE: 208Y/120 V, 3PH, 4W, S/N	RATING:100 A		
VA	VA	VA	MOUNTING: SURFACE	KAIC: 10,000 A		
			LOAD	P	BKR	CKT
840			HSP #1 MOTOR OPERATED VALVE	3	20	1
	840		-	-	-	3
		840	-	-	-	5
0			SPARE	1	20	7
	480		BUS A TEST POWER	1	20	9
		480	SOUTH RESERVOIR LIGHTS	1	20	11
240			CONTROL VALVE, 8" & 12"	1	20	13
	120		HSP #1 PANAMETRICS	1	20	15
		480	HSP #1 PANEL HEATER	1	20	17
480			CATHODIC PROTECTION PANEL	1	20	19
	480		SWGR LIGHTS, RECEPTACLES	1	20	21
		480	HSP #10 TEST POWER	1	20	23
840			HSP #10 MOTOR OPERATED VALVE	3	20	25
	840		-	-	-	27
		840	-	-	-	29

Panelboard Design

- **View 2 of 3:**
- **Total L1, L2, and L3 VA loads at bottom**
- **Total both sides of VA load subtotals at bottom**

Panelboard Schedule Calculation

		480	HSP #10 TEST POWER	1	20	23	24
840			HSP #10 MOTOR OPERATED VALVE	3	20	25	26
	840		-	-	-	27	28
		840	-	-	-	29	30
840			HSP #6 MOTOR OPERATED VALVE	3	20	31	32
	840		-	-	-	33	34
		840	-	-	-	35	36
480			HSP #6 HEATER	1	20	37	38
	360		TANK A, LIGHTS, RECEPTACLES	1	20	39	40
		480	TANK A, HEATER	1	20	41	42
3720			TOTAL "L1"			7200	
	3960		TOTAL "L2"			6720	
		4440	TOTAL "L3"			7320	
			TOTAL LOAD (VA) =		21240		
			PHASES =		3		
			VOLTAGE (V) =		208		
			TOTAL CURRENT (A) =		59.0		
			DERATING =		1.25		
			MINIMUM BUS RATING (A) =		73.7		
			SELECTED BUS RATING (A) =		100		

Panelboard Design

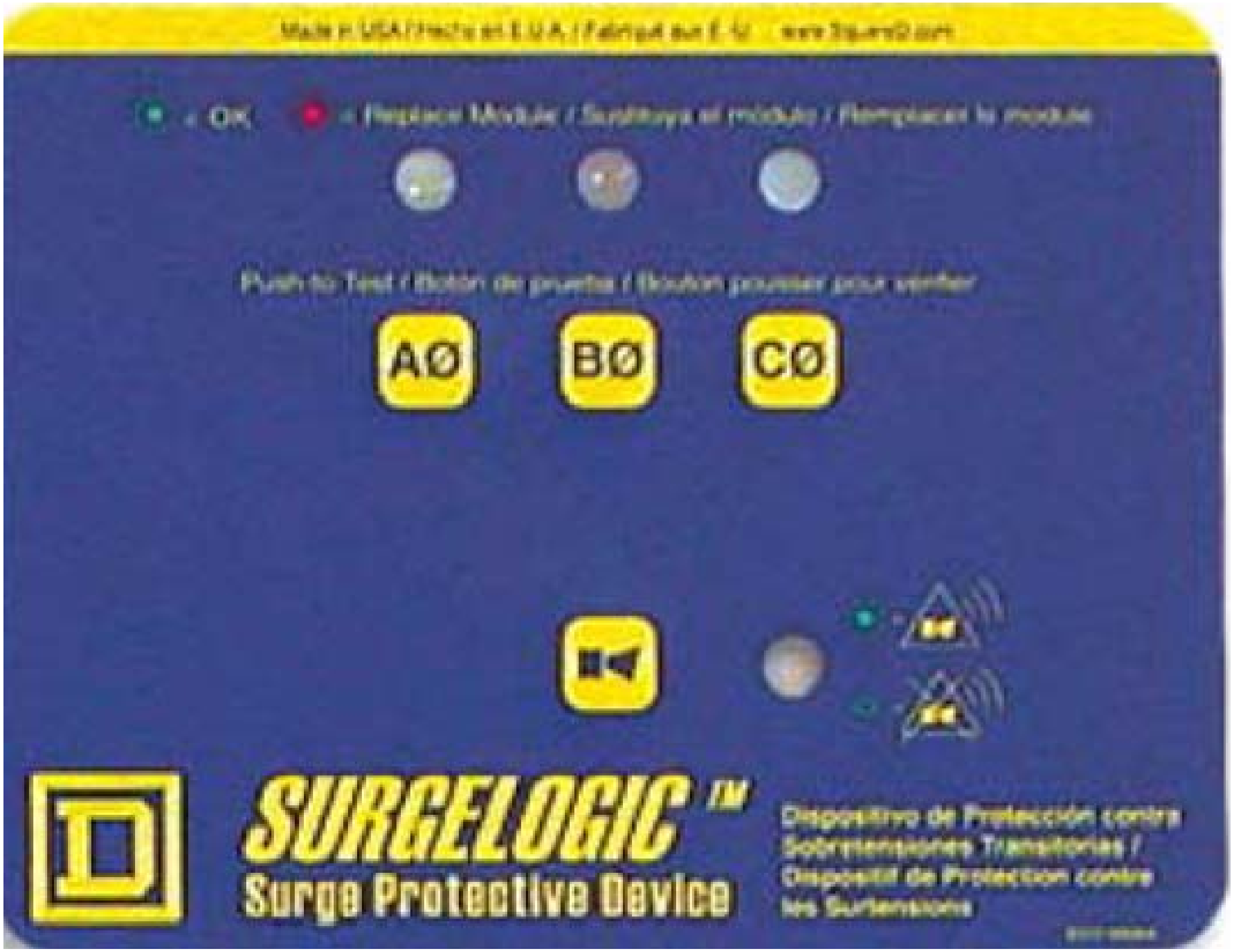
- **View 3 of 3:**
- **Add all VA loads for entire panelboard**
- **Calculate continuous current demand**
- **Multiply by 125% to calculate minimum current bus rating**
- **Select next available bus rating size**

Panelboard Schedule Calculation

-	-	-	35	36
HSP #6 HEATER	1	20	37	38
TANK A, LIGHTS, RECEPTACLES	1	20	39	40
TANK A, HEATER	1	20	41	42
TOTAL "L1"		7200		
TOTAL "L2"		6720		
TOTAL "L3"		7320		
TOTAL LOAD (VA) =		21240		
PHASES =		3		
VOLTAGE (V) =		208		
TOTAL CURRENT (A) =		59.0		
DERATING =		1.25		
MINIMUM BUS RATING (A) =		73.7		
SELECTED BUS RATING (A) =		100		

TVSS Design

- **TVSS = Transient Voltage Surge Suppression**
- **A TVSS unit is designed to protect downstream equipment from the damaging effects of a high voltage spike or transient**
- **The TVSS unit essentially clips the higher portions of the voltage spike and shunts that energy to ground**
- **Thus, the TVSS unit should be sized to accommodate higher levels of energy**
- **The small multiple outlet strip for your home television or computer is similar but not the same**


= OK
= Replace Module / Sustituya el módulo / Remplacer le module
Push to Test / Botón de prueba / Bouton pousser pour vérifier
AØ
BØ
CØ
SURGELOGIC TM
Surge Protective Device
Dispositivo de Protección contra Sobretensiones Transitorias / Dispositif de Protection contre les Surtensions

TVSS Design

- **Energy level depends on where in the power system you place these TVSS units**
- **The lower in the power system the TVSS unit is located, the less likely the voltage spike will be high**
- **Some of the energy is dissipated through various transformers and lengths of cables, or impedance**
- **However, it would be prudent engineering to always place a TVSS unit in front of each panelboard for additional protection for all loads fed from the panelboard**

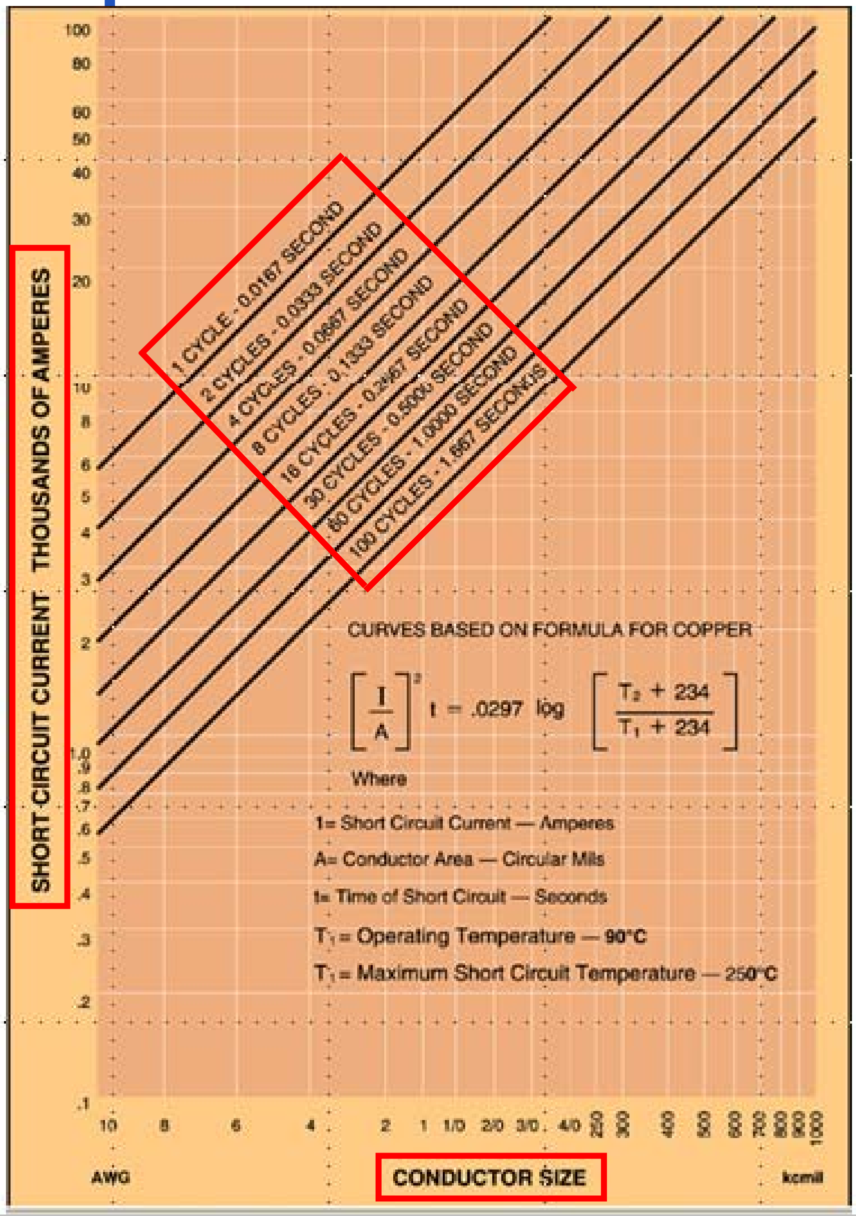
TVSS Design

- **Cost is not great for TVSS units**
- **Prudent investment for insurance to protect loads**
- **More important is placing TVSS units further upstream in power system to protect all loads**
- **480 V switchgear, 480 V motor control center, 480 V panelboard, 208 V panelboard, etc.**
- **Important to have LED lights indicating functionality of TVSS unit**

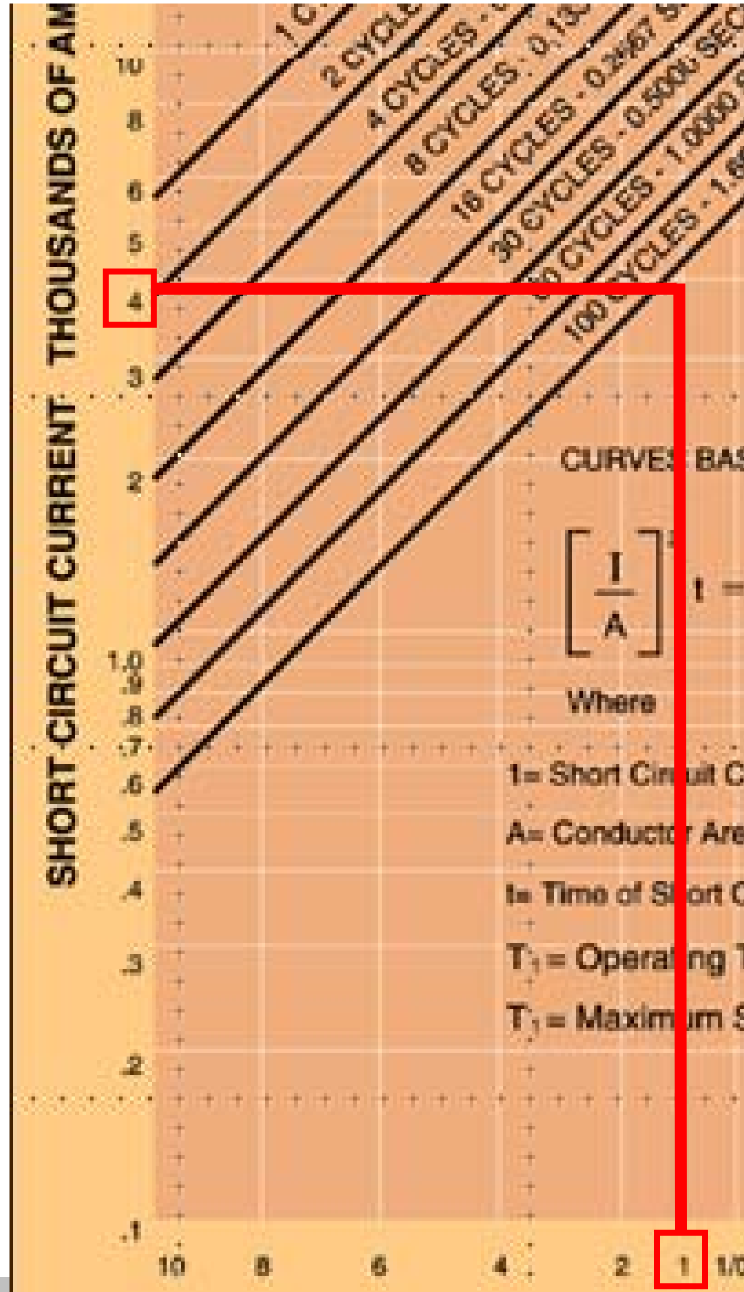
Short Circuit Impact on Conductors

- **The available short circuit can have an impact on the size of the conductors in each circuit**
- **The upstream breaker or fuse must clear the fault <u>before</u> the conductor burns up**
- **The “time to burn” depends on the size of the conductor and the available short circuit**
- **Most important: the higher the short circuit, the quicker the fault must be cleared**
- **Okonite has an excellent table that shows this relationship**

Short Circuit Impact on Conductors



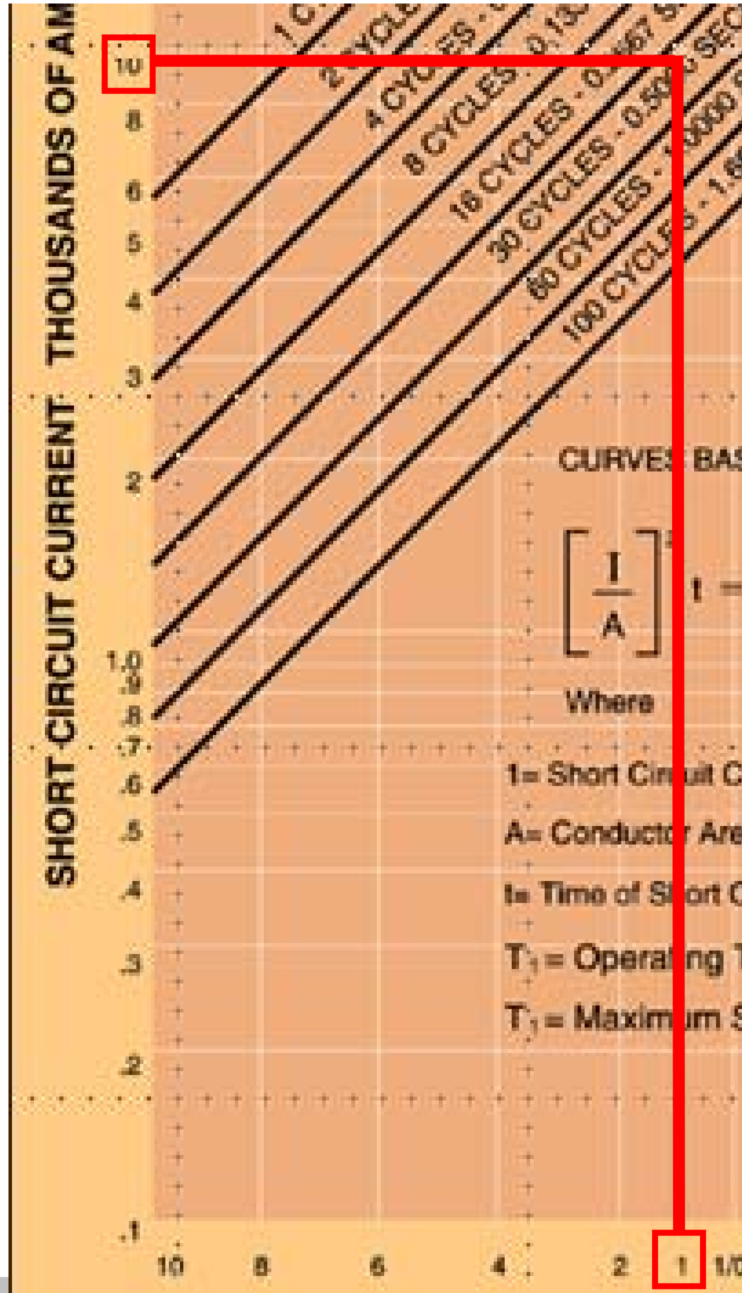
4000 A Short Circuit



Must clear fault within 100 cycles or 1.667 sec

1 AWG (42.41 mm^2)

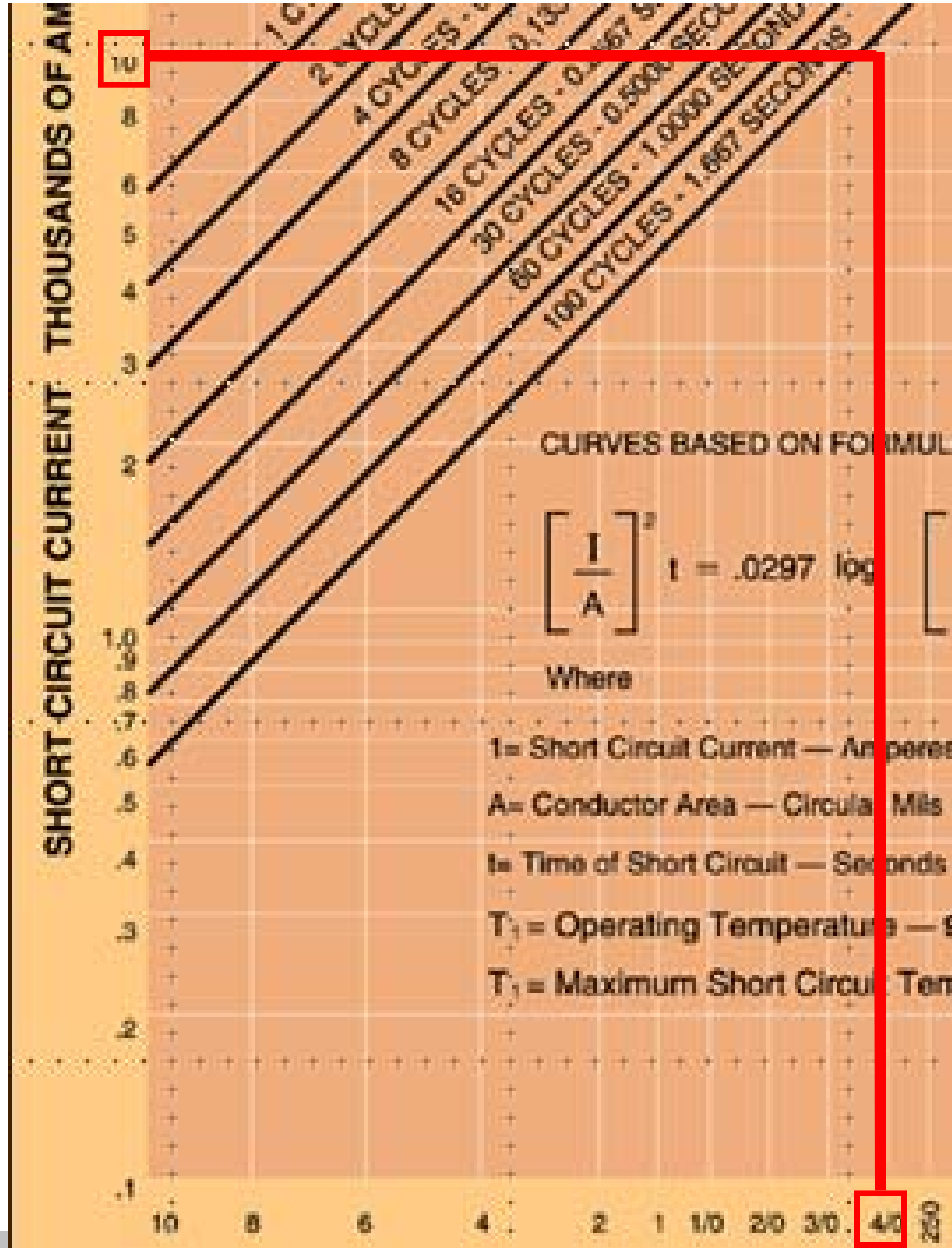
10000 A Short Circuit



Must clear fault within 16 cycles or 0.267 sec

1 AWG (42.41 mm²)

10000 A Short Circuit



Must clear fault within 100 cycles or 1.67 sec

4/0 AWG ($107.2\ mm^2$)

Short Circuit Impact on Conductors

- **For same short circuit, larger conductor allows more time to clear fault**
- **Must select proper breaker size, or adjust trip setting if adjustable breaker to clear fault within the “burn through” time**
- **Same for fuses when fuses are used**