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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

Selected Agenda, 1 of 4

- **Simple Design for 480 V, 100 Hp Pump (60)**
- **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**
- **Voltage Drop Considerations (27)**
- **Add 2nd 100 Hp Pump (10)**

Selected Agenda, 2 of 4

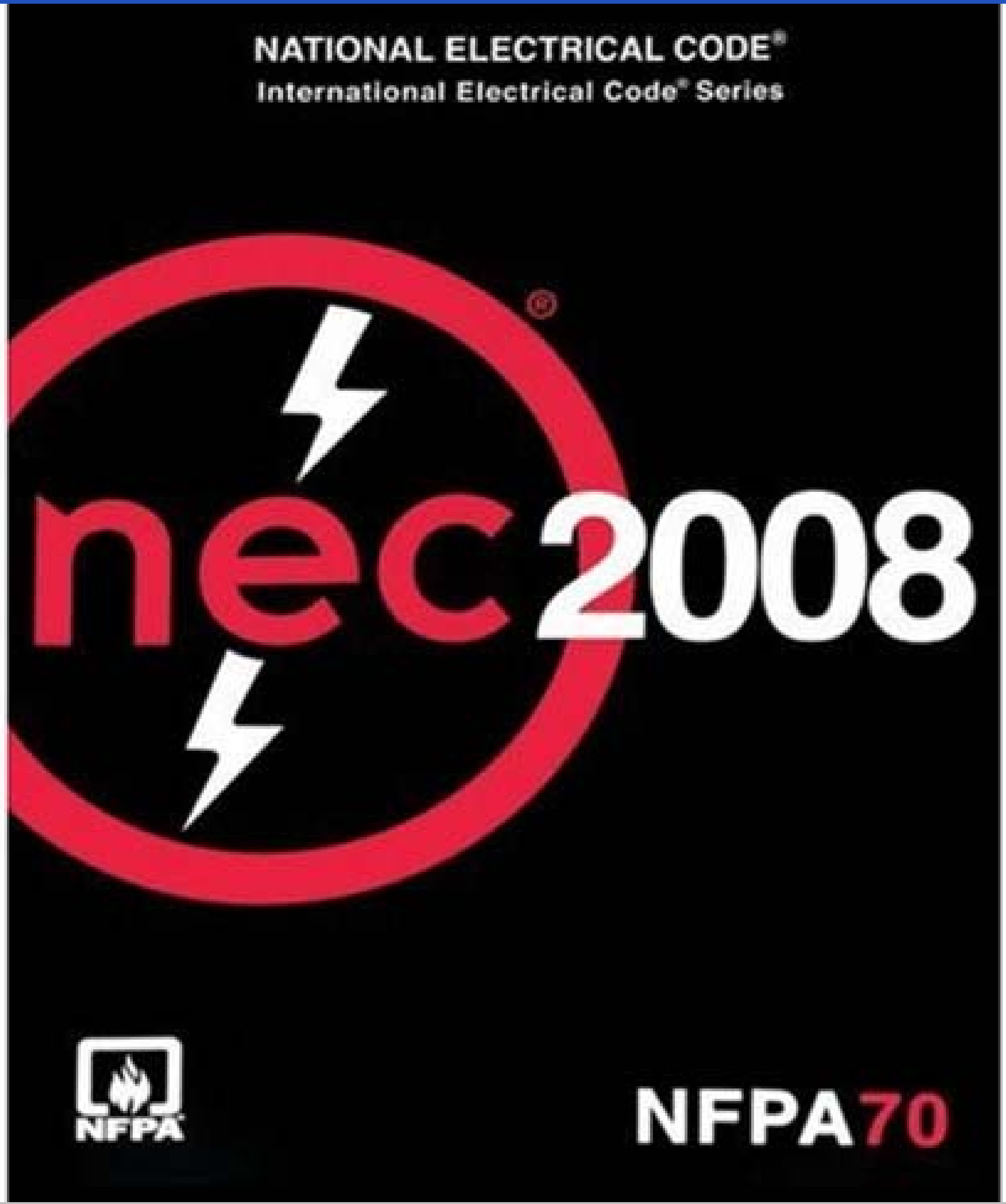
- Cable Temperature Considerations (13)
- Simple Circuit Design for 120 V, 1-Phase Load (20)
- Panelboard Design & Calculation (11)
- TVSS Design (5)
- Short Circuit Impact on Conductors (6)
- Reliability Analysis & Considerations (7)
- Reliability Calculations per IEEE 493 (40)
- Motors, VFDs, Cables from VFDs (13)
- Lighting Design, Photometric Calculation (9)
- K-Factor Calculation for Dry-Type Transformers (7)

Selected Agenda, 3 of 4

- **Power System Summary (90)**
- A. Prepare Load Study Calculation
- B. Size Transformer to 480 V Loads
- C. Size 480 V Motor Control Center (MCC)
- D. Select Short Circuit Rating of 480 V MCC
- E. Size 480 V Feeder from Transformer to MCC
- F. Size Transformer 12 kV Primary Disconnect
- G. Select Surge Protection at Transformer Primary
- H. Size 12 kV Feeder to Transformer (MV Cable)

Selected Agenda, 4 of 4

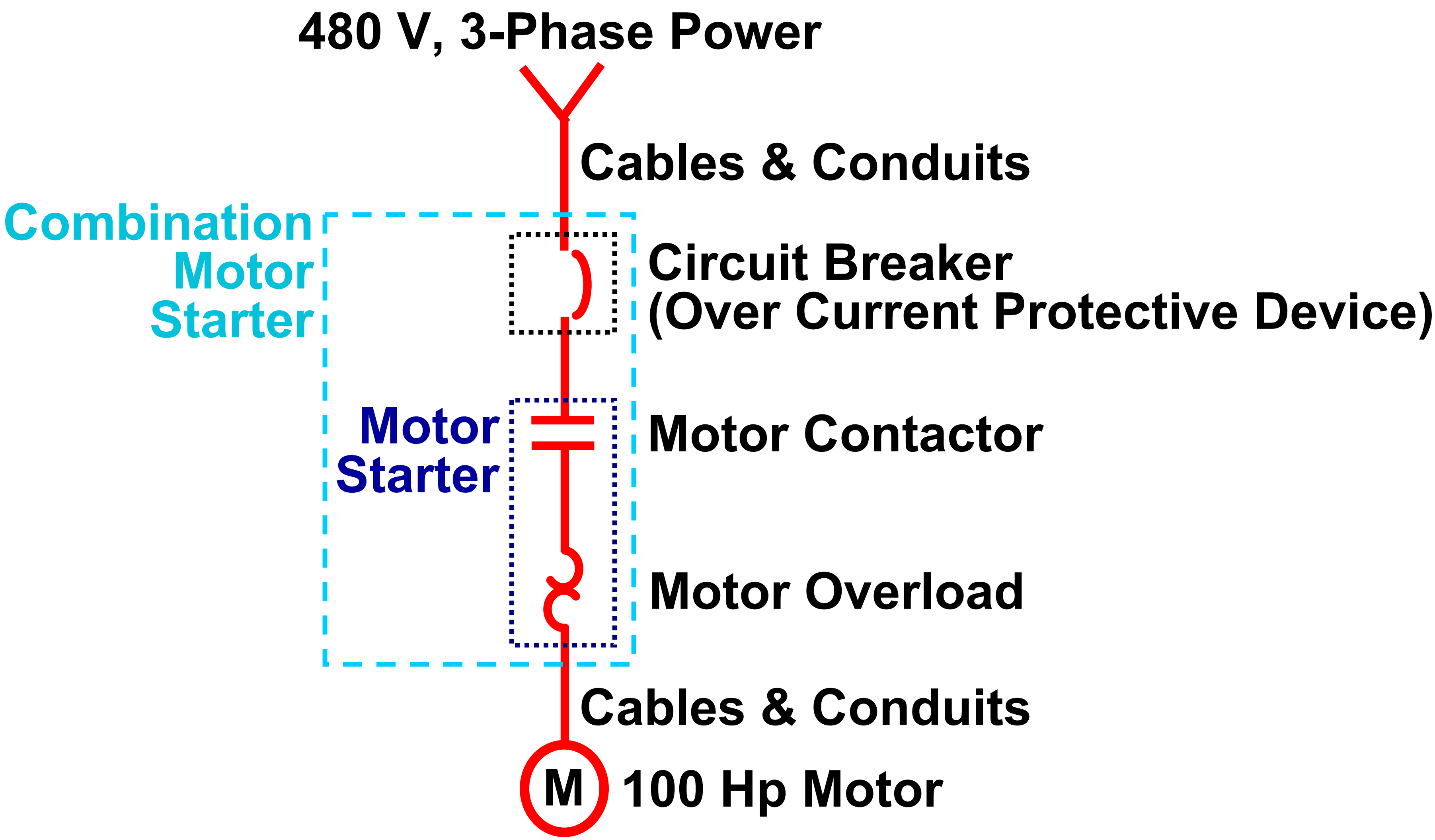
- Utility Voltage Supply Affects Reliability (2)
- System Optimization-Siting Main Substation (4)
- Electrical Center of Gravity (3)
- MV vs. LV Feeders and Losses (11)
- Transformer Sizing & Overloading (26)
- Emergency Standby Engine-Generators (3)
- Automatic Transfer Switches (6)
- UPS (4)
- Swgr Aux and Control Power (15)


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. Determine Full-Load Current, IFL**
- **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,

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

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 required 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. Size Overcurrent Protection, Breaker
- 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
- Maximum 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 short-time 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).]						
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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					
Size (AWG or kcmil)	Area			Diameter		Diameter		Area		Uncoated		Coated		Aluminum	
	mm^2	Circular mils	Quantity	mm	in.	mm	in.	mm^2	$in.^2$	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	
	mm^2	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	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. Size Grounding Conductor
- 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 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

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	⅜	—	—	—	—	—	—	—	—	—	—	—	—
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 mm	Nominal Internal Diameter in.	Total Area 100% mm²	Total Area 100% in.²	60% mm²	60% in.²	1 Wire 53% mm²	1 Wire 53% in.²	2 Wires 31% mm²	2 Wires 31% in.²	Over 2 Wires 40% mm²	Over 2 Wires 40% 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

Size (AWG or kcmil)	X_L (Reactance) for All Wires: PVC, Aluminum Conduits	X_L (Reactance) for All Wires: Steel Conduit	Alternating-Current Resistance for Uncoated Copper Wires: PVC Conduit	Alternating-Current Resistance for Uncoated Copper Wires: Aluminum Conduit	Alternating-Current Resistance for Uncoated Copper Wires: Steel Conduit	Alternating-Current Resistance for Aluminum Wires: PVC Conduit	Alternating-Current Resistance for Aluminum Wires: Aluminum Conduit	Alternating-Current Resistance for Aluminum Wires: Steel Conduit	Effective Z at 0.85 PF for Uncoated Copper Wires: PVC Conduit	Effective Z at 0.85 PF for Uncoated Copper Wires: Aluminum Conduit	Effective Z at 0.85 PF for Uncoated Copper Wires: Steel Conduit	Effective Z at 0.85 PF for Aluminum Wires: PVC Conduit	Effective Z at 0.85 PF for Aluminum Wires: Aluminum Conduit	Effective Z at 0.85 PF for Aluminum Wires: 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

Size (AWG or kcmil)	X_L (Reactance) for All Wires: PVC, Aluminum Conduits	X_L (Reactance) for All Wires: Steel Conduit	Alternating-Current Resistance for Uncoated Copper Wires: PVC Conduit	Alternating-Current Resistance for Uncoated Copper Wires: Aluminum Conduit	Alternating-Current Resistance for Uncoated Copper Wires: Steel Conduit	Alternating-Current Resistance for Aluminum Wires: PVC Conduit	Alternating-Current Resistance for Aluminum Wires: Aluminum Conduit	Alternating-Current Resistance for Aluminum Wires: Steel Conduit	Effective Z at 0.85 *PF* for Uncoated Copper Wires: PVC Conduit	Effective Z at 0.85 *PF* for Uncoated Copper Wires: Aluminum Conduit	Effective Z at 0.85 *PF* for Uncoated Copper Wires: Steel Conduit	Effective Z at 0.85 *PF* for Aluminum Wires: PVC Conduit	Effective Z at 0.85 *PF* for Aluminum Wires: Aluminum Conduit	Effective Z at 0.85 *PF* for Aluminum Wires: 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 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 = 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 = 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 = 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 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	—

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		Total Area 100%		60%		1 Wire 53%	
		mm	in.	mm²	in.²	mm²	in.²	mm²	in.²
12	3/8	—	—	—	—	—	—	—	—
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.	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
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 mm²**
- **Fill Factor = 951.7 mm²/2124 mm² = 44.8%**
- **FF > 40%, and is in violation of the NEC**
- **For PVC, a conduit diameter of 63 mm has an area of 3029 mm²**
- **Fill Factor = 951.7 mm²/3029 mm² = 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 2^{nd} 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	3/8	—	—	—	—	—	—	—	—
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	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

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 36°C to 40°C = 175 A x 0.88 = 154 A
- Close enough to target ampacity of 155 A, OK
- But for second temperature range:
- For derating at 46°C to 50°C = 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 higher 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 (3 m) 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.

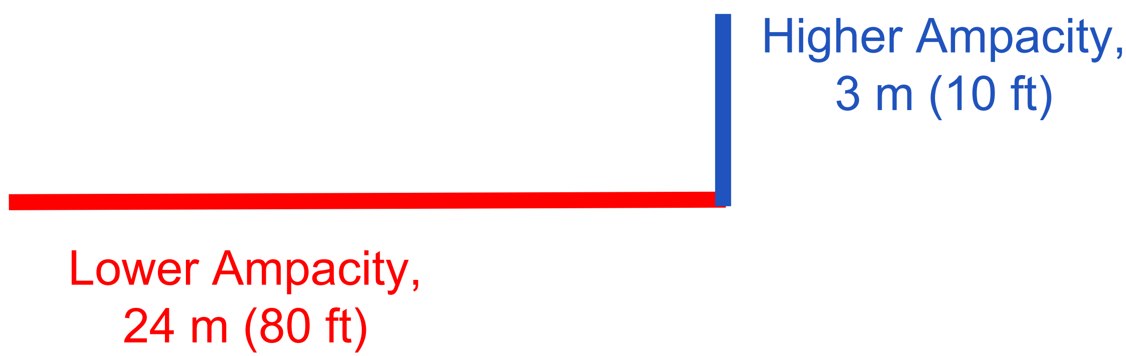
Exception: Where two different ampacities apply to adjacent portions of a circuit, the higher ampacity shall be permitted to be used beyond the point of transition, a distance equal to 3.0 m (10 ft) or 10 percent of the circuit length figured at the higher ampacity, whichever is less.

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

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

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^2xR**
- **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		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	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 Schedule Calculation

- **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 Schedule Calculation

- **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 Schedule Calculation

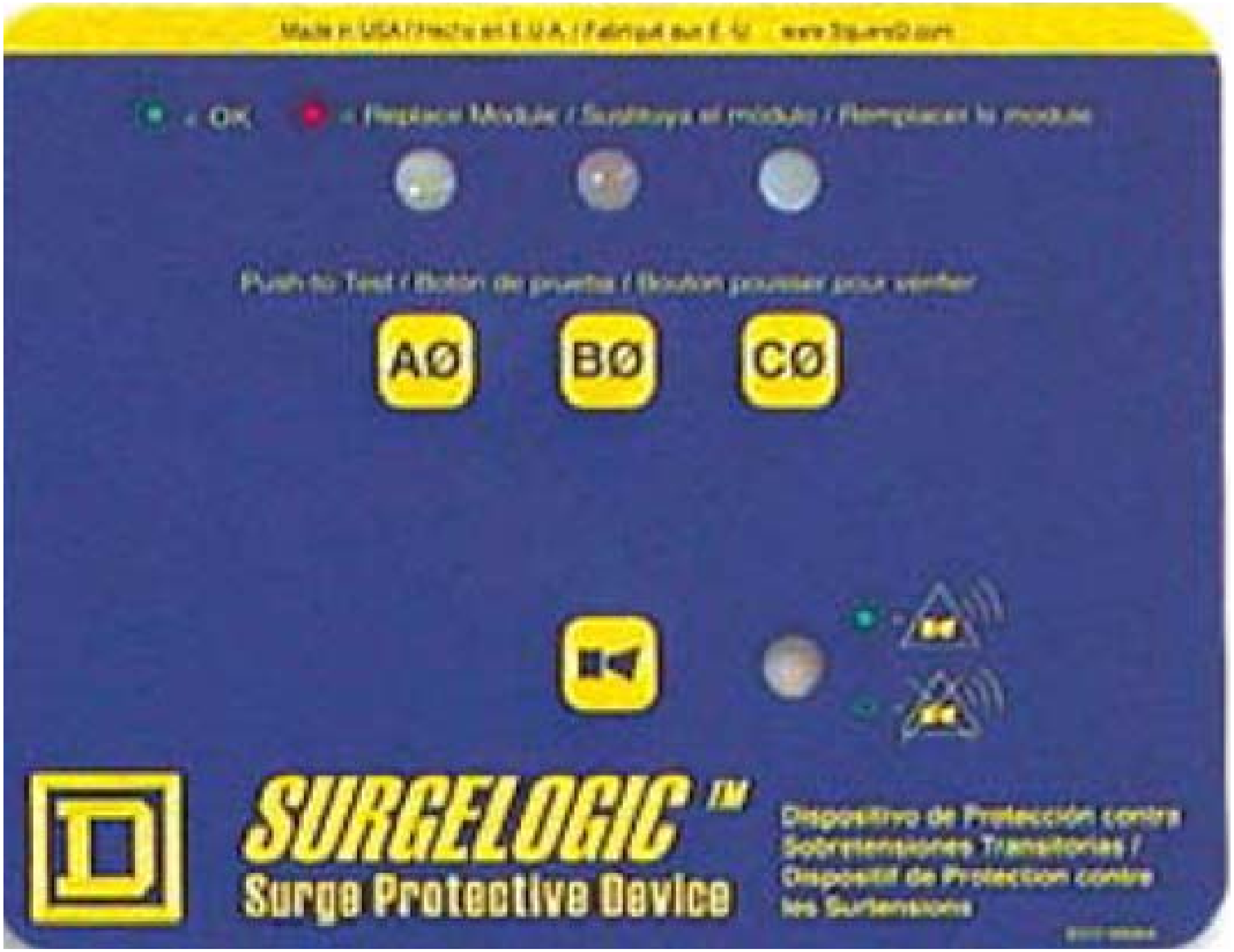
- **View 3 of 3:**
- **Add all VA loads for entire panelboard**
- **Calculate continuous current demand**
- **Multiply by 125% to calculate minimum current bus rating**
- **Select next available bus rating size**

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
AØ
BØ
CØ
SURGELOGIC™
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

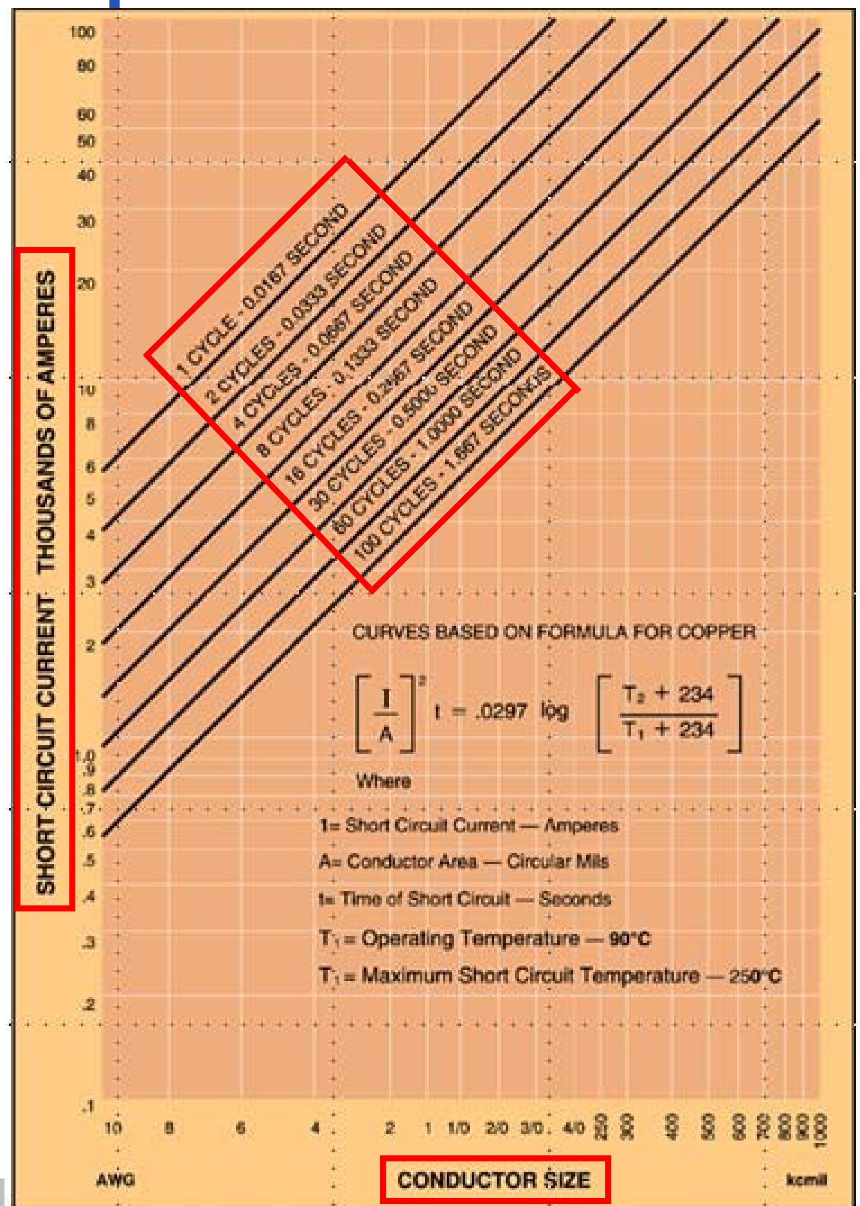
TVSS Design

- 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

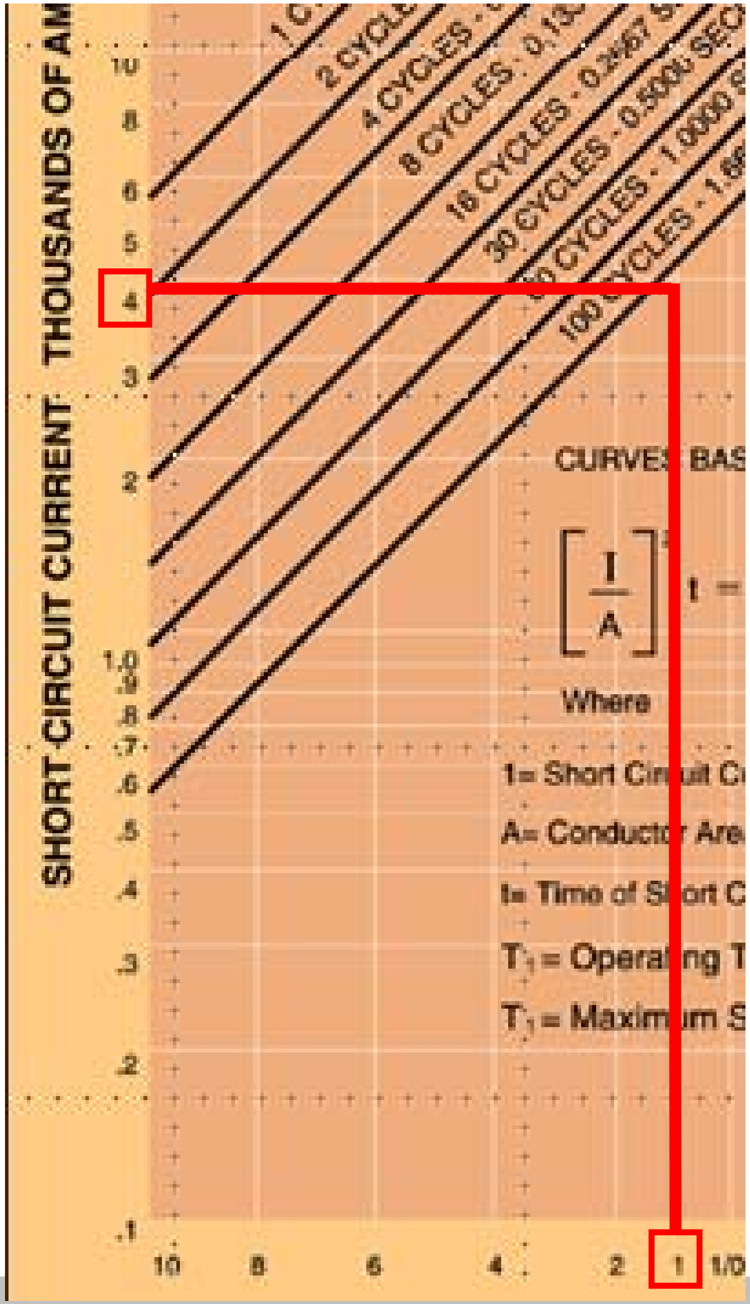
Short Circuit Impact on Conductors

- **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



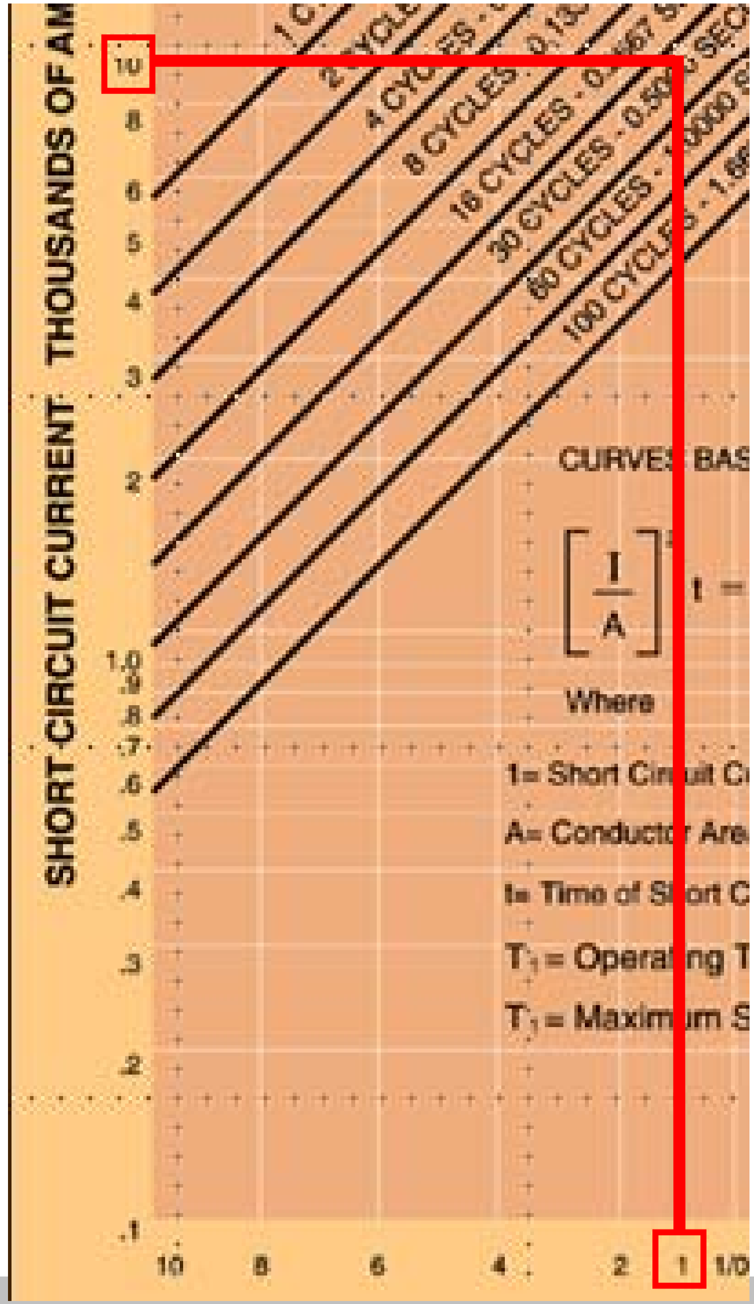
4000 A Short Circuit



Must clear fault within 100 cycles or 1.667 sec

1 AWG (42.41 mm^2)

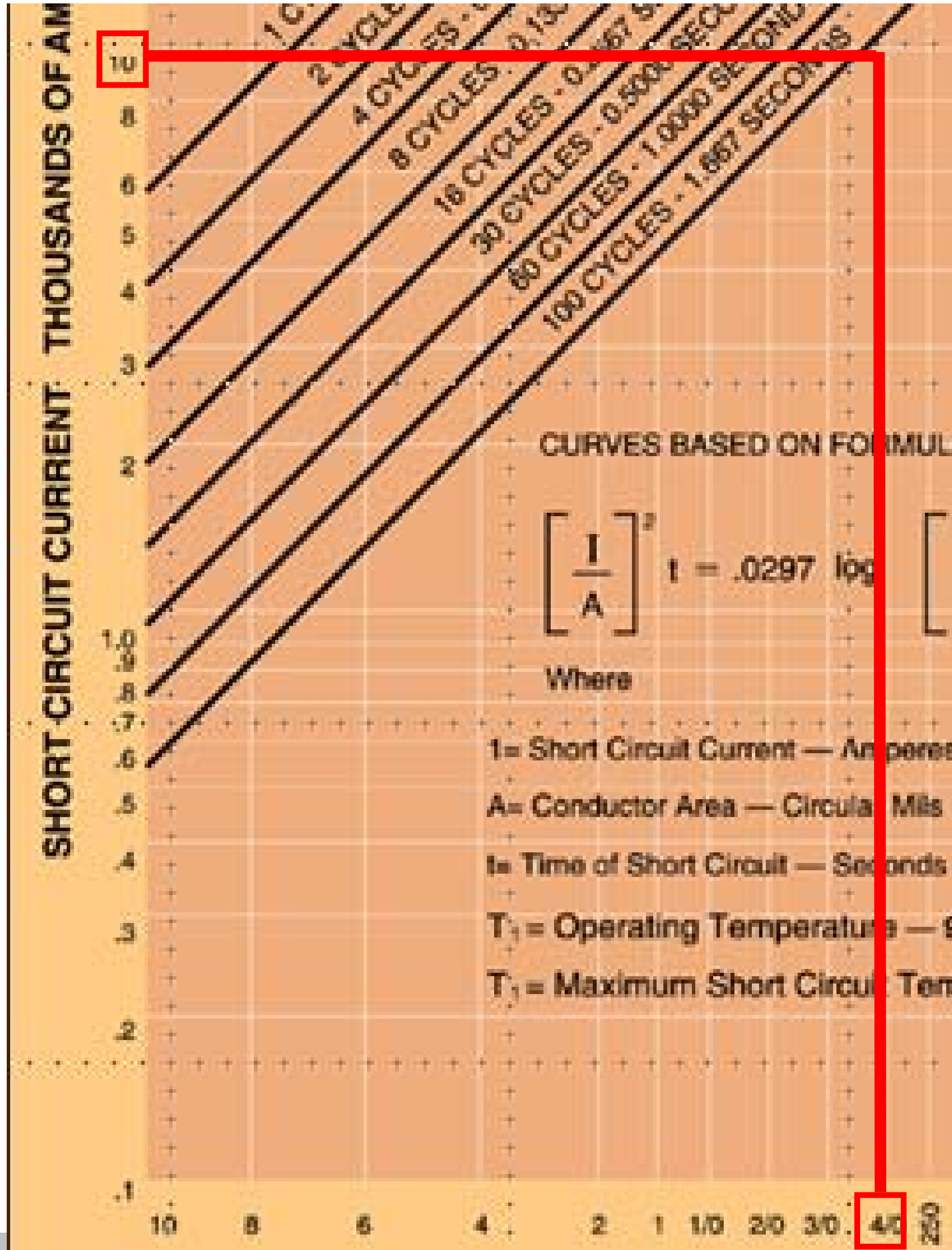
10000 A Short Circuit



Must clear fault within 16 cycles or 0.267 sec

1 AWG (42.41 mm^2)

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

Redundant Power Trains for Increased Reliability

- **The most basic driving element in increasing power system reliability is to have redundant or alternate power trains to power the end load device should a particular piece of the power system fail or be unavailable**
- **The unavailability of equipment can a simple failure, but also planned maintenance**

Redundant Power Trains for Increased Reliability

- The most common method by far is designing a power system with two power trains, A and B
- Such an A and B system then requires a second source of power
- Could be a second utility source, or a standby diesel engine-generator or other source of power

Failure Analysis – Single Point of Failure

- **Failure analysis is driven by the concept of "single points of failure"**
- **A single point of failure is a single point in the power system beyond which the power system is down from the failed piece of equipment**
- **Example is the single transformer, or MCC, etc. in the above example**

Failure Analysis – Coincident Damage

- **A secondary failure analysis concept is "coincident damage"**
- **Coincident damage is where the failure of one piece of equipment damages a piece of the alternate equipment power train**
- **Example is a pull box with both A circuit and B circuit cables**
- **Should the A cables explode during fault conditions, the arc flash could easily damage the B cables in close proximity**

Limitations of Redundancy

- **Easy to keep adding equipment to power system to increase reliability**
- **Also adding cost**
- **Degree of final power system redundancy depends on owner's available budget**
- **Simply adding more power trains results in diminishing returns on investment, or asymptotic curve**

Limitations of Redundancy

- The driving factor for owner is what value is placed on continued operation
- Or can be how catastrophic an outage is to the plant and for how long
- If the plant can be down without great adverse impact, then adding costs to the power system for increased reliability is not necessary
- This is rarely the case

Limitations of Redundancy

- **So, we have to find an acceptable common ground to establish design criteria**
- **A hospital is one obvious example where reliability requirements are very high**
- **Another example is a highway tunnel where the public could be at risk should the power system fail**

Reliability Calculation for Power Systems

- **Reliability calculation can be performed on any power system**
- **Most useful when comparing the reliability index between different systems**

Reliability Calculation for Power Systems

- **Gastonia wanted to improve reliability and safety of existing power system**
- **We originally identified about 20 alternatives**
- **Narrowed down to about 6 alternatives**
- **Added slight variations to 6 alternatives for a total of 16 options representing alternative paths**
- **Calculated reliability index for all 16 options**
- **Provided cost estimate for each option to assign “value” to reliability improvements**

Reliability Calculation for Power Systems

- **Reliability Index = λ x r = (failure rate per year) x (hours of downtime per year)**
- **IEEE Standard 493 (*also known as the Gold Book*)**

IEEE Std 493-1997
(Revision of IEEE Std 493-1990)

IEEE Recommended Practice for the Design of Reliable Industrial and Commercial Power Systems

Sponsor

Power Systems Reliabilty Subcommittee
of the
Power Systems Engineering Committee
of the
IEEE Industry Applications Society

Approved 16 December 1997

IEEE Standards Board

Reliability Calculation for Power Systems

- **For reliability values for typical electrical equipment in a power system:**
- **Used IEEE 493, Table 7-1, page 105: Reliability Data of Industrial Plants, for transformers, breakers, cables, swgr, gens, etc.**
- **Data represents many years of compiling data by IEEE on failure types and failure rates**
- **Data is updated periodically**
- **For comparison purposes, important to be consistent in use of reliability data**

Typical IEEE Reliability Data for Equipment

EQUIPMENT	λ	r	Hrs/Yr
Breakers, 480 V	0.0027	4.0	0.0108
Breakers, 12.47 kV	0.0036	2.1	0.0076
Cables, LV	0.00141	10.5	0.0148
Cables, HV	0.00613	19.0	0.1165
Cable Terms, LV	0.0001	3.8	0.0004
Cable Terms, HV	0.0003	25.0	0.0075

Typical IEEE Reliability Data for Equipment

EQUIPMENT	λ	r	Hrs/Yr
Switches	0.0061	3.6	0.0220
Transformers	0.0030	130.0	0.3900
Switchgear Bus, LV	0.0024	24.0	0.0576
Switchgear Bus, HV	0.0102	26.8	0.2733
Relays	0.0002	5.0	0.0010
Standby Eng-Gens	0.1691	478.0	80.8298

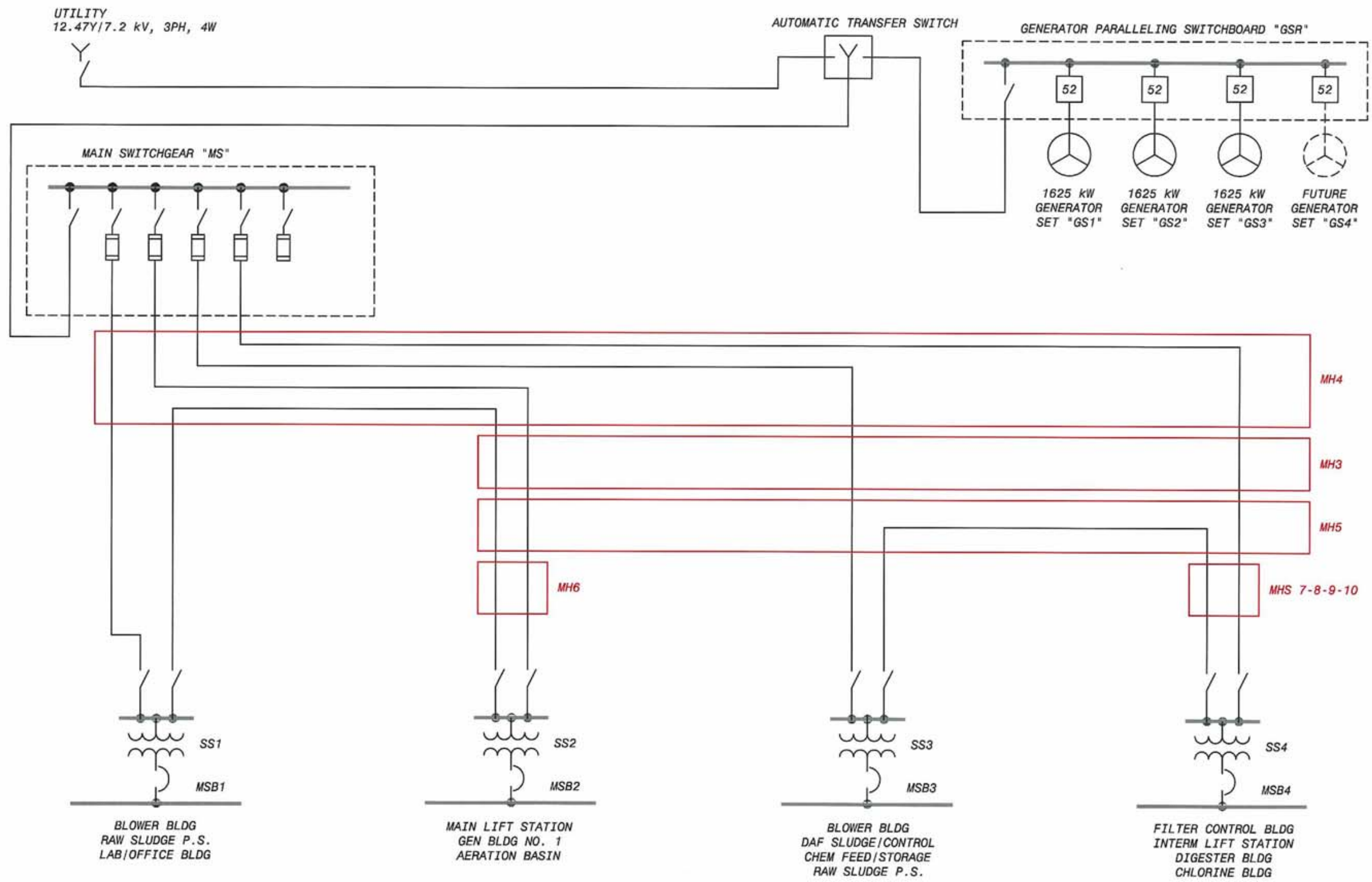
Reliability Calculation for Power Systems

- **For reliability values for utility circuits:**
- **Could use IEEE 493, Table 7-3, page 107: Reliability Data of Electric Utility Circuits to Industrial Plants**
- **Typical utility circuit options:**
- **Loss of Single Circuit = 2.582 hrs/yr**
- **Double Circuit, Loss of 1 Circuit: 0.2466 hrs/yr**
- **Loss of Double Circuit = 0.1622 hrs/yr**

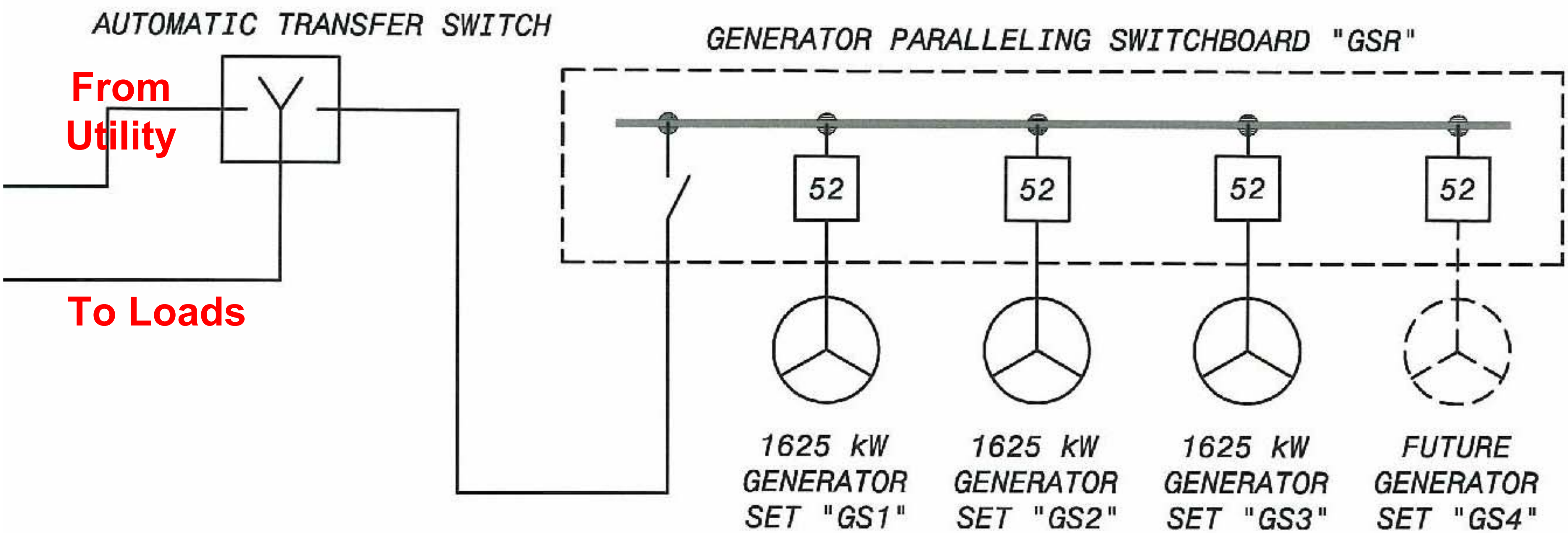
Reliability Calculation for Power Systems

- **Use <u>actual</u> historical outage data for Gastonia Electric (electric utility) Feeder No. 10-1 to Long Creek WWTP for past 5 years: 19.37144 minutes outage per year**
- **Gastonia Electric Feeder 10-1 to Long Creek WWTP = 0.0022 hrs/yr (19.37144 min/yr)**
- ***Better than IEEE data of 2.582 hrs/yr for single circuit!***

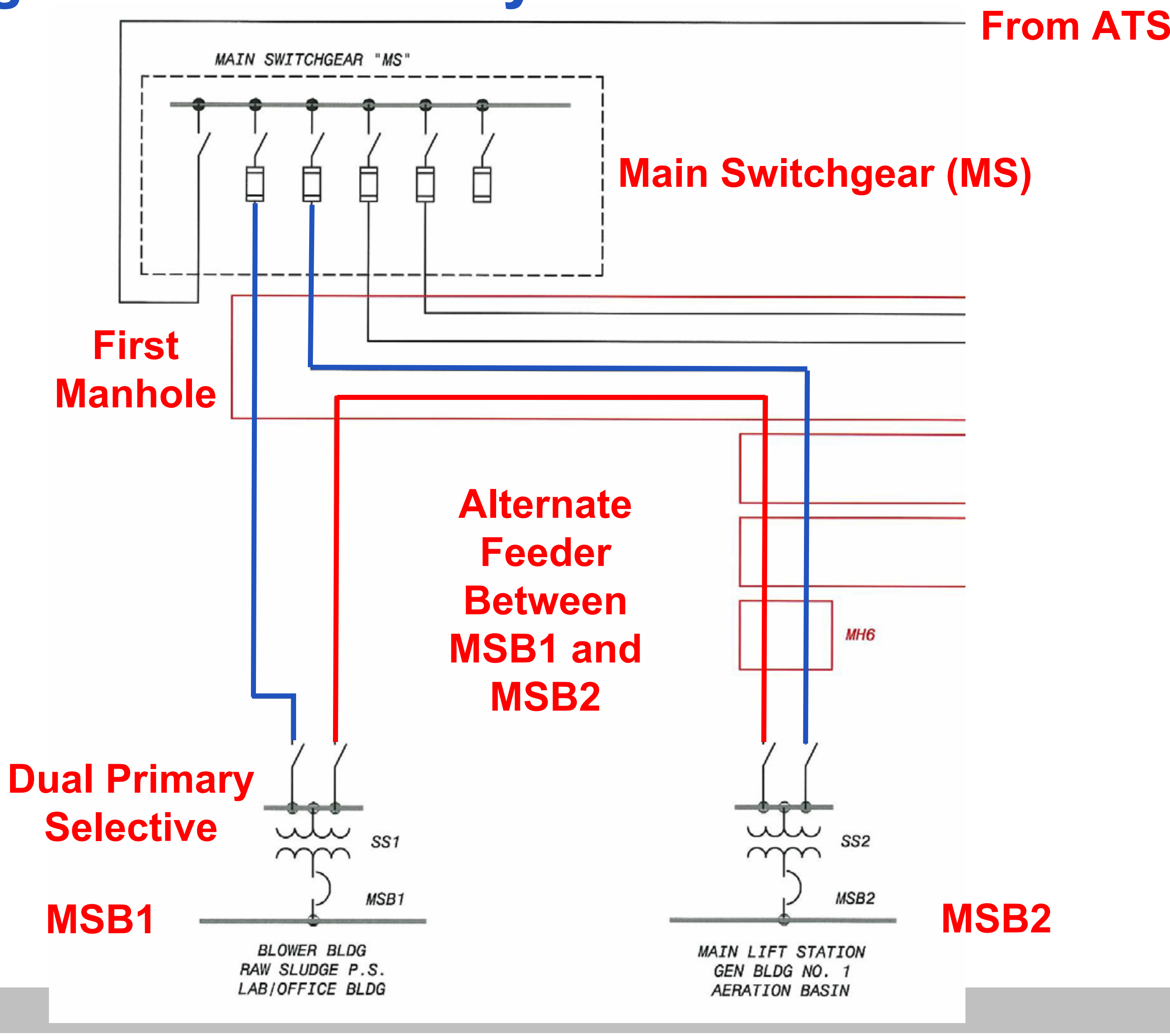
Existing WWTP Power System



Existing WWTP Power System



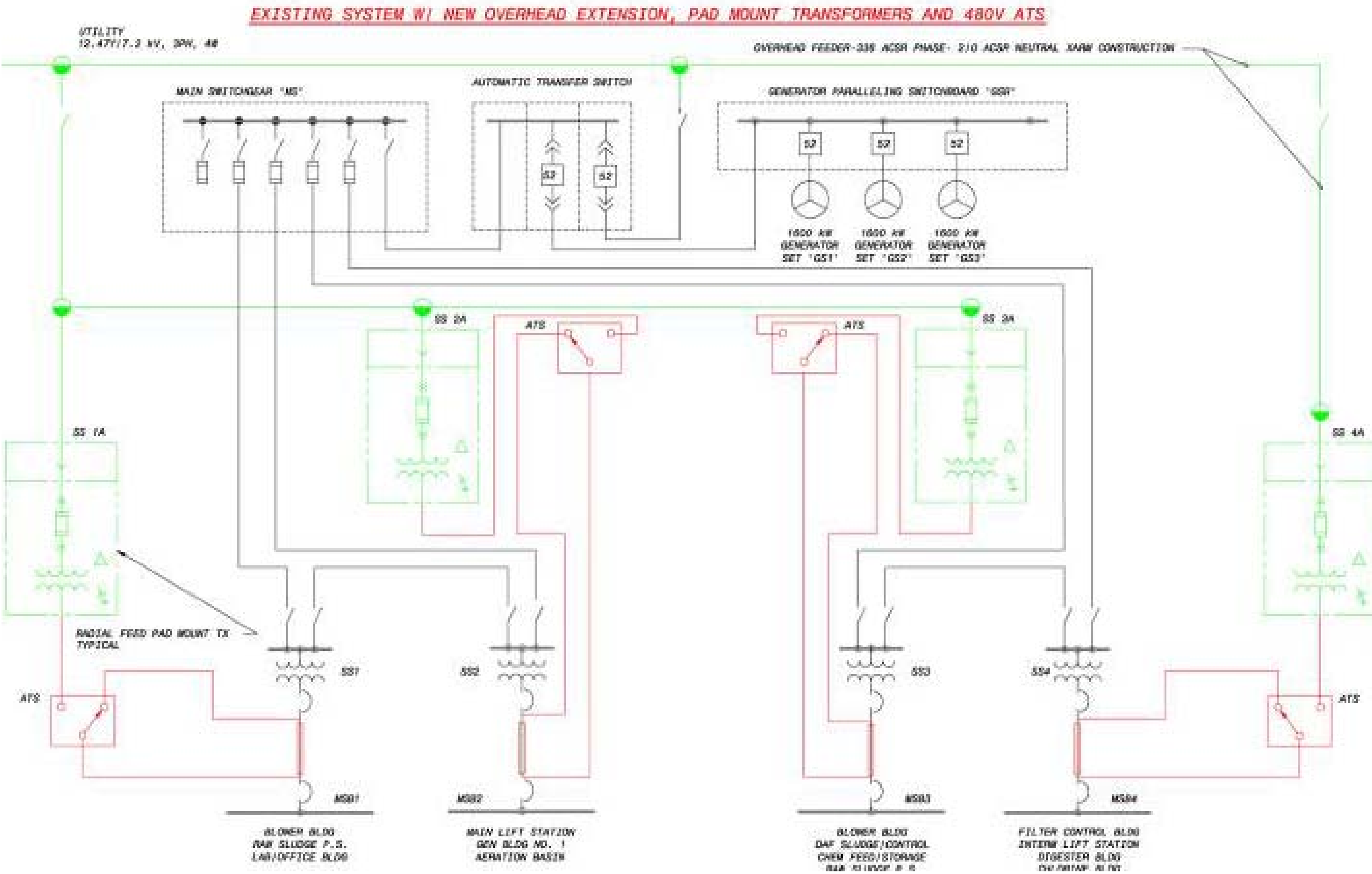
Existing WWTP Power System



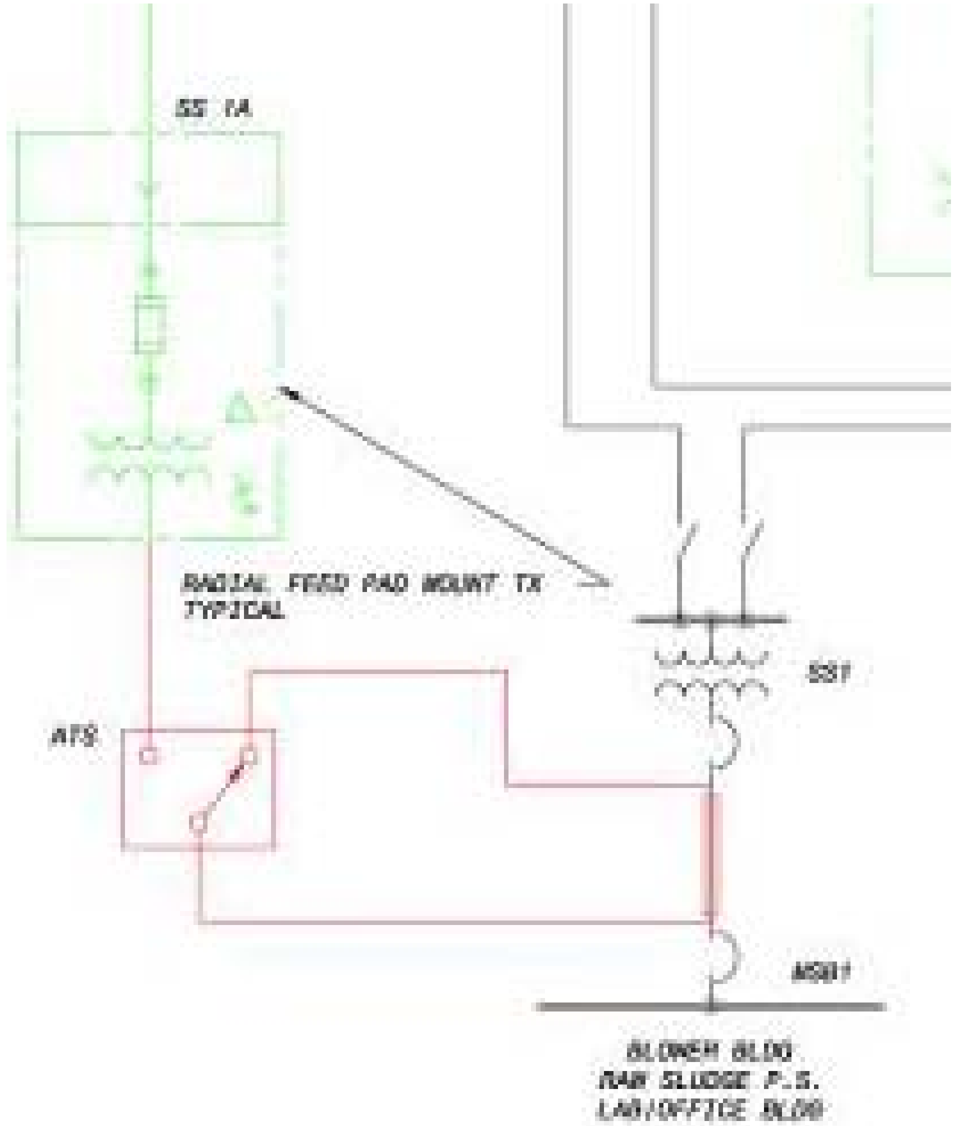
Reliability Calculations – Existing System

POWER TRAIN	INDEX
1A: Existing to MSB1	1.6355
1B: Existing to MSB1 via SS2	1.5583
1C: Existing to MSB3	1.6515
1D: Existing to MSB3 via SS4	1.5801

Alternative 2



Alternative 2



Reliability Calculations - Proposed System

Alternative 2: Pad Mounted Transformer with ATS

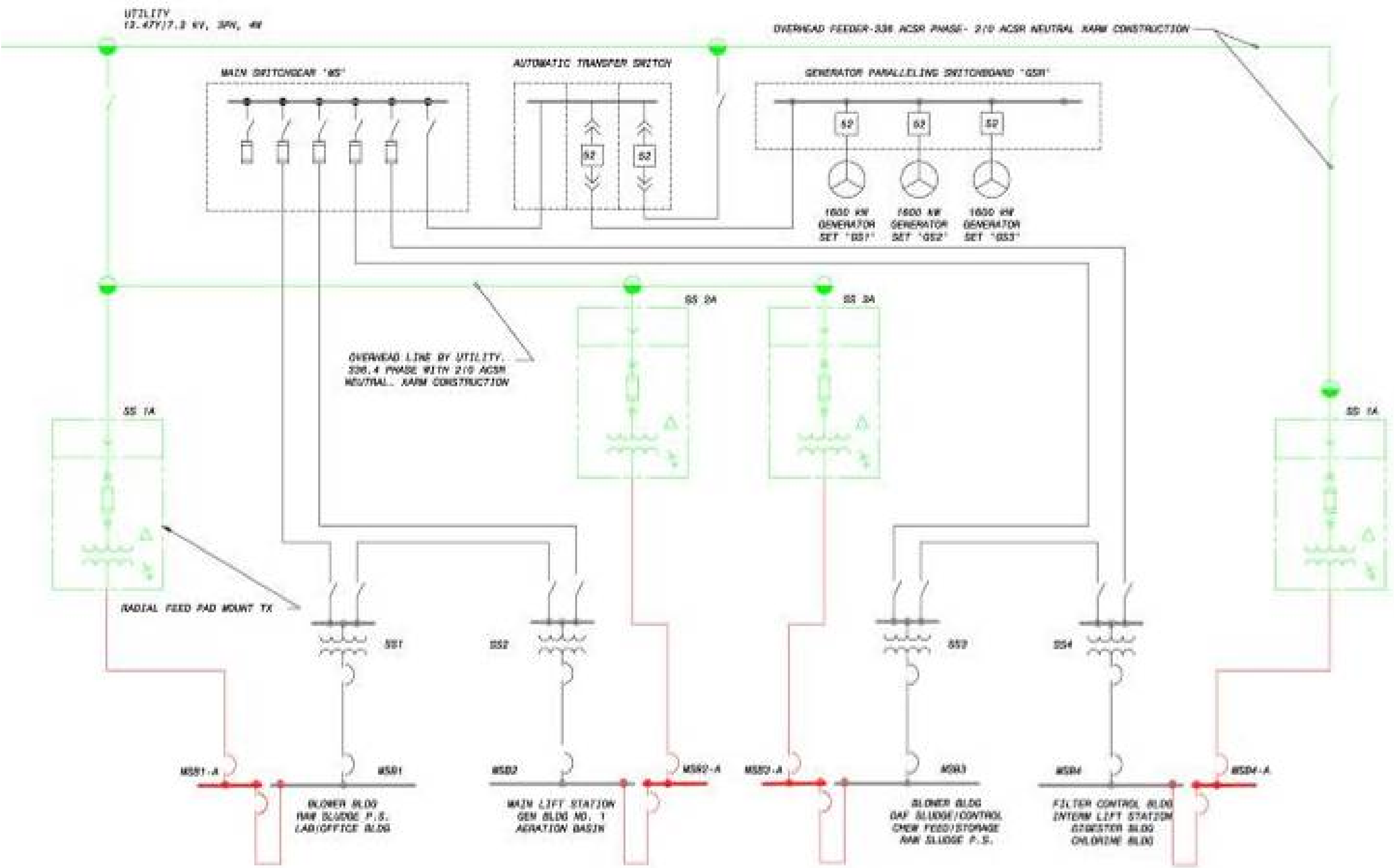
POWER TRAIN	INDEX
• 2A: New OH line w/ATS to MSB1	1.0307
• 2B: New OH line w/ATS MSB1 via SS2	0.8567
• Comparison to Existing:	
◦ 1A: Existing to MSB1	1.6355
◦ 1B: Existing to MSB1 via SS2	1.5583

Reliability Calculations - Proposed System

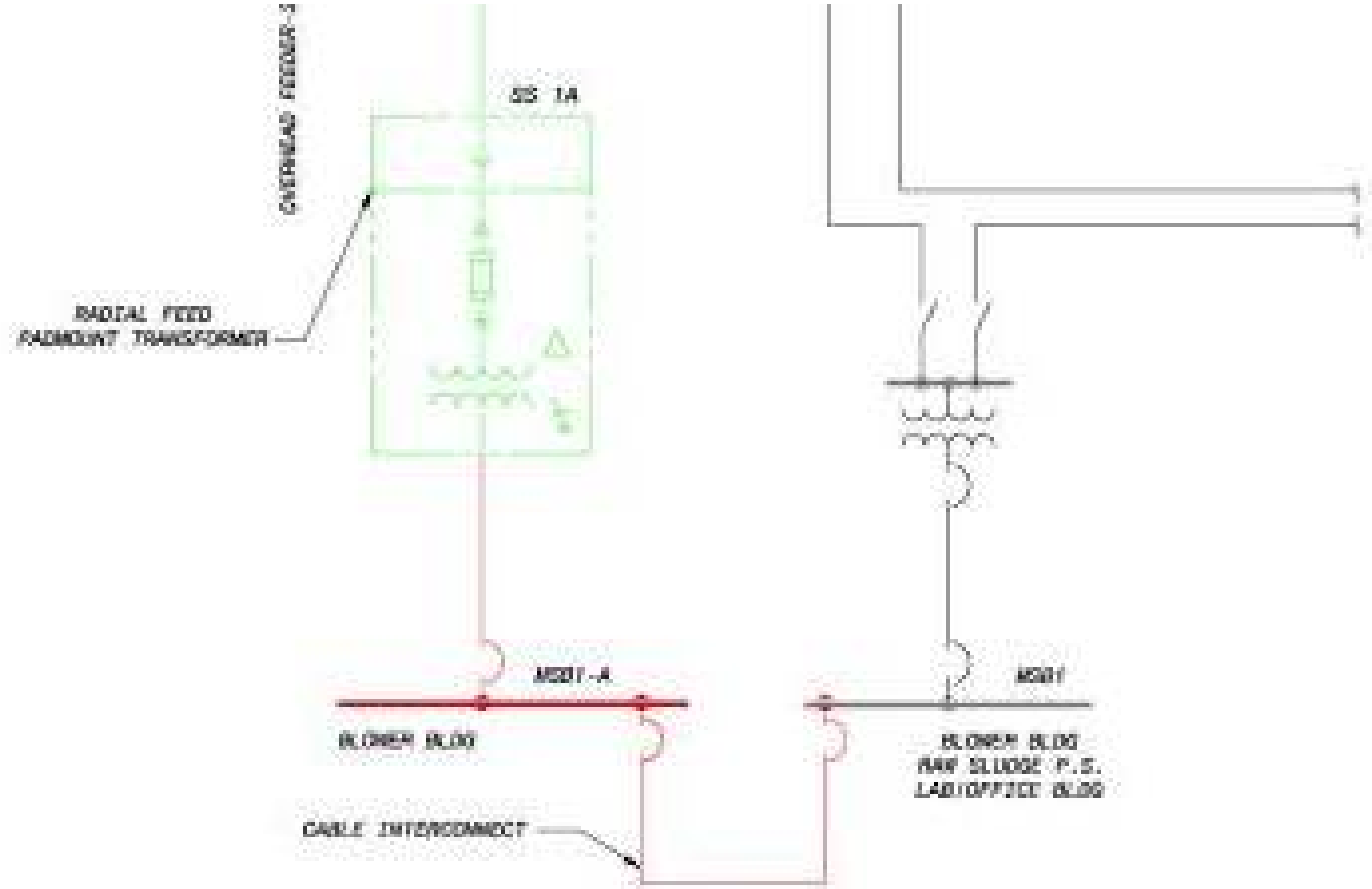
Alternative 2: (4) Padmount Transformers with Automatic Transfer Switches

$860,000

Alternative 3



Alternative 3



Reliability Calculations - Proposed System

Alternative 3: (4) Padmount Transformers with Redundant MSBs

POWER TRAIN	INDEX
• 3A: Transformer to M-T-M MSB1/1A	0.7306
• 3B: Transformer to M-T-M MSB1/1A via SS2	0.7165

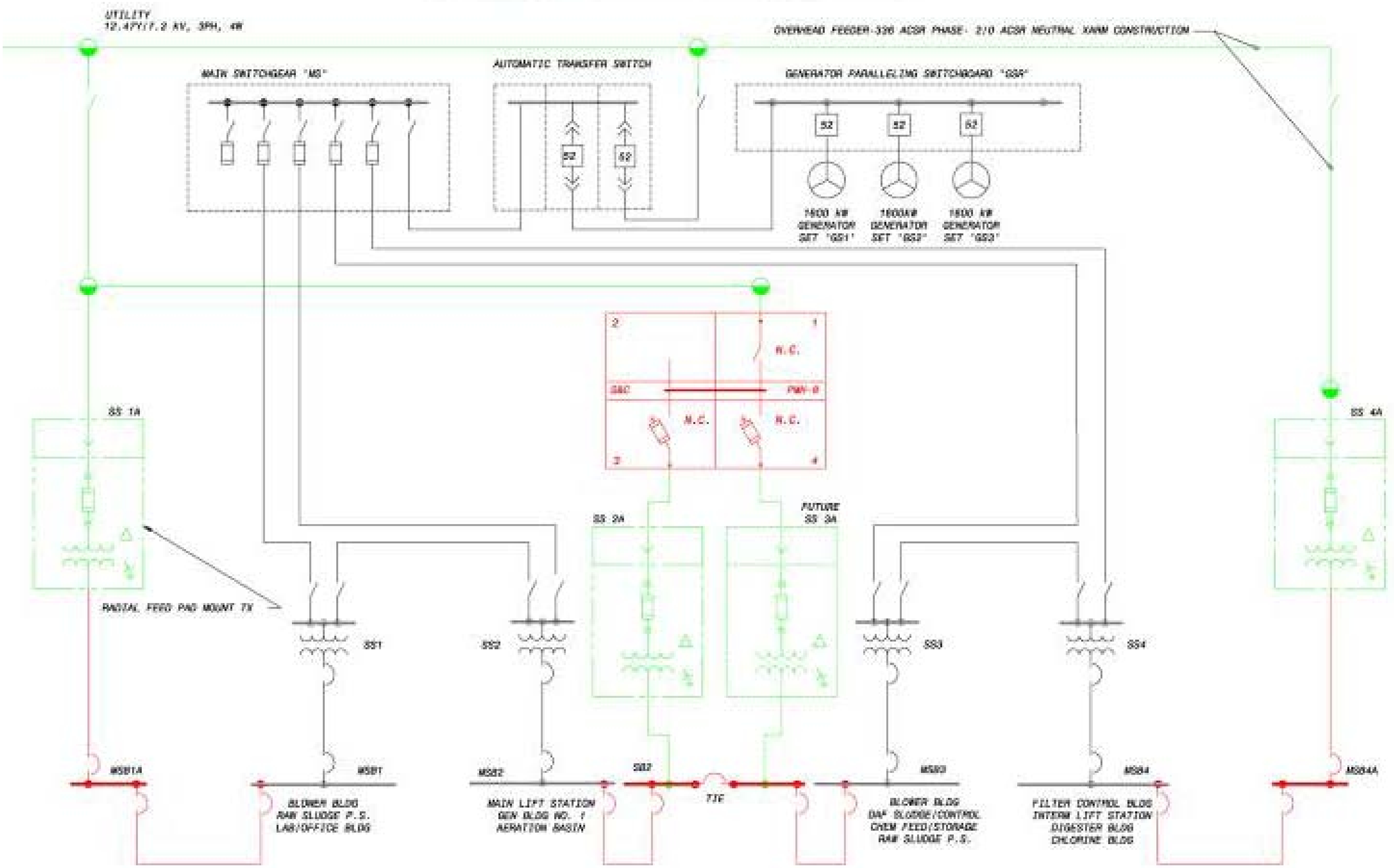
- Comparison to Existing:
  - 1A: Existing to MSB1 — 1.6355
  - 1B: Existing to MSB1 via SS2 — 1.5583

Reliability Calculations - Proposed System

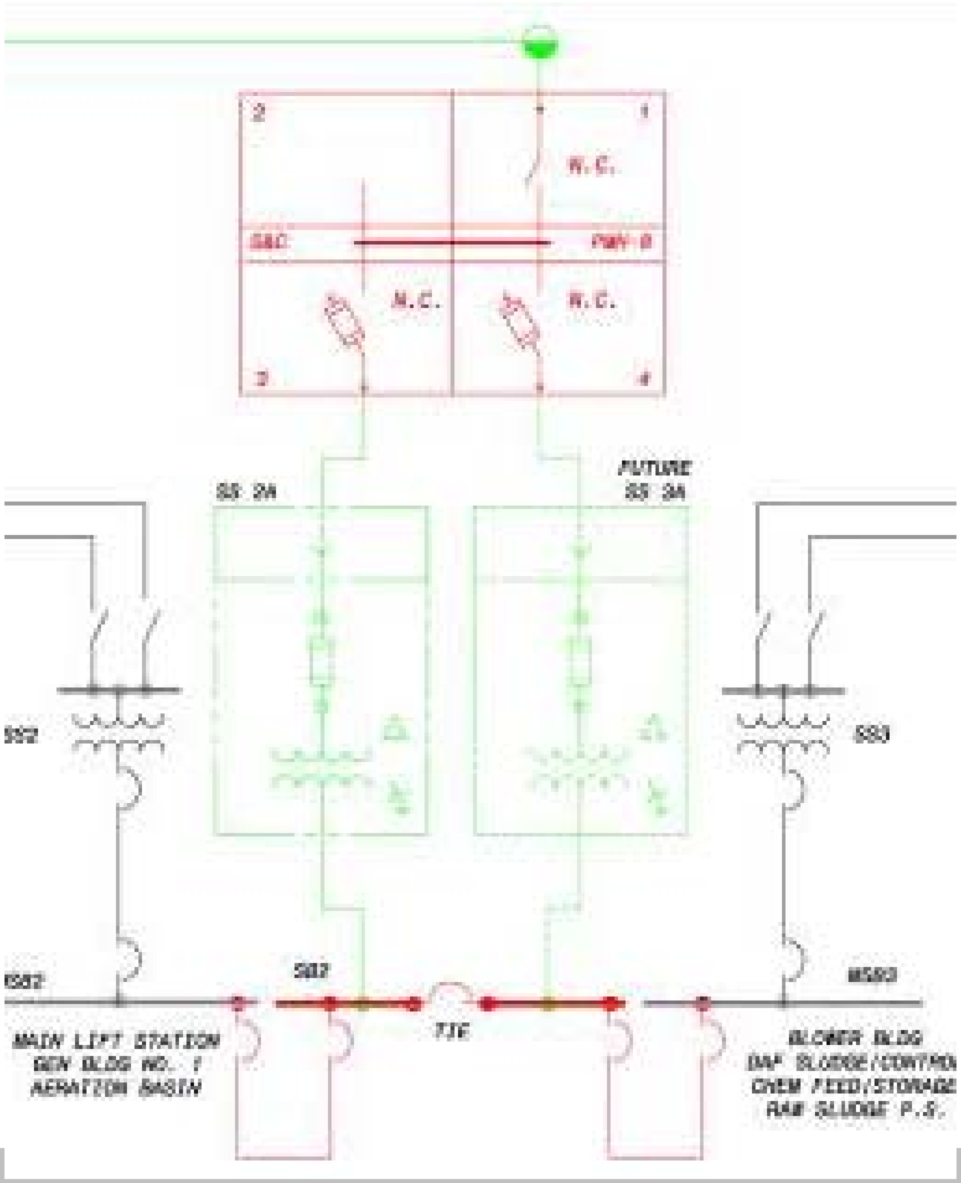
Alternative 3: (4) Padmount Transformers with Redundant MSBs

$1,100,000

Alternative 6



Alternative 6



Reliability Calculations - Proposed System

Alternative 6: (3) Padmount Transformers with PMH Switch Supplying MSB-2 & MSB-3

POWER TRAIN	INDEX
6A: Transformer to PMH to MSB-2/2A	0.8118
6B: Transformer to PMH to MSB-2A to MSB-3A	0.8496

- Comparison to Existing:
  - 1A: Existing to MSB1 — 1.6355
  - 1B: Existing to MSB1 via SS2 — 1.5583

Reliability Calculations - Proposed System

Alternative 6: (3) Padmount Transformers with PMH Switch Supplying MSB-2 & MSB-3

$1,160,000

Reliability Calculations - Proposed System

DESCRIPTION	APP. COST
Alternative 2: (4) Padmount Transformers with Automatic Transfer Switches	$860,000
Alternative 3: (4) Padmount Transformers with Redundant MSBs	$1,100,000
Alternative 6: (3) Padmount Transformers with PMH Switch Supplying MSB-2 & MSB-3	$1,160,000

Reliability Calculations - Proposed System

DESCRIPTION	APP. COST
Alternative 2: (4) Padmount Transformers with Automatic Transfer Switches	$860,000
Alternative 3: (4) Padmount Transformers with Redundant MSBs	$1,100,000
Alternative 6: (3) Padmount Transformers with PMH Switch Supplying MSB-2 & MSB-3	$1,160,000

Reliability Calculations - Proposed System

DESCRIPTION	Rel. Index
Existing System	1.6355
Alternative 2: (4) Padmount Transformers with Automatic Transfer Switches	1.0307
Alternative 3: (4) Padmount Transformers with Redundant MSBs	0.7306
Alternative 6: (3) Padmount Transformers with PMH Switch Supplying MSB-2 & MSB-3	0.8118

Reliability Calculations

SUMMARY OF RELIABILITY ANALYSIS	
DESCRIPTION	λr (forced hrs of downtime/year)
OPTION 1A: EXISTING DISTRIBUTION SYSTEM WITH UTILITY/GENERATOR TO MSB1	
Source 1: 12.47 kV Single Circuit Electric Utility to ATS	0.7703
Source 2: Plant Engine-Generators, 3-1600 kW, to ATS	81.5352
Combine 12.47 kV Sources #1 & #2 to ATS	0.7631
Distribution System From ATS to MS Swgr Main Fused Switch	0.4341
Combine 12.47 kV Sources #1 & #2 to ATS	0.7631
Combine 12.47 kV Sources #1 & #2 to ATS to MS Swgr Main Fused Switch	1.1972
Distribution System From MS Swgr Feeder to SS1 Primary Switch	0.2644
Distribution System From SS1 Primary Switch to Transformer to MSB1	1.3711
Distribution System From MS Swgr Feeder to SS1 Primary Switch	0.2644
TOTAL OPTION 1A	**1.6355**
OPTION 1B: EXISTING DISTRIBUTION SYSTEM WITH UTILITY/GENERATOR TO MSB1 & VIA SS2	
Source 1: 12.47 kV Single Circuit Electric Utility to ATS	0.7703
Source 2: Plant Engine-Generators, 3-1600 kW, to ATS	81.5352
Combine 12.47 kV Sources #1 & #2 to ATS	0.7631
Distribution System From ATS to MS Swgr Main Fused Switch	0.4341
Combine 12.47 kV Sources #1 & #2 to ATS	0.7631
Combine 12.47 kV Sources #1 & #2 to ATS to MS Swgr Main Fused Switch	1.1972
Distribution System From MS Swgr Feeder to SS1 Primary Switch	0.2644
Distribution System From MS Swgr Feeder to SS2 Primary Switch to SS1 Primary Switch	0.6408
Distribution System From MS Swgr Feeder to SS1 Primary Switch	0.2644
Combine MS Feeder to SS1 Switch & MS Feeder to SS2 Switch to SS1 Switch	0.1872
Distribution System From SS1 Primary Switch to Transformer to MSB1	1.3711
Combine MS Feeder to SS1 Switch & MS Feeder to SS2 Switch to SS1 Switch	0.1872
TOTAL OPTION 1B	**1.5583**

Reliability Calculations

OPTION 1C: EXISTING DISTRIBUTION SYSTEM WITH UTILITY/GENERATOR TO MSB3	
Source 1: 12.47 kV Single Circuit Electric Utility to ATS	0.7703
Source 2: Plant Engine-Generators, 3-1600 kW, to ATS	81.5352
Combine 12.47 kV Sources #1 & #2 to ATS	0.7631
Distribution System From ATS to MS Swgr Main Fused Switch	0.4341
Combine 12.47 kV Sources #1 & #2 to ATS	0.7631
Combine 12.47 kV Sources #1 & #2 to ATS to MS Swgr Main Fused Switch	1.1972
Distribution System From MS Swgr Feeder to SS3 Primary Switch	0.3326
Distribution System From SS3 Primary Switch to Transformer to MSB3	1.3189
Distribution System From MS Swgr Feeder to SS3 Primary Switch	0.3326
TOTAL OPTION 1C	**1.6515**
OPTION 1D: EXISTING DISTRIBUTION SYSTEM WITH UTILITY/GENERATOR TO MSB3 & VIA SS4	
Source 1: 12.47 kV Single Circuit Electric Utility to ATS	0.7703
Source 2: Plant Engine-Generators, 3-1600 kW, to ATS	81.5352
Combine 12.47 kV Sources #1 & #2 to ATS	0.7631
Distribution System From ATS to MS Swgr Main Fused Switch	0.4341
Combine 12.47 kV Sources #1 & #2 to ATS	0.7631
Combine 12.47 kV Sources #1 & #2 to ATS to MS Swgr Main Fused Switch	1.1972
Distribution System From MS Swgr Feeder to SS3 Primary Switch	0.3326
Distribution System From MS Swgr Feeder to SS4 Primary Switch to SS3 Primary Switch	1.2159
Distribution System From MS Swgr Feeder to SS3 Primary Switch	0.3326
Combine MS Feeder to SS3 Switch & MS Feeder to SS4 Switch to SS3 Switch	0.2612
Distribution System From SS3 Primary Switch to Transformer to MSB3	1.3189
Combine MS Feeder to SS3 Switch & MS Feeder to SS4 Switch to SS3 Switch	0.2612
TOTAL OPTION 1D	**1.5801**

Reliability Calculations

OPTION 2A: NEW OVERHEAD LINE TO TRANSFORMER TO 480 V ATS TO MSB1 MAIN BREAKER	
Source 3: 12.47 kV Single Circuit Tap Electric Utility to SS1A to 480 V ATS EP Lugs	1.2178
Combine 12.47 kV Sources #1 & #2 to ATS to MS Swgr Main Fused Switch	1.1972
Distribution System From MS Swgr Feeder to SS1 Primary Switch	0.2644
Combine 12.47 kV Sources to ATS to MS Swgr to SS1 Primary Switch	1.4616
Distribution System From SS1 Primary Switch to Transformer to 480 V ATS NP Lugs	1.3149
Combine 12.47 kV Sources to ATS to MS Swgr to SS1 Primary Switch	1.4616
Combine Option 1A with 2 Sources to ATS to MS to SS1 to 480 V ATS NP Lugs	2.7765
Source 3: 12.47 kV Single Circuit Tap Electric Utility to SS1A to 480 V ATS EP Lugs	1.2178
Combine Source 3 with 12.47 kV Tap with Option 1A: ATS-MS-SS1-480 V ATS NP Lugs	0.8465
Distribution System From 480 V ATS to MSB1 Main Breaker	0.1841
Combine Source 3 with 12.47 kV Tap with Option 1A: ATS-MS-SS1-480 V ATS NP Lugs	0.8465
TOTAL OPTION 2A	**1.0307**
OPTION 2B: NEW OVERHEAD LINE TO TRANSFORMER TO 480 V ATS TO MSB1 MAIN BREAKER VIA SS2	
Source 3: 12.47 kV Single Circuit Tap Electric Utility to SS1A to 480 V ATS EP Lugs	1.2178
Combine MS Feeder to SS1 Switch & MS Feeder to SS2 Switch to SS1 Switch	0.1872
Distribution System From SS1 Switch to Transformer to 480 V ATS NP Lugs	1.3149
Combine MS Feeder to SS1 Switch & MS Feeder to SS2 Switch to SS1 Switch	0.1872
Combine Option 1B with SS1 and SS1 via SS2 Switch to 480 V ATS NP Lugs	1.5021
Source 3: 12.47 kV Single Circuit Tap Electric Utility to SS1A to 480 V ATS EP Lugs	1.2178
Combine Source 3 with 12.47 kV Tap with Option 1B: ATS-MS-SS1 and SS1 via SS2-480 V ATS NP Lugs	0.6726
Distribution System From 480 V ATS to MSB1 Main Breaker	0.1841
Combine Source 3 with 12.47 kV Tap with Option 1B: ATS-MS-SS1 and SS1 via SS2-480 V ATS NP Lugs	0.6726
TOTAL OPTION 2B	**0.8567**

Reliability Calculations

OPTION 3A: NEW OVERHEAD LINE TO TRANSFORMER TO MSB1-A WITH MAIN-TIE-MAIN TO MSB1	
Source 3: 12.47 kV Single Circuit Tap Electric Utility to SS1A to MSB1-A	1.2643
Source 1: 12.47 kV Single Circuit Electric Utility to ATS	0.7703
Source 2: Plant Engine-Generators, 3-1600 kW, to ATS	81.5352
Source 1: 12.47 kV Single Circuit Electric Utility to ATS	0.7703
Combine 12.47 kV Sources #1 & #2 to ATS	0.7631
Distribution System From ATS to MS Swgr Main Fused Switch	0.4341
Combine 12.47 kV Sources #1 & #2 to ATS	0.7631
Combine 12.47 kV Sources #1 & #2 to ATS to MS Swgr Main Fused Switch	1.1972
Distribution System From MS Swgr Feeder to SS1 Primary Switch	0.2644
Distribution System From SS1 Primary Switch to Transformer to MSB1	1.3711
Distribution System From MS Swgr Feeder to SS1 Primary Switch	0.2644
Combine Existing Distribution System to ATS-MS-SS1-Transformer-MSB1	1.6355
Bus-Tie Breaker from MSB1 to MSB1-A	0.0955
Combine Existing Distribution System to ATS-MS-SS1-Transformer-MSB1	1.6355
Combine Existing Distribution to MSB1 with Bus-Tie Breaker from MSB1 to MSB1-A	1.7310
Source 3: 12.47 kV Single Circuit Tap Electric Utility to SS1A to MSB1-A	1.2643
TOTAL OPTION 3A	**0.7306**

Reliability Calculations

OPTION 3B: NEW OH LINE TO TRANSFORMER TO MSB1-A WITH MAIN-TIE-MAIN TO MSB1 VIA SS2	
Source 3: 12.47 kV Single Circuit Tap Electric Utility to SS1A to MSB1-A	1.2643
Source 1: 12.47 kV Single Circuit Electric Utility to ATS	0.7703
Source 2: Plant Engine-Generators, 3-1600 kW, to ATS	81.5352
Source 1: 12.47 kV Single Circuit Electric Utility to ATS	0.7703
Combine 12.47 kV Sources #1 & #2 to ATS	0.7631
Distribution System From ATS to MS Swgr Main Fused Switch	0.4341
Combine 12.47 kV Sources #1 & #2 to ATS	0.7631
Combine 12.47 kV Sources #1 & #2 to ATS to MS Swgr Main Fused Switch	1.1972
Distribution System From MS Swgr Feeder to SS1 Primary Switch	0.2644
Distribution System From MS Swgr Feeder to SS2 Primary Switch to SS1 Primary Switch	0.6408
Distribution System From MS Swgr Feeder to SS1 Primary Switch	0.2644
Combine MS Feeder to SS1 Switch & MS Feeder to SS2 Switch to SS1 Switch	0.1872
Distribution System From SS1 Primary Switch to Transformer to MSB1	1.3711
Combine MS Feeder to SS1 Switch & MS Feeder to SS2 Switch to SS1 Switch	0.1872
Combine Existing System to SS1 Switch & Via SS2 Switch to MSB1	1.5583
Bus-Tie Breaker from MSB1 to MSB1-A	0.0955
Combine Existing System to SS1 Switch & Via SS2 Switch to MSB1	1.5583
Combine Existing System to MSB1-A with Bus-Tie Breaker from MSB1 to MSB1-A	1.6538
Source 3: 12.47 kV Single Circuit Tap Electric Utility to SS1A to MSB1-A	1.2643
TOTAL OPTION 3B	**0.7165**

Reliability Calculations – Detailed Calculations

OPTION 6A: NEW OVERHEAD LINE TO PMH-8 TO TRANSFORMER TO MAIN-TIE-MAIN MSB2-A	
Source 3: 12.47 kV Single Circuit Tap Electric Utility to PMH-8 to Transformer to MSB2-A	1.6310
Source 1: 12.47 kV Single Circuit Electric Utility to ATS	0.7703
Source 2: Plant Engine-Generators, 3-1600 kW, to ATS	81.5352
Source 1: 12.47 kV Single Circuit Electric Utility to ATS	0.7703
Combine 12.47 kV Sources #1 & #2 to ATS	0.7631
Distribution System From ATS to MS Swgr Main Fused Switch	0.4341
Combine 12.47 kV Sources #1 & #2 to ATS	0.7631
Combine 12.47 kV Sources #1 & #2 to ATS to MS Swgr Main Fused Switch	1.1972
Distribution System From MS Swgr Feeder to SS2 Primary Switch	0.2644
Distribution System From MS Swgr Feeder to SS1 Primary Switch to SS2 Primary Switch	0.5482
Distribution System From MS Swgr Feeder to SS2 Primary Switch	0.2644
Combine MS Feeder to SS2 Switch & MS Feeder to SS1 Switch to SS2 Switch	0.1784
Distribution System From SS2 Primary Switch to Transformer to MSB2	1.3559
Combine MS Feeder to SS2 Switch & MS Feeder to SS1 Switch to SS2 Switch	0.1784
Combine Existing System to SS2 Switch & Via SS1 Switch to MSB2	1.5343
Bus-Tie Breaker from MSB2 to MSB2-A	0.0821
Combine Existing System to SS2 Switch & Via SS1 Switch to MSB2	1.5343
Combine Existing System to MSB2-A with Bus-Tie Breaker from MSB2 to MSB2-A	1.6164
Source 3: 12.47 kV Single Circuit Tap Electric Utility to PMH-8 to Transformer to MSB2-A	1.6310
TOTAL OPTION 6A	**0.8118**

Reliability Calculations – Detailed Calculations

OPTION 6B: NEW OVERHEAD LINE TO PMH-8 TO TRANSFORMER TO MSB2-A TO MSB3-A		
	Source 3: 12.47 kV Single Circuit Tap Electric Utility to PMH-8 to Transformer to MSB3-A	1.6994
	Source 1: 12.47 kV Single Circuit Electric Utility to ATS	0.7703
	Source 2: Plant Engine-Generators, 3-1600 kW, to ATS	81.5352
	Source 1: 12.47 kV Single Circuit Electric Utility to ATS	0.7703
	Combine 12.47 kV Sources #1 & #2 to ATS	0.7631
	Distribution System From ATS to MS Swgr Main Fused Switch	0.4341
	Combine 12.47 kV Sources #1 & #2 to ATS	0.7631
	Combine 12.47 kV Sources #1 & #2 to ATS to MS Swgr Main Fused Switch	1.1972
	Distribution System From MS Swgr Feeder to SS3 Primary Switch	0.3326
	Distribution System From MS Swgr Feeder to SS4 Primary Switch to SS3 Primary Switch	1.2159
	Distribution System From MS Swgr Feeder to SS3 Primary Switch	0.3326
	Combine MS Feeder to SS3 Switch & MS Feeder to SS4 Switch to SS3 Switch	0.2612
	Distribution System From SS3 Primary Switch to Transformer to MSB3	1.3559
	Combine MS Feeder to SS3 Switch & MS Feeder to SS4 Switch to SS3 Switch	0.2612
	Combine Existing System to SS3 Switch & Via SS4 Switch to MSB3	1.6171
	Bus-Tie Breaker from MSB3 to MSB3-A	0.0821
	Combine Existing System to SS3 Switch & Via SS4 Switch to MSB3	1.6171
	Combine Existing System to MSB3-A with Bus-Tie Breaker from MSB3 to MSB3-A	1.6992
	Source 3: 12.47 kV Single Circuit Tap Electric Utility to PMH-8 to Transformer to MSB3-A	1.6994
	TOTAL OPTION 6B	**0.8496**

Reliability Calculations – Detailed Calculations

COMPONENTS		λ (failures/year)	r (hrs of downtime/failure)	λr (forced hrs of downtime/year)
OPTION 1A: EXISTING DISTRIBUTION SYSTEM WITH UTILITY/GENERATOR TO MSB1				
Source 1: 12.47 kV Single Circuit Electric Utility to ATS				
12.47 kV single utility circuit, Gastonia Electric 5-yr SAIDI=19.37144		---	---	0.0022
12.47 kV cable terminations (at riser pole)		0.0018	25.0	0.0450
Cables in parallel =	2			
Number of terminations =	6			
Failures/year, each =	0.0003			
Failures/year, total =	0.0018			
12.47 kV cables, underground, repair (riser to ATS)		0.0184	26.5	0.4873
Cables in parallel =	2			
Length of circuit (ft) =	500			
Failures/year per 1000 circuit feet =	0.00613			
Failures/year, total =	0.0184			
12.47 kV cable terminations (at ATS breaker)		0.0018	25.0	0.0450
Cables in parallel =	2			
Number of terminations =	6			
Failures/year, each =	0.0003			
Failures/year, total =	0.0018			
12.47 kV metal-clad breaker, replace (ATS incoming from utility)		0.0036	2.1	0.0076
12.47 kV switchgear bus-insulated, 2 breakers (ATS)		0.0068	26.8	0.1822
12.47 kV relay (assumed for ATS controls)		0.0002	5	0.0010
Source 1: 12.47 kV Single Circuit Electric Utility to ATS				**0.7703**

Reliability Calculations – Detailed Calculations

Source 2: Plant Engine-Generators, 3-1600 kW, to ATS					
12.47 kV standby diesel engine-generator (G1/2/3)			0.1691	478	80.8298
12.47 kV metal-clad breaker, replace (G1/2/3 breaker)			0.0036	2.1	0.0076
12.47 kV cable terminations (at G1/2/3 breaker)			0.0009	25.0	0.0225
	Cables in parallel =	1			
	Number of terminations =	3			
	Failures/year, each =	0.0003			
	Failures/year, total =	0.0009			
12.47 kV cables, underground, repair (G1/2/3 breaker to gen swgr)			0.0005	26.5	0.0122
	Cables in parallel =	1			
	Length of circuit (ft) =	25			
	Failures/year per 1000 circuit feet =	0.00613			
	Failures/year, total =	0.0005			
12.47 kV cable terminations (at gen swgr breakers)			0.0009	25.0	0.0225
	Cables in parallel =	1			
	Number of terminations =	3			
	Failures/year, each =	0.0003			
	Failures/year, total =	0.0009			
12.47 kV metal-clad breaker, replace (gen swgr)			0.0036	2.1	0.0076
12.47 kV switchgear bus-insulated, 3 breakers (gen swgr)			0.0102	26.8	0.2734
12.47 kV relay (gen swgr)			0.0002	5	0.0010
12.47 kV cable terminations (at gen swgr bus tap)			0.0018	25.0	0.0450
	Cables in parallel =	2			
	Number of terminations =	6			
	Failures/year, each =	0.0003			
	Failures/year, total =	0.0018			
12.47 kV cables, underground, repair (gen swgr to ATS breaker)			0.0029	26.5	0.0780
	Cables in parallel =	2			
	Length of circuit (ft) =	80			
	Failures/year per 1000 circuit feet =	0.00613			
	Failures/year, total =	0.0029			
12.47 kV cable terminations (at ATS breaker)			0.0018	25.0	0.0450
	Cables in parallel =	2			
	Number of terminations =	6			
	Failures/year, each =	0.0003			
	Failures/year, total =	0.0018			
12.47 kV metal-clad breaker, replace (ATS incoming from gens)			0.0036	2.1	0.0076
12.47 kV switchgear bus-insulated, 2 breakers (ATS)			0.0068	26.8	0.1822
12.47 kV relay (assumed for ATS controls)			0.0002	5	0.0010
Source 2: Plant Engine-Generators, 3-1600 kW, to ATS					**81.5352**

Reliability Calculations – Detailed Calculations

Failures/year, each =	0.0003			
Failures/year, total =	0.0018			
12.47 kV metal-clad breaker, replace (ATS incoming from gens)		0.0036	2.1	0.0076
12.47 kV switchgear bus-insulated, 2 breakers (ATS)		0.0068	26.8	0.1822
12.47 kV relay (assumed for ATS controls)		0.0002	5	0.0010
Source 2: Plant Engine-Generators, 3-1600 kW, to ATS				**81.5352**
Source 1: 12.47 kV Single Circuit Electric Utility to ATS				**0.7703**
Combine 12.47 kV Sources #1 & #2 to ATS				**0.7631**
Distribution System From ATS to MS Swgr Main Fused Switch				
12.47 kV cable terminations (at ATS bus)		0.0018	25.0	0.0450
Cables in parallel =	2			
Number of terminations =	6			
Failures/year, each =	0.0003			

Reliability Calculations – Detailed Calculations

Distribution System From ATS to MS Swgr Main Fused Switch					
12.47 kV cable terminations (at ATS bus)			0.0018	25.0	0.0450
	Cables in parallel =	2			
	Number of terminations =	6			
	Failures/year, each =	0.0003			
	Failures/year, total =	0.0018			
12.47 kV cables, underground, repair (ATS to MS main switch)			0.0018	26.5	0.0487
	Cables in parallel =	2			
	Length of circuit (ft) =	50			
	Failures/year per 1000 circuit feet =	0.00613			
	Failures/year, total =	0.0018			
12.47 kV cable terminations (at MS main switch)			0.0018	25.0	0.0450
	Cables in parallel =	2			
	Number of terminations =	6			
	Failures/year, each =	0.0003			
	Failures/year, total =	0.0018			
12.47 kV metal-enclosed switch, replace (MS main switch)			0.0061	3.6	0.0220
12.47 kV switchgear bus-insulated, 3+ switches (MS)			0.0102	26.8	0.2734
Distribution System From ATS to MS Swgr Main Fused Switch					**0.4341**
Combine 12.47 kV Sources #1 & #2 to ATS					**0.7631**
Combine 12.47 kV Sources #1 & #2 to ATS to MS Swgr Main Fused Switch					**1.1972**

Reliability Calculations – Detailed Calculations

Distribution System From MS Swgr Feeder to SS1 Primary Switch					
12.47 kV metal-enclosed switch, replace (MS feeder to SS1)			0.0061	3.6	0.0220
12.47 kV cable terminations (at MS feeder to SS1)			0.0009	25.0	0.0225
	Cables in parallel =	1			
	Number of terminations =	3			
	Failures/year, each =	0.0003			
	Failures/year, total =	0.0009			
12.47 kV cables, underground, repair (MS feeder to SS1 switch)			0.0066	26.5	0.1754
	Cables in parallel =	1			
	Length of circuit (ft) =	360			
	Failures/year per 1000 circuit feet =	0.00613			
	Failures/year, total =	0.0066			
12.47 kV cable terminations (at SS1 primary selective switch)			0.0009	25.0	0.0225
	Cables in parallel =	1			
	Number of terminations =	3			
	Failures/year, each =	0.0003			
	Failures/year, total =	0.0009			
12.47 kV metal-enclosed switch, replace (SS1 primary selective)			0.0061	3.6	0.0220
Distribution System From MS Swgr Feeder to SS1 Primary Switch					**0.2644**

Reliability Calculations – Detailed Calculations

Distribution System From SS1 Primary Switch to Transformer to MSB1					
12.47 kV switchgear bus-insulated, 2 switches (SS1 primary)			0.0068	26.8	0.1822
Transformer, 12.47 kV-480 V, replace (SS1)			0.0030	342.0	1.0260
480 V transformer secondary breaker (SS1 secondary)			0.0027	4	0.0108
480 V cable terminations (at SS1 transformer secondary breaker)			0.0033	3.8	0.0125
	Cables in parallel =	11			
	Number of terminations =	33			
	Failures/year, each =	0.0001			
	Failures/year, total =	0.0033			
480 V cables, abovegrade, repair (SS1 secondary breaker to MSB1)			0.0056	10.5	0.0586
	Cables in parallel =	11			
	Length of circuit (ft) =	120			
	Failures/year per 1000 circuit feet =	0.00141			
	Failures/year, total =	0.0056			
480 V cable terminations (at MSB1 main breaker)			0.0033	3.8	0.0125
	Cables in parallel =	11			
	Number of terminations =	33			
	Failures/year, each =	0.0001			
	Failures/year, total =	0.0033			
480 V metalclad drawout breaker (MSB1 main breaker)			0.0027	4	0.0108
480 V switchgear bus-bare, 7 breakers (MSB1)			0.0024	24	0.0576
Distribution System From SS1 Primary Switch to Transformer to MSB1					**1.3711**
Distribution System From MS Swgr Feeder to SS1 Primary Switch					**0.2644**
OPTION 1A: EXISTING DISTRIBUTION SYSTEM WITH UTILITY/GENERATOR TO MSB1					**1.6355**

Motors

Component	Energy Loss, FL (%)
Motors: 1 to 10 Hp	14.00 to 35.00
Motors: 10 to 200 Hp	6.00 to 12.00
Motors: 200 to 1500 Hp	4.00 to 7.00
Motors: 1500 Hp and up	2.30 to 4.50
Variable Speed Drives	6.00 to 15.00
Motor Control Centers	0.01 to 0.40
MV Starters	0.02 to 0.15
MV Switchgear	0.005 to 0.02
LV Switchgear	0.13 to 0.34

Reference: ANSI/IEEE Standard 141 (Red Book), Table 55

Motors

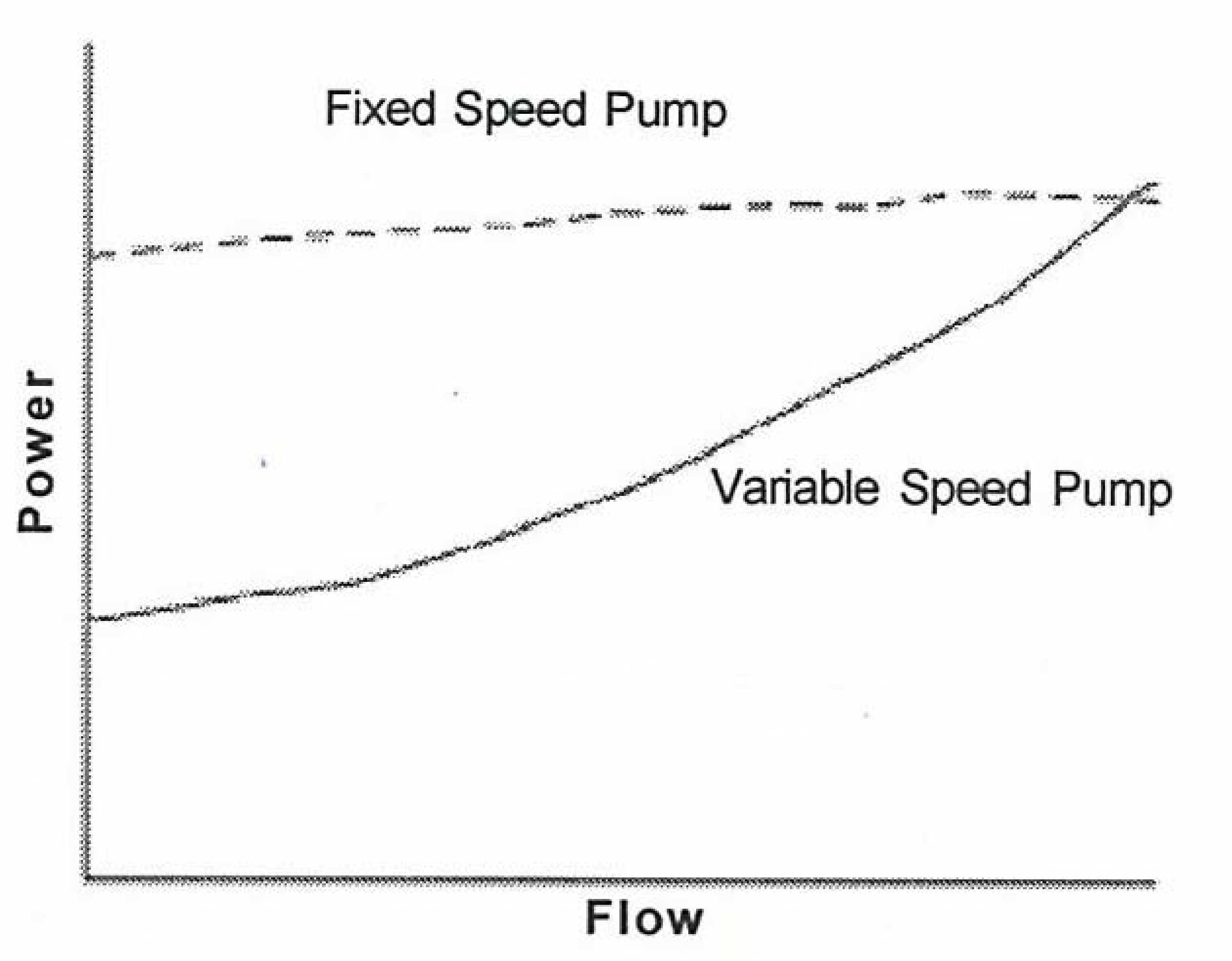
- Motor driven systems represent about 60% of all electrical energy used
- Energy Policy Act of 1992 set min efficiencies for motors in the U.S.
- Manufacturers have increased motor efficiencies in the interim
- Premium-efficiency motors can therefore decrease losses

Reference: Copper Development Association

Variable Frequency Drives

- Very common device for energy efficiency
- AC to DC to Variable output with V/Hz constant
- Not suitable in all cases
- Optimum: Must have varying load
- Or dictated by application
- Example: Chemical feed pumps, small Hp, but precise dosing

Variable Frequency Drives



Reference: Energy Savings in Industry, Chapter 5, UNEP-IETC

Cables from VFDs to Motors

- VFDs convert 480 V at 60 Hz to a variable voltage with variable frequency
- VFD holds constant the ratio of V/Hz
- Nominal is 480 V/60 Hz = 8.0 at 100% motor speed
- If you want 50% speed, reduce the voltage to 240 V
- But need to correspondingly reduce the frequency by 50% or else motor won't operate
- Thus frequency is 30 Hz at 240 V, or 240 V/30 Hz = 8.0 constant

Cables from VFDs to Motors

- Same for any speed in the operating range
- If you want 37% speed:
- 480 V x 0.37 = 177.6 V
- If V/Hz is held constant at 8.0,
- Then frequency is V/8.0 = 177.6 V/8.0 = 22.2 Hz

Cables from VFDs to Motors

- **The VFD works similar to a UPS where incoming AC in rectified to DC, then inverted back to AC**
- **Because of the nearly infinite range of frequencies possible, the associated carrier frequencies of the VFD output circuit can generate abnormal EMF**
- **This EMF can corrupt adjacent circuit cables**
- **One method is to provide shielding around the cables between the VFD and the motor**

Cables from VFDs to Motors

- This shielding can easily be a steel conduit
- This works if the conduit is dedicated between the VFD and the motor
- If part of the cable run is in underground ductbank, then the PVC conduit in the ductbank no longer provides that shielding

Cables from VFDs to Motors

- Possible to install a steel conduit thru the ductbank to counteract
- But that would then restrict flexibility in the future to move these VFD cables to a spare conduit which would then be PVC
- Too costly to install all ductbank with RGS conduit

Cables from VFDs to Motors

- Also, if the cables pass thru a manhole or pull box along the way, it is very difficult to keep the VFD cables sufficiently separated from the other normal circuits
- If EMF is a problem with adjacent circuits, easy solution is to select 600 V, 3-conductor, shielded cables

Cables from VFDs to Motors

- However, the true nature of the EMF problem from VFD cables is not well known or calculated
- Much depends on the type of VFD installed, 6-pulse, 12-pulse, 18-pulse
- If there is an reactor on the output of the VFD
- How well the reactor mitigates harmonics
- What the length of the cable run is, i.e., introducing impedance in the circuit from the cable

Cables from VFDs to Motors

- **More significantly, the actual current flowing thru the cable can impact the EMF**
- **And, exactly what the voltage and frequency is at any one time since the voltage and frequency will vary**
- **In the end, right now, until more is known, prudent engineering is to specify shielded cables for VFDs with motors 60-100 Hp and above**

California Title 24

- California's mandate for energy efficiency
- Three major elements: architectural design, HVAC, lighting
- Lighting: limiting watts/sq ft by room classification, motion sensors, etc.
- Title 24 revised Oct 2005 to close loopholes
- Prior: lighting indoors in air conditioned spaces
- Now: all lighting indoors and now outdoors

Lighting Design

- HID lighting: HPS, LPS, MH, MV
- More efficient than incandescent or fluorescent
- Fluorescent provides better uniformity
- LPS is most efficient; poor in visual acuity
- And now LED in increasing applications

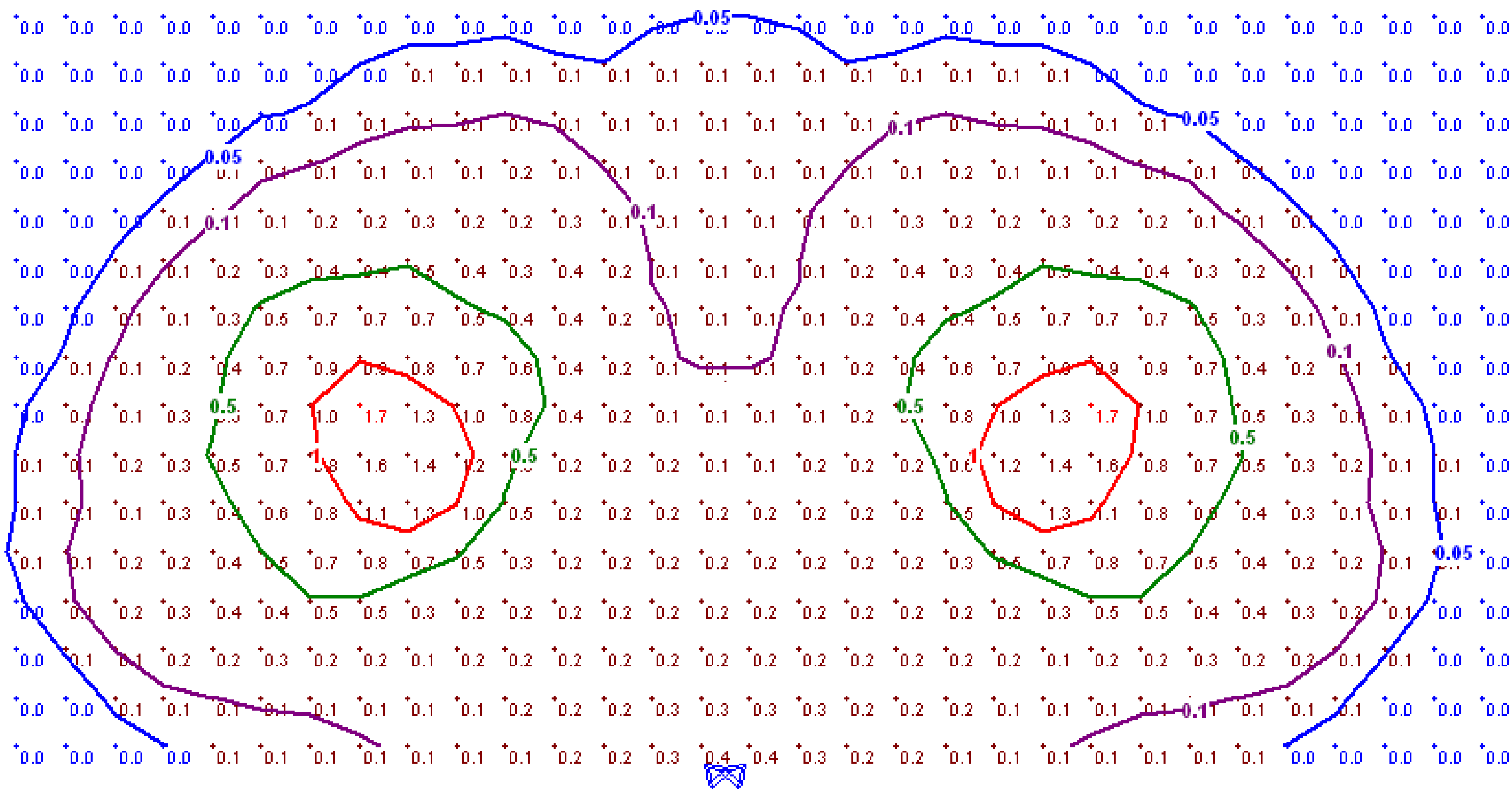
Lighting Design

- **Outdoor lighting on poles more complicated**
- **Factors:**
  - **Pole height**
  - **Pole spacing**
  - **Fixtures per pole**
  - **Fixture lamps type**
  - **Fixture wattage**
  - **Fixture light distribution pattern**
- **Photometric analysis using software (Visual, AGI32, etc.)**
- **Calculate average fc illumination & uniformity**
- **Life safety illumination for egress: 1 fc average, 0.1 fc one point**

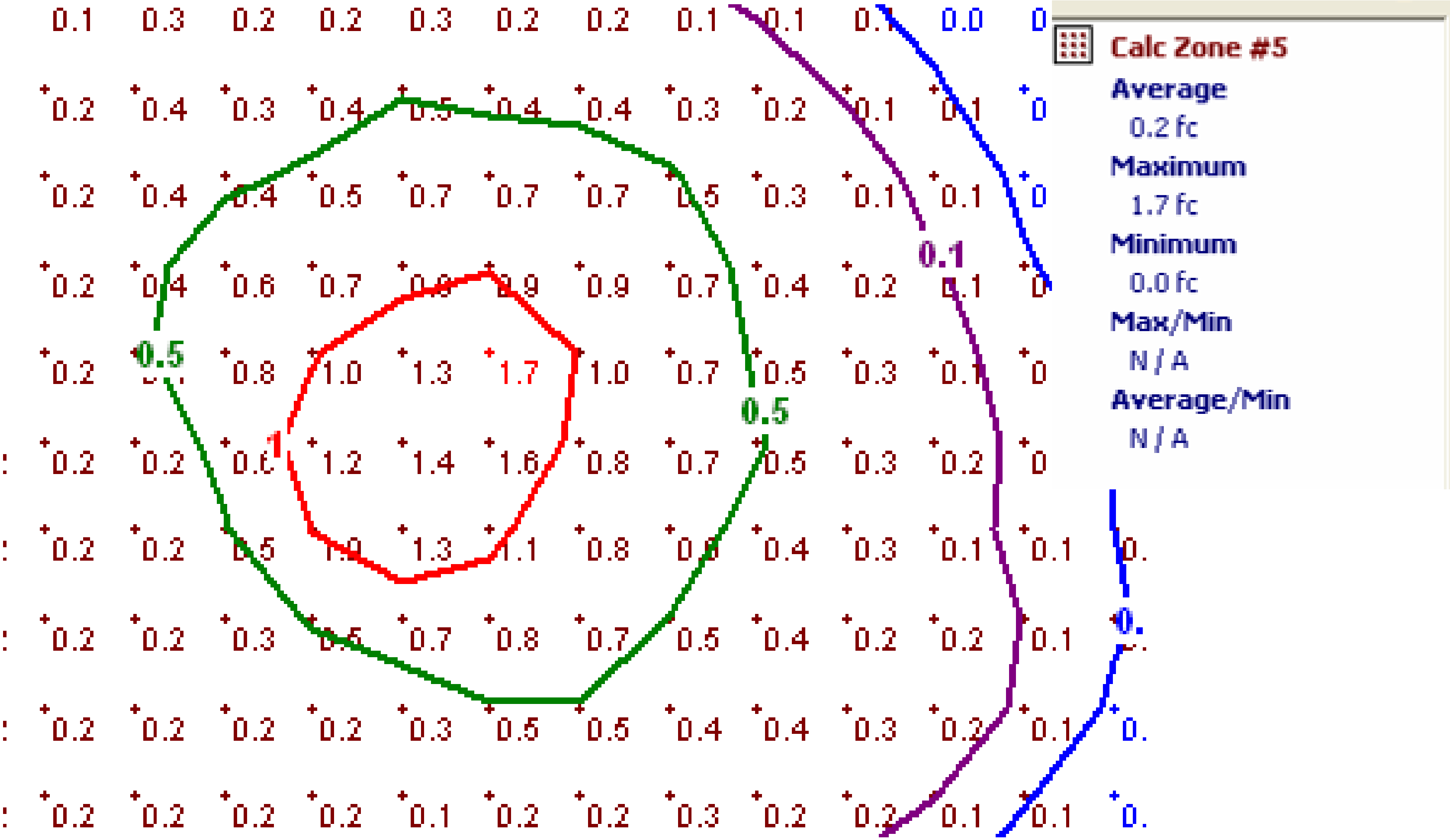
Photometric Calculations – Lighting

Photometric Calculations – Lighting

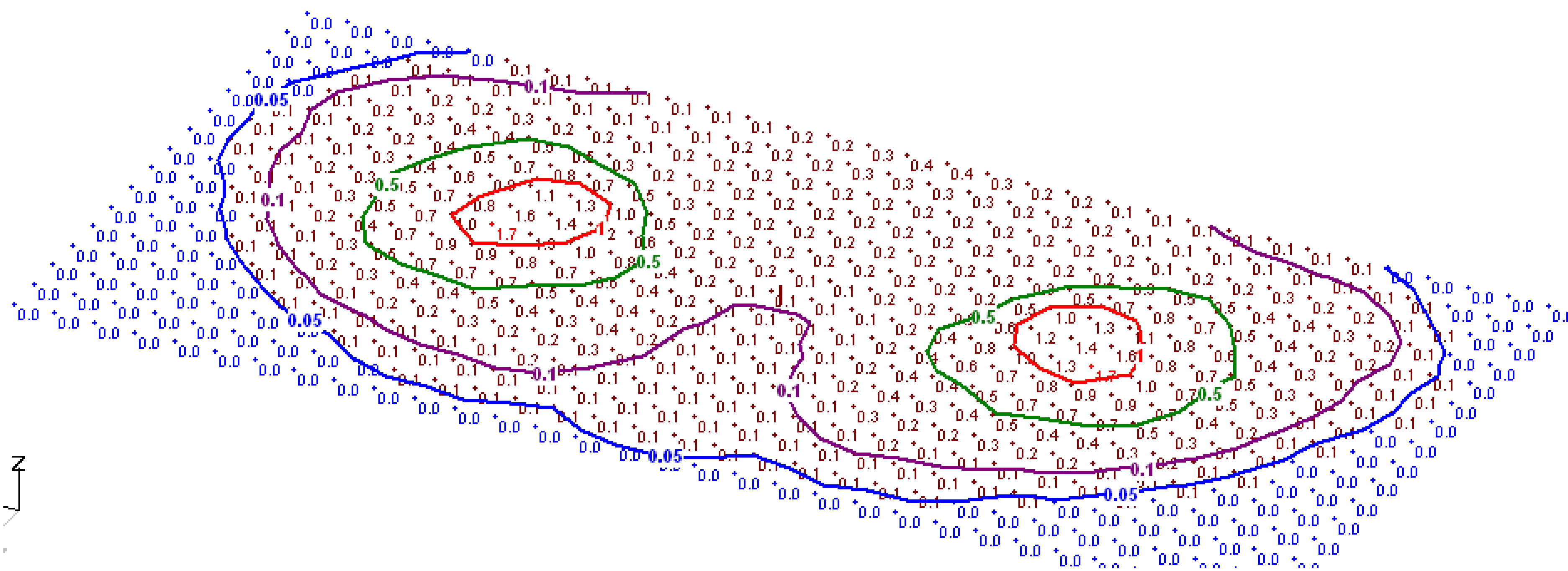
Photometric Calculations – Lighting



Photometric Calculations – Lighting



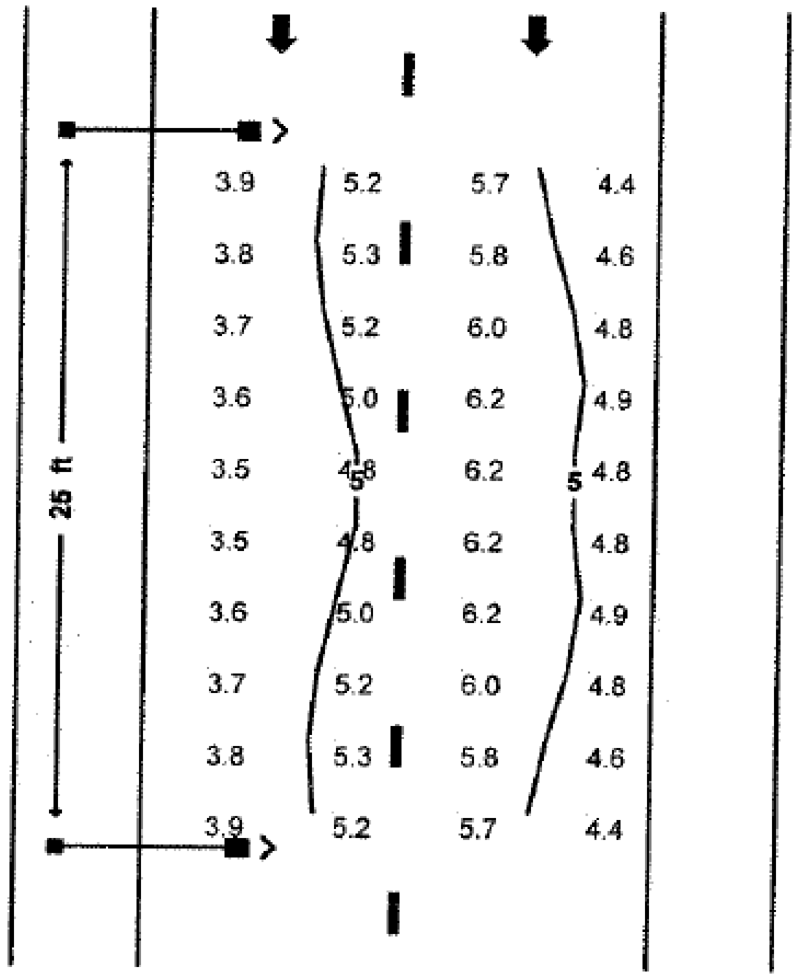
Photometric Calculations – Lighting



Photometric Calculations – Roadway Lighting

Visual Roadway Lighting Tool - GE 150 W HPS at 25 OC

Illuminance



Grid Statistics

Average	4.9	fc
Max	6.2	fc
Min	3.5	fc
Max/Min	1.8	
Avg/Min	1.4	

Grid Properties

Number of Rows	10	
Row Spacing	2.5	ft
Number of Columns	4	
Column Spacing	6	ft

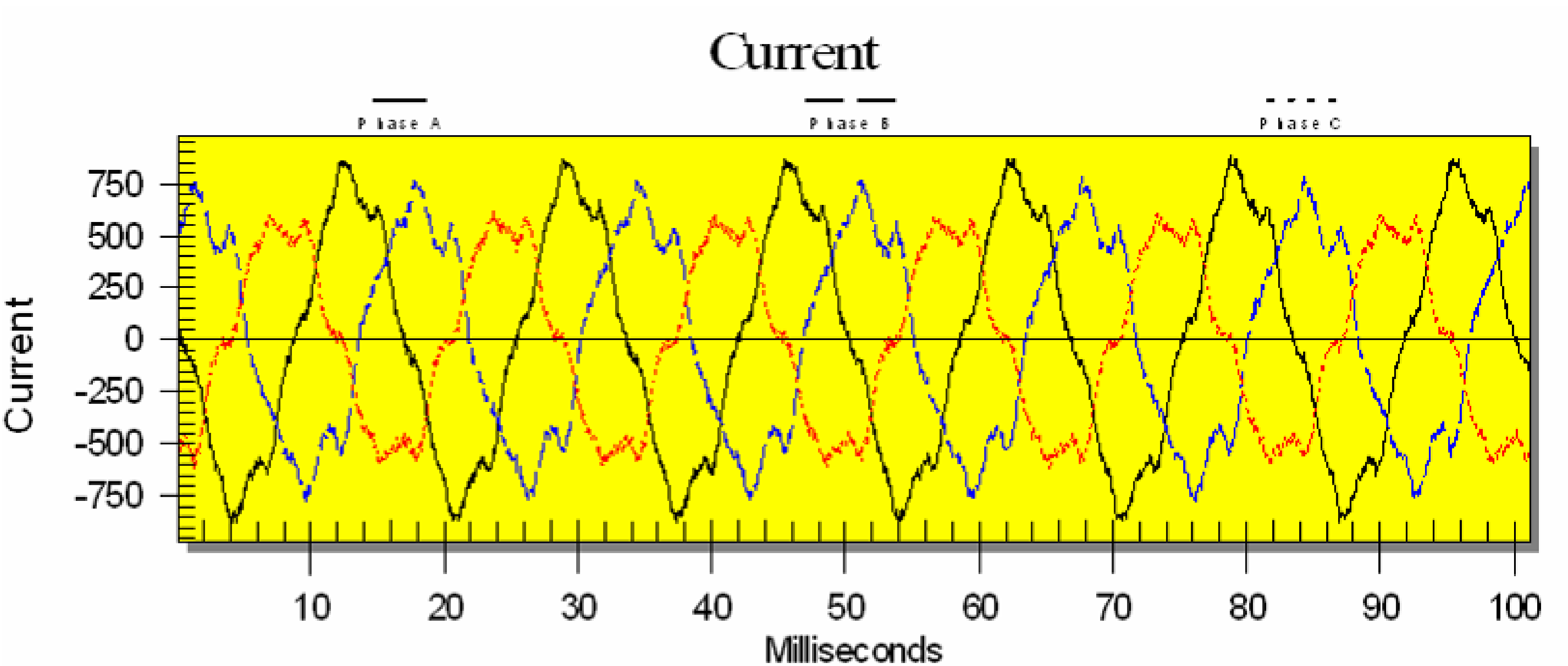
K-Factor Calculations – Dry-Type Transformers

- **K-Factor is a measure of the amount of harmonics in a power system**
- **K-Factor can be used to specify a dry-type transformer such that it can handle certain levels of harmonic content**
- **K-Factor rated transformers are generally built to better dissipate the additional heat generated from harmonic current and voltage**

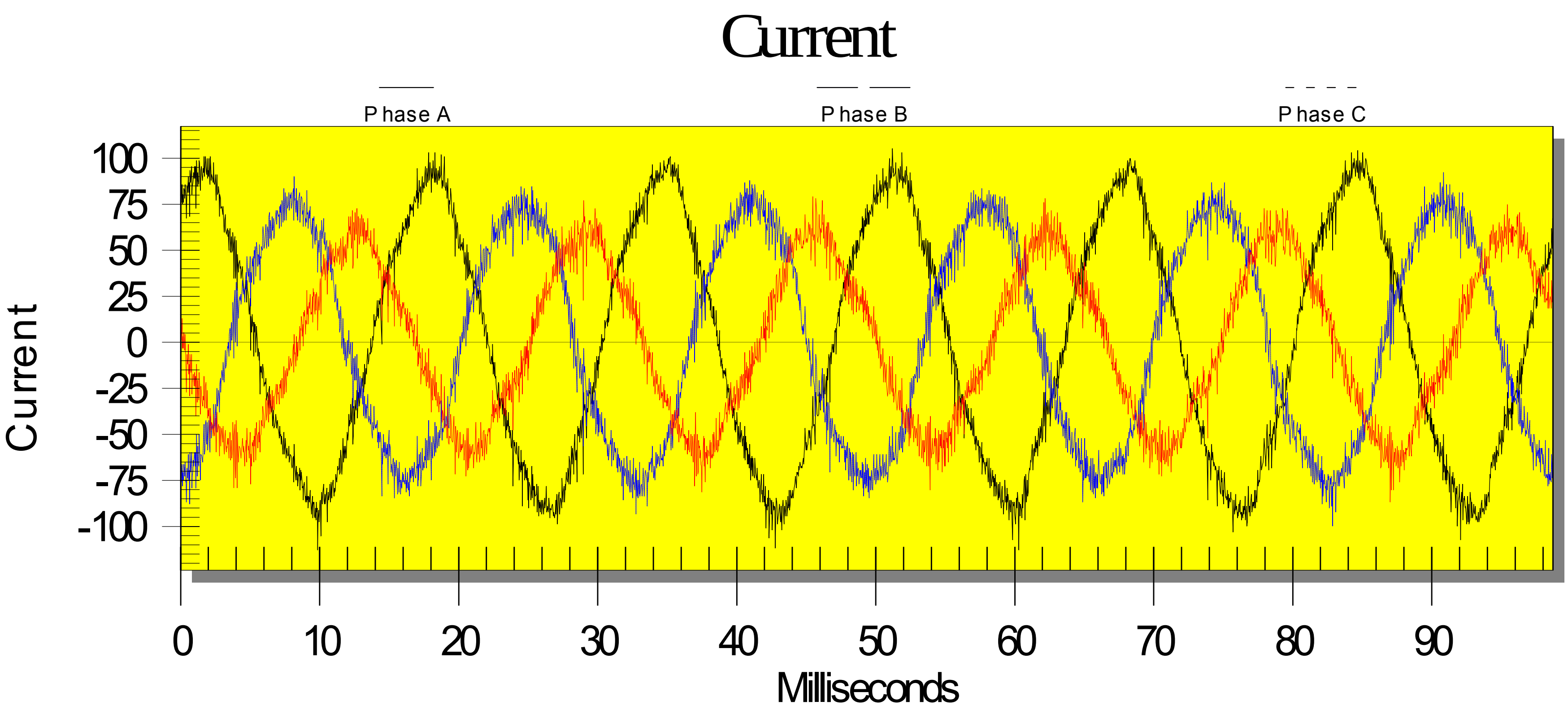
K-Factor Calculations – Dry-Type Transformers

- **Harmonic content is small cycle waveforms along the sine wave that distort the original sine wave**
- **The slightly higher RMS voltage and current on the sine waves is useless since it raises the voltage and current**

K-Factor Calculations – Dry-Type Transformers



K-Factor Calculations – Dry-Type Transformers



K-Factor Calculations – Dry-Type Transformers

- **To calculate K-Factor, must have a power systems analysis software program like ETAP or SKM, etc.**
- **Model all harmonic-producing equipment: biggest culprit is the 6-pulse VFD**
- **Formula for calculating K-Factor:**

$$\text{K-Factor} = \sum I_{h\ p.u.}^{2} \times h^{2}$$

- **Where,** $I_{h\ p.u.}$ **= Current harmonic in per unit**
- **Where,** h **= Odd harmonic (3, 5, 7, 9, 11, 13, etc.)**

K-Factor Calculations – Dry-Type Transformers

```
                                           BRANCH TABULATION
Project:  Motorola High Voltage Upgrade   ====================                                 Page:       38
Location: Plantation, Florida              PowerStation 3.0.1C                                  Date:   08-08-2000
Contract: 25865A-1                                                                              SN:     PBPOWERINC
Engineer: PB Power Inc.                   Study Case:  Normal                                   File:   Motorola1
```

Branch ID	% Harmonic Current Contents in 1 MVA Base																
	2	3	4	5	6	7	8	9	10	11	12	13	14	15	17	19	23
	25	29	31	35	37	41	43	47	49	53	55	59	61	65	67	71	73
PT-1	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
T-1(SUB-1)	0.00	0.00	0.00	16.34	0.00	11.24	0.00	0.00	0.00	6.56	0.00	5.47	0.00	0.00	4.05	3.57	2.79
	2.54	2.08	1.92	1.62	1.53	1.32	1.24	1.10	1.03	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
T-2(SUB-2)	0.00	0.00	0.00	6.52	0.00	3.79	0.00	0.00	0.00	1.15	0.00	0.97	0.00	0.00	0.74	0.66	0.53
	0.48	0.40	0.37	0.31	0.29	0.24	0.23	0.19	0.18	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
T-3(SUB-3)	0.00	0.00	0.00	21.14	0.00	14.88	0.00	0.00	0.00	9.14	0.00	7.73	0.00	0.00	5.91	5.30	4.28
	3.98	3.36	3.15	2.74	2.63	2.31	2.21	1.99	1.89	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
T-4(SUB-4)	0.00	0.00	0.00	9.41	0.00	5.34	0.00	0.00	0.00	1.53	0.00	1.32	0.00	0.00	1.03	0.93	0.75
	0.69	0.57	0.52	0.44	0.41	0.34	0.31	0.26	0.24	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
T-5(SUB-5)	0.00	0.00	0.00	4.46	0.00	2.19	0.00	0.00	0.00	0.13	0.00	0.12	0.00	0.00	0.10	0.00	0.00
	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
T-6(SUB 6)	0.00	0.00	0.00	20.47	0.00	12.80	0.00	0.00	0.00	5.44	0.00	4.58	0.00	0.00	3.48	3.11	2.50
	2.30	1.92	1.79	1.53	1.46	1.26	1.19	1.05	0.98	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
T-7(SUB-7)	0.00	0.00	0.00	16.37	0.00	10.66	0.00	0.00	0.00	5.48	0.00	4.49	0.00	0.00	3.20	2.77	2.08
	1.87	1.48	1.34	1.10	1.03	0.86	0.80	0.69	0.63	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
T-8(SUB-8)	0.00	0.00	0.00	18.20	0.00	10.33	0.00	0.00	0.00	2.86	0.00	2.44	0.00	0.00	1.88	1.68	1.33
	1.22	0.99	0.90	0.73	0.67	0.54	0.49	0.39	0.34	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

K-Factor Calculations – Dry-Type Transformers

Substation Transformer T-8 K-Factor Calculation

Nominal kVA Rating:		3000			
Fundamental Primary Current: *		66.0			
Harmonic	$\%I_{h\,p.u.}$ *	$I_{h\,p.u.}$	$(I_{h\,p.u.})^2$	h^2	$(I_{h\,p.u.})^2 \cdot h^2$
3	0.00	0.00000	0.00000	9	0.00000
5	6.90	0.06900	0.00476	25	0.11903
7	3.92	0.03920	0.00154	49	0.07530
9	0.00	0.00000	0.00000	81	0.00000
11	1.09	0.01090	0.00012	121	0.01438
13	0.92	0.00920	0.00008	169	0.01430
15	0.00	0.00000	0.00000	225	0.00000
17	0.71	0.00710	0.00005	289	0.01457
19	0.64	0.00640	0.00004	361	0.01479
21	0.00	0.00000	0.00000	441	0.00000
23	0.50	0.00500	0.00003	529	0.01323
25	0.46	0.00460	0.00002	625	0.01323
27	0.00	0.00000	0.00000	729	0.00000
29	0.37	0.00370	0.00001	841	0.01151
31	0.34	0.00340	0.00001	961	0.01111
33	0.00	0.00000	0.00000	1089	0.00000
35	0.28	0.00280	0.00001	1225	0.00960
37	0.25	0.00250	0.00001	1369	0.00856
39	0.00	0.00000	0.00000	1521	0.00000
41	0.20	0.00200	0.00000	1681	0.00672
43	0.18	0.00180	0.00000	1849	0.00599
45	0.00	0.00000	0.00000	2025	0.00000
47	0.15	0.00150	0.00000	2209	0.00497
49	0.13	0.00130	0.00000	2401	0.00406
				K Factor =	0.34

System Design Summary

- A. Prepare Load Study Calculation
- B. Size Transformer to 480 V Loads
- C. Size 480 V Motor Control Center (MCC)
- D. Select Short Circuit Rating of 480 V MCC
- E. Size 480 V Feeder from Transformer to MCC
- F. Size Transformer 12 kV Primary Disconnect
- G. Select Surge Protection at Transformer Primary
- H. Size 12 kV Feeder to Transformer (MV Cable)

System Design: Load Study

- A. Prepare Load Study Calculation
- Must have list of loads for facility
- Is facility load 500 kW, or 5,000 kW?
- Cannot size anything without loads
- Detailed information is best approach
- Line item for each major load, i.e., pump, fan, etc.
- Can lump smaller receptacle loads together for now

System Design: Load Study

- Pumps
- Fans
- Compressors
- Valves
- 480 V transformer to 120 V auxiliary loads
- Lighting
- Etc.

System Design: Load Study

BLUE HIGHLIGHTED AREA FOR INPUT DATA

EQUIPMENT NAME	LOAD TYPE	LOAD	PF	DEM FACT	CONNECTED KW-C	CONNECTED KVAR-C	CONNECTED KVA-C	CONNECTED AMPS-C	RUNNING KW-R	RUNNING KVAR-R	RUNNING KVA-R	RUNNING AMPS
Treated Water Pump 1 to Main East Zone	AFD	350.00	0.95	1.00	326.68	107.4	343.9	431.59	326.7	107.4	343.9	431.59
Treated Water Pump 2 to Main East Zone	AFD	350.00	0.95	1.00	326.68	107.4	343.9	431.59	326.7	107.4	343.9	431.59
Treated Water Pump 1 to Main West Zone	AFD	200.00	0.95	0.00	186.65	61.3	196.5	246.60	0.0	0.0	0.0	0.00
Treated Water Pump 2 to Main West Zone	AFD	200.00	0.95	0.00	186.65	61.3	196.5	246.60	0.0	0.0	0.0	0.00
Thunderbird well Pump No. 10	AFD	150.00	0.95	1.00	141.24	46.4	148.7	186.60	141.2	46.4	148.7	186.60
Thunderbird well Pump No. 13	AFD	150.00	0.95	1.00	141.24	46.4	148.7	186.60	141.2	46.4	148.7	186.60
Thunderbird well Pump No. 17	AFD	150.00	0.95	1.00	141.24	46.4	148.7	186.60	141.2	46.4	148.7	186.60
Thunderbird well Pump No. 23	AFD	150.00	0.95	1.00	141.24	46.4	148.7	186.60	141.2	46.4	148.7	186.60
Nacimento Turnout Feed	KVA	25.0	0.80	0.80	20.00	15.0	25.0	31.38	16.0	12.0	20.0	25.10
TWP disc. valves (0.5HP each, West)	MOTOR	1.00	0.72	0.00	0.92	0.9	1.3	2.10	0.0	0.0	0.0	0.00
TWP disc. valves (0.5HP each, East)	MOTOR	1.00	0.72	0.00	0.92	0.9	1.3	2.10	0.0	0.0	0.0	0.00
LT-TWPS	KVA	30.00	0.80	0.70	24.00	18.0	30.0	37.65	16.8	12.6	21.0	26.36
Overflow Basin Pump 1	MOTOR	5.00	0.82	1.00	4.24	3.0	5.2	7.60	4.2	3.0	5.2	7.60
Overflow Basin Pump 2	MOTOR	5.00	0.82	0.00	4.24	3.0	5.2	7.60	0.0	0.0	0.0	0.00
Backwash Recovery Pump 1	AFD	5.00	0.95	1.00	5.90	1.9	6.2	7.80	5.9	1.9	6.2	7.80
Backwash Recovery Pump 2	AFD	5.00	0.95	0.00	5.90	1.9	6.2	7.80	0.0	0.0	0.0	0.00
MPC-1	KVA	5.00	0.80	0.80	4.00	3.0	5.0	6.28	3.2	2.4	4.0	5.02
MPC-2	KVA	5.00	0.80	0.80	4.00	3.0	5.0	6.28	3.2	2.4	4.0	5.02
MPC-4	KVA	5.00	0.80	0.80	4.00	3.0	5.0	6.28	3.2	2.4	4.0	5.02
VBF-1001	MOTOR	0.50	0.60	1.00	0.48	0.6	0.8	1.10	0.5	0.6	0.8	1.10
Existing Feed PVE-6110	KVA	30.00	0.80	0.90	24.00	18.0	30.0	37.65	21.6	16.2	27.0	33.89
Existing Feed PVE-6113	KVA	30.00	0.80	0.90	24.00	18.0	30.0	37.65	21.6	16.2	27.0	33.89
Existing Feed PVE-6117	KVA	30.00	0.80	0.90	24.00	18.0	30.0	37.65	21.6	16.2	27.0	33.89
Existing Feed PVE-6123	KVA	30.00	0.80	0.90	24.00	18.0	30.0	37.65	21.6	16.2	27.0	33.89
Pachaged Heat Pump PHP-101	KVA	28.00	0.80	1.00	22.40	16.8	28.0	35.14	22.4	16.8	28.0	35.14
Site Lighting (3)	KVA	10.00	0.80	1.00	8.00	6.0	10.0	12.55	8.0	6.0	10.0	12.55
Site Lighting (1)	KVA	3.00	0.80	1.00	2.40	1.8	3.0	3.77	2.4	1.8	3.0	3.77
Membrane Power Panel (PP-MEMB)	KVA		0.92	1.00	244.40	101.51	264.64	332.15	185.7	76.6	200.8	252.07
Membrane Power Panel (PP-CHEM)	KVA		0.99	1.00	138.18	24.25	140.29	176.08	135.0	21.6	136.8	171.66
				0.00		0.0	0.0	0.00	0.0	0.0	0.0	0.00
TOTAL BUS LOADS					2181.6	799.7	2323.5		1711.2	625.4	1821.9	
CONNECTED FLA		2916.3		**P.F**	0.939							
RUNNING FLA		2286.7		**P.F.**	0.939							

1 of 4
2 of 4
3 of 4
4 of 4

BLACK & VEATCH

System Design: Load Study

- View 1 of 4:
- Each load and type is entered in the spreadsheet
- Load types can be AFD = adjustable frequency drive, or motor, or kVA

System Design: Load Study

BLUE HIGHLIGHTED AREA FOR INPUT DATA

EQUIPMENT NAME	LOAD TYPE	LOAD
Treated Water Pump 1 to Main East Zone	AFD	350.00
Treated Water Pump 2 to Main East Zone	AFD	350.00
Treated Water Pump 1 to Main West Zone	AFD	200.00
Treated Water Pump 2 to Main West Zone	AFD	200.00
Thunderbird well Pump No. 10	AFD	150.00
Thunderbird well Pump No. 13	AFD	150.00
Thunderbird well Pump No. 17	AFD	150.00
Thunderbird well Pump No. 23	AFD	150.00
Nacimento Turnout Feed	KVA	25.0
TWP disc. valves (0.5HP each, West)	MOTOR	1.00
TWP disc. valves (0.5HP each, East)	MOTOR	1.00
LT-TWPS	KVA	30.00
Overflow Basin Pump 1	MOTOR	5.00

System Design: Load Study

- **View 2 of 4:**
- **PF and demand factor is entered for each load**
- **Power factor = from standard motor design tables, unless actual is known**
- **Demand Factor = Ratio of actual demand to nameplate rating, or 0.00 if standby load or off**
- **Example: Pump demand = 8.1 Hp, from 10 Hp rated motor, DF = 8.1 Hp/10 Hp = 0.81**
- **Example: Small transformer demand = 3.4 kVA, from 5 kVA rated transformer, DF = 3.4 kVA/5 kVA = 0.68**

System Design: Load Study

BLUE HIGHLIGHTED AREA FOR INPUT DATA

EQUIPMENT NAME	LOAD TYPE	LOAD	PF	DEM FACT
Treated Water Pump 1 to Main East Zone	AFD	350.00	0.95	1.00
Treated Water Pump 2 to Main East Zone	AFD	350.00	0.95	1.00
Treated Water Pump 1 to Main West Zone	AFD	200.00	0.95	0.00
Treated Water Pump 2 to Main West Zone	AFD	200.00	0.95	0.00
Thunderbird well Pump No. 10	AFD	150.00	0.95	1.00
Thunderbird well Pump No. 13	AFD	150.00	0.95	1.00
Thunderbird well Pump No. 17	AFD	150.00	0.95	1.00
Thunderbird well Pump No. 23	AFD	150.00	0.95	1.00
Nacimento Turnout Feed	KVA	25.0	0.80	0.80
TWP disc. valves (0.5HP each, West)	MOTOR	1.00	0.72	0.00
TWP disc. valves (0.5HP each, East)	MOTOR	1.00	0.72	0.00
LT-TWPS	KVA	30.00	0.80	0.70
Overflow Basin Pump 1	MOTOR	5.00	0.82	1.00

Off

On

System Design: Load Study

- View 3 of 4:
- Connected values represent any load “connected” to the power system regardless of operation or not
- Running values represent “actual operating” loads at max demand
- If a pump is a standby, or backup, or spare, this pump would be turned off, or shown as zero, in the running columns
- The Demand Factor entry of zero is what turns off any particular load

System Design: Load Study

- **View 3 of 4:**
- **All connected values are calculated from input of load Hp, kVA, and power factor with formulas below:**
- **1 Hp = 0.746 kW**
- **kVA = kW/PF**

$$\text{Amps} = \frac{\text{kVA}}{\text{Sq Rt }(3) \times \text{kV}}$$

- **$kVA^2 = kW^2 + kVAR^2$**

System Design: Load Study

	DEM FACT	CONNECTED				RUNNING			
		KW-C	KVAR-C	KVA-C	AMPS-C	KW-R	KVAR-R	KVA-R	AMPS
	1.00	326.68	107.4	343.9	431.59	326.7	107.4	343.9	431.59
	1.00	326.68	107.4	343.9	431.59	326.7	107.4	343.9	431.59
Off	0.00	186.65	61.3	196.5	246.60	0.0	0.0	0.0	0.00
Off	0.00	186.65	61.3	196.5	246.60	0.0	0.0	0.0	0.00
	1.00	141.24	46.4	148.7	186.60	141.2	46.4	148.7	186.60
	1.00	141.24	46.4	148.7	186.60	141.2	46.4	148.7	186.60
On	1.00	141.24	46.4	148.7	186.60	141.2	46.4	148.7	186.60
On	1.00	141.24	46.4	148.7	186.60	141.2	46.4	148.7	186.60
	0.80	20.00	15.0	25.0	31.38	16.0	12.0	20.0	25.10
	0.00	0.92	0.9	1.3	2.10	0.0	0.0	0.0	0.00
	0.00	0.92	0.9	1.3	2.10	0.0	0.0	0.0	0.00
	0.70	24.00	18.0	30.0	37.65	16.8	12.6	21.0	26.36
	1.00	4.24	3.0	5.2	7.60	4.2	3.0	5.2	7.60

System Design: Load Study

- View 4 of 4:
- Calculate connected FLA and running FLA
- Running FLA is more significant since it represents the actual maximum demand from which the power system is sized
- Cannot simply add each kVA because of different PF
- Must sum each column of kW and kVAR
- Calculate kVA = Sq Rt (kW^2 + $kVAR^2$)
- Calculate Amps = kVA/[Sq Rt (3) x kV]

System Design: Load Study

FOR INPUT DATA	LOAD TYPE	LOAD	PF	DEM FACT	CONNECTED KW-C	KVAR-C	KVA-C	AMPS-C	RUNNING KW-R	KVAR-R	KVA-R	AMPS
n East Zone	AFD	350.00	0.95	1.00	326.68	107.4	343.9	431.59	326.7	107.4	343.9	431.59
in East Zone	AFD	350.00	0.95	1.00	326.68	107.4	343.9	431.59	326.7	107.4	343.9	431.59
n West Zone	AFD	200.00	0.95	0.00	186.65	61.3	196.5	246.60	0.0	0.0	0.0	0.00
in West Zone	AFD	200.00	0.95	0.00	186.65	61.3	196.5	246.60	0.0	0.0	0.0	0.00
	AFD	150.00	0.95	1.00	141.24	46.4	148.7	186.60	141.2	46.4	148.7	186.60
	AFD	150.00	0.95	1.00	141.24	46.4	148.7	186.60	141.2	46.4	148.7	186.60
	AFD	150.00	0.95	1.00	141.24	46.4	148.7	186.60	141.2	46.4	148.7	186.60
3	AFD	150.00	0.95	1.00	141.24	46.4	148.7	186.60	141.2	46.4	148.7	186.60
	KVA	25.0	0.80	0.80	20.00	15.0	25.0	31.38	16.0	12.0	20.0	25.10
h, West)	MOTOR	1.00	0.72	0.00	0.92	0.9	1.3	2.10	0.0	0.0	0.0	0.00
h, East)	MOTOR	1.00	0.72	0.00	0.92	0.9	1.3	2.10	0.0	0.0	0.0	0.00
	KVA	30.00	0.80	0.70	24.00	18.0	30.0	37.65	16.8	12.6	21.0	26.36
	MOTOR	5.00	0.82	1.00	4.24	3.0	5.2	7.60	4.2	3.0	5.2	7.60
	MOTOR	5.00	0.82	0.00	4.24	3.0	5.2	7.60	0.0	0.0	0.0	0.00
	AFD	5.00	0.95	1.00	5.90	1.9	6.2	7.80	5.9	1.9	6.2	7.80
	AFD	5.00	0.95	0.00	5.90	1.9	6.2	7.80	0.0	0.0	0.0	0.00
	KVA	5.00	0.80	0.80	4.00	3.0	5.0	6.28	3.2	2.4	4.0	5.02
	KVA	5.00	0.80	0.80	4.00	3.0	5.0	6.28	3.2	2.4	4.0	5.02
	KVA	5.00	0.80	0.80	4.00	3.0	5.0	6.28	3.2	2.4	4.0	5.02
	MOTOR	0.50	0.60	1.00	0.48	0.6	0.8	1.10	0.5	0.6	0.8	1.10
	KVA	30.00	0.80	0.90	24.00	18.0	30.0	37.65	21.6	16.2	27.0	33.89
	KVA	30.00	0.80	0.90	24.00	18.0	30.0	37.65	21.6	16.2	27.0	33.89
	KVA	30.00	0.80	0.90	24.00	18.0	30.0	37.65	21.6	16.2	27.0	33.89
	KVA	30.00	0.80	0.90	24.00	18.0	30.0	37.65	21.6	16.2	27.0	33.89
01	KVA	28.00	0.80	1.00	22.40	16.8	28.0	35.14	22.4	16.8	28.0	35.14
	KVA	10.00	0.80	1.00	8.00	6.0	10.0	12.55	8.0	6.0	10.0	12.55
	KVA	3.00	0.80	1.00	2.40	1.8	3.0	3.77	2.4	1.8	3.0	3.77
2-NEW)	KVA		0.92	1.00	244.40	101.51	264.64	332.15	185.7	76.6	200.8	252.07
2-CHEN)	KVA		0.99	1.00	138.18	24.25	140.29	176.08	135.0	21.6	136.8	171.66
				0.00		0.0	0.0	0.00	0.0	0.0	0.0	0.00
					2181.6	799.7	2323.5		1711.2	625.4	1821.9	
CONNECTED FLA		2916.3		**P.F**	0.939							
RUNNING FLA		2286.7		**P.F.**	0.939							

BLACK & VEATCH

System Design: Size Transformer

- B. <u>Size Transformer to 480 V Loads</u>
- From load study, running FLA = 2286.7 A
- Size transformer to accommodate this total load
- kVA = Sq Rt (3) x IFL x kV
- kVA = 1.732 x 2286.7 A x 0.48 kV = 1901 kVA
- Next standard transformer size is 2000 kVA

System Design: Size Transformer

System Design: Size 480 V MCC

- C. <u>Size 480 V Motor Control Center (MCC)</u>
- From load study, running FLA = 2286.7 A
- MCC bus rating = FLA x 125%
- MCC bus rating = 2286.7 A x 1.25 = 2858 A
- Next standard MCC bus size is 3000 A
- MCC main breaker will be fully sized at 3000 A

System Design: Size 480 V MCC

System Design: Short Circuit of 480 V MCC

- D. <u>Select Short Circuit Rating of 480 V MCC</u>
- Very important
- If undersized, could explode and start fire during short circuit conditions
- Danger of arc flash, based on I^2xT
- Energy released is proportional to the square of the current x the time duration
- Time duration is calculated on clearing time of upstream OCPD, breaker, fuse, relay

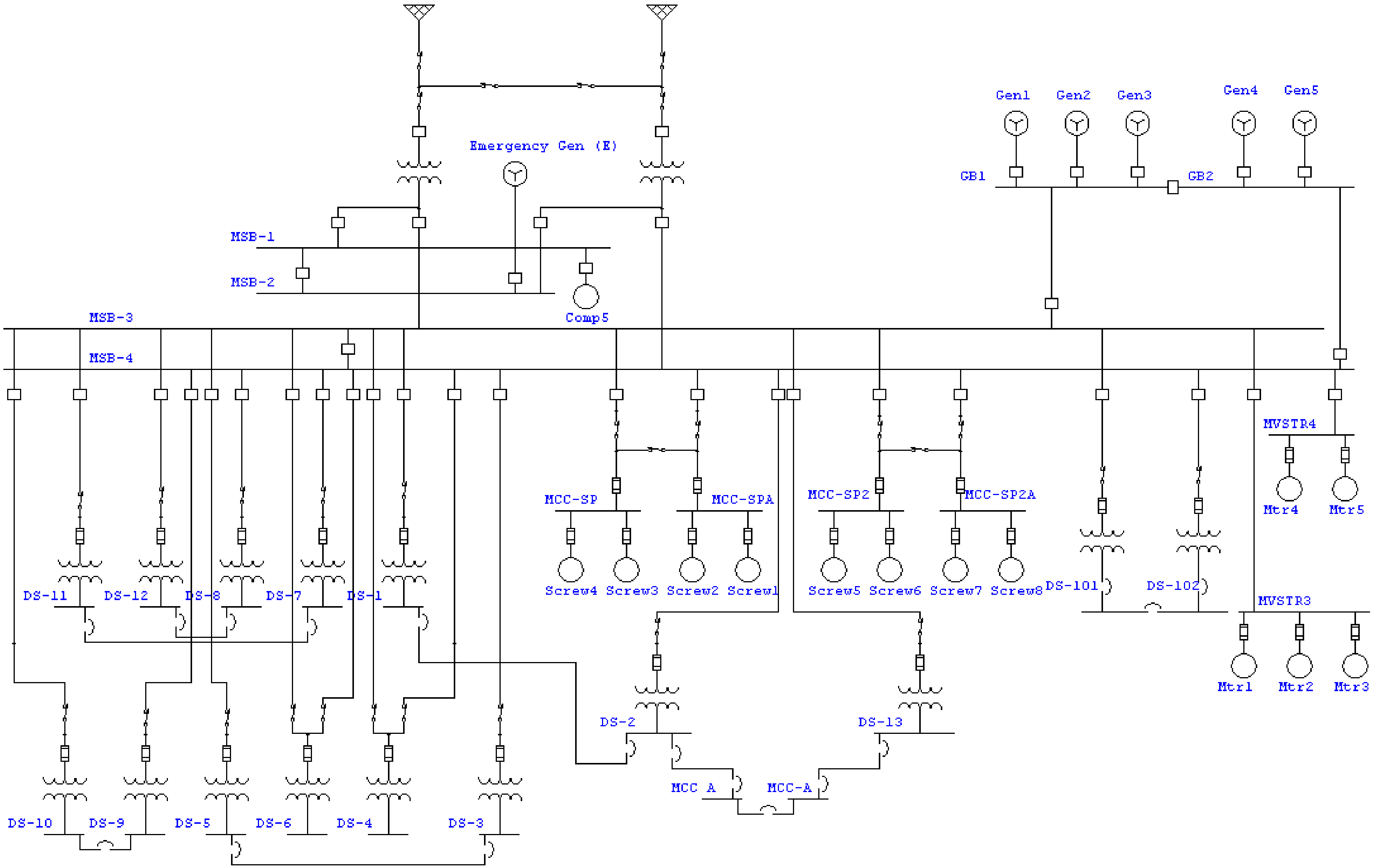
System Design: Short Circuit of 480 V MCC

- Selection of OCPD at too high a trip setting will delay clearing time
- Selection of OCPD with too long a time delay before trip will delay clearing time
- Both settings will allow the energy from I^2 to increase
- If electrical equipment is not sized, or braced, for maximum fault current, could explode
- Usually use power systems analysis software like ETAP or SKM to more accurately calculate fault duty at each bus
- Fault duty at each bus then determines minimum short circuit rating of electrical equipment

System Design: Load Flow Study

- Before a short circuit study can be performed using power systems analysis software, a model of the power system must be created
- System modeling parameters include the following:
- - Utility short circuit contribution
- - Transformers
- - Motors
- - Conductor sizes and lengths
- - On-site generation, etc.

System Design: Sample Power System Model



System Design: Sample Load Flow Study

Load Flow Results
Utility Substation USS-A

Bus 3 Phase Totals

Bus Name	In/Out Service	Design Volts	Phase	LF Volts	Angle Degree	PU Volts	%VD
BUS-0004	In	16,340	A	9,433.90	0.00	1.00	0.00
BUS-0021	In	4,160	C	2,331.93	88.27	0.97	2.91
BUS-0022	In	4,160	C	2,331.54	88.28	0.97	2.92
BUS-0062	In	480	A	264.17	-62.23	0.95	4.67
BUS-0064	In	480	A	263.73	-62.34	0.95	4.84
ATS	In	208	A	113.20	-62.96	0.94	5.74

System Design: Load Flow Study Results

- From results of load flow study,
- The voltage at each bus is calculated
- The Vdrop at each bus is also calculated
- The last bus, ATS, shows a Vdrop greater than 5%
- The load flow study can be programmed to automatically display all buses exceeding a Vdrop greater than 5%, or any other threshold

System Design: Sample Short Circuit Study

Short Circuit Results
Utility Substation USS-A

Bus Fault Contribution

Unbalanced / Single Phase Comprehensive Fault Study Settings

Faulted Bus Selection	Fault All Buses One By One	Motor Contribution	Yes
Fault Current Calculation	RMS	Transformer Tap	Yes
Asym Fault Current at Time	0.50	Transformer Phase Shift	Yes

Fault Location	Bus LL		-------------- Initial Symmetrical RMS				-----------				Asym. RMS Amps @ 0.50 Cycles		------ 3-Phase Asym Amps (RMS) ------				
Bus Name	Voltage		3-Phase Amps	3-Phase MVA	SLG Amps	SLG MVA	LL Amps	LLG Amps	----X/R----		3-Phase Amps	SLG Amps	1/2 Cycle	2 Cycles	3 Cycles	5 Cycles	8 Cycles
BUS-0004	16,340	A:	1,503	14.18	901	8.50	0	0	3P:	2.12	1,580	1,019	1,580	1,503	1,503	1,503	1,503
		B:	1,503	14.18	0	0.00	0	0	SLG:	3.19	1,580	0	1,580	1,503	1,503	1,503	1,503
		C:	1,503	14.18	0	0.00	0	0	LLG:	INF	1,580	0	1,580	1,503	1,503	1,503	1,503
BUS-0021	4,160	A:	2,478	5.95	2,846	6.84	0	0	3P:	3.74	2,903	3,415	2,903	2,481	2,478	2,478	2,478
		B:	2,478	5.95	0	0.00	0	0	SLG:	4.15	2,903	0	2,903	2,481	2,478	2,478	2,478
		C:	2,478	5.95	0	0.00	0	0	LLG:	INF	2,903	0	2,903	2,481	2,478	2,478	2,478
BUS-0022	4,160	A:	2,431	5.84	2,763	6.64	0	0	3P:	3.36	2,779	3,199	2,779	2,432	2,431	2,431	2,431
		B:	2,431	5.84	0	0.00	0	0	SLG:	3.55	2,779	0	2,779	2,432	2,431	2,431	2,431
		C:	2,431	5.84	0	0.00	0	0	LLG:	INF	2,779	0	2,779	2,432	2,431	2,431	2,431
BUS-0062	480	A:	5,583	1.55	6,183	1.71	0	0	3P:	5.80	7,231	8,313	7,231	5,656	5,592	5,583	5,583
		B:	5,583	1.55	0	0.00	0	0	SLG:	6.93	7,231	0	7,231	5,656	5,592	5,583	5,583
		C:	5,583	1.55	0	0.00	0	0	LLG:	INF	7,231	0	7,231	5,656	5,592	5,583	5,583
BUS-0064	480	A:	5,047	1.40	5,531	1.53	0	0	3P:	6.17	6,624	7,524	6,624	5,132	5,058	5,047	5,047
		B:	5,047	1.40	0	0.00	0	0	SLG:	7.35	6,624	0	6,624	5,132	5,058	5,047	5,047
		C:	5,047	1.40	0	0.00	0	0	LLG:	INF	6,624	0	6,624	5,132	5,058	5,047	5,047
ATS	208	A:	3,850	0.46	3,605	0.43	0	0	3P:	3.95	4,569	3,980	4,569	3,857	3,851	3,850	3,850
		B:	3,850	0.46	0	0.00	0	0	SLG:	2.84	4,569	0	4,569	3,857	3,851	3,850	3,850
		C:	3,850	0.46	0	0.00	0	0	LLG:	INF	4,569	0	4,569	3,857	3,851	3,850	3,850
BUS-0023	4,160	A:	2,373	5.70	2,665	6.40	0	0	3P:	3.00	2,649	2,983	2,649	2,374	2,373	2,373	2,373
		B:	2,373	5.70	0	0.00	0	0	SLG:	3.04	2,649	0	2,649	2,374	2,373	2,373	2,373

System Design: Sample Short Circuit Study

Fault Location Bus Name	Bus LL Voltage		3-Phase Amps	3-Phase MVA	SLG Amps	SLG MVA	LL Amps
			---------------- Initial Symmetrical RMS ---				
BUS-0004	16,340	A:	1,503	14.18	901	8.50	0
		B:	1,503	14.18	0	0.00	0
		C:	1,503	14.18	0	0.00	0
BUS-0021	4,160	A:	2,478	5.95	2,846	6.84	0
		B:	2,478	5.95	0	0.00	0
		C:	2,478	5.95	0	0.00	0
BUS-0022	4,160	A:	2,431	5.84	2,763	6.64	0
		B:	2,431	5.84	0	0.00	0
		C:	2,431	5.84	0	0.00	0
BUS-0062	480	A:	5,583	1.55	6,183	1.71	0
		B:	5,583	1.55	0	0.00	0
		C:	5,583	1.55	0	0.00	0
BUS-0064	480	A:	5,047	1.40	5,531	1.53	0
		B:	5,047	1.40	0	0.00	0
		C:	5,047	1.40	0	0.00	0
ATS	208	A:	3,850	0.46	3,605	0.43	0
		B:	3,850	0.46	0	0.00	0
		C:	3,850	0.46	0	0.00	0

System Design: Short Circuit of 480 V MCC

- From results of SKM short circuit study, the fault duty at the 480 V bus = 5,583 A
- This particular power system had a very low fault duty contribution from the utility
- This low fault duty shows up at all downstream buses
- Select next available short circuit rating for a 480 V MCC

System Design: Short Circuit of 480 V MCC

- **If power systems analysis software is not available, can use a conservative approximation**
- **The "MVA method" represents the worst case fault current thru transformer**
- **Transformers naturally limit the current thru transformer to secondary bushings**
- **Need transformer impedance, or assume typical is 5.75%Z, plus or minus**
- **Assume utility supply can provide infinite short circuit amperes to transformer primary (i.e., substation across the street)**

System Design: Short Circuit of 480 V MCC

- MVA method calculation:

$$I_{sc} = \frac{\text{Transformer kVA}}{\text{Sq Rt (3)} \times \text{kV} \times \%Z}$$

- Where, Isc = Short Circuit Current
- kV = Transformer secondary voltage rating
- For this example with a 2000 kVA transformer,

$$I_{sc} = \frac{2000 \text{ kVA}}{\text{Sq Rt (3)} \times .48 \text{ kV} \times 0.0575} = 41{,}838 \text{ A}$$

- 41,838 A x 1.25 = 52,298 A, select next available short circuit rating for a standard 480 V MCC = 65,000 A

System Design: 480 V Feeder from Transf to MCC

- E. Size 480 V Feeder from Transformer to MCC
- First calculate IFL from transformer secondary

$$IFL = \frac{\text{Transformer kVA}}{\text{Sq Rt (3) x kV}}$$

$$IFL = \frac{\text{2000 kVA}}{\text{Sq Rt (3) x 0.48 kV}} = 2405.7\ A$$

- IFL x 125% = 2405.7 A x 1.25 = 3007 A
- No one makes a cable to handle 3000 A

System Design: 480 V Feeder from Transf to MCC

- **Must use parallel sets of conductors**
- **Each conduit will have A, B, C, and GND cables, plus neutral if required for 1-phase loads**
- **Standard engineering practice is to use 500 kcmil (253 mm^2) or 600 kcmil (304 mm^2) conductors**
- **Why?**
- **Largest standard conductor that will fit easily into a standard 103 mm conduit**
- **For this example, we will use 500 kcmil (253 mm^2) conductors**

NEC Table 310.16, Conductor Ampacity

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
	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
1/0	125	150	170
2/0	145	175	195
3/0	165	200	225
4/0	195	230	260
250	215	255	290
300	240	285	320
350	260	310	350
400	280	335	380
500	320	380	430
600	355	420	475

System Design: 480 V Feeder from Transf to MCC

- **Per NEC Table 310.16,**
- **A single 500 kcmil (253 mm^2) conductor has an ampacity of 380 A**
- **Calculate quantity of parallel sets:**
- **Parallel sets = Target Ampacity/Conductor Ampacity**
- **Parallel sets = 3007 A/380 A = 7.91**
- **Round up to 8 parallel sets of 3-500 kcmil (253 mm^2)**
- **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
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

System Design: 480 V Feeder from Transf to MCC

- **Select grounding conductor**
- **Per NEC Table 250.122,**
- **Based on 3000 A trip rating**
- **Grounding conductor = 400 kcmil (203 mm^2)**

- **Total cables = 8 sets of 3-500 kcmil (253 mm^2), 1-400 kcmil (203 mm^2) GND**
- **Or, total 24-500 kcmil (253 mm^2), 8-400 kcmil (203 mm^2) GND**

System Design: 480 V Feeder from Transf to MCC

- Calculate total cross-sectional area of each set of cables
- Per NEC Chapter 9, Table 5, for XHHW cables
- Area of 500 kcmil (253 mm^2) cable = 450.6 mm^2
- Area of 400 kcmil (203 mm^2) cable = 373.0 mm^2
- Total cross-sectional area of each parallel set = 3 x 450.6 mm^2 + 1 x 373.0 mm^2 = 1724.8 mm^2
- Select conduit to maintain FF < 40%

System Design: 480 V Feeder from Transf to MCC

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

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.	mm²	in.²	mm²	in.²	mm²	in.²
12	3/8	—	—	—	—	—	—	—	—
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

System Design: 480 V Feeder from Transf to MCC

- **Per NEC Chapter 9, Table 4:**
- **For RMC, a conduit diameter of 103 mm has an area of 8316 mm^2**
- **Fill Factor = 1724.8 mm^2/8316 mm^2 = 20.7%**
- **FF < 40%, OK**
- **For large cables in one conduit, it is not recommended to approach the FF = 40% due to the excessive pulling tensions when installing the cables**

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	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

System Design: 480 V Feeder from Transf to MCC

- **Per NEC Chapter 9, Table 4:**
- **For PVC, a conduit diameter of 103 mm has an area of 8091 mm^2**
- **Fill Factor = 1724.8 mm^2/8091 mm^2 = 21.3%**
- **FF < 40%, OK**

- **Final Feeder: 8 sets each of 103 mm conduit, 3-500 kcmil (253 mm^2), 1-400 kcmil (203 mm^2) GND**

System Design: Transformer 12 kV Disconnect

- F. Size Transformer 12 kV Primary Disconnect
- First calculate IFL from transformer primary

$$IFL = \frac{\text{Transformer kVA}}{\text{Sq Rt (3)} \times \text{kV}}$$

$$IFL = \frac{2000 \text{ kVA}}{\text{Sq Rt (3)} \times 12 \text{ kV}} = 96.2 \text{ A}$$

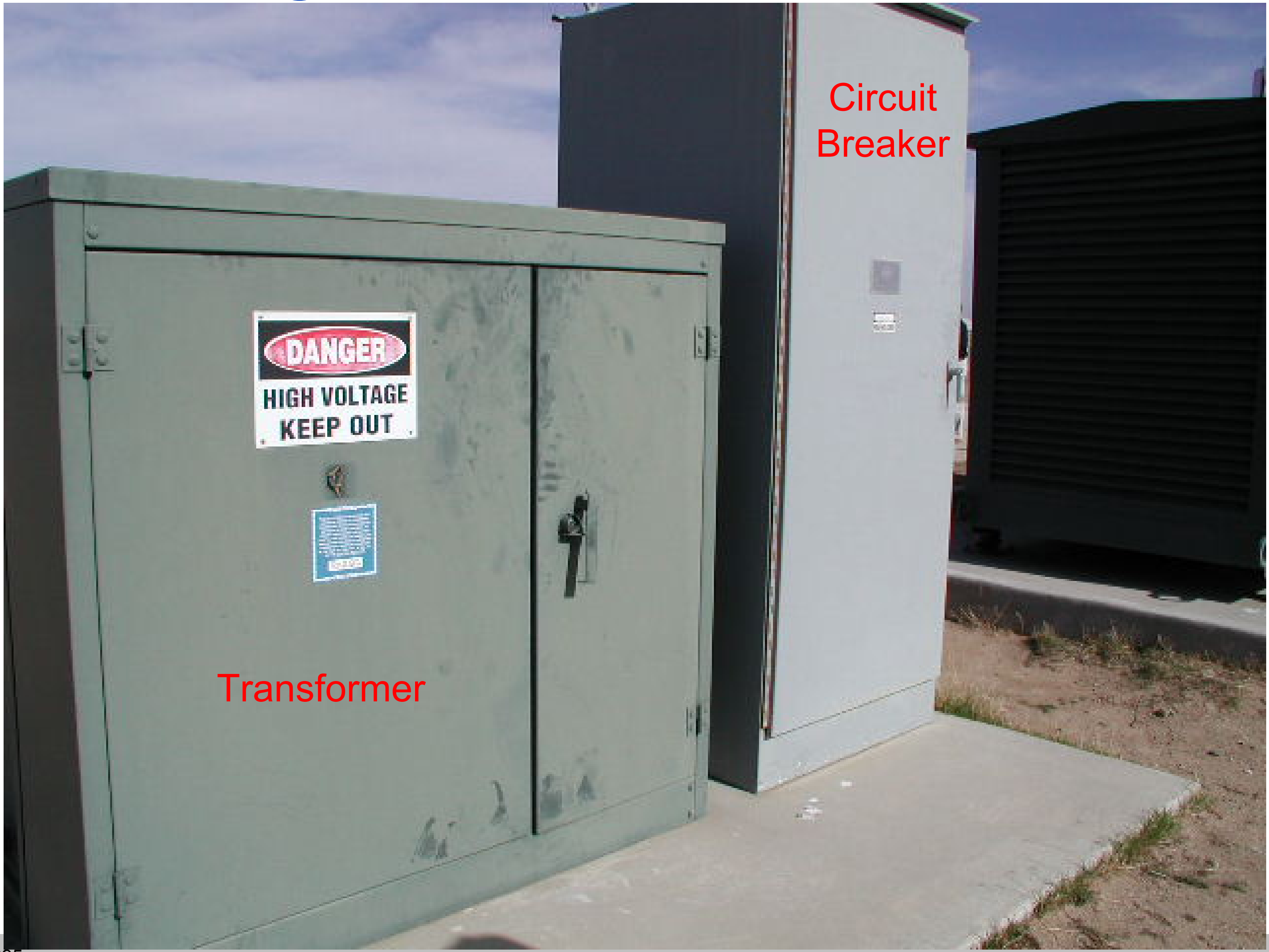
- IFL x 125% = 96.2 A x 1.25 = 120.3 A

System Design: Transformer 12 kV Disconnect

- **Most common 12 kV disconnect devices are:**
- **a) Metal-enclosed fused load interrupter switches**
- **b) Metal-clad vacuum breaker switchgear with OCPD, or relay**

System Design: Transformer 12 kV Disconnect

System Design: Transformer 12 kV Disconnect



System Design: Transformer 12 kV Disconnect

- **Minimum bus rating of metal-enclosed fused load interrupter switches = 600 A**
- **Bus rating > IFL x 125%**
- **600 A > 120.3 A, OK**

System Design: Transformer 12 kV Disconnect

- **Minimum bus rating of metal-clad vacuum breaker switchgear = 1200 A**
- **Bus rating > IFL x 125%**
- **1200 A > 120.3 A, OK**

System Design: Transformer 12 kV Disconnect

- Size fuse for OCPD with metal-enclosed fused load interrupter switches
- NEC governs maximum size of fuses for transformer protection
- NEC Table 450.3(A), Maximum Rating or Setting of Overcurrent Protection for Transformers Over 600 Volts (as a Percentage of Transformer-Rated Current)
- For transformer IFL = 96.2 A

System Design: Transformer 12 kV Disconnect

Table 450.3(A) Maximum Rating or Setting of Overcurrent Protection for Transformers Over 600 Volts (as a Percentage of Transformer-Rated Current)

		Primary Protection over 600 Volts		Secondary Protection (See Note 2.)		
				Over 600 Volts		600 Volts or Less
Location Limitations	Transformer Rated Impedance	Circuit Breaker (See Note 4.)	Fuse Rating	Circuit Breaker (See Note 4.)	Fuse Rating	Circuit Breaker or Fuse Rating
Any location	Not more than 6%	600% (See Note 1.)	300% (See Note 1.)	300% (See Note 1.)	250% (See Note 1.)	125% (See Note 1.)
	More than 6% and not more than 10%	400% (See Note 1.)	300% (See Note 1.)	250% (See Note 1.)	225% (See Note 1.)	125% (See Note 1.)
Supervised locations only (See Note 3.)	Any	300% (See Note 1.)	250% (See Note 1.)	Not required	Not required	Not required
	Not more than 6%	600%	300%	300% (See Note 5.)	250% (See Note 5.)	250% (See Note 5.)
	More than 6% and not more than 10%	400%	300%	250% (See Note 5.)	225% (See Note 5.)	250% (See Note 5.)

System Design: Transformer 12 kV Disconnect

- **Per NEC Table 450.3(A),**
- **For transformer typical impedance = 5.75%**
- **Maximum size fuse = IFL x 300%**
- **Maximum size fuse = 96.2 A x 3.0 = 288.7 A**
- **NEC allows next higher size available**
- **Thus, fuse = 300 A**
- **Although NEC dictates maximum, standard engineering practice is to select fuse at IFL x 125% = 120.3 A, or round up to 150 A**

System Design: Transformer 12 kV Disconnect

- **Select OCPD relay trip setting with metal-clad vacuum breaker switchgear**
- **NEC governs maximum relay trip setting for transformer protection**
- **NEC Table 450.3(A), Maximum Rating or Setting of Overcurrent Protection for Transformers Over 600 Volts (as a Percentage of Transformer-Rated Current)**
- **For transformer IFL = 96.2 A**

System Design: Transformer 12 kV Disconnect

Table 450.3(A) Maximum Rating or Setting of Overcurrent Protection for Transformers Over 600 Volts (as a Percentage of Transformer-Rated Current)

		Primary Protection over 600 Volts		Secondary Protection (See Note 2.)		
				Over 600 Volts		600 Volts or Less
Location Limitations	Transformer Rated Impedance	Circuit Breaker (See Note 4.)	Fuse Rating	Circuit Breaker (See Note 4.)	Fuse Rating	Circuit Breaker or Fuse Rating
Any location	Not more than 6%	600% (See Note 1.)	300% (See Note 1.)	300% (See Note 1.)	250% (See Note 1.)	125% (See Note 1.)
	More than 6% and not more than 10%	400% (See Note 1.)	300% (See Note 1.)	250% (See Note 1.)	225% (See Note 1.)	125% (See Note 1.)
Supervised locations only (See Note 3.)	Any	300% (See Note 1.)	250% (See Note 1.)	Not required	Not required	Not required
	Not more than 6%	600%	300%	300% (See Note 5.)	250% (See Note 5.)	250% (See Note 5.)
	More than 6% and not more than 10%	400%	300%	250% (See Note 5.)	225% (See Note 5.)	250% (See Note 5.)

System Design: Transformer 12 kV Disconnect

- Per NEC Table 450.3(A),
- For transformer typical impedance = 5.75%
- Maximum relay trip setting = IFL x 600%
- Maximum relay trip setting = 96.2 A x 6.0 = 577.4 A
- NEC allows next higher relay trip setting available
- Thus, relay trip setting = 600 A
- Although NEC dictates maximum, standard engineering practice is to set relay trip setting at IFL x 125% = 120.3 A

System Design: Transformer 12 kV Disconnect

- **In order to calculate the proper relay settings, the current transformer (CT) turns ratio must be selected**
- **The turns ratio of the CT is based on the maximum expected current = IFL = 96.2 A**
- **This could be a 100:5 CT, such that when the CT senses 100 A on the 12 kV cable, it outputs 5 A on the CT secondary for direct input into the relay**
- **However, saturation of the CT should be avoided in case the transformer must temporarily supply power greater than its nameplate rating**

System Design: Transformer 12 kV Disconnect

- **Standard engineering practice is to size the CT such that the expected maximum current is about 2/3 of the CT ratio**
- **For this transformer IFL = 96.2 A**
- **The 2/3 point = 96.2 A/(2/3) = 144.3 A**
- **Select next standard available CT ratio of 150:5**

System Design: Transformer 12 kV Disconnect

- **For many years the most common type of overcurrent relay was an induction disk type of relay**
- **Depending on the secondary CT current input to the relay, the disk would rotate a corresponding angle**
- **Today's technology uses electronic-based relays**
- **As such, electronic relays are more accurate in sensing pick-up and contain smaller incremental gradations of available settings than induction disk relays**

System Design: Transformer 12 kV Disconnect

- For example: Induction disk relays had available tap settings in increments of 1 A or 0.5 A
- Today's electronic relays have tap settings in increments of 0.01 A
- Thus, a more exact tap setting could be selected, thereby making coordination with upstream and downstream devices much easier

System Design: Surge Protection at Transformer

- **G. <u>Select Surge Protection at Transformer Primary</u>**
- **Prudent to install surge arresters at line side terminals of transformer for protection**
- **Helps to clip high voltage spikes or transients from utility switching or lightning strikes**
- **Should be about 125% of nominal supply voltage from utility**
- **Don't want to be too close to nominal utility supply voltage**
- **Must allow utility voltage supply variations**

System Design: Surge Protection at Transformer

- Example, for delta circuit, most common:
- Utility Nominal Supply Voltage x 125%
- 12 kV x 1.25% = 15 kV
- Thus, surge arrester voltage rating = 15 kV, minimum
- Could select higher voltage if utility has widely varying voltage supply
- Surge arrester is connected phase-to-ground

System Design: Surge Protection at Transformer

- **If wrong selection of 8.6 kV surge arrester on 12 kV circuit, then the surge arrester would probably explode upon energization because it will shunt to ground any voltage higher than 8.6 kV**
- **The switchgear would be under short circuit conditions and the fuse would blow or the relay would trip**

System Design: 12 kV Feeder to Transformer

- H. Size 12 kV Feeder to Transformer (MV Cable)
- Sizing 15 kV conductors for 12 kV circuits still uses transformer IFL = 96.2 A
- IFL x 125% = 96.2 A x 1.25 = 120.3 A
- Select conductor size based on NEC tables
- Similar to 600 V cables, depends on aboveground or underground installation for Medium Voltage (MV) cable

System Design: 12 kV Feeder to Transformer

- **One of the more popular 15 kV cables is rated as follows:**
- **- 15 kV, 100% or 133% insulation**
- **- 15 kV with 133% insulation = 15 kV x 1.33 = 20 kV (optional rating for circuit voltages between 15 kV and 20 kV)**
- **- MV-105 = medium voltage cable, rated for 105°C conductor temperature (previous rating was MV-90, and had lower ampacity)**

System Design: 12 kV Feeder to Transformer

- - EPR insulation = Ethylene Propylene Rubber insulation (traditional insulation versus newer cross-linked polyethylene, or XLP)
- - Cu = copper conductor
- - Shielded = Copper tape wrapped around EPR insulation (to aid in containing electric field and an immediate ground fault return path)
- - PVC jacket = overall jacket around cable

System Design: Okonite 15 kV Cable

THE OKONITE COMPANY

COMPACT STRAND CONSTRUCTION

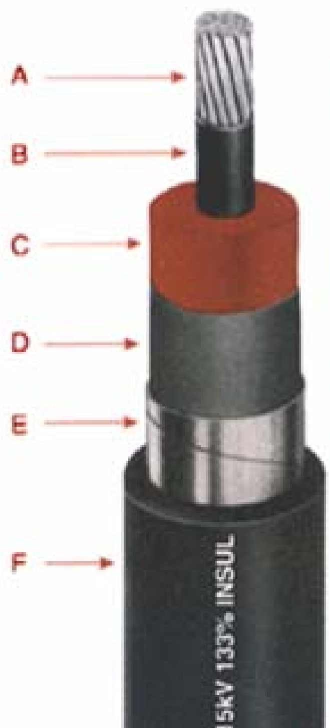
Product Data
Section 2: Sheet 9

Okoguard®-Okoseal® Type MV-105

15kV Shielded Power Cable

One Okopact® (Compact Stranded) Copper Conductor/105°C Rating
100% and 133% Insulation Level

UL



A Uncoated, Okopact (Compact Stranded) Copper Conductor

B Strand Screen-Extruded Semiconducting EPR

C Insulation-Okoguard EPR

D Insulation Screen-Extruded semiconducting EPR

E Shield-Copper Tape

F Jacket Okoseal

Insulation

Okoguard is Okonite's registered trade name for its exclusive ethylene-propylene rubber (EPR) based, thermosetting compound,

System Design: Okonite 15 kV Cable

System Design: 12 kV Feeder to Transformer

- For aboveground applications, use NEC Table 310.73
- NEC Table 310.73 = Ampacities of an Insulated Triplexed or Three Single-Conductor Copper Cables in Isolated Conduit in Air Based on Conductor Temperature of 90°C (194°F) and 105°C (221°F) and Ambient Air Temperature of 40°C (104°F)
- For IFL x 125% = 120.3 A

System Design: 12 kV Feeder to Transformer

Table 310.73 Ampacities of an Insulated Triplexed or Three Single-Conductor Copper Cables in Isolated Conduit in Air Based on Conductor Temperatures of 90°C (194°F) and 105°C (221°F) and Ambient Air Temperature of 40°C (104°F)

	Temperature Rating of Conductor [See Table 310.13(C).]			
	2001–5000 Volts Ampacity		5001–35,000 Volts Ampacity	
Conductor Size (AWG or kcmil)	90°C (194°F) Type MV-90	105°C (221°F) Type MV-105	90°C (194°F) Type MV-90	105°C (221°F) Type MV-105
8	55	61	—	—
6	75	84	83	93
4	97	110	110	120
2	130	145	150	165
1	155	175	170	190
1/0	180	200	195	215
2/0	205	225	225	255
3/0	240	270	260	290
4/0	280	305	295	330
250	315	355	330	365
350	385	430	395	440
500	475	530	480	535
750	600	665	585	655
1000	690	770	675	755

System Design: 12 kV Feeder to Transformer

- **Per NEC Table 310.73, for 15 kV, MV-105,**
- **4 AWG (21.15 mm^2) ampacity = 120 A**
- **2 AWG (33.62 mm^2) ampacity = 165 A**
- **4 AWG (21.15 mm^2) is not a common size in 15 kV cables**
- **2 AWG (33.62 mm^2) is much more common and available**
- **Thus, select 2 AWG (33.62 mm^2) for phase conductors**

System Design: 12 kV Feeder to Transformer

- **Select grounding conductor**
- **Use NEC Table 250.122**
- **Relay trip setting would be set to 120 A, so overcurrent rating would be 200 A per NEC table**

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

System Design: 12 kV Feeder to Transformer

- **Per NEC Table 250.122,**
- **Grounding conductor is 6 AWG (13.30 mm^2)**
- **Does grounding cable for 12 kV circuit need to be rated for 15 kV, same as phase cables?**
- **No.**
- **Grounding conductor is not being subject to 12 kV voltage**
- **Circuit = 3-2 AWG (33.62 mm^2), 15 kV, 1-6 AWG (13.30 mm^2) GND**

System Design: 12 kV Feeder to Transformer

- Select conduit size for 12 kV circuit
- For 15 kV cable dimensions, use Okonite data sheet

System Design: 12 kV Feeder to Transformer

1-Catalog Number
2-Conductor Size - AWG or kcmil
3-Conductor Size - mm2
4-Approx. Dia. over Insulation(in.)
5-Approx. Dia. over Screen(in.)
6-Jacket Thickness - mils
7-Jacket Thickness - mm
8-Approx. O.D. - Inches
09-Approx. O.D. - mm
10-Approx. Net Weight lbs./1000'
11-Approx. Ship Weight lbs./1000'
12-Ampacities Conduit in Air(1)
13-Ampacities Direct Burial(2)
14-Ampacities Underground Duct(3)
15-Conduit Size-Inches*(4)

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Okoguard Insulation: 175 mils(4.45mm), 100% Insulation Level														
115-23-3011	2	33.6	0.66	0.72	80	2.03	0.91	23.0	585	655	165	225	165	3
115-23-3013	1	42.4	0.69	0.75	80	2.03	0.94	23.8	660	755	190	260	185	3
115-23-3015	1/0	53.5	0.73	0.79	80	2.03	0.98	24.8	750	845	215	295	215	3
115-23-3017	2/0	67.4	0.77	0.83	80	2.03	1.02	25.8	860	955	255	335	245	3
115-23-3019	3/0	85.0	0.82	0.88	80	2.03	1.06	27.0	995	1090	290	380	275	3
115-23-3021	4/0	107.0	0.87	0.93	80	2.03	1.12	28.3	1160	1260	330	435	315	3
115-23-3023	250	127.0	0.91	0.97	80	2.03	1.16	29.4	1310	1425	365	475	345	3 1/2
115-23-3027	350	177.0	1.01	1.07	80	2.03	1.26	32.0	1675	1815	440	575	415	3 1/2
115-23-3031	500	253.0	1.13	1.21	80	2.03	1.39	35.4	2230	2425	535	700	500	4
115-23-3035	750	380.0	1.31	1.39	80	2.03	1.58	40.0	3300	3565	655	865	610	5
115-23-3037	1000	507.0	1.47	1.55	110	2.79	1.79	45.6	4095	4365	755	1005	690	5
Okoguard Insulation: 220 mils(5.59mm), 133% Insulation Level														
▲115-23-3111	2	33.6	0.75	0.81	80	2.03	1.00	25.3	670	765	165	225	165	3
115-23-3113	1	42.4	0.78	0.84	80	2.03	1.03	26.1	745	840	190	260	185	3
▲115-23-3115	1/0	53.5	0.82	0.88	80	2.03	1.07	27.1	840	915	215	295	215	3
▲115-23-3117	2/0	67.4	0.86	0.92	80	2.03	1.11	28.1	955	1050	255	335	245	3
115-23-3119	3/0	85.0	0.91	0.97	80	2.03	1.16	29.3	1090	1190	290	380	275	3 1/2
▲115-23-3121	4/0	107.0	0.96	1.02	80	2.03	1.21	30.7	1265	1375	330	435	315	3 1/2
▲115-23-3123	250	127.0	1.01	1.07	80	2.03	1.25	31.8	1415	1550	365	475	345	3 1/2
▲115-23-3127	350	177.0	1.11	1.18	80	2.03	1.37	34.7	1810	1950	440	575	415	4
▲115-23-3131	500	253.0	1.22	1.30	80	2.03	1.49	37.7	2355	2555	535	700	500	5
▲115-23-3135	750	380.0	1.40	1.48	80	2.03	1.66	42.2	3246	3511	655	865	610	5
▲115-23-3139	1000	507.0	1.56	1.66	110	2.79	1.91	48.5	4290	4705	755	1005	690	6

System Design: 12 kV Feeder to Transformer

- **For Okonite 100% insulation, cable outer diameter = 23.0 mm**
- **Cable cross-sectional area = Pi x $d^2/4$**
- **Cable cross-sectional area = 3.14 x 23.0 $mm^2/4$**
- **Cable cross-sectional area = 415.5 mm^2**

System Design: 12 kV Feeder to Transformer

- **For Okonite 133% insulation, cable outer diameter = 25.3 mm**
- **Cable cross-sectional area = Pi x $d^2/4$**
- **Cable cross-sectional area = 3.14 x 25.3 $mm^2/4$**
- **Cable cross-sectional area = 502.7 mm^2**

System Design: 12 kV Feeder to Transformer

- **For grounding conductor = 6 AWG (13.30 mm^2)**
- **Use NEC Chapter 9, Table 5, XHHW Insulation**

System Design: 12 kV Feeder to Transformer

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

System Design: 12 kV Feeder to Transformer

- **Per NEC Chapter 9, Table 5, for 6 AWG (13.30 mm^2)**
- **Cable cross-sectional area = 38.06 mm^2**
- **Total cable cross-sectional area with 15 kV, <u>100%</u> insulation = 3 x 415.5 mm^2 + 1 x 38.06 mm^2 = 1246.4 mm^2**
- **Total cable cross-sectional area with 15 kV, <u>133%</u> insulation = 3 x 502.7 mm^2 + 1 x 38.06 mm^2 = 1508.1 mm^2**
- **Select conduit for FF < 40%**

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	3/8	—	—	—	—	—	—	—	—
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

System Design: 12 kV Feeder to Transformer

- **Per NEC Chapter 9, Table 4:**
- **For RMC, a conduit diameter of 78 mm has an area of 4840 mm^2**
- **For 15 kV, 100% insulation:**
- **Fill Factor = 1246.4 mm^2/4840 mm^2 = 25.8%**
- **FF < 40%, OK**

System Design: 12 kV Feeder to Transformer

- Per NEC Chapter 9, Table 4:
- For RMC, a conduit diameter of 78 mm has an area of 4840 mm^2
- For 15 kV, 133% insulation:
- Fill Factor = 1508.1 mm^2/4840 mm^2 = 31.2%
- FF < 40%, OK

System Design: 12 kV Feeder to Transformer

- **For underground applications, use NEC Table 310.77**
- **NEC Table 310.77 = Ampacities of Three Insulated Copper in Underground Electrical Ductbanks (Three Conductors per Electrical Duct) Based on Ambient Earth Temperature of 20°C (68°F), Electrical Duct Arrangement per Figure 310.60, 100 Percent Load Factor, Thermal Resistance (RHO) of 90, Conductor Temperatures of 90°C (194°F) and 105°C (221°F)**
- **For IFL x 125% = 120.3 A**

System Design: 12 kV Feeder to Transformer

Table 310.77 Ampacities of Three Single-Insulated Copper Conductors in Underground Electrical Ducts (Three Conductors per Electrical Duct) Based on Ambient Earth Temperature of 20°C (68°F), Electrical Duct Arrangement per Figure 310.60, 100 Percent Load Factor, Thermal Resistance (RHO) of 90, Conductor Temperatures of 90°C (194°F) and 105°C (221°F)

	Temperature Rating of Conductor [See Table 310.13(C).]			
	2001–5000 Volts Ampacity		5001–35,000 Volts Ampacity	
Conductor Size (AWG or kcmil)	90°C (194°F) Type MV-90	105°C (221°F) Type MV-105	90°C (194°F) Type MV-90	105°C (221°F) Type MV-105
One Circuit (See Figure 310.60, Detail 1.)				
8	64	69	—	—
6	85	92	90	97
4	110	120	115	125
2	145	155	155	165
1	170	180	175	185
1/0	195	210	200	215
2/0	220	235	230	245
3/0	250	270	260	275
4/0	290	310	295	315
250	320	345	325	345
350	385	415	390	415
500	470	505	465	500
750	585	630	565	610
1000	670	720	640	690

System Design: 12 kV Feeder to Transformer

- **Per NEC Table 310.77, for 15 kV, MV-105,**
- **4 AWG (21.15 mm^2) ampacity = 125 A**
- **2 AWG (33.62 mm^2) ampacity = 165 A**
- **4 AWG (21.15 mm^2) is not a common size in 15 kV cables**
- **2 AWG (33.62 mm^2) is much more common and available**
- **Thus, select 2 AWG (33.62 mm^2) for phase conductors**

System Design: 12 kV Feeder to Transformer

- **Per NEC Table 250.122,**
- **Grounding conductor is still 6 AWG (13.30 mm^2)**
- **Circuit = 3-2 AWG (33.62 mm^2), 15 kV, 1-6 AWG (13.30 mm^2) GND**

System Design: 12 kV Feeder to Transformer

- **Select conduit size for 12 kV circuit**
- **For 15 kV cable dimensions, use Okonite data sheet**

System Design: 12 kV Feeder to Transformer

- **For grounding conductor = 6 AWG (13.30 mm^2)**
- **Use NEC Chapter 9, Table 5, XHHW Insulation**

System Design: 12 kV Feeder to Transformer

- Per NEC Chapter 9, Table 5, for 6 AWG (13.30 mm^2)
- Cable cross-sectional area = 38.06 mm^2

- Total cable cross-sectional area with 15 kV, <u>100%</u> insulation = 3 x 415.5 mm^2 + 1 x 38.06 mm^2 = 1246.4 mm^2
- Total cable cross-sectional area with 15 kV, <u>133%</u> insulation = 3 x 502.7 mm^2 + 1 x 38.06 mm^2 = 1508.1 mm^2
- Select conduit for FF < 40%

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

System Design: 12 kV Feeder to Transformer

- **Per NEC Chapter 9, Table 4:**
- **For PVC, a conduit diameter of 78 mm has an area of 4693 mm^2**
- **For 15 kV, 100% insulation:**
- **Fill Factor = 1246.4 mm^2/4693 mm^2 = 26.6%**
- **FF < 40%, OK**

System Design: 12 kV Feeder to Transformer

- **Per NEC Chapter 9, Table 4:**
- **For PVC, a conduit diameter of 78 mm has an area of 4693 mm^2**
- **For 15 kV, 133% insulation:**
- **Fill Factor = 1508.1 mm^2/4693 mm^2 = 32.1%**
- **FF < 40%, OK**

Utility Voltage Supply Affects Reliability

- **Most utility distribution circuits are 12 kV, 13.8 kV, etc.**
- **Obtaining a higher utility voltage circuit will increase reliability**
- **Don't always have a choice in utility voltage**
- **If available, a higher transmission voltage like 46 kV, 60 kV, etc. is advantageous**

Utility Voltage Supply Affects Reliability

- Higher voltage circuit means more power transfer capability
- Also means fewer direct connections to other customers
- Also means lesser chances for the line to fail or impacted by other customers
- Transmission circuits usually feed distribution substations down to 12 kV

System Optimization – Siting Main Substation

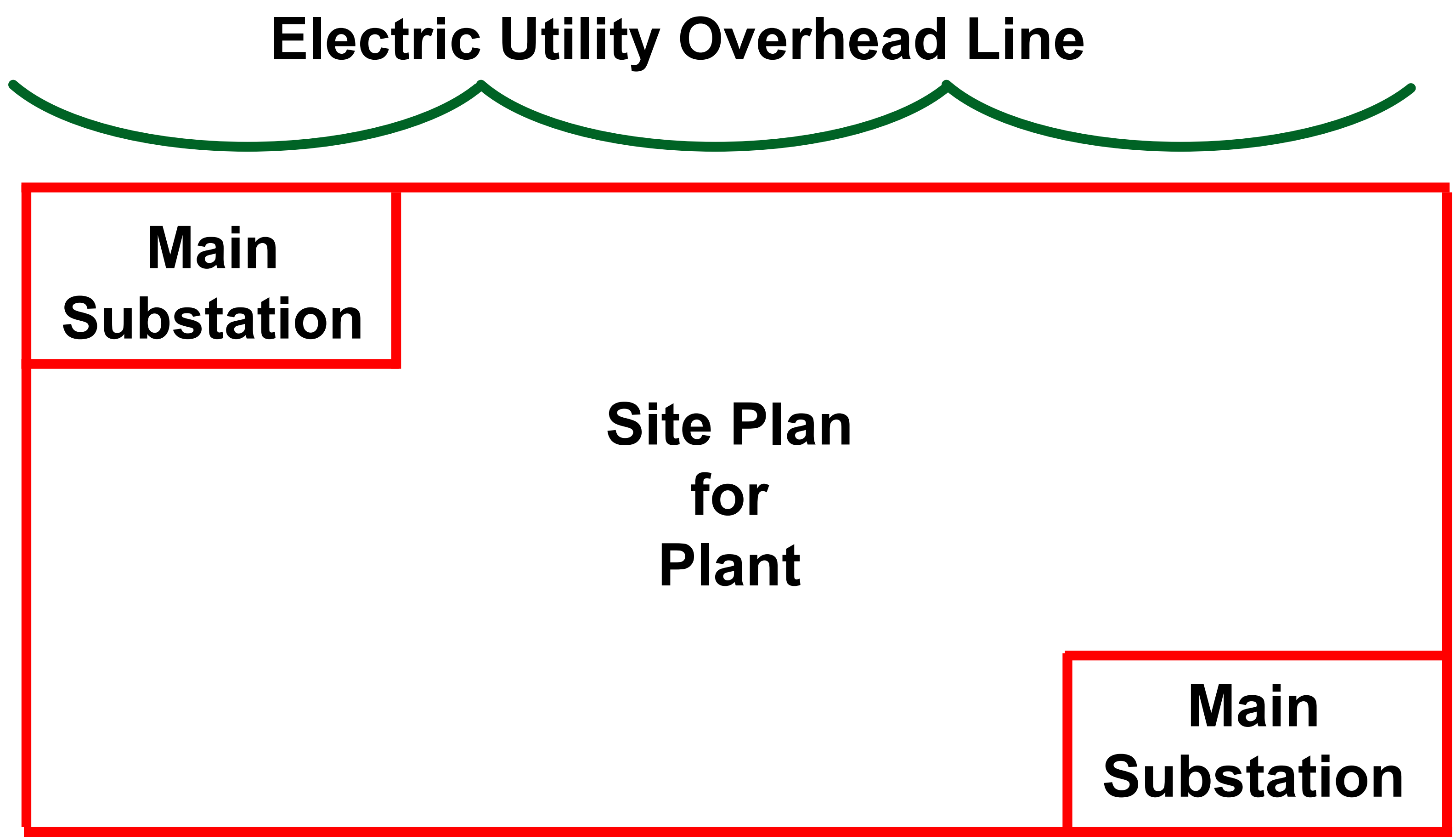
- In siting the utility substation for a plant, system optimization helps to reduce costs
- Most utilities are only obligated to bring service to the nearest property line
- If you want the place the utility substation at the opposite corner, you will have to pay for the extra construction around the plant or thru the plant

Location of Main Substation

- Electric utility circuit is usually MV
- Voltage: 12.47 kV or 13.8 kV, 3-phase
- Capacity: 7-12 MW per circuit for bulk power
- Main substation near existing lines
- Utility obligated to bring service to property line
- Represent large revenue stream of kWh

Reference: Rule 16, Service Extensions, per SCE, LADWP, PG&E, SMUD

Location of Main Substation



Location of Main Substation

- You pay for extension of line around property
- You pay for extension of line within property
- Line losses increase = square of current x resistance, or I^2R

CAVEATS

- Pay for losses in longer feeder circuit as in kWh
- May be limited in choices of site plan
- Need to catch layout early in conceptual stages

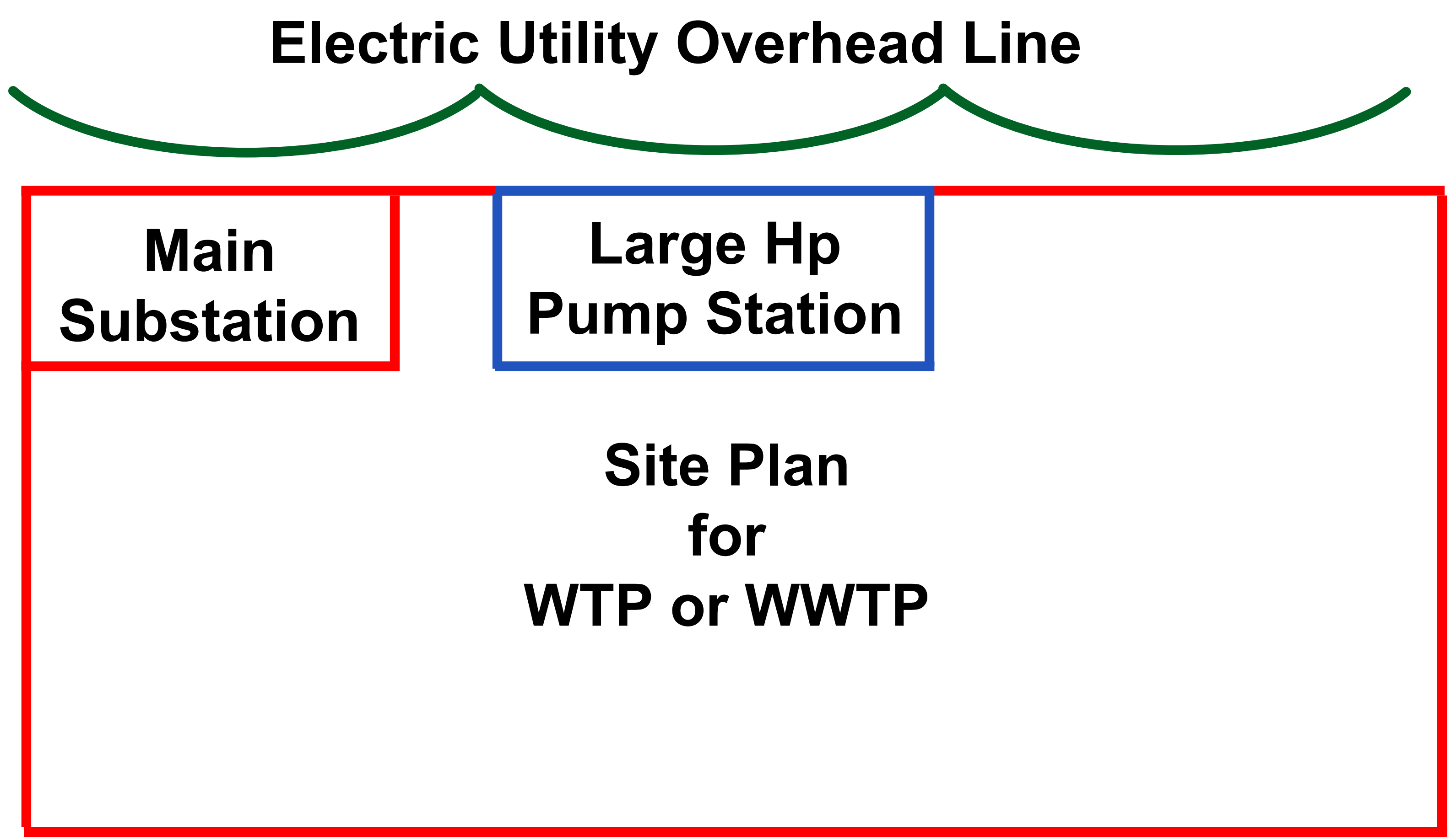
Electrical Center of Gravity

- Should optimize location of large load center balanced with small loads
- Example is pump station, with 10-100 Hp pumps
- Optimized location would have pump station next to main substation
- Minimize voltage drop and losses in feeder cables

Location of Large Load Centers

- Locate large load centers near main substation
- Example: Pump stations with large Hp motors
- Minimize losses in feeder conductors
- Optimum: electrical “center-of-gravity” of all loads
- Run SKM, ETAP, etc., power systems software to optimize system

Location of Large Load Centers



Double Ended Substation

- Also known as a main-tie-main power system
- The main-tie-main can be both at 12 kV or 480 V to take advantage of two separate power sources
- At 480 V, there are two 12 kV to 480 V transformers feeding two separate 480 V buses with a tie breaker between

Double Ended Substation

- **At 12 kV, there are two 12 kV sources with a 12 kV tie breaker between**
- **The two 12 kV sources should be from different circuits for optimum redundancy**
- **If not, reliability is reduced, but at least there is a redundant 12 kV power train**

Double Ended Substation

- **For process optimization, the loads should be equally distributed between the buses**
- **Example, four 100 Hp pumps**
- **Should be Pumps 1 and 3 on Bus A, and Pumps 2 and 4 on Bus B**
- **If all four pumps were on Bus A, and Bus A failed, you have zero pumps available**

Double Ended Substation

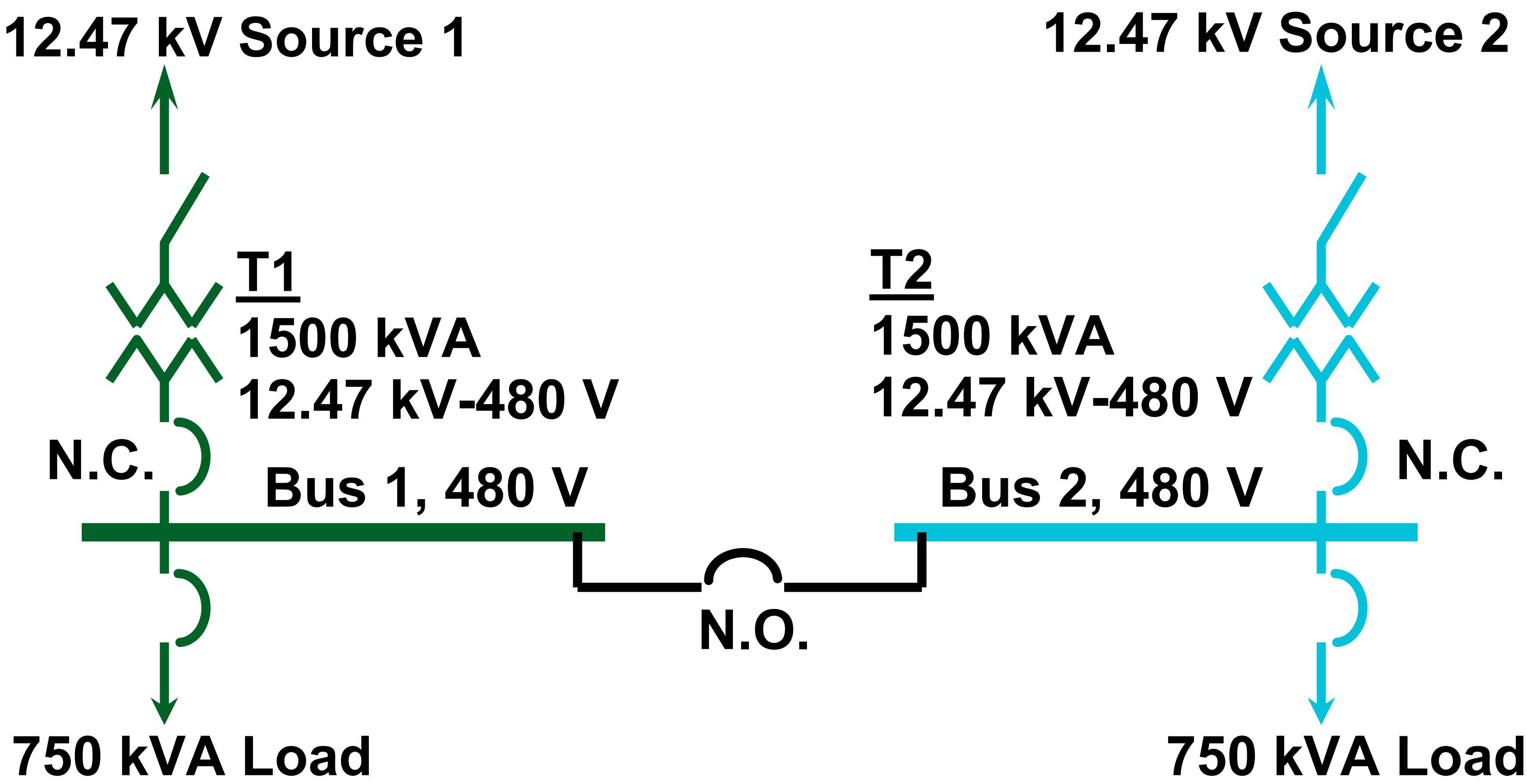
- **Normally, main breaker A and main breaker B is closed and the tie breaker is open**
- **For full redundancy, both transformers are sized to carry the full load of both buses**
- **Normally, they are operating at 50% load**
- **In the previous example, each transformer is sized at 2000 kVA, but operating at 1000 kVA when the tie breaker is open**

Double Ended Substation

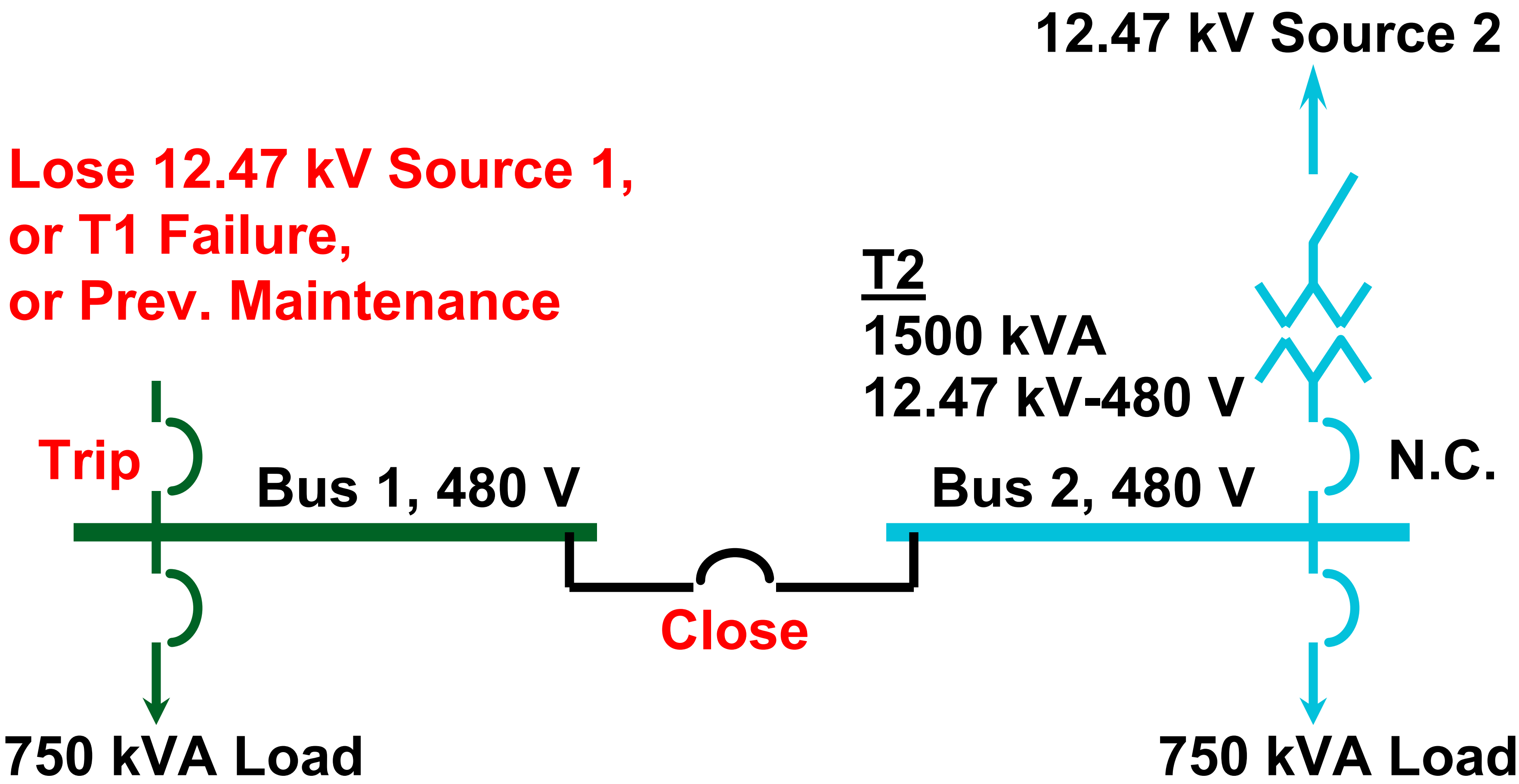
Double Ended Substation

Double Ended Substation

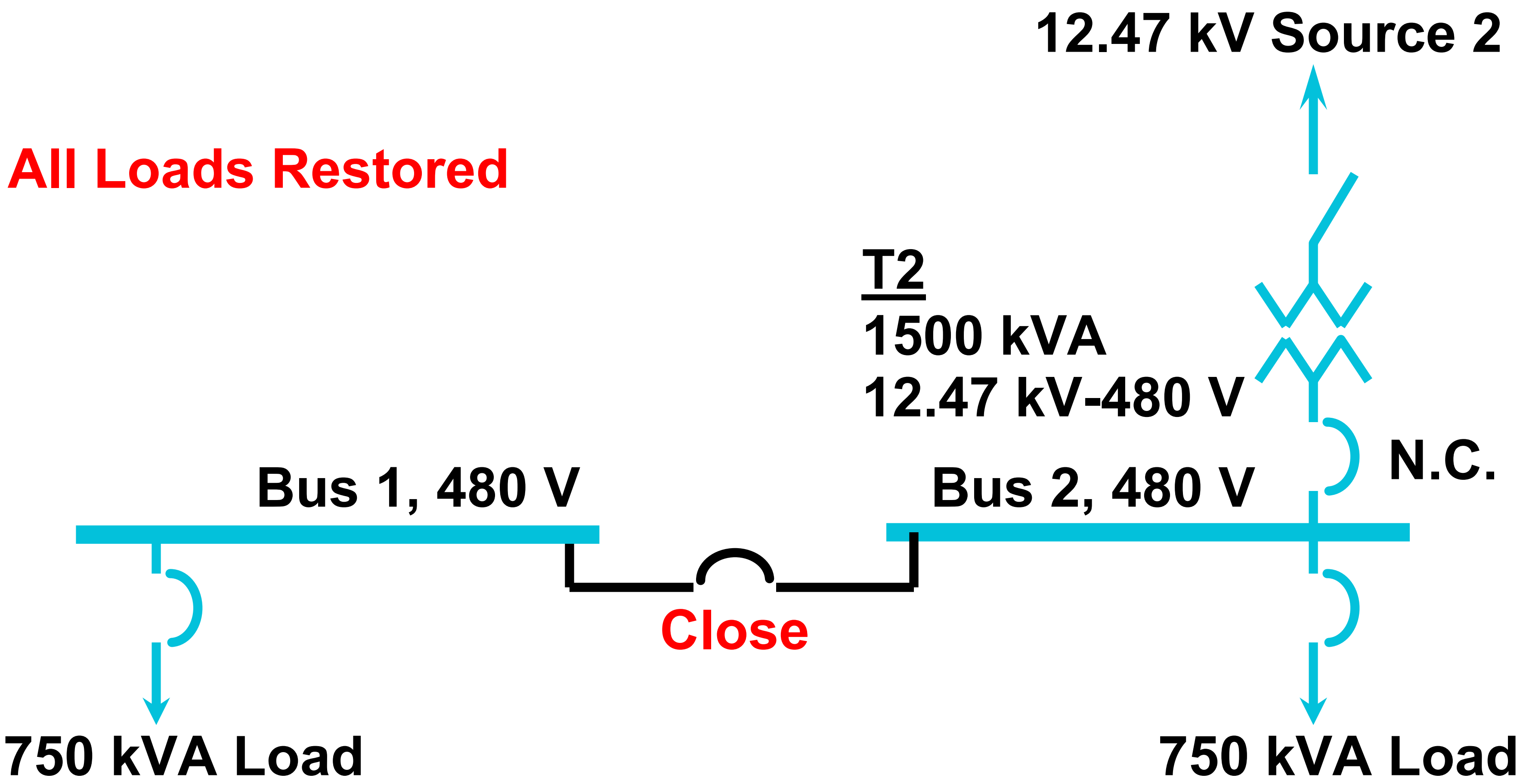
Dual Redundant Transformers, Main-Tie-Main



Dual Redundant Transformers, Main-Tie-Main



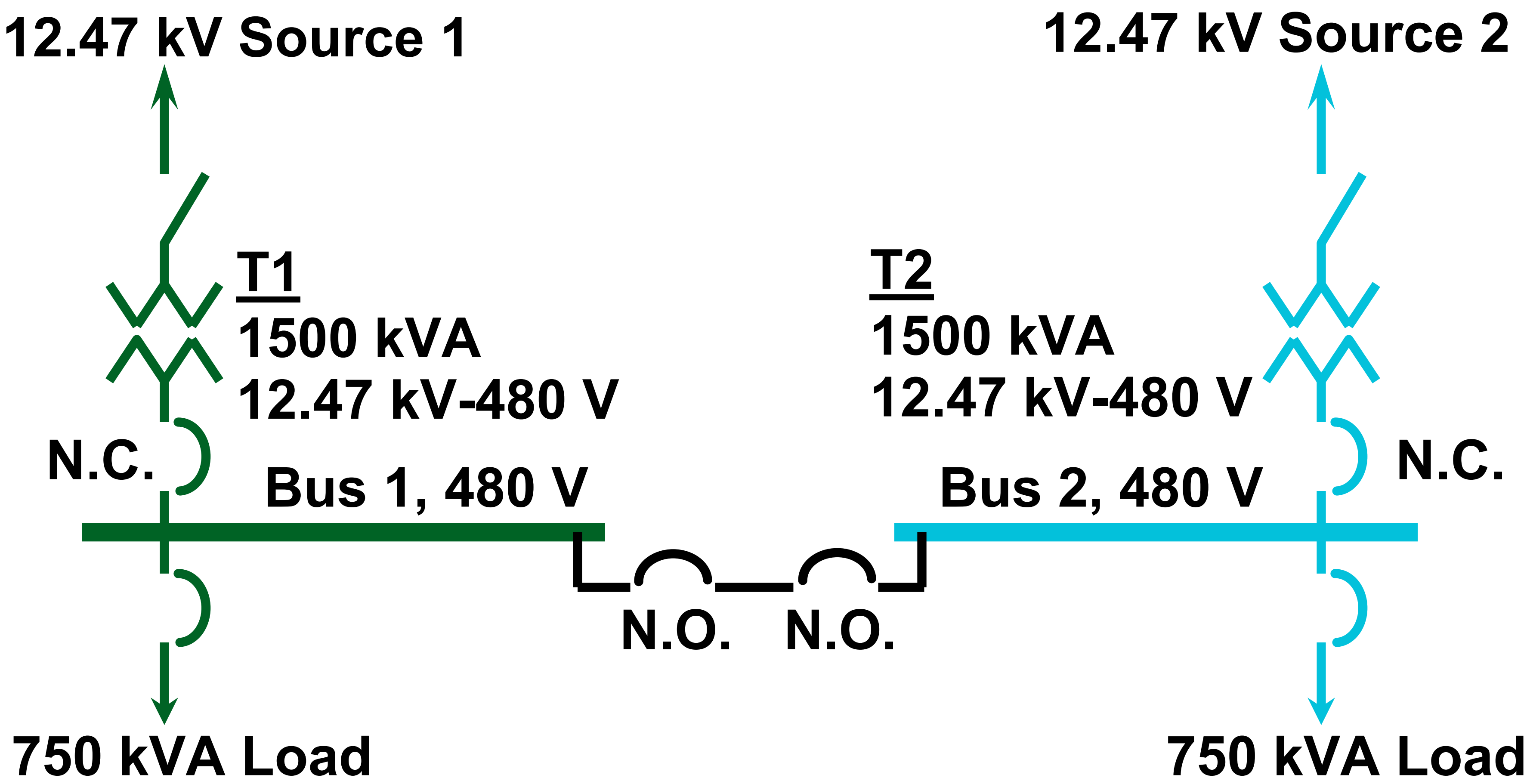
Dual Redundant Transformers, Main-Tie-Main



Main-Tie-Tie Main System

- **For personnel safety, a dummy tie breaker is added to create a main-tie-tie-main system**
- **When working on Bus A for maintenance, all loads can be shifted to Bus B for continued operation**
- **Then the tie breaker is opened and Bus A is dead**
- **However, the line side of the tie breaker is still energized**
- **Hence, a dummy tie is inserted to eliminate the presence of voltage to the tie breaker**

Main-Tie-Tie Main System



MV vs. LV Feeders

- Recall: I^2xR losses increase with square of current
- Worst case is large load far away
- Fuzzy math: increase voltage and reduce current
- Example: 1,500 kVA of load, 3-phase
- Current at 480 V = 1500/1.732/.48 = 1804 A
- Current at 4.16 kV = 1500/1.732/4.16 = 208 A
- Current at 12.47 kV = 1500/1.732/12.47 = 69 A

MV vs. LV Feeders

- **Sizing feeders: 100% noncontinuous + 125% of continuous**

Reference: NEC 215.2(A)(1)

- **Engineering practice is 125% of all loads**
- **Sometimes a source of over-engineering**

MV vs. LV Feeders

- Example: 2-500 Hp pumps + 1-500 Hp standby
- Worst-worst: All 3-500 Hp pumps running
- What if system shuts down or fails
- May need 4th pump as standby

MV vs. LV Feeders

- Recall: I^2R losses increase with resistance
- As conductor diameter increases, resistance decreases
- Can increase all conductors by one size to decrease resistance
- Thereby decreasing line losses & increase energy efficiency
- Comes at increased cost for cables/raceway

Reference: Copper Development Association

MV vs. LV Feeders

- **480 V: "drop more Cu in ground" w/600 V cable**
- **5 kV cable: more expensive than 600 V cable**
- **15 kV cable: more expensive than 5 kV cable**
- **4.16 kV switchgear: more expensive than 480 V switchgear or motor control centers**
- **12.47 kV swgr: more expensive than 4.16 kV**
- **Underground ductbank is smaller with MV cables**

MV vs. LV Feeders

- Previous example with 1,500 kVA load:
- At 480 V, ampacity = 1804 A x 125% = 2255 A
- Ampacity of 600 V cable, 500 kcmil, Cu = 380 A

Reference: NEC Table 310.16

- Need six per phase: 6 x 380 A = 2280 A
- Feeder: 18-500 kcmil + Gnd in 6 conduits

MV vs. LV Feeders

- **At 4.16 kV, ampacity = 208 A x 125% = 260 A**
- **Ampacity of 5 kV cable, 3/0 AWG, Cu = 270 A**

Reference: NEC Table 310.77, for MV-105, 1 ckt configuration

- **Feeder: 3-3/0 AWG, 5 kV cables + Gnd in 1 conduit**

MV vs. LV Feeders

- At 12.47 kV, ampacity = 69 A x 125% = 87 A
- Ampacity of 15 kV cable, 6 AWG, Cu = 97 A
- Ampacity of 15 kV cable, 2 AWG, Cu = 165 A

Reference: NEC Table 310.77, for MV-105, 1 ckt configuration

- 2 AWG far more common; sometimes costs less
- Larger conductor has less R, hence less losses
- Feeder: 3-2 AWG, 15 kV cables + G in 1 conduit

MV vs. LV Feeders

- **Use of MV-105 is superior to MV-90 cable for same conductor size**
- **The 105 or 90 refers to rated temperature in C**
- **MV-90 is being slowly phased out by manufacturers today**

MV vs. LV Feeders

- **Higher ampacity available from MV-105**

Conductor Size	MV-90 Amps	MV-105 Amps
2 AWG, 5 kV	145 A	155 A
2/0 AWG, 5 kV	220 A	235 A
4/0 AWG, 5 kV	290 A	310 A
500 kcmil, 5 kV	470 A	505 A

Reference: NEC Table 310.77, 1 circuit configuration

MV vs. LV Feeders

- **Multiple circuits in ductbank require derating**
- **Heat rejection due to I^2R is severely limited**
- **Worst case: middle & lower conduits; trapped**

No. of Circuits	Ampacity
1	270 A
3	225 A
6	185 A

Reference: NEC Table 310.77, for 3/0 AWG, Cu, 5 kV, MV-105

- **NEC based on Neher-McGrath (ETAP software)**

Transformer Sizing

- **Two basic types of transformers:**
- **Liquid-filled transformers (2 types)**
  - Pad-Mount type
  - Substation type
- **Dry-type transformers**

Liquid-Filled: Pad-Mount Type Transformer

Liquid-Filled: Substation Type Transformer

Dry-Type Transformer

Dry-Type Transformer

Transformer Sizing

- Common mistake is to oversize transformers
- Example: Average load is 1,500 kVA, then transformer is 1,500 or even 2,000 kVA
- Prudent engineering: cover worst case demand
- There's a better way and still use solid engineering principles

Transformer Sizing

- Use the temperature rise rating and/or add fans for cooling
- For liquid-filled transformers in 1,500 kVA range:
- Standard rating is 65°C rise above ambient of 30°C
- Alternate rating is 55/65°C, which increases capacity by 12%

Reference: ANSI/IEEE Standard 141 (Red Book), section 10.4.3

Transformer Sizing

- Capacity can be further increased with fans
- OA = liquid-immersed, self-cooled
- FA = forced-air-cooled

Reference: ANSI/IEEE Standard 141 (Red Book), Table 10-11

- In 1,500 kVA range, adding fans increases capacity by 15%

Reference: Westinghouse Electrical Transmission & Distribution Reference Book

Transformer Sizing

- Example: 1,500/1,932 kVA, OA/FA, 55/65°C
  OA, 55°C = 1,500 kVA
  OA, 65°C = 1,680 kVA (1.12 x 1,500)
  FA, 55°C = 1,725 kVA (1.15 x 1,500)
  FA, 65°C = 1,932 kVA (1.15 x 1.12 x 1,500)
- Increased capacity by 29%
- Avoid larger transformer and higher losses
- Note: All we did was cool the transformer

Transformer Sizing

- **Same concept for dry-type transformers**
- **AA = dry-type, ventilated self-cooled**
- **FA = forced-air-cooled**

Reference: ANSI/IEEE Standard 141 (Red Book), Table 10-11

- **Adding fans increases capacity by 33.3%**

Reference: ANSI Standard C57.12.51, Table 6

- **Example: 1,500/2000 kVA, AA/FA**

Transformer Losses

- Transformers are ubiquitous throughout water & wastewater plants
- Transformer losses = 2 components:
- No-load losses + load losses
- No-load = constant when transformer energized
- Load = vary with the loading level

Transformer Losses

- Losses for 1,500 kVA transformer (W)

Type	No-Load	Full-Load	Total (W)
Dry-Type	4,700	19,000	23,700
Liquid (sub)	3,000	19,000	22,000
Liquid (pad)	2,880	15,700	18,580

Reference: Square D Power Dry II, Pad-Mount, & Substation Transformers

Transformer Losses

- **Efficiencies for 1,500 kVA transformer at various loading levels (%)**

Type	100%	75%	50%
Dry-Type	98.44	98.65	98.76
Liquid (sub)	98.55	98.80	98.98
Liquid (pad)	98.78	98.97	99.10

Reference: Square D Power Dry II, Pad-Mount, & Substation Transformers

Transformer Losses

- **Trivial difference between 98.44% (dry) and 98.78% (liquid), or 0.34%?**
- **Assume 10-1500 kVA transformers for 1 year at $0.14/kWh = $62,550 savings**

Transformer Losses

- **Heat Contribution for 1,500 kVA transformer at various loading levels (Btu/hr)**

Type	100%	75%	50%
Dry-Type	80,860	52,510	32,240
Liquid (sub)	75,065	46,700	26,445
Liquid (pad)	N/A	N/A	N/A

Reference: Square D Power Dry II & Substation Transformers

Transformer Losses

- **Energy Policy Act 2005 effective Jan 1, 2007; uses NEMA TP-1 standards as reference**
- **Mandates transformers meet efficiency levels, especially at low loads > larger share of total**
- **Target: higher grade of grain oriented steel**
- **Thinner gauge and purer material quality**
- **Reduces heat from eddy/stray currents**

Reference: New Energy Regulations to Impact the Commercial Transformer Market, Electricity Today, March 2007

Transformer Overloading

- Can you exceed the rating of a transformer?
- Without loss of life expectancy?
- Depends on the following conditions:
- Frequency of overload conditions
- Loading level of transformer prior/during to overload
- Duration of overload conditions

Reference: ANSI/IEEE C57.92, IEEE Guide for Loading Mineral-Oil-Immersed Power Transformers Up to and Including 100 MVA

Transformer Overloading

- **Allowable overload for *liquid-filled* transformer, 1 overload/day**

Duration	90%	70%	50%
0.5 hrs	1.80xRated	2.00xRated	2.00xRated
1.0 hrs	1.56xRated	1.78xRated	1.88xRated
2.0 hrs	1.38xRated	1.54xRated	1.62xRated
4.0 hrs	1.22xRated	1.33xRated	1.38xRated
8.0 hrs	1.11xRated	1.17xRated	1.20xRated

Reference: Square D Substation Transformers

Transformer Overloading

- **Overloading a transformer is not strictly taboo**
- **Okay if you can engineer the system and control the conditions, i.e., dual redundant transformers**
- **Allows purchase of smaller transformer**
- **Less losses, higher energy efficiency, lower energy costs**

Transformer Overloading

- Spill containment issues with liquid-filled: PCB, mineral oil, silicone, etc.
- Mitigated by using environmentally benign fluid:
- Envirotemp FR3 is soy-based, fire-resistant, PCB-free, can cook with it
- Meets NEC & NESC standards for less-flammable, UL listed for transformers

Reference: Cooper Power Systems Envirotemp FR3 Fluid

Transformer Overloading

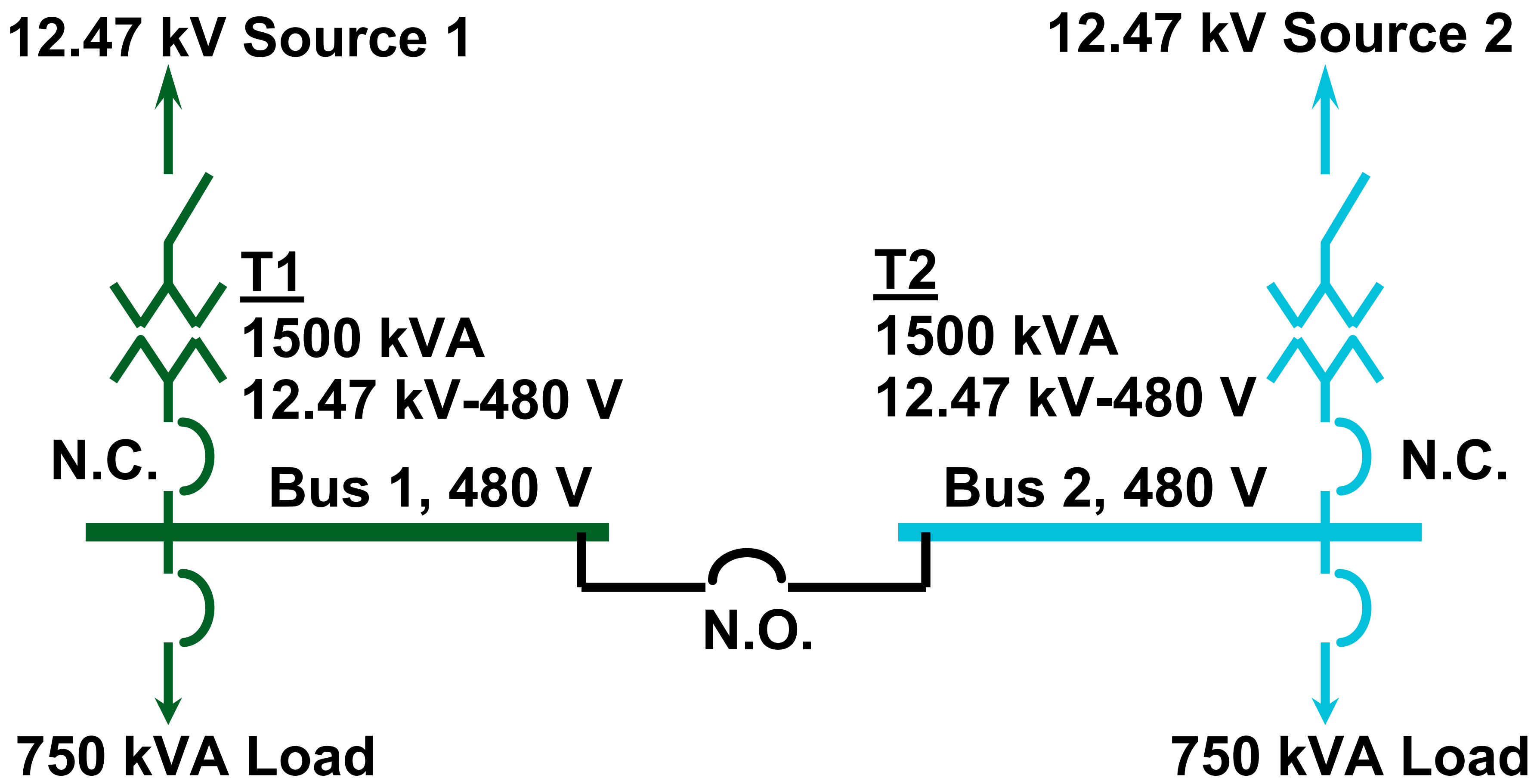
- For a typical transformer: 1,500 kVA, 5/15 kV primary, 480Y/277 V secondary
- Cost is about 45% to 93% higher for dry-type vs. liquid-filled
- Adding fans and temp ratings costs are incremental: capital cost only

Reference: 2000 Means Electrical Cost Data, Section 16270

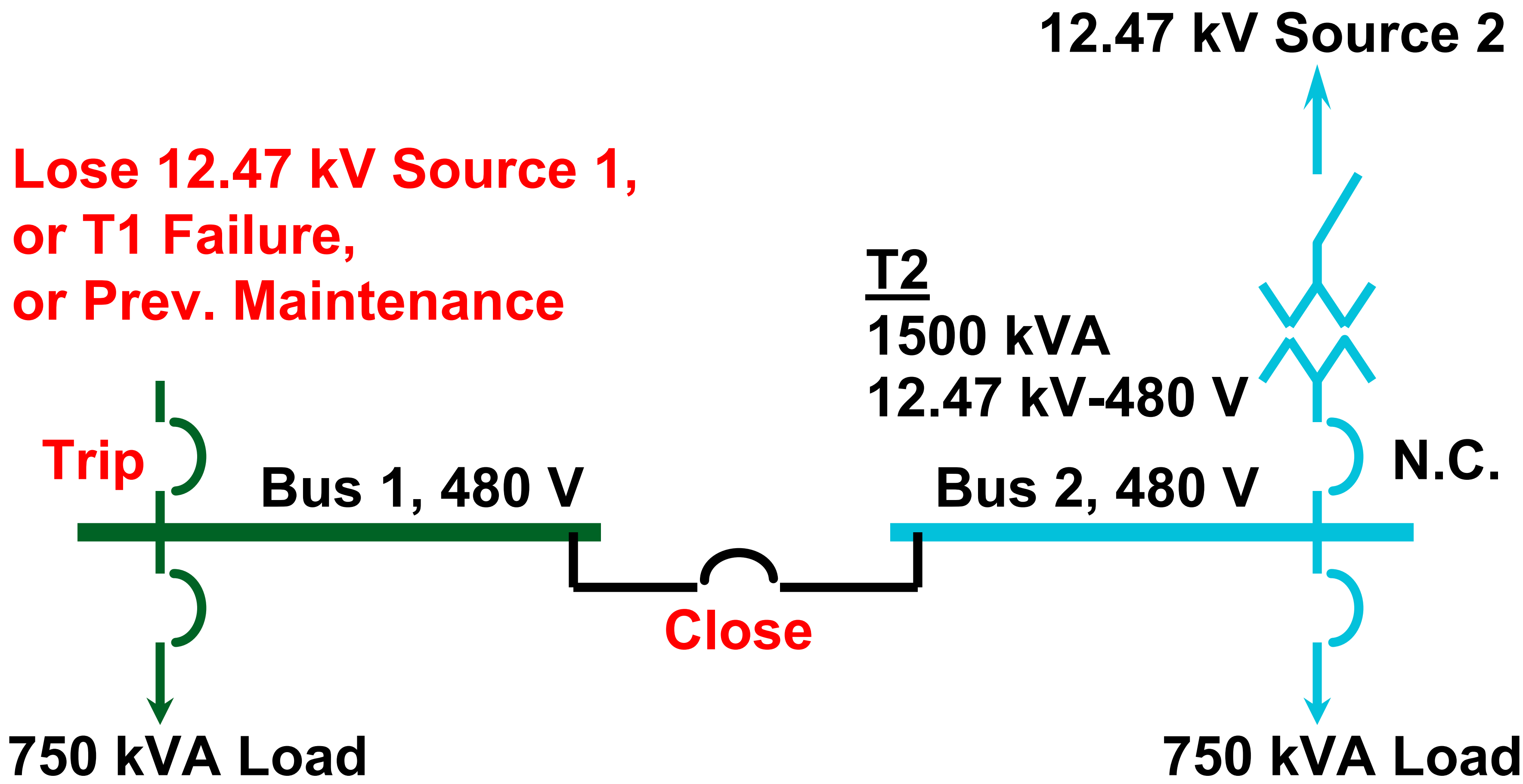
Transformer Overloading

- **Maintenance/Reliability**
- **Most significant and salient point**
- **Not advisable to have radial feed to one transformer to feed all loads**
- **Dual-redundant source to two transformers with main-tie-main configuration for reliability and redundancy; transformers at 50% capacity**
- **Decision Point: Lower capital cost with radial system vs. high reliability and flexibility**

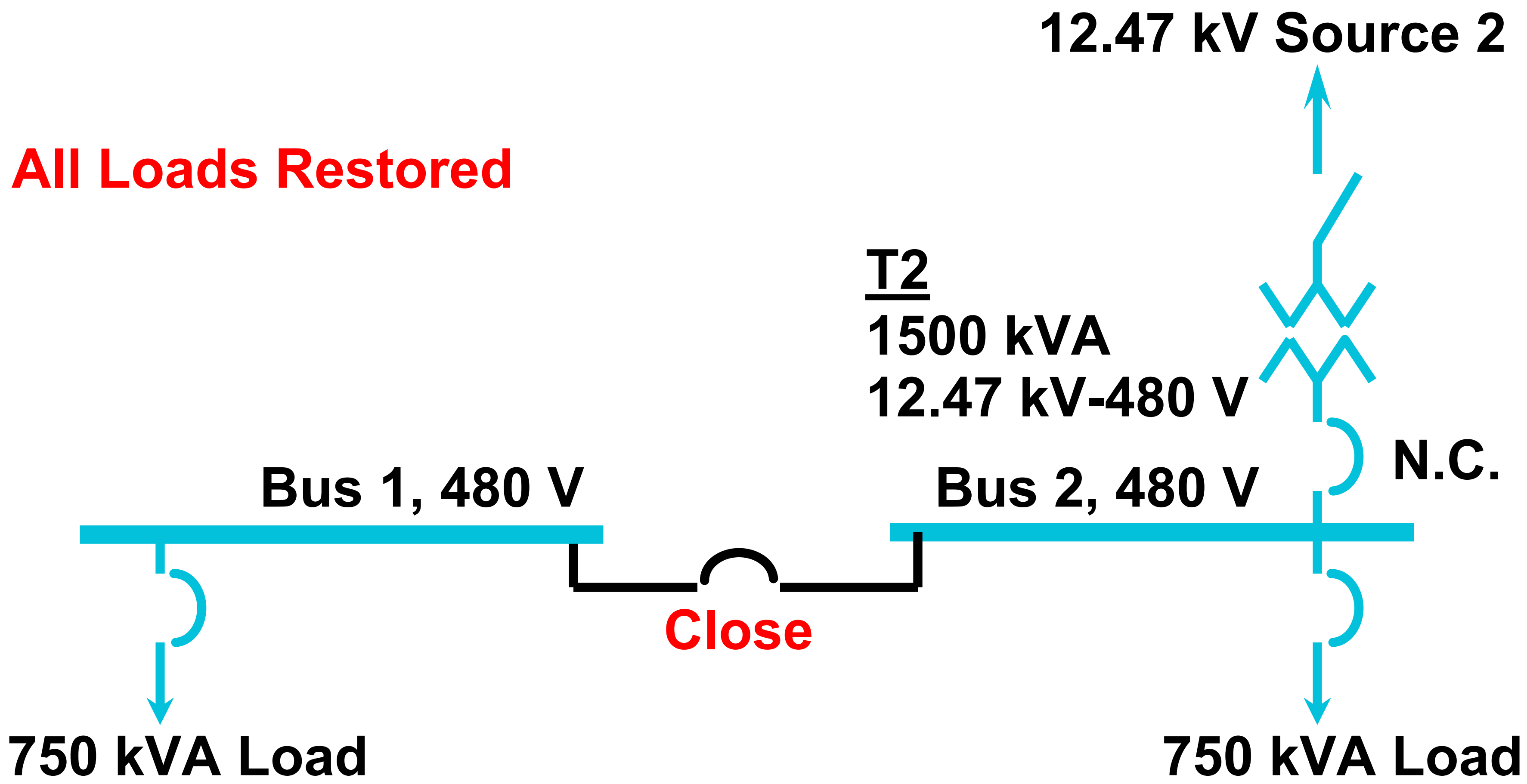
Dual Redundant Transformers, Main-Tie-Main



Dual Redundant Transformers, Main-Tie-Main



Dual Redundant Transformers, Main-Tie-Main



Emergency/Standby Engine-Generators

- **Very common source of alternate power on site**
- **Diesel is most common choice for fuel**
- **Generator output at 480 V or 12 kV**
- **NEC Article 700, Emergency Systems, directed at life safety**
- **Emergency: ready to accept load in 10 seconds maximum**

Emergency/Standby Engine-Generators

- **NEC Article 701, Legally Required Standby Systems, directed at general power & ltg**
- **Standby: ready to accept load in 60 seconds maximum**
- **Both are legally required per federal, state, govt. jurisdiction**
- **Similar requirements, but more stringent for emergency**
- **Example: equipment listed for emergency, exercising equipment, markings, separate raceway**

Emergency/Standby Engine-Generators

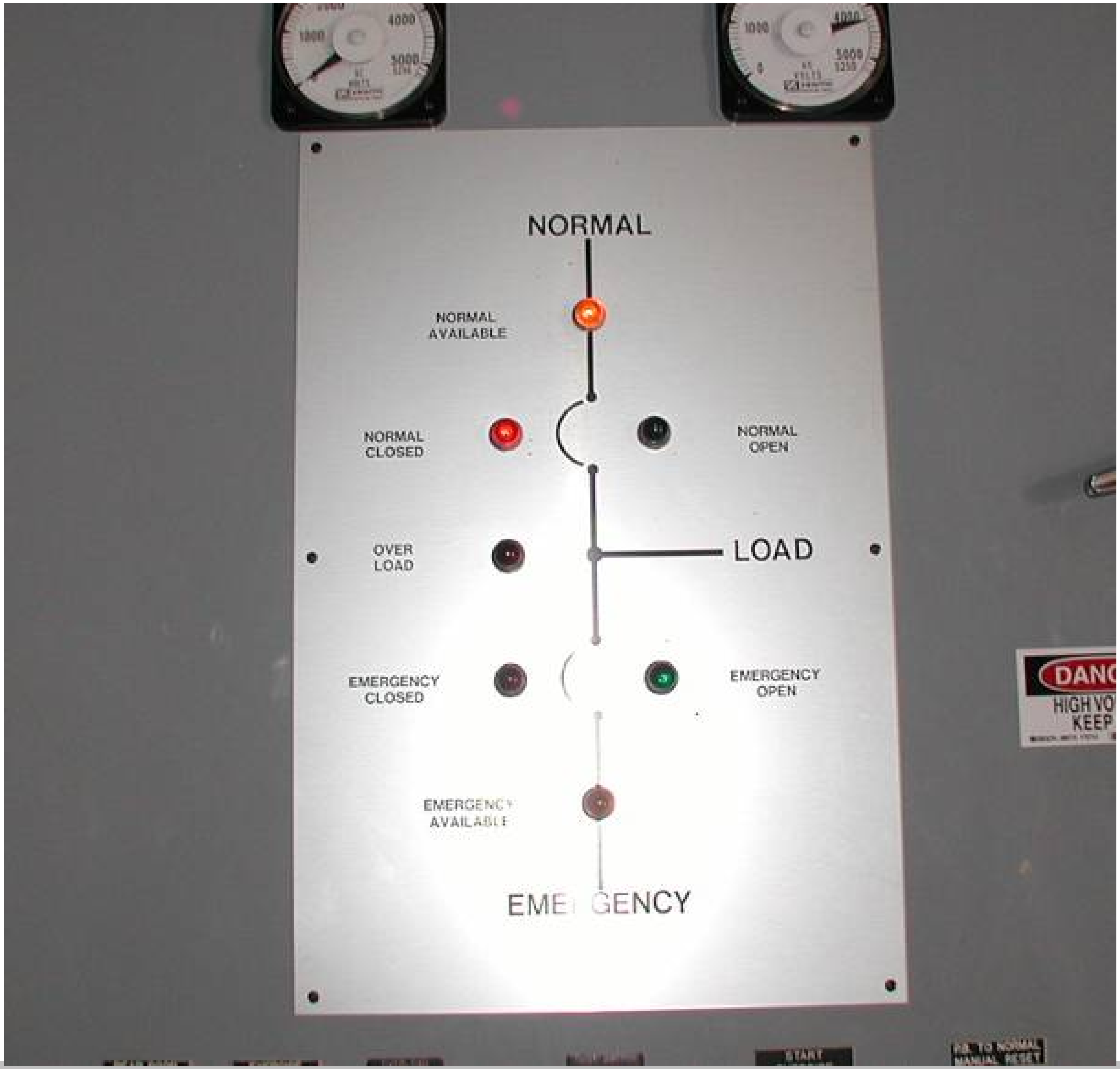
- **NEC Article 702, Optional Standby Systems, directed at non-life safety, alternate source**
- **Even less stringent requirements**

Automatic Transfer Switches

- Used in conjunction with emergency/standby power sources
- Constantly sensing presence of normal power source, utility, using UV relay
- When normal power source fails, automatic sends signal to start engine-generator
- When up to speed, transfers from NP to EP, in open transition

Automatic Transfer Switches

Automatic Transfer Switches



Automatic Transfer Switches

- **Open transition: Break-Before-Make, or finite dead time**
- **Upon return of utility power, initiate time delay**
- **To ensure utility power is stable and not switching of circuits while restoring system**
- **After time delay timeout, ATS transfers back to NP, in open transition**
- **Plant loads will be down momentarily**

Automatic Transfer Switches

- **Option is Closed transition: Make-Before-Break, no dead time**
- **For brief time, the engine-generator is operating in parallel with utility**
- **Plant loads stay up**
- **In closed transition, then subject to utility regulations for parallel generation**

Automatic Transfer Switches

- **Need to match voltage, frequency, and phase angle with utility source**
- **Phase angle is most important, worst case is 180 degrees out of phase**
- **Other consideration is preventing small generator feeding out of plant into utility distribution network**
- **Load would be too large for small generator**
- **Generator can't generate enough power and excitation collapses**
- **Would trip out on low voltage and/or low frequency**

Uninterruptible Power Supply (UPS) Systems

- UPS units are very common sources of backup AC power for a variety of uses
- They can be very large to power 100s of kWs of critical loads in the power system
- Or they can be small on the order of a few kW to power control system functions

Uninterruptible Power Supply (UPS) Systems

- **A true UPS is always on line**
- **Incoming AC is converted to DC thru a bridge rectifier to a DC bus**
- **The DC bus charges a battery bank**
- **Power from the DC bus is then inverted to AC for use by loads**
- **If normal power fails, power to the loads is maintained without interruption**
- **AC output power is being drawn from the batteries**
- **Battery bank is no longer being charged**

Uninterruptible Power Supply (UPS) Systems

- **An off-line unit is technically not a UPS since there is a static switch for transferring between sources**
- **An off-line unit feeds the load directly from the incoming utility AC power**
- **A portion of the incoming AC power is rectified to DC and charges a battery bank**
- **If normal power fails, the static switch transfers to the inverter AC output**
- **Again, the AC output power is being drawn from the battery bank**

Uninterruptible Power Supply (UPS) Systems

- **Some off-line units today employ very fast static transfer switches that allege to be so fast the loads won't notice**
- **Need to research this carefully since some computer loads cannot handle a momentary outage**
- **However, a reliable power system design would include a true on-line UPS unit so the momentary outage question is no longer relevant**

Switchgear Auxiliaries

- **Switchgear auxiliaries are an important component in power system reliability**
- **Applies to both 12 kV switchgear and 480 V switchgear, or whatever is in the power system**
- **The ability to continue to operate after utility power fails is critical**

Switchgear Auxiliaries

- Key Components:
- Control power for tripping
- Charging springs
- Relays
- PLC for automatic functions

Switchgear Control Power for Tripping Breakers

- If there is a fault in the system, the relay must sense the fault condition and send a trip signal to the breaker to clear the fault
- A fault could happen at any time
- Could be minutes after the utility circuit fails
- Must clear the fault

Switchgear Control Power for Tripping Breakers

- **The circuit breaker contactor is held closed under normal operations**
- **When a fault is detected, the trip coil in the breaker control circuit operates the charged spring to quickly open the contactor**
- **If control power is available, the motor operated spring immediately recharges for the next operation**
- **Typical demand from the charging motor is about 7 A for about 5-10 seconds**

Switchgear Control Power

- **Maintaining a secure source of power for control of the switchgear is essential**
- **If there is a fault in the system, the relay must sense the fault condition and send a trip signal to the breaker to clear the fault**
- **Several sources of control power:**
- **Stored energy in a capacitor**
- **120 VAC**
- **125 VDC or 48 VDC**

Switchgear Control: Stored Energy (Capacitors)

- Only useful for non-critical systems
- Amount of stored energy is limited
- Not commonly used

Switchgear Control: 120 VAC

- Only operational while 120 VAC is available
- First option is obviously 120 VAC from the utility
- If utility fails, then could be a small UPS
- Not well liked by maintenance personnel since they have to be continually checking the operability and functionality of small UPS units all over the place

Switchgear Control: 120 VDC or 48 VDC

- **Most reliable since control power is obtained directly from the battery bank**
- **There is no conversion to AC**
- **Less chance of component failure**

Switchgear Relays

- Can be powered from 120 VAC
- For reliability, select 125 VDC, particularly when there is a battery bank for switchgear control
- Relays are a critical component in order to detect the presence of a fault on a circuit
- Again, the fault must be cleared

PLC for Overall Substation Control

- **A PLC can be just as critical to switchgear operation if there are other automatic functions carried out by the PLC**
- **The PLC can also detect alarm signals and send them on to the central control room or dial a phone number for help**
- **For reliability, select 125 VDC as the power source for the PLC**
- **Or the same small UPS used for switchgear control power**

Elbow Terminations for MV Cable

- **Terminations for MV cable can sometimes be a point of failure in the power system**
- **Most common is the use of stress cones and skirts with bare surfaces exposed**
- **The concept is to prevent a flashover from the phase voltage to a grounded surface, or ground fault**

Elbow Terminations for MV Cable

- Dirt and dust build up along the cable from the termination can create a flashover path, especially with moisture
- The skirts help to break up the voltage field as it tries to bridge the gap to the grounded potential
- A molded elbow has no exposed energized surfaces
- The elbow also contains the electric field within thereby decreasing chances for corona
- The molded elbow costs a little more but provides another level of reliability in the power system

Demand Side Management

- **Managing the duty cycle on large continuous loads can keep systems at a minimum**
- **Example: Clean-in-Place heater, 400 kW, 480 V**
  400 kW x 2 hour warm-up cycle = 800 kWh
  200 kW x 4 hour warm-up cycle = 800 kWh
  Lower energy cost in dollars if off-peak
- **Program CIP via SCADA CIP to start before maintenance crews arrive via PLC or SCADA**
- **400 kW would have increased system size**

Questions ….?

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