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High Reliability Power System Design

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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

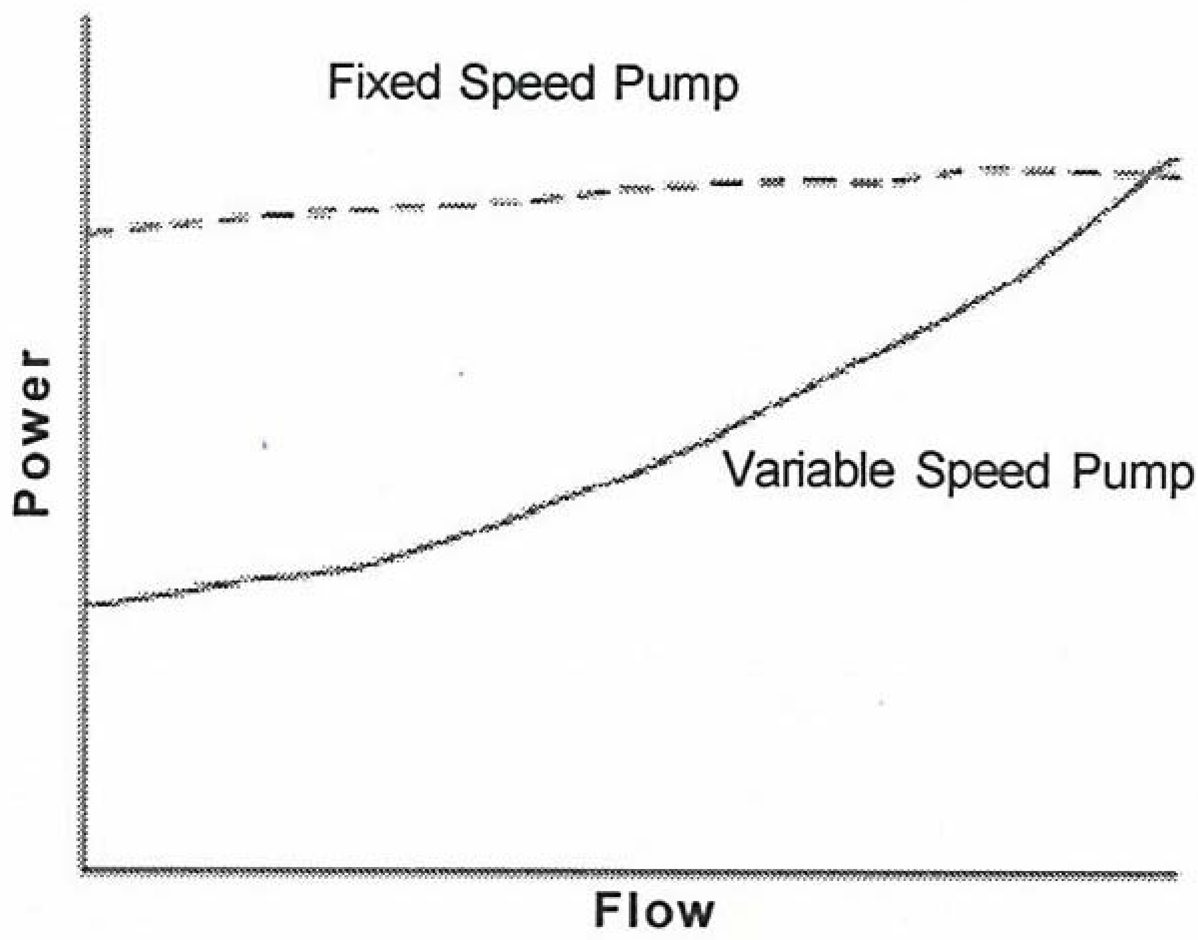
- Motor driven systems represent about 60% of all electrical energy used
- Energy Policy Act of 1992 set min efficiencies for motors in the U.S.
- Manufacturers have increased motor efficiencies in the interim
- Premium-efficiency motors can therefore decrease losses

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

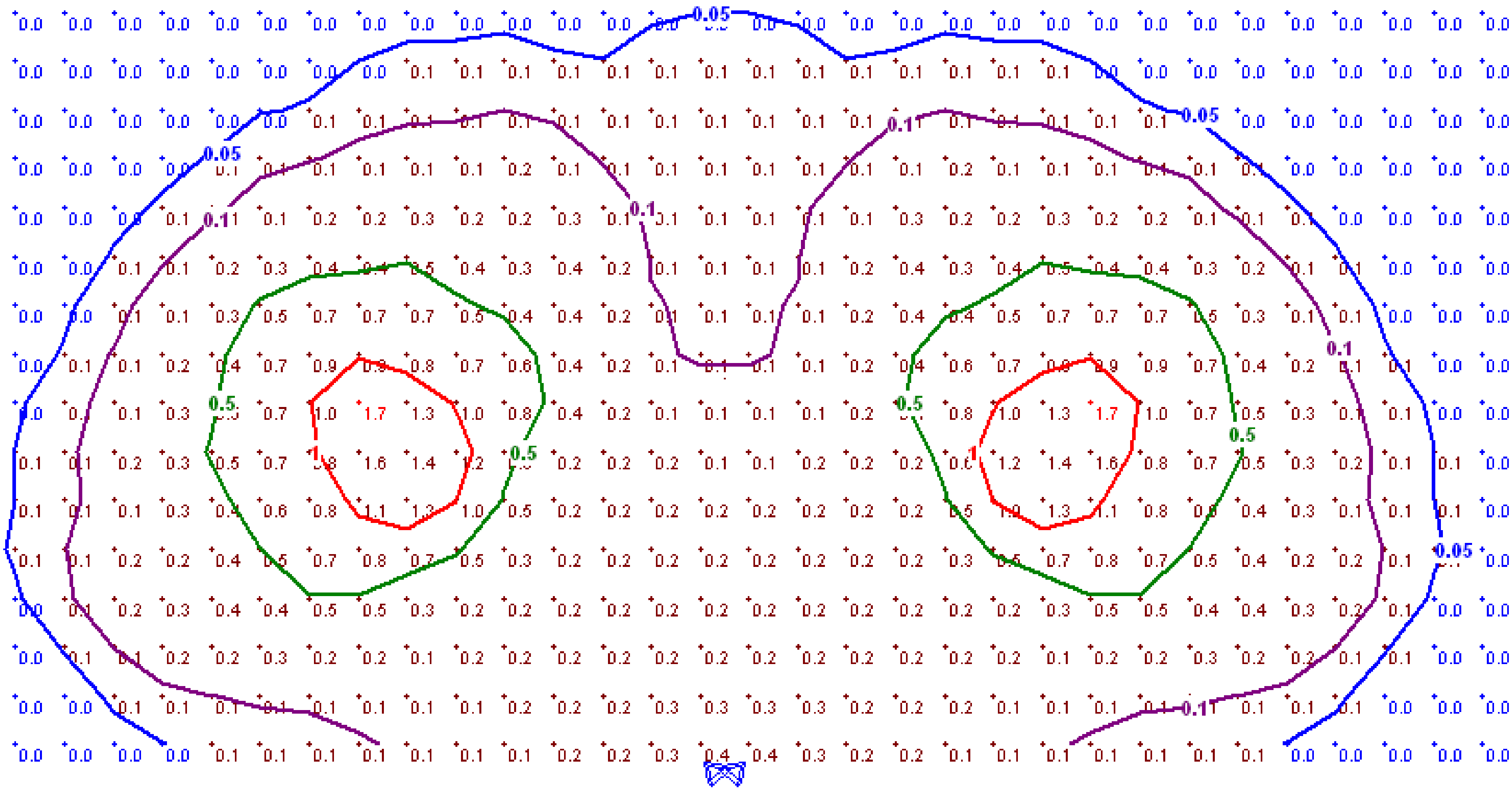
Lighting Design

- 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

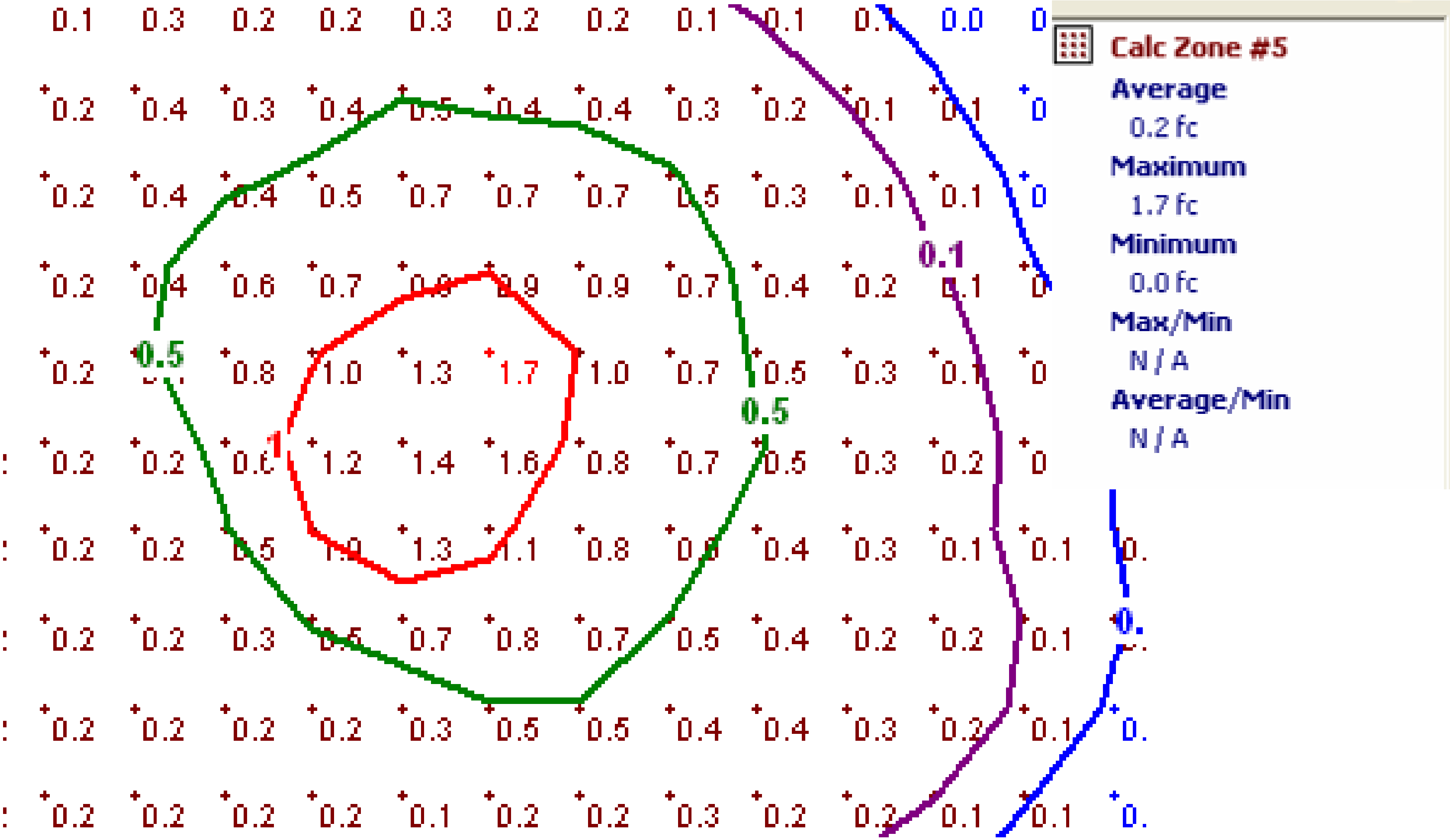
Photometric Calculations – Lighting

Photometric Calculations – Lighting

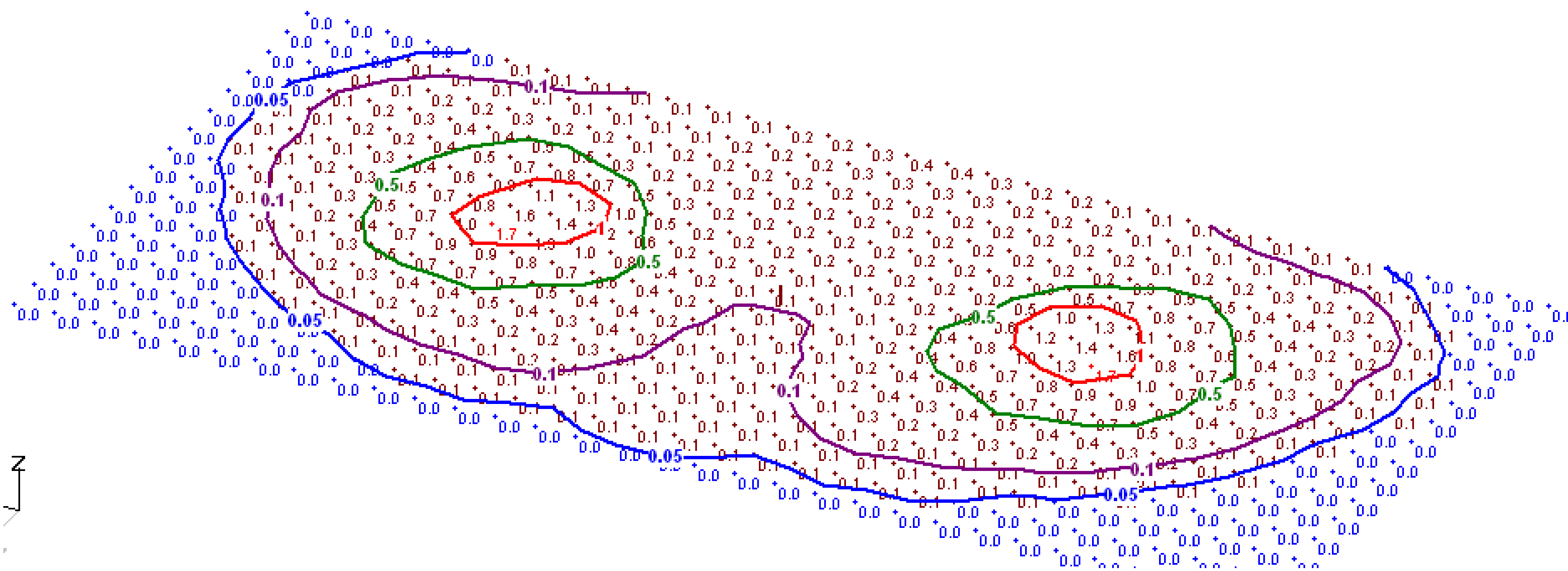
Photometric Calculations – Lighting



Photometric Calculations – Lighting



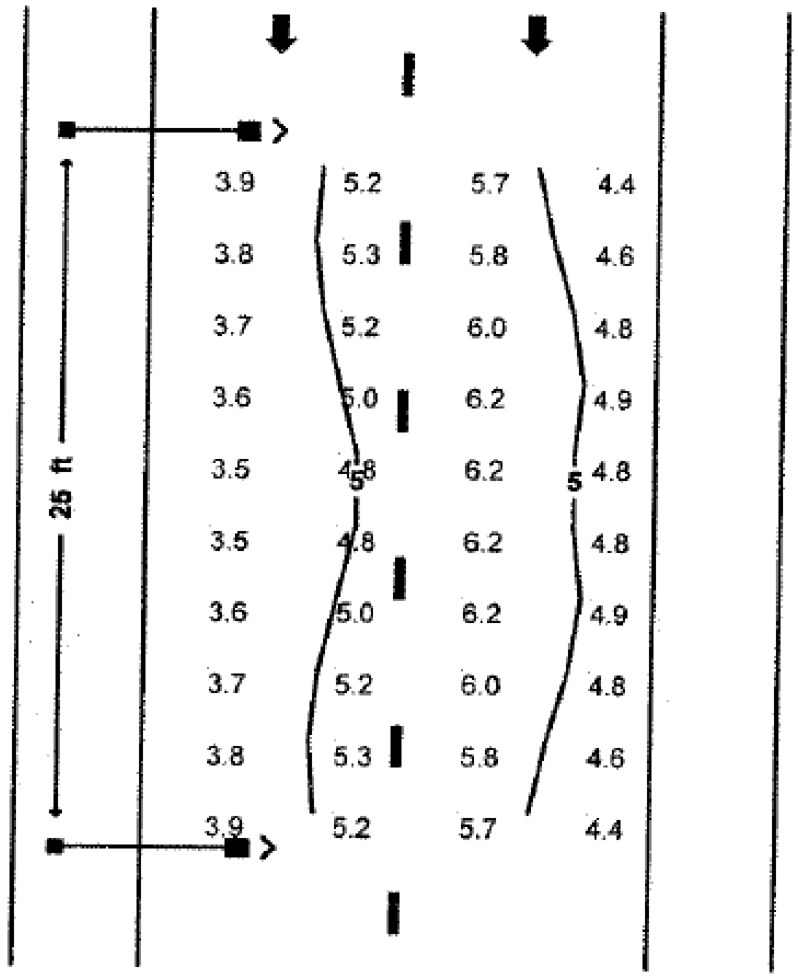
Photometric Calculations – Lighting



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

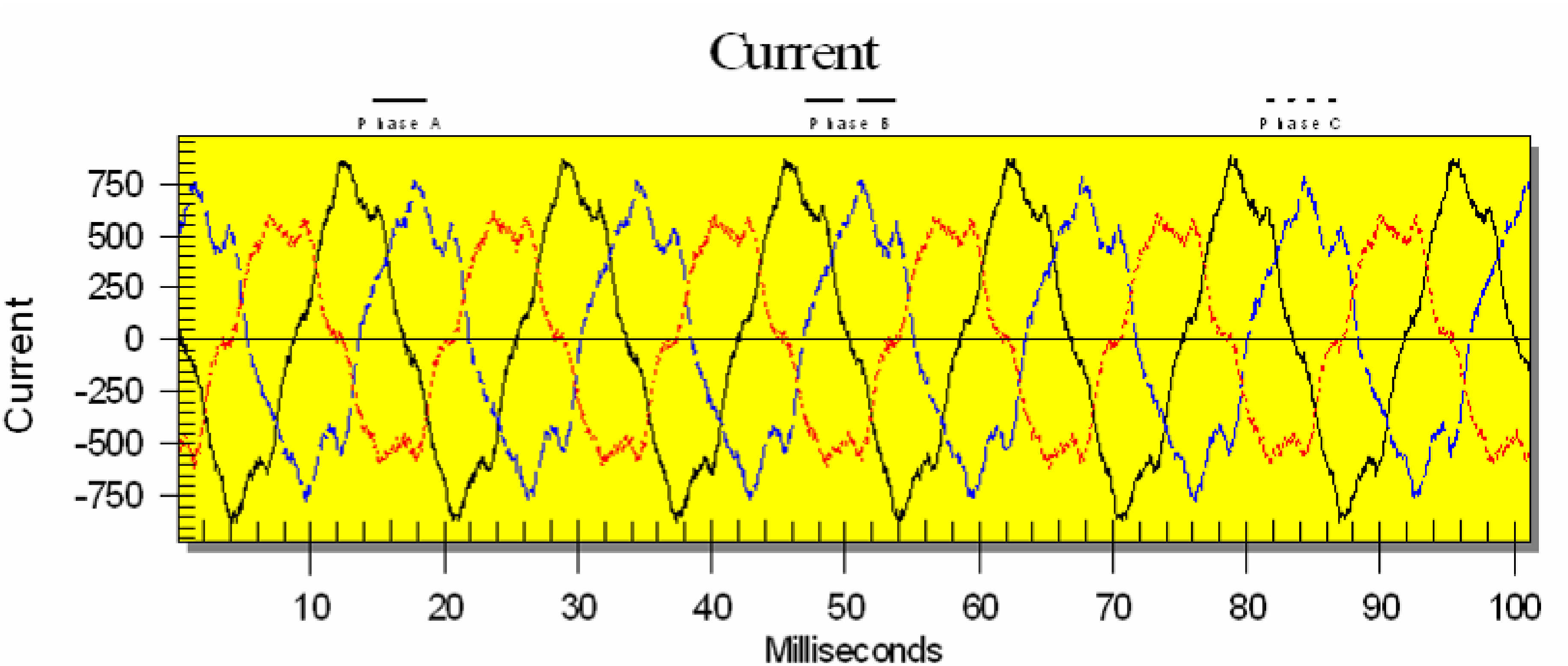
K-Factor Calculations – Dry-Type Transformers

- **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**

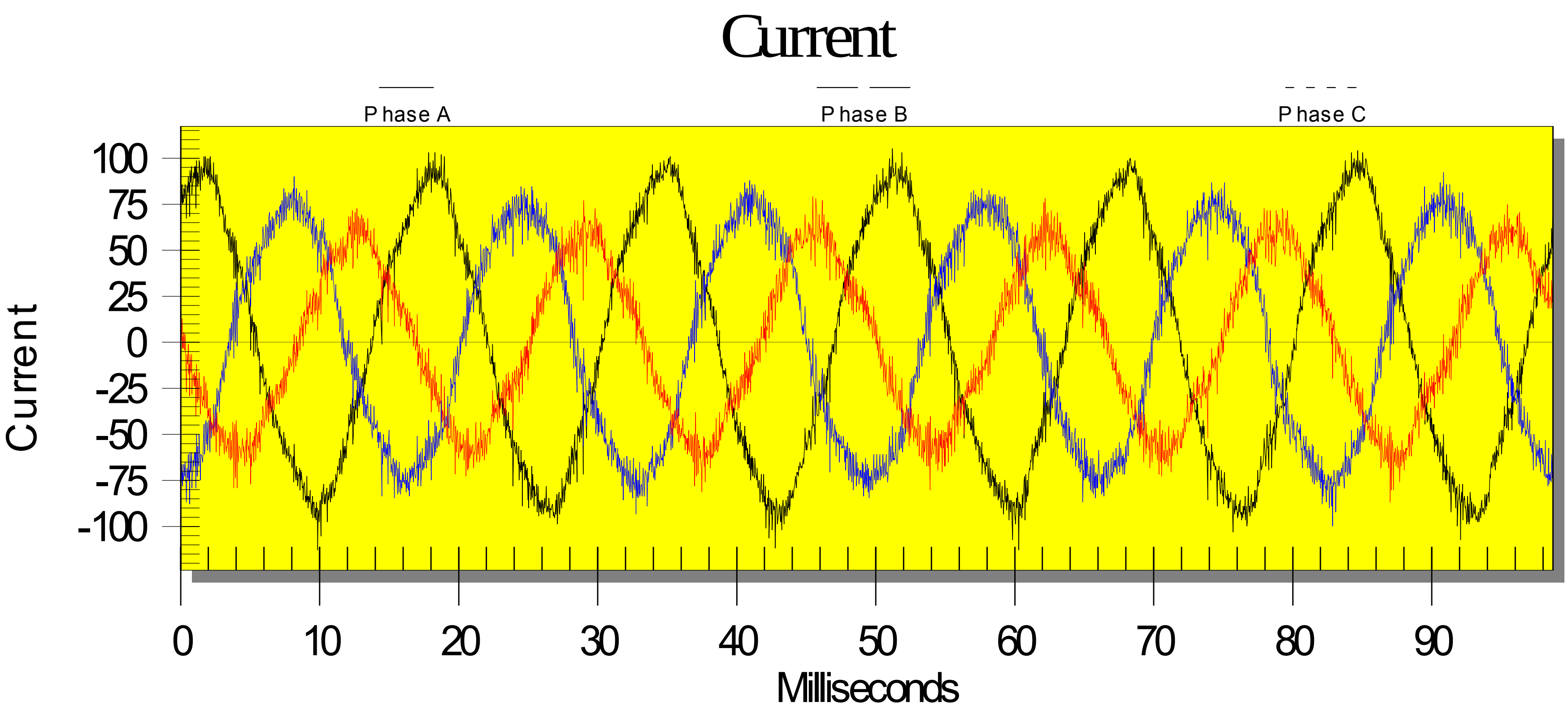
K-Factor Calculations – Dry-Type Transformers

- **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:    Motorolal
```

% Harmonic Current Contents in 1 MVA Base

Branch ID	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. <u>Prepare Load Study Calculation</u>**
- **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	KVAR-C	KVA-C	AMPS-C	RUNNING KW-R	KVAR-R	KVA-R	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

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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	Off 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	On 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

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
-NENR)	KVA		0.92	1.00	244.40	101.51	264.64	332.15	185.7	76.6	200.8	252.07
-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. Size Transformer to 480 V Loads**
- **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. Select Short Circuit Rating of 480 V MCC**
- **Very important**
- **If undersized, could explode and start fire during short circuit conditions**
- **Danger of arc flash, based on I^2T**
- **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**

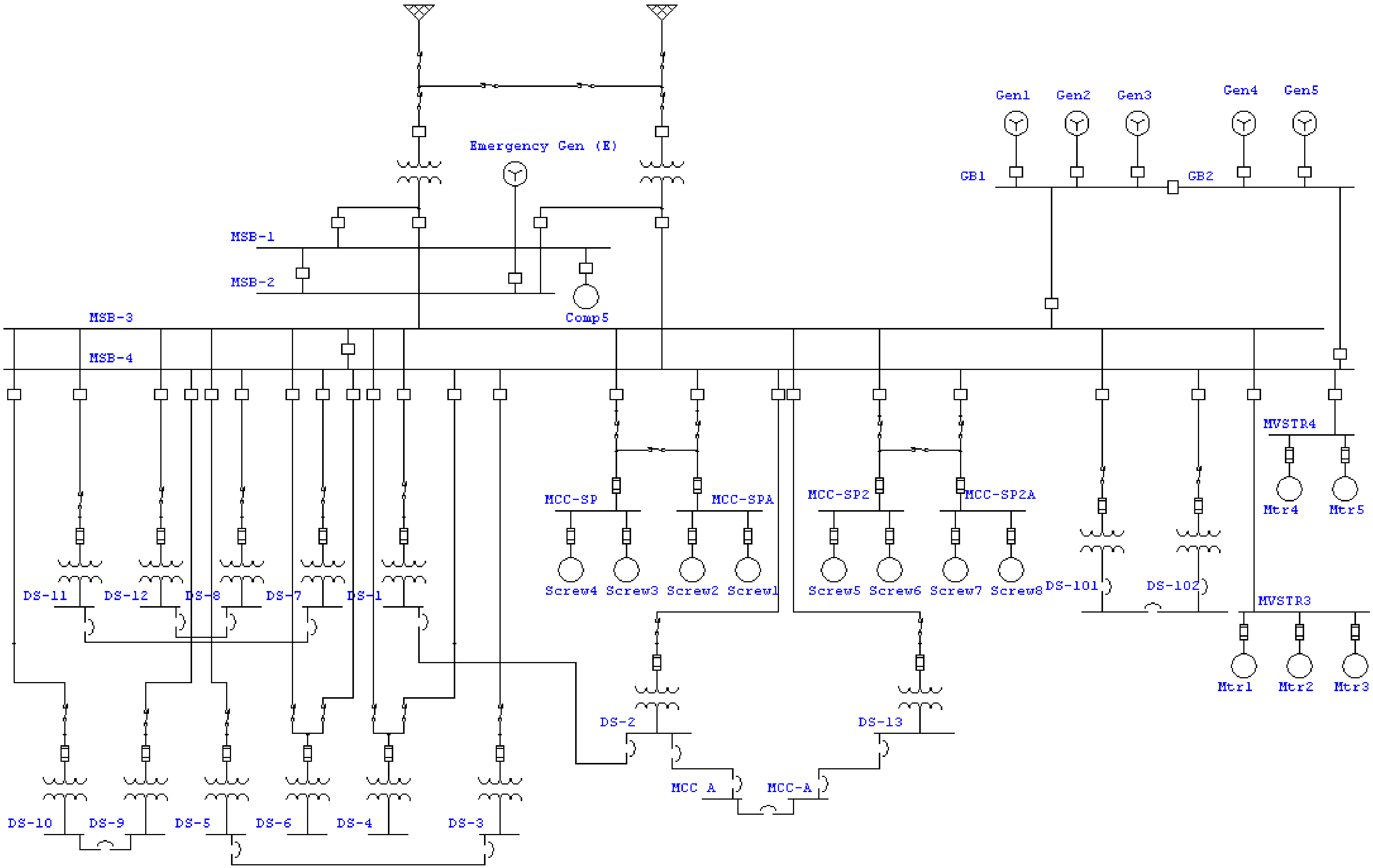
System Design: Short Circuit of 480 V MCC

- **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

			-------------- Initial Symmetrical RMS					-------------			Asym. RMS Amps @ 0.50 Cycles		------ 3-Phase Asym Amps (RMS) ------				
Fault Location Bus Name	**Bus LL 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		Initial Symmetrical RMS 3-Phase Amps	3-Phase MVA	SLG Amps	SLG MVA	LL Amps
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:**

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

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

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

- **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. <u>Size 480 V Feeder from Transformer to MCC</u>**
- **First calculate IFL from transformer secondary**

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

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

- **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^2 conduit**
- **For this example, we will use 500 kcmil (253 mm^2)**

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		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

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

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^2 conduit, 3-500 kcmil (253 mm^2), 1-400 kcmil (203 mm^2) GND**

System Design: Transformer 12 kV Disconnect

- F. <u>Size Transformer 12 kV Primary Disconnect</u>
- First calculate IFL from transformer primary

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

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

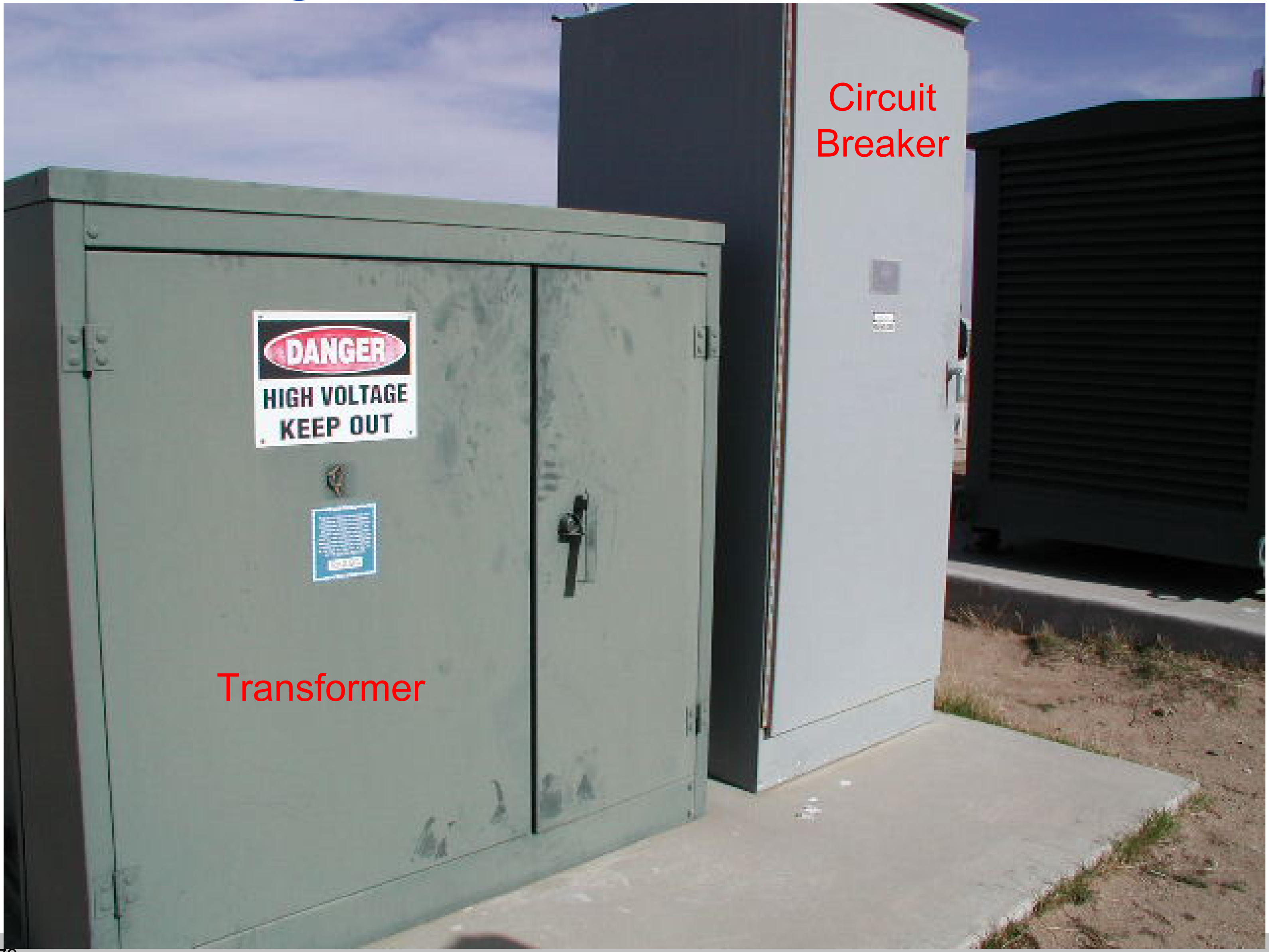
- IFL x 125% = 96.2 A x 1.25 = 120.3 A

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. <u>Size 12 kV Feeder to Transformer (MV Cable)</u>**
- **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

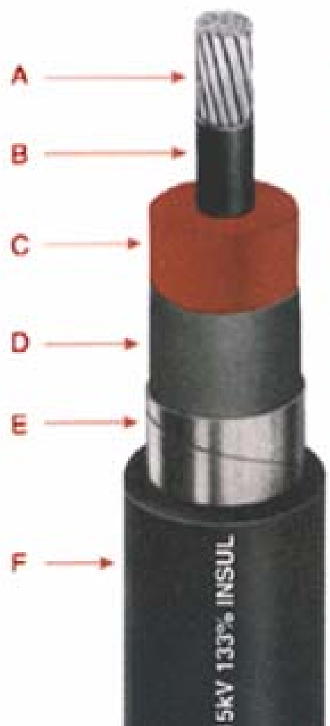
Product Data
Section 2: Sheet 9

COMPACT STRAND CONSTRUCTION

Okoguard®-Okoseal® Type MV-105

15kV Shielded Power Cable

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



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 cables, 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.	mm²	in.²	mm²	in.²	mm²	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

System Design: 480 V Feeder from Transf to MCC

- **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: 480 V Feeder from Transf to MCC

- **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 cables, use Okonite data sheet**
- **Same as for RMC conduit**

System Design: 12 kV Feeder to Transformer

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

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

System Design: 480 V Feeder from Transf to MCC

- 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: 480 V Feeder from Transf to MCC

- **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

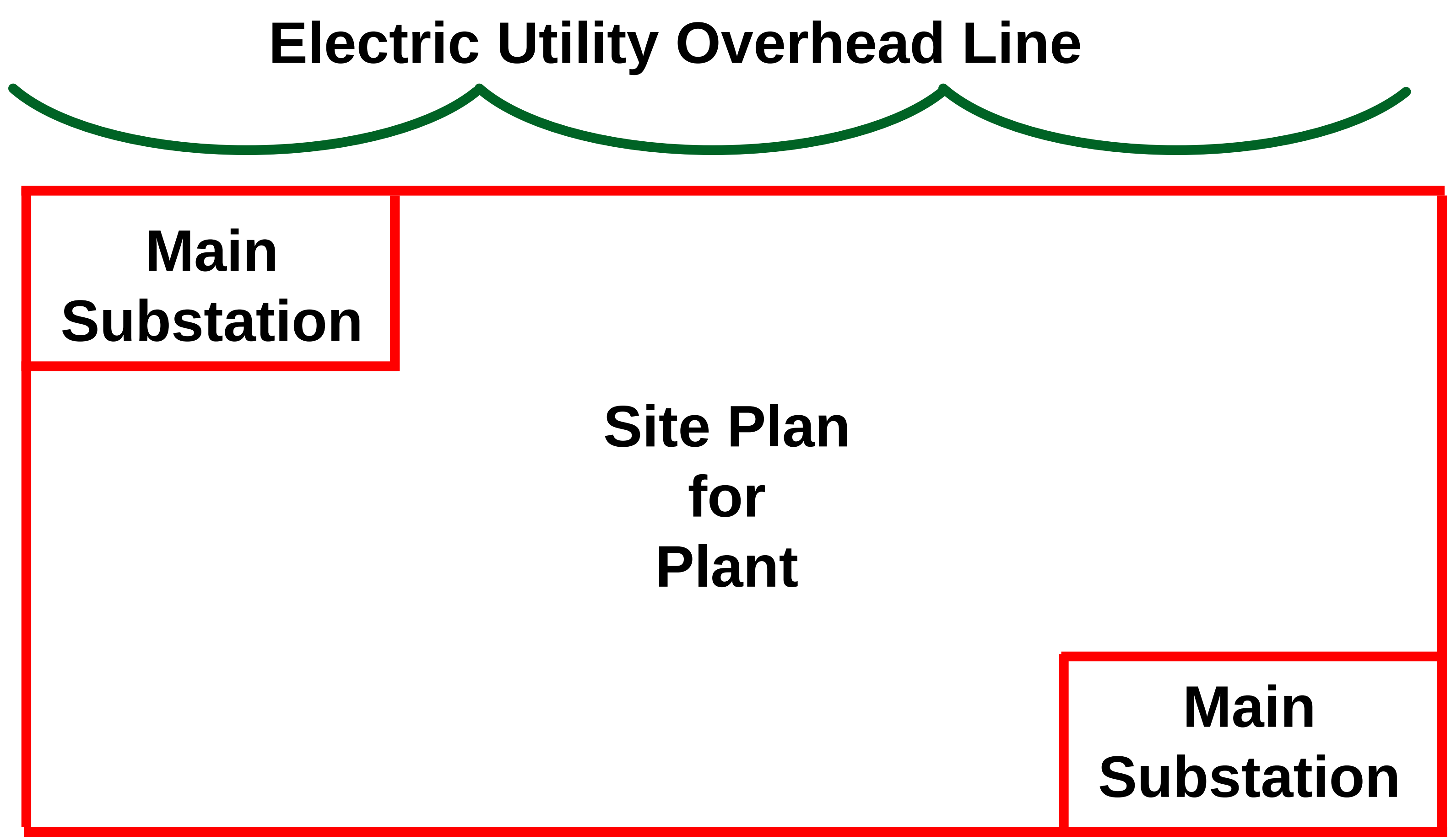
- **In siting the utility substation for a plant, system optimization helps to reduce costs**
- **Most utilities are only obligated to bring service to the nearest property line**
- **If you want the place the utility substation at the opposite corner, you will have to pay for the extra construction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

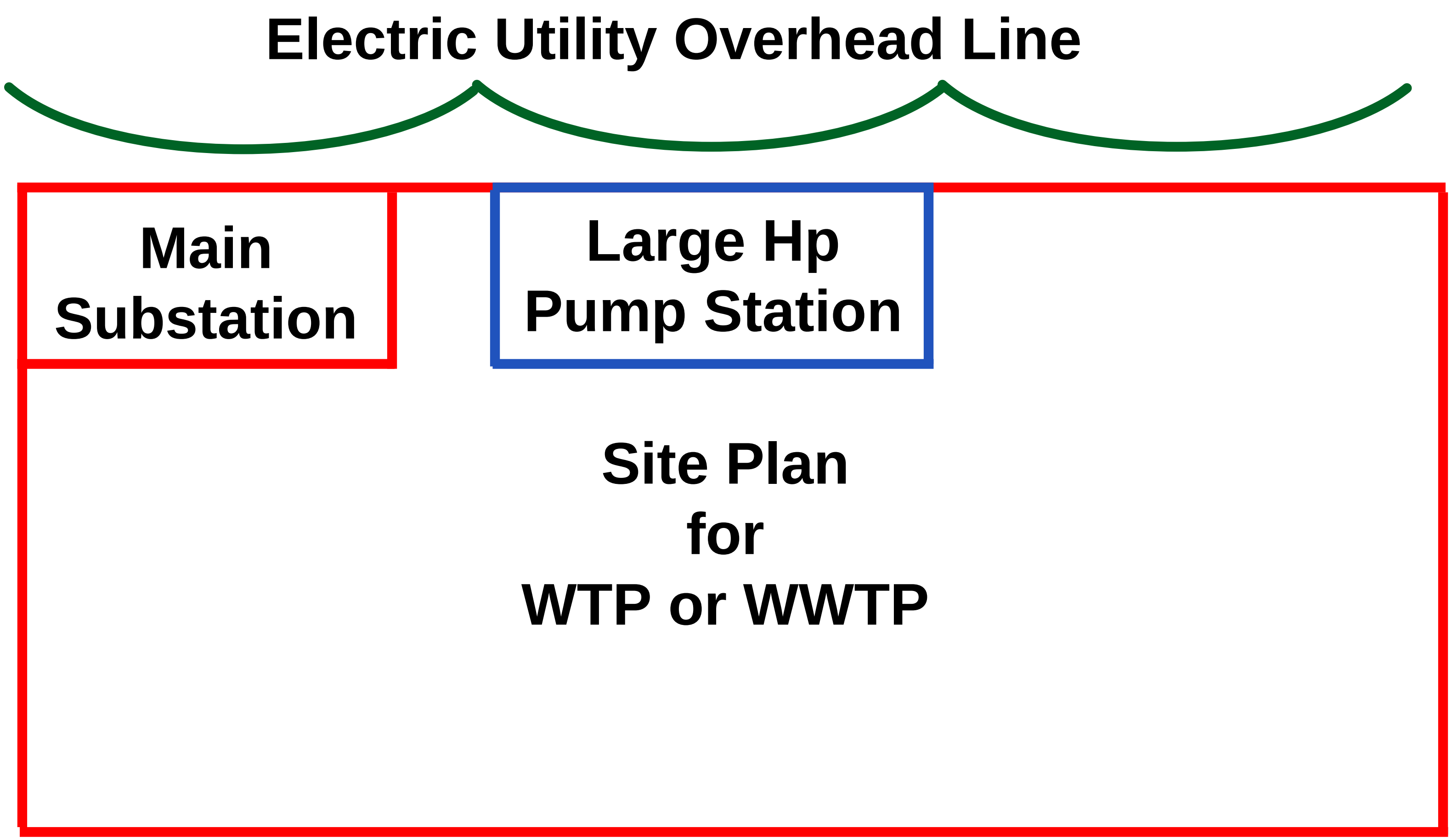
Electrical Center of Gravity

- 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

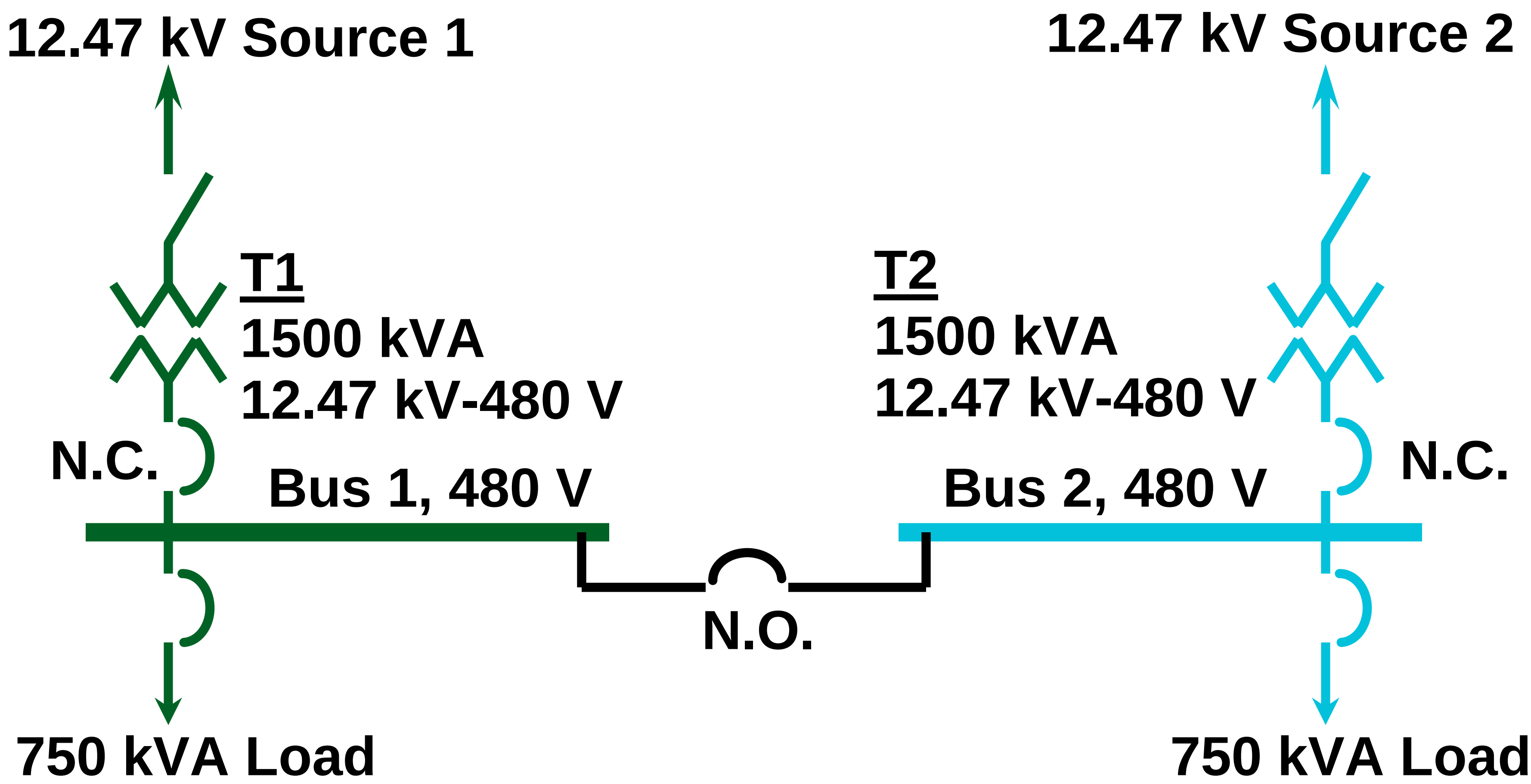
- **Normally, main breaker A and main breaker B is closed and the tie breaker is open**
- **For full redundancy, both transformers are sized to carry the full load of both buses**
- **Normally, they are operating at 50% load**
- **In the previous example, each transformer is sized at 2000 kVA, but operating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

Double Ended Substation

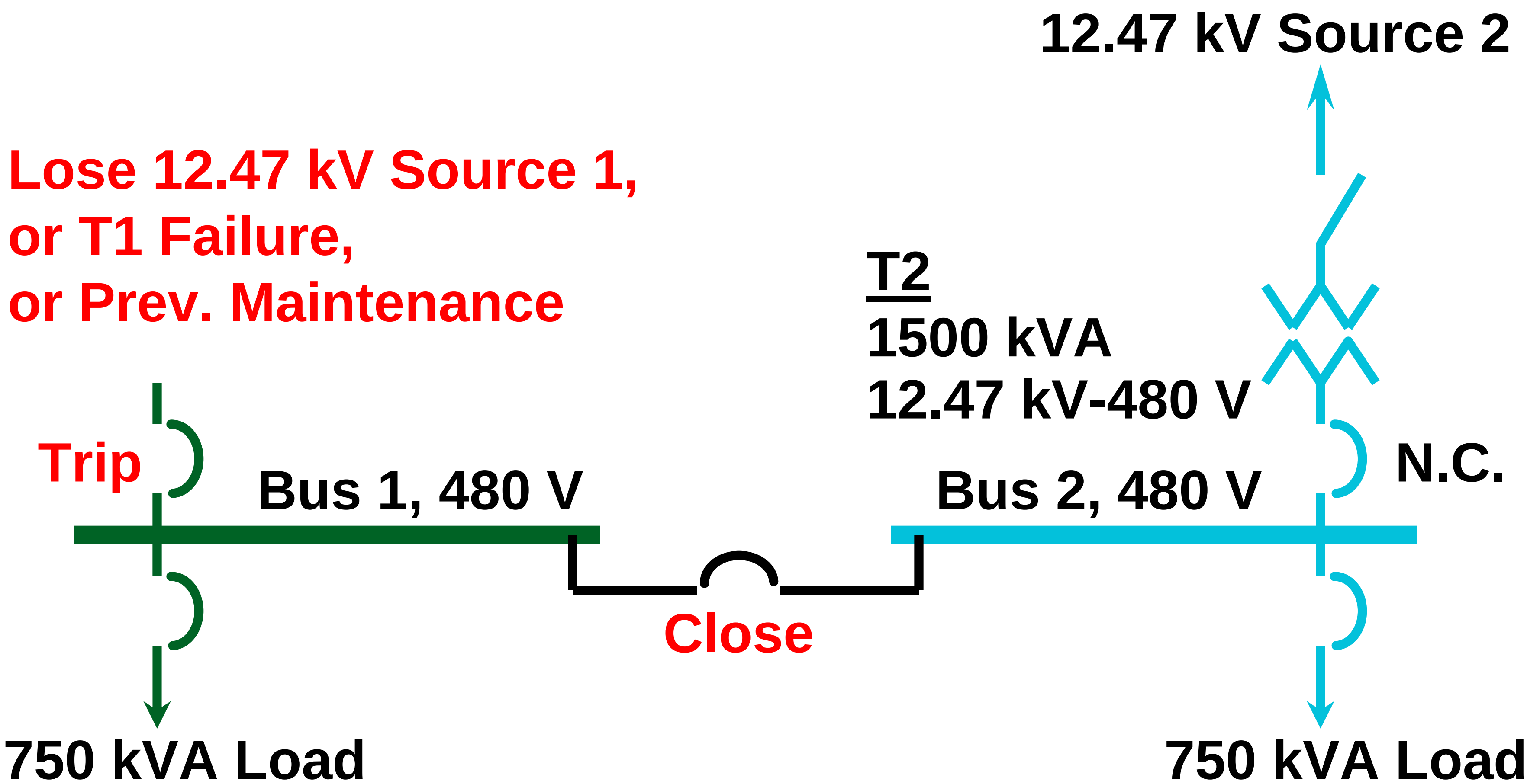
Double Ended Substation

Double Ended Substation

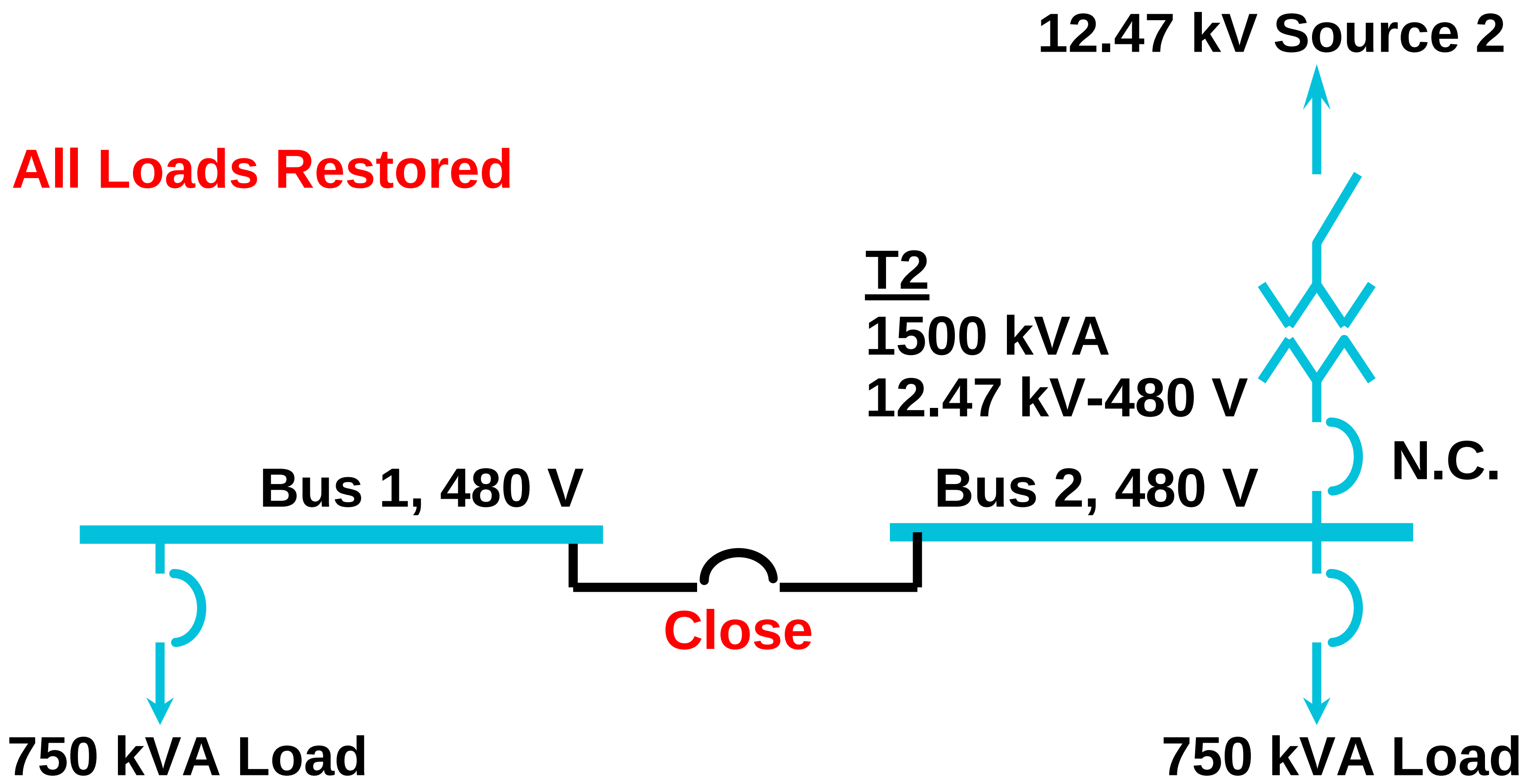
Dual Redundant Transformers, Main-Tie-Main



Dual Redundant Transformers, Main-Tie-Main



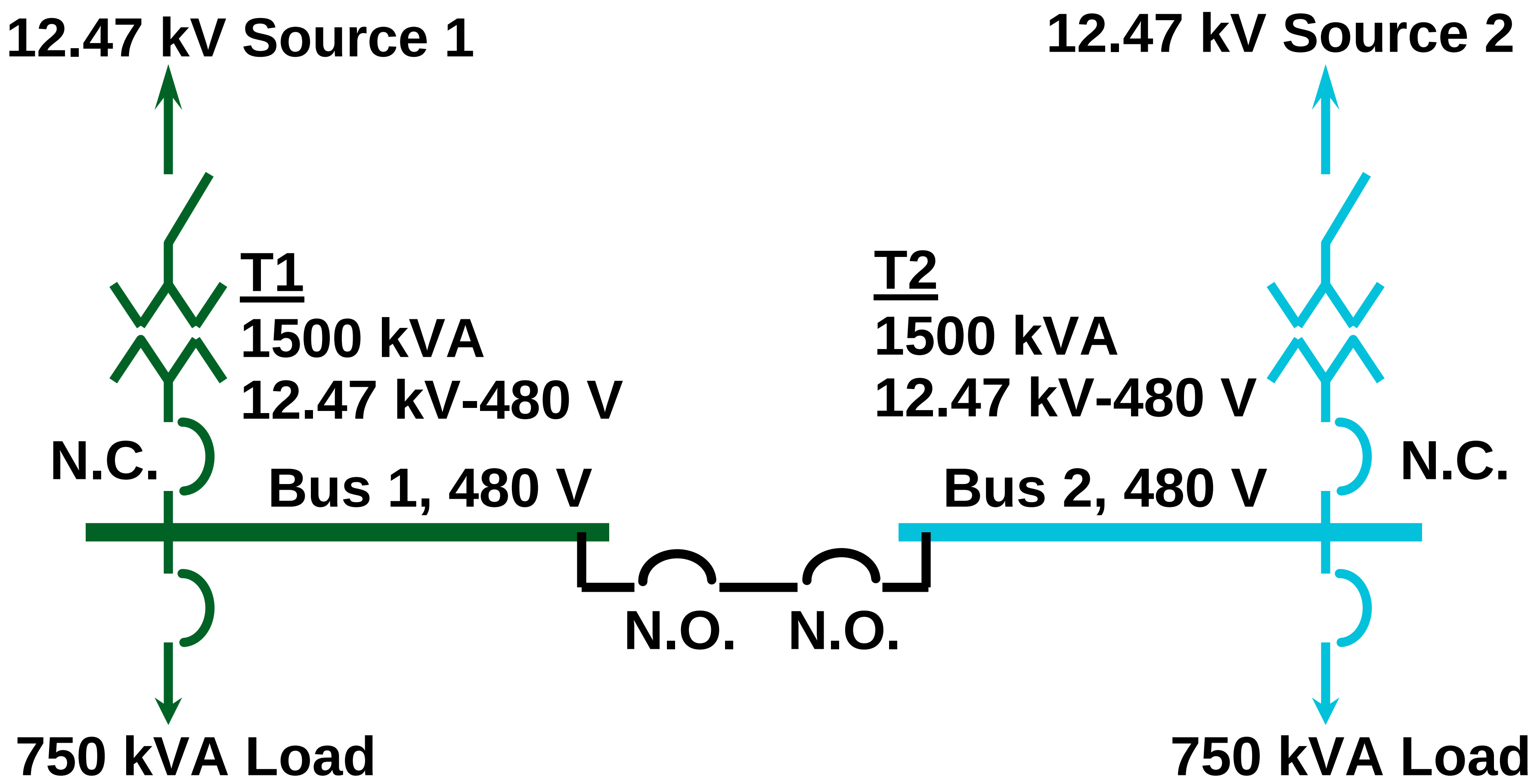
Dual Redundant Transformers, Main-Tie-Main



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^2R 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

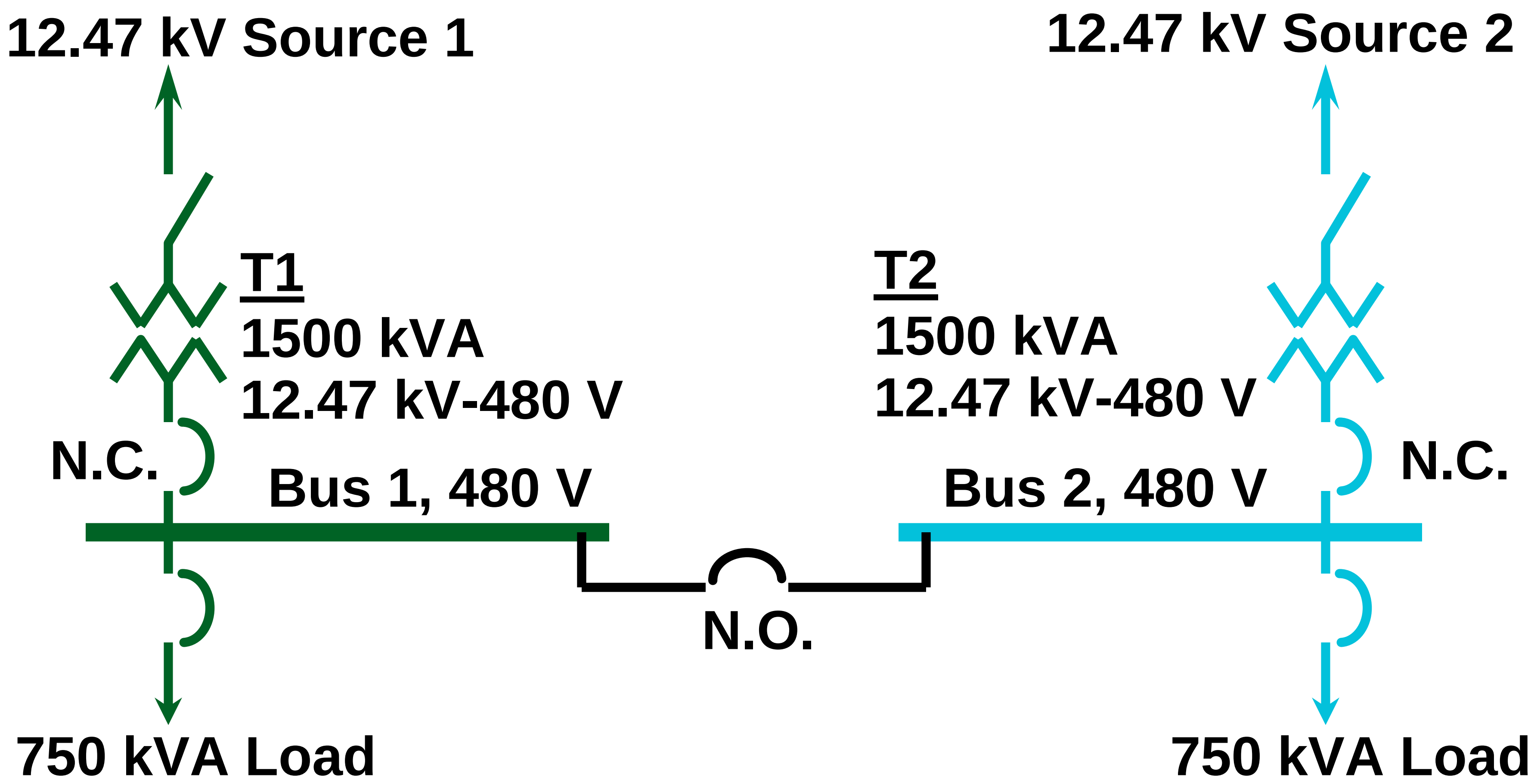
- **For a typical transformer: 1,500 kVA, 5/15 kV primary, 480Y/277 V secondary**
- **Cost is about 45% to 93% higher for dry-type vs. liquid-filled**
- **Adding fans and temp ratings costs are incremental: capital cost only**

Reference: 2000 Means Electrical Cost Data, Section 16270

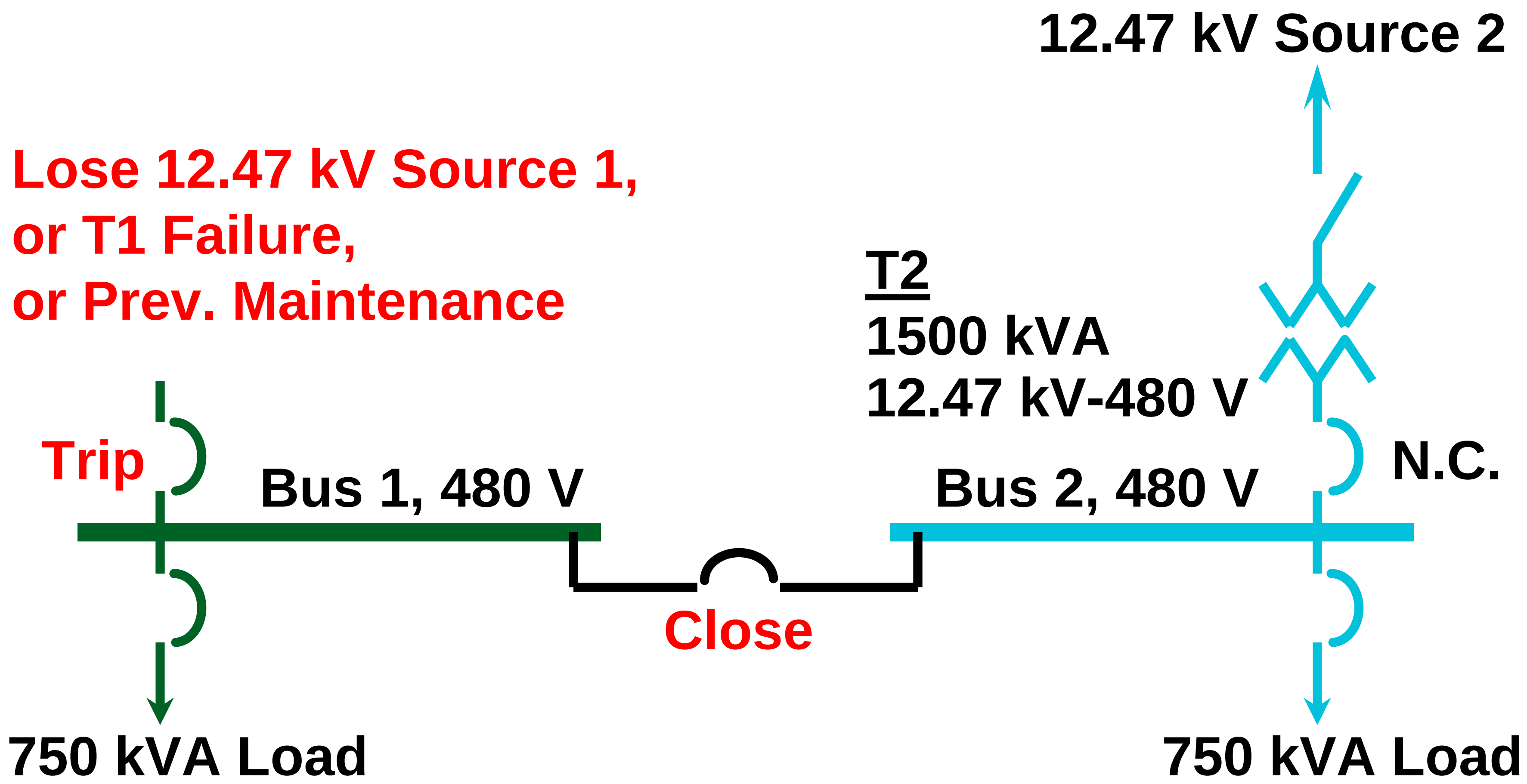
Transformer Overloading

- **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**

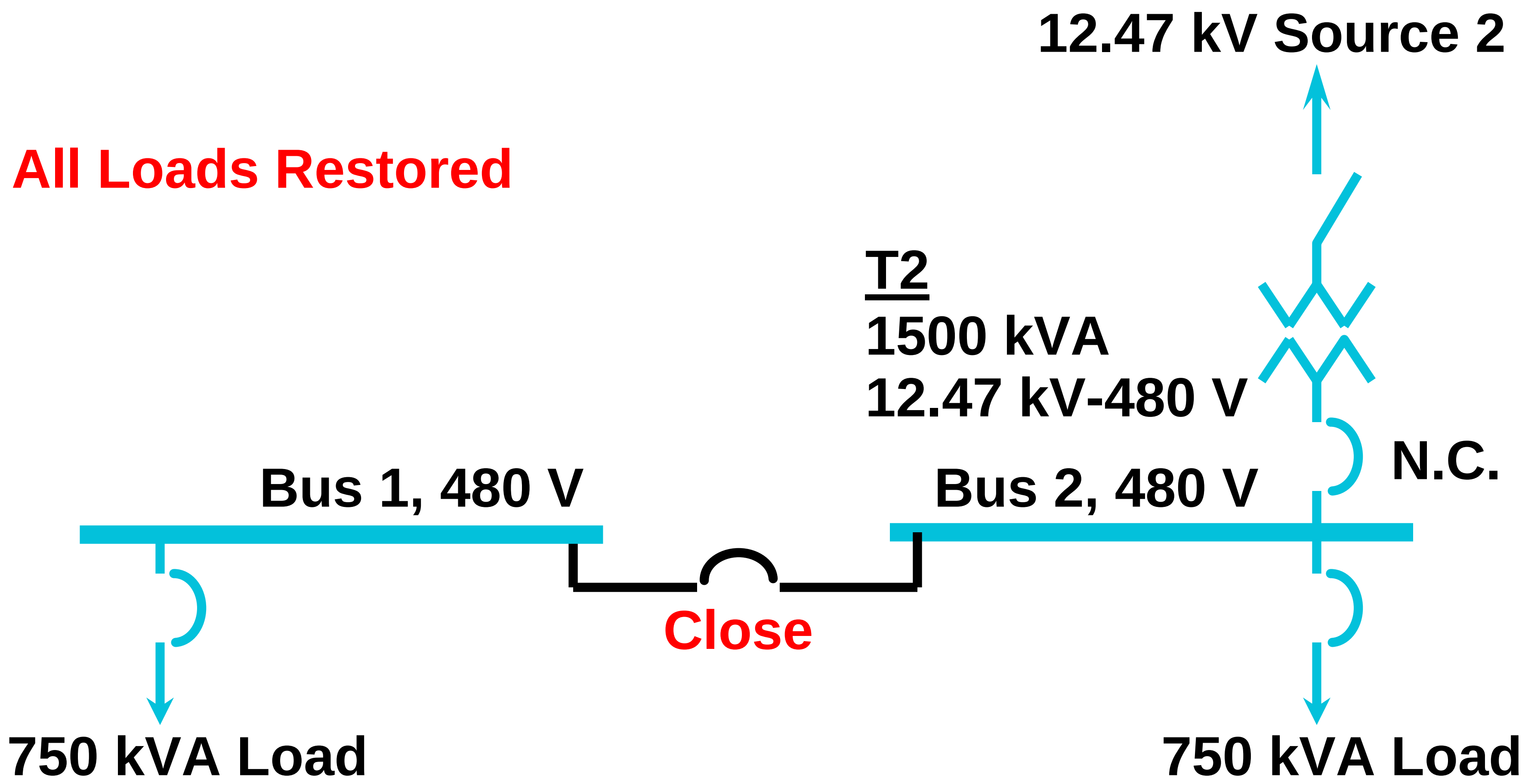
Dual Redundant Transformers, Main-Tie-Main



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

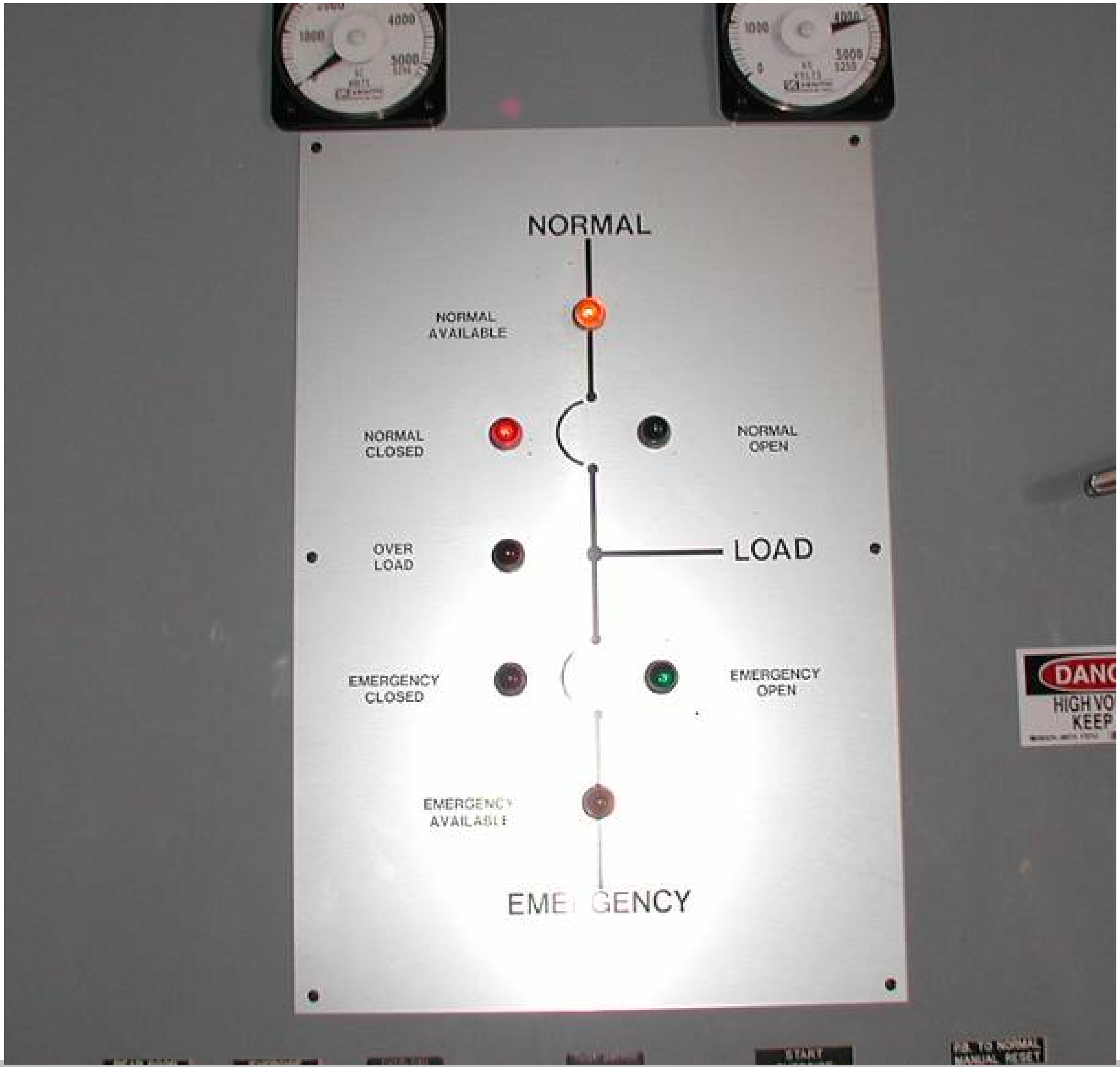
- **NEC Article 702, Optional Standby Systems, directed at non-life safety, alternate source**
- **Even less stringent requirements**

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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