HV
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Project Engineering Requirements - Pt 2

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Opening Joke

Q. How do Electrical Engineers meditate?

A. They contemplate V = IR

Ohmmmmmmmmmmmmmmmmmmmmmm…

Presentation Objectives – Part 1

- **Understand some of the basic steps to start a petro/Chem project as the lead electrical engineer… and be successful.**
- **Whom you should interface with on a regular base.**
- **How to CYA successfully without upsetting your boss.**
- **How to achieve the impossible of on time and under budget project.**

Presentation Objectives – Part 1

Some comments for Part I

- **Estimating Challenges**
  - **Can you control who does the work?**
  - **Do you have time to include key documents to establish basis for estimate**
    - **Simplified one line**
      - **Equipment ratings, configuration, etc**
    - **Basic layout plan**
      - **Equipment included, building size, etc**
    - **Routing plan**
      - **Cable costs add up very quickly**

Presentation Objectives – Part 1

Some comments for Part I

- **Estimating Challenges**

  It seems like management has the number already established (7-10% of total scope) and it feels like the estimator's goal is to justify a number higher than this.

- **Clarifications / Exclusions**

  I have found that too many exclusions increase the chance that your proposal will be tossed.

  An alternate approach would be to provide perhaps two (2) prices

  - **Base price based on your best interpretation of the RFQ**
  - **Alternate price based on listed assumptions/exclusions**

    Sometimes better than asking for RFQ clarifications and tipping your hand which may give ideas to your competitors.

Presentation Objectives – Part 2

In Part 1 we talked in general terms….

In Part 2 we will discuss specifics focusing on areas that can have major impacts to cost and schedule.

…typically project goals vary between End User and EPC

Project Goals

End User Goals

- **Exceed design requirements**
- **Budget (avoid change orders)**
- **Schedule**
- **Safe operation**
- **Operability**
- **Maximize reliability with specific design**

Project Goals

EPC Goals

- **Meet design requirements**
- **Under budget (find opportunity for change-orders if initial design requirements are changed)**
- **Meet or be ahead of schedule**
- **Safe operation**

Project Definition

- Service Voltage and Design Configuration
- System Grounding
- Equipment Ratings
- Special Requirements
- Special Considerations
- Constraints
- One Line Development
- Physical Layout
- Equipment Specifications
- Schedule - Drawing / Document Development

Service Voltage

Service Voltage

- **Based on load list, determine service requirements**
- **Selection Criteria**
  - **Cost**
  - **Reliability**

Service Voltage

What are the loads?

- **Size**
- **Operation**

How far are the loads from the substation?

- **Voltage drop**
- **Motor starting**
- **Controls**

Service Voltage

NEMA MG-1

Motor Size	System Voltage	Motor Voltage
Induction motor 3,500 HP and above	13.8 kV 12.47 kV	13.2 kV 12 kV
Induction Motor 1,000 – 12,000 HP	6.9 kV	6.6 kV
Induction Motor 400 – 7,000 HP	4.16 kV 4.8 kV	4.0 kV 4.6 kV
Induction Motor 200 – 4,000 HP	2.4 kV	2.3 kV
Induction Motor up to 600 HP	480 V	460 V

Note: For motors operating only on VFDs, the voltage and frequency to be mutually agreed upon by the purchaser and vendor

Motor Operation

- Continuous Operation vs. Frequent Switching
  - MV breaker vs. MV starter
- Fixed Speed vs. Variable Speed
  - Across the line vs. Variable speed drive
- Across the line (ATL) starting vs. Soft starting
  - Full voltage non-reversing (FVNR)
  - Solid state reduced voltage (SSRV)
  - Variable frequency/speed drive (VFD)

Motor Operation

Motor Application Examples:

1. 1000 hp vessel pump motor, ATL starting, rigid system
2. 2500 hp product pump motor, weak system
3. (3) 2500 hp product pump motors, weak system
4. 7000 hp compressor motor on rigid system

Motor Operation

Example #1

1,000 hp pump motor for vessel loading on a rigid system

Available service voltages are 480 V, 4.16 kV, 13.8 kV

Motor is started frequently (4-5 times daily)

1000 hp, 4000 V induction motor

High efficiency motor

FVNR starter

Motor Operation

Example #2

2500 hp pipeline product pump motor on weak system

Available service voltages are 480 V, 4.16 kV, 13.8 kV

Motor is started daily

2500 hp, 4000 V induction motor

High efficiency motor

VFD application

- **Fused switch**
- **FVNR Starter**
- **Breaker**
- **Sync transfer**

Motor Operation

<u>**Example #3**</u>

Three (3) 2500 hp pipeline product pump motors on weak system

Available service voltages are 480 V, 4.16 kV, 13.8 kV

Motor is started daily. Two (2) motors run at full load, one (1) motor is used for "fine tuning"

2500 hp, 4000 V induction motor

High efficiency motor

VFD application

- **Individual VFDs (if serving different customers)**
- **Single VFD with sync transfer (run 2 units across the line and use third unit to control flow)**

Motor Operation

Example

7000 hp (FLA @ 4000 V = 842 A) compressor motor on rigid system

Available service voltages are 480 V, 4.16 kV, 13.8 kV

Motor is started 1-2 times per year

7000 hp, 4000 V or 13.2 kV sync motor

Breaker

Brown Field

Identify Loads based on Load List

- **If you don't have an accurate load list, <u>obtain an accurate load list</u>.**
- **Determine future growth requirements**
- **Determine capacity of existing system**
- **Determine ability to expand existing equipment**
- **Determine reliability of existing system**

Green Field

Identify Loads based on Load List

- **If you don't have an accurate load list, <u>obtain an accurate load list</u>.**
- **Determine future growth requirements**
- **Determine capacity requirements**
- **Determine reliability requirements**

Service

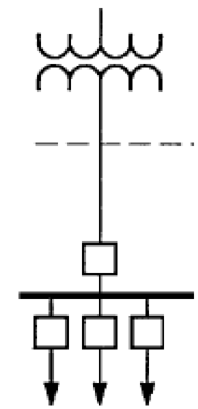
Radial System

<u>Pros</u>

- **Less Expensive**
- **Smaller footprint**
- **Simpler control/protection schemes**

<u>Cons</u>

- **Less reliable**
- **Less flexible for maintenance**



Service

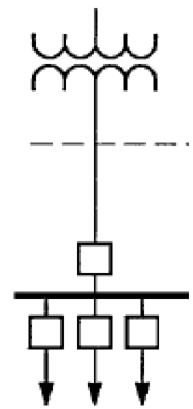
Radial System

<u>Pros</u>

- **Less Expensive**
- **Smaller footprint**
- **Simpler control/protection schemes**

<u>Cons</u>

- **Less reliable**
- **Less flexible for maintenance**



Service

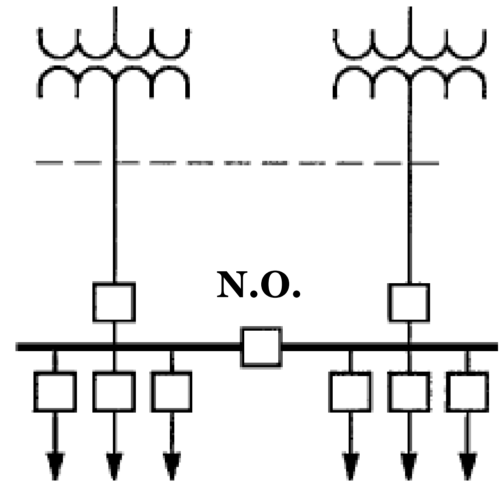
Main-Tie-Main (M-T-M) Arrangement

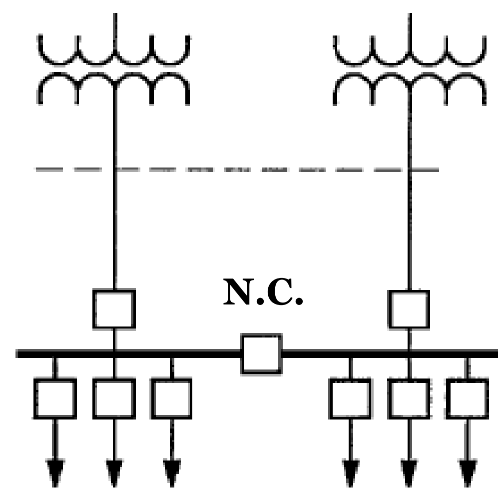
<u>Pros</u>

- **Higher operation flexibility**
- **Higher maintenance flexibility**
- **Higher reliability**

<u>Cons</u>

- o **More complex control/protection sch.**
- o **Higher cost**



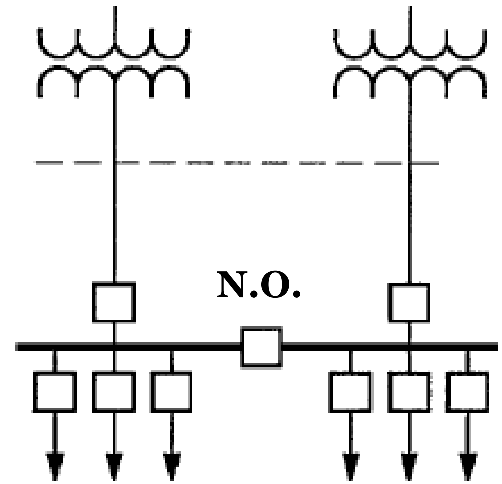


Service

Main-Tie-Main Arrangement

How are transformer sized?

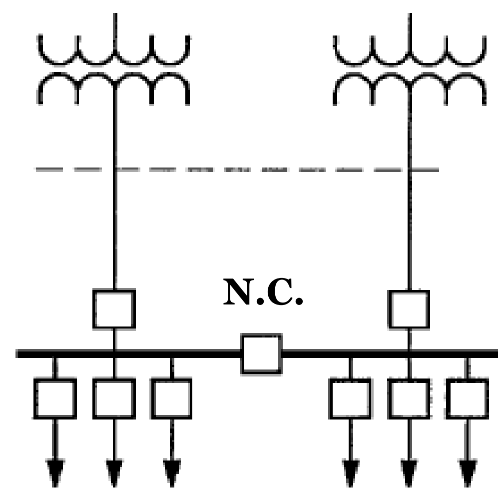
- **Each xfmr rated for 100% of plant**
- **Each xfmr rated for 50% of plant**
- **Future growth?**



Significant cost impact

Special Considerations:

S.C. implications for close-tie transition



System Grounding

System Grounding

- **Solidly grounded**
- **Low resistance ground (LRG)**
- **High resistance ground (HRG)**

System Grounding

Solidly grounded

<u>Pros</u>

- **Typically lower cost …unless G.F. relays are added to the larger LV starters**
- **Independent of upstream primary transformer protection**
- **Independent of downstream protective devices**

<u>Cons</u>

- **More damage to equipment**
- **Higher arc flash hazard exposure**
- **Trips on ground faults**

System Grounding

Low resistance grounding (LRG) (typically 200 – 1000 A)

Pros

- **Ground fault current is easier to predict**
- **Limits damage to equipment**
- **Lower arc flash hazard exposure**

Cons

- **Higher cost (requires LRG unit and G.F. relays)**
- **Trips for ground faults**
- **Breaker/relaying required for upstream primary transformer protection**
- **Difficulties with operating downstream fuses**
- **More dependent on proper grounding system**
- **Coordination becomes more difficult with multiple sources**

System Grounding

High resistance grounding (HRG) (typically 3-10 amps)

<u>Pros</u>

- **Immediate tripping for ground fault is not required**
- **Limits damage to equipment**
- **Independent of upstream primary transformer protection**
- **Independent of downstream protective devices**
- **Lower arc flash hazard exposure**
- **Simplifies/eliminates ground fault coordination**

<u>Cons</u>

- **More dependent on proper grounding system**
- **Higher cost (associated with HGR unit, possibly lower cost if factoring in cost of G.F. relays on LV starters)**

Project Studies

Initial studies should be performed are

- **Short circuit study**
- **Load flow / motor starting study**

The results of these two studies will allow you to proceed with procurement of the major apparatus

- **Transformers**
- **Switchgear**
- **Disconnect switches**
- **Bus**

Project Studies

Often the schedule does not permit you to build a complete model (schedule is such that equipment must be purchased when PO is issued).

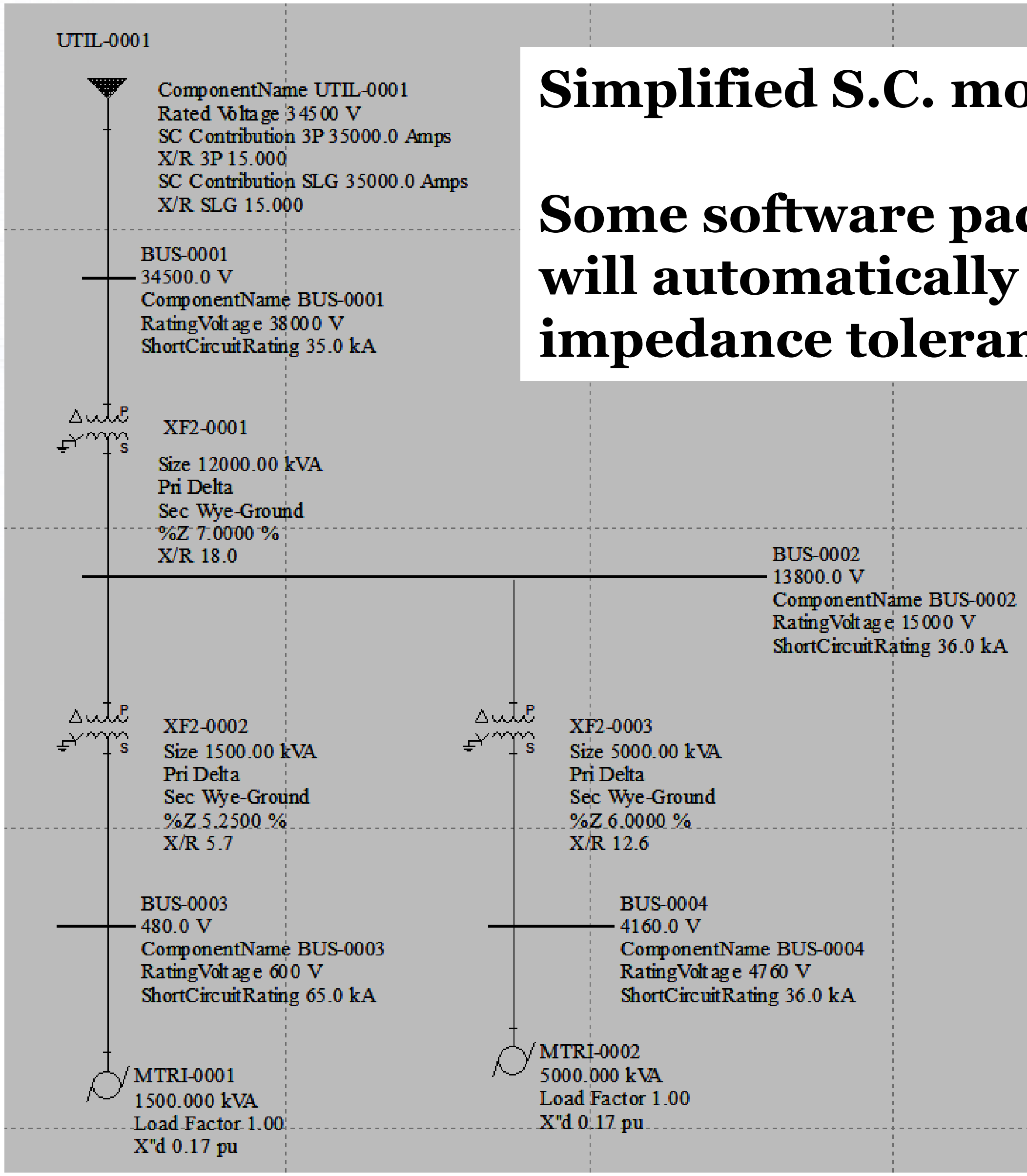
Simplified /conservative models must be created

Project Studies

Short-Circuit Model

- If utility / source short-circuit is not known, assume infinite bus or maximum interrupting rating of upstream equipment
- Set pre-fault voltage to 1.05 p.u.
- No cable impedances
- Use lower tolerance for transformer nominal impedances
- Lump motors to equal transformer kVA

Project Studies



Simplified S.C. model

Some software packages will automatically adjust impedance tolerances.

Project Studies

<u>Short-Circuit Model</u>

Use the correct calculation method

If purchasing ANSI equipment – ANSI Method

If purchasing IEC equipment – IEC Method (60909 vs 61363)

•60909 – Electrical gear feeding process equipment

•61363 – Ship propulsions systems

Project Studies

The simplified model will provide conservative results.

....sometimes too conservative.

The engineer will have to make a decision whether further analysis is required or if the equipment can be purchased based on these results.

Equipment Ratings

What determines equipment ratings?

- **Nominal voltage**
- **BIL**
- **Continuous current**
- **Short circuit**
- **Operating conditions**
- **Application**
- **Frequency**

Nominal Voltage

The nominal voltage rating is determined by the following:

- **Available service voltage**
- **Load data**
- **Circuit distance**
- **Cost**

Nominal Voltage

For Brown Field projects, the most economic solution is to make work what is available. Expanding existing line-ups of switchgear, MCC, and panelboards is generally less expensive than installing a new step-down transformer and complete line-ups of equipment.

For Green Field projects, you have more flexibility which typically provides for a more efficient installation.

Nominal Voltage

Preferred Breaker Ratings

Col 2

(1) Indoor

(2) ,(3) Outdoor

ANSI C37.06-2000
Page 10

Table 4 – Preferred dielectric withstand ratings and external insulation (1)

			Dielectric Withstand Test Voltages						
			Power Frequency		Impulse Test 1.2 x 50 µsec wave		Switching Impulse		
Line No.	Rated Maximum Voltage kV, rms	Rating Table No.	1 Minute Dry kV, rms	10 Second Wet kV, rms	Full Wave (2)(6) Withstand kV, Peak	2 µsec Chopped Wave Withstand kV, Peak Minimum Time to Sparkover	Withstand Voltage Terminal to Ground With Breaker Closed kV, Peak	Withstand Voltage Terminal to Terminal on One Phase with Circuit Breaker Open kV, Peak	Minimum Creepage(5) Distance of External Insulation to Ground mm
	Col 1	Col 2	Col 3	Col 4	Col 5	Col 6	Col 7	Col 8	Col 9
1	4.76	1	19	(3)	60	(3)	(3)	(3)	(3)
2	8.25	1	36	(3)	95	(3)	(3)	(3)	(3)
3	15.0	1	36	(3)	95	(3)	(3)	(3)	(3)
4	15.5	2	50	45	110	142	(3)	(3)	250
5	25.8	2	60	50	150	194	(3)	(3)	420
6	25.8 (4)	2	60	50	125	(3)	(3)	(3)	420
7	27.0	1	60	(3)	125	(3)	(3)	(3)	(3)
8	38.0	1	80	(3)	150	(3)	(3)	(3)	(3)
9	38.0	2	80	75	200	258	(3)	(3)	610
10	38.0 (4)	2	80	75	150	(3)	(3)	(3)	610
11	48.3	2	105	95	250	322	(3)	(3)	780
12	72.5	2	160	140	350	452	(3)	(3)	1170
13	123	3	260	230	550	710	(3)	(3)	1990
14	145	3	310	275	650	838	(3)	(3)	2340
15	170	3	365	315	750	968	(3)	(3)	2750
16	245	3	425	350	900	1160	(3)	(3)	3960
17	362	3	555	(3)	1300	1680	825	900	5850
18	550	3	860	(3)	1800	2320	1175	1300	8890
19	800	3	960	(3)	2050	2640	1425	1500	12900

NOTES
(1) For circuit breakers applied in gas insulated substations, see Table 5.
(2) 1.2 x 50 µ seconds positive and negative wave as defined in ANSI/IEEE Std. 4. All impulse values are phase-to-phase and phase-to-ground and across the open contacts.
(3) Not required.
(4) These circuit breakers are intended for application on grounded wye distribution circuits equipped with surge arresters.
(5) Minimum creepage corresponds to Light Pollution level. Refer to ANSI/IEEE C37.010 for special cases of pollution level, or to the manufacturer.
(6) For outdoor circuit breakers rated 123 kV and above and that have isolating gaps in series with the interrupting gaps, or have additional gaps in the resistor or capacitor circuits, the impulse test for interrupters and resistors shall be 75% of the value shown in column 5.

Nominal Voltage and Spacing

NEMA SG6 Standard for <u>Outdoor</u> Equipment

Note: although this standard has been withdrawn, it is still very widely used. New standard is IEEE 1427-2006

Table 36-2

OUTDOOR SUBSTATIONS—BASIC PARAMETERS

Line No.	Rated Max. Volt, kV rms	Rated Withstand Voltage: Impulse 1.2 x 50 µs Wave kV Crest	Rated Withstand Voltage: 60 Hz kV rms, Wet, 10 sec.	Minimum Metal-to-Metal Distance Between Rigidly Supported Energized Conductors, Inches (meters)	Ground Clearance, Inches (meters): Recommended	Ground Clearance, Inches (meters): Minimum	Recommended Phase Spacing, Center to Center, Inches (meters): Horn Gap Switch and Expulsion Type Fuses	Recommended Phase Spacing, Center to Center, Inches (meters): Horizontal Break Disc. Switches	Recommended Phase Spacing, Center to Center, Inches (meters): Bus Supports, Vertical Brk. Disc. Switches Power Fuses Non-expulsion Types Rigid Conductors	Recommended Minimum Clearance Between Overhead Conductor and Ground for Personal Safety, Feet (Meters)	Withstand S.S., Crest kV
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)
1	8.3	95	30	7 (0.18)	7.5 (0.19)	6 (0.15)	36 (0.91)	30 (0.76)	18 (0.46)	8 (2.44)	. . .
2	15.5	110	45	12 (0.30)	10 (0.25)	7 (0.18)	36 (0.91)	30 (0.76)	24 (0.61)	9 (2.74)	. . .
3	27	150	60	15 (0.38)	12 (0.30)	10 (0.25)	48 (1.22)	36 (0.91)	30 (0.76)	10 (3.05)	. . .
4	38.	200	80	18 (0.46)	15 (0.38)	13 (0.33)	60 (1.52)	48 (1..22)	36 (0.91)	10 (3.05)	. . .
5	48.3	250	100	21 (0.53)	18 (0.46)	17 (0.43)	72 (1.83)	60 (1.52)	48 (1.22)	10 (3.05)	. . .
6	72.5	350	145	31 (0.79)	29 (0.74)	25 (0.64)	84 (2.13)	72 (1.83)	60 (1.52)	11 (3.35)	. . .
7	123	550	230	53 (1.35)	47 (1.19)	42 (1.07)	120 (3.05)	108 (2.74)	84 (2.13)	12 (3.66)	. . .
8	145	650	275	63 (1.60)	52.5 (1.33)	50 (1.27)	144 (3.66)	132 (3.35)	96.(2.44)	13 (3.96)	. . .
9	170	750	315	72 (1.83)	61.5 (1.56)	58 (1.47)	168 (4.27)	156 (3.96)	108 (2.74)	14 (4..27)	. . .
10	245	900	385	89 (2.26)	76 (1.93)	71 (1.80)	192 (4.88)	192 (4.88)	132 (3.35)	15 (4.57)	. . .
11	245	1050	455	105 (2.67)	90.5 (2.30)	83 (2.11)	216 (5.49)	216 (5.49)	156 (3.96)	16 (4.88)	. . .
12	362	1050	455	105 (2.67)	90.5 (2.30)	84 (2.13)*	216 (5.49)	216 (5.49)	156 (3.96)	16 (4.88)	650
13	362	1300	525	119 (3.02)	106 (2.69)	104 (2.64)*	. . .	. . .	174 (4.43)	18 (5.49)	739
14	550	1550	620	. . .	. . .	124 (3.15)*	. . .	. . .	. . .	. . .	808
15	550	1800	710	. . .	. . .	144 (3.66)*	. . .	. . .	300 (7.62)	. . .	898
16	800	2050	830	. . .	. . .	166 (4.22)*	. . .	. . .	. . .	. . .	982

NOTE—For insulator data, refer to ANSI C29.8 and C29.9.

*Ground clearance for voltages 362 kV and above is selected on the premise that at this level; selection of the insulation depends on switching surge levels of the system. The values were selected from Table 1 of IEEE Transaction Paper T-72-131-6 (Vol. No. 5, page 1924), which is a report of the Transmission Substations Subcommittee. For additional switching surge values and ground clearances, refer to ANSI C2.

Nominal Voltage

Class I Power Transformers

Table 5—Dielectric insulation levels for distribution transformers and Class I power transformers[a]

Application	Basic lightning impulse insulation level (BIL) (kV crest)	Chopped-wave impulse levels		Front-of-wave impulse levels		
		Minimum voltage (kV crest)	Minimum time to flashover (µs)	Minimum voltage (kV crest)	Specific time to sparkover (µs)	Low-frequency test level (kV rms)
	Column 1	Column 2	Column 3	Column 4	Column 5	Column 6
Distribution	30	36	1.0	—	—	10
	45	54	1.5	—	—	15
	60	69	1.5	—	—	19
	75	88	1.6	—	—	26
	95	110	1.8	—	—	34
	125	145	2.25	—	—	40
	150	175	3.0	—	—	50
	200	230	3.0	—	—	70
	250	290	3.0	—	—	95
	350	400	3.0	—	—	140
Power	45	50	1.5	—	—	10
	60	66	1.5	—	—	15
	75	83	1.5	—	—	19
	95	105	1.8	165	0.5	26
	110	120	2.0	195	0.5	34
	150	165	3.0	260	0.5	50
	200	220	3.0	345	0.5	70
	250	275	3.0	435	0.5	95
	350	385	3.0	580	0.58	140

Class I power transformers shall include power transformers with high-voltage windings of 69 kV and below.

Nominal Voltage

Class II Power Transformers

Table 6—Dielectric insulation levels for Class II power transformers[a]

Nominal system voltage (kV)	Basic lightning impulse insulation level (BIL) (kV crest)	Chopped wave level (kV crest)	Switching impulse level (BSL) (kV crest)	Low frequency test levels: Induced-voltage test (phase to ground): One hour level (kV rms)	Low frequency test levels: Induced-voltage test (phase to ground): Enhancement level kV rms)	Low frequency test levels: Applied-voltage test level (kV rms)
Column 1	Column 2	Column 3	Column 4	Column 5	Column 6	Column 7
15 and below	110	120	—	—	—	34
25	150	165	—	—	—	50
34.5	200	220	—	—	—	70
46	250	275	—	—	—	95
69	250	275	—	—	—	95
	350	385	—	—	—	140
115	350	385	280	105	120	140
	450	495	375	105	120	185
	550	605	460	105	120	230
138	450	495	375	125	145	185
	550	605	460	125	145	230
	650	715	540	125	145	275
161	550	605	460	145	170	230
	650	715	540	145	170	275
	750	825	620	145	170	325
230	650	715	540	210	240	275
	750	825	620	210	240	325
	825	905	685	210	240	360
	900	990	745	210	240	395
345	900	990	745	315	360	395
	1050	1155	870	315	360	460
	1175	1290	975	315	360	520
500	1130	1430	1080	475	550	—
	1425	1570	1180	475	550	—
	1550	1705	1290	475	550	—
	1675	1845	1390	475	550	—
765	1800	1980	1500	690	800	—
	1925	2120	1600	690	800	—
	2050	2255	1700	690	800	—

Class II power transformers shall include power transformers with high-voltage windings from 115 kV through 765 kV.

Nominal Voltage

Application	Nominal system voltage (kV rms)	Maximum system voltage (from ANSI C84-1-1995) (kV rms)	Basic lightning impulse insulation levels (BIL) in common use (kV crest)			
Distribution	1.2	—	**30**	—	—	—
	2.5	—	**45**	—	—	—
	5.0	—	**60**	—	—	—
	8.7	—	**75**	—	—	—
	15.0	—	**95**	—	—	—
	25.0	—	**150**	**125**	—	—
	34.5	—	**200**	**150**	125	—
	46.0	48.3	**250**	200	—	—
	69.0	72.5	**350**	250	—	—
Power	1.2	—	**45**	**30**	—	—
	2.5	—	**60**	**45**	—	—
	5.0	—	**75**	**60**	—	—
	8.7	—	**95**	**75**	—	—
	15.0	—	**110**	**95**	—	—
	25.0	—	**150**	—	—	—
	34.5	—	**200**	—	—	—
	46.0	48.3	**250**	200	—	—
	69.0	72.5	**350**	250	—	—
	115.0	121.0	550	**450**	350	—
	138.0	145.0	650	**550**	450	—
	161.0	169.0	750	**650**	550	—
	230.0	242.0	900	825	**750**	650
	345.0	362.0	1 175	1050	900	—
	500.0	550.0	1 675	1550	1425	1300
	765.0	800.0	2050	1925	1800	—

NOTES

1—BIL values in **bold** typeface are listed as standard in one or more of ANSI C57.12.10-1988 [B1], ANSI C57.12.20-1997 [B3], ANSI C57.12.22-1989 [B5], IEEE Std C57.12.23-1992 [B12], ANSI C57.12.24-1992 [B6], ANSI C57.12.25-1990 [B7], and IEEE Std C57.12.26-1992 [B13].

C57.12.00 – Table 4

Nominal Voltage

HV Bushings

Table 1 - Bushing Data						
System Voltage		Bushing	Creepage Distance in Inches			
Nominal kV	Maximum kV	BIL kV	Light [1]	Medium [1]	Heavy [1]	Extra-Heavy [1]
34.5	38.0	200	22	27	35	42
46	48.0	250	29	37	46	56
69	72.5	350	44	55	69	85
115	121.0	550	73	91	115	141
138	145.0	650	88	110	138	169
161	169.0	750	102	128	161	198
230	242.0	900	146	183	230	282
345	362.0	1175	220	274	345	423
500	550.0	1675	318	398	500	614
765	800.0	2050	487	609	765	939

Table 2 - Contamination Multipliers	
Contamination Level	Multiplying Factor
Light	28mm/kV
Medium	35mm/kV
Heavy	44mm/kV
Extra Heavy	54mm/kV

Notes:

[1] Creepage distances shown in Table 1 are recommended values, based on IEEE standards C57.19.100-1995 & C37.010-1999.
Table 2 shows the multiplying factor for each level of contamination. The multiplying factors are applied to nominal line to ground voltage.

Nominal Voltage

Outdoor Bushings and Insulators

It is a common practice to increase BIL and/or Creep for outdoor installations, especially at lower voltages.

For example, and outdoor 15 kV substation may include 27 kV or 38 kV insulators and/or bushings.

CenterPoint 138 kV Substation Requirements

Bus and Switch Insulator Leakage Distance	132 in. creep (equivalent to 750 kV BIL or extra creep 650 kV BIL)
Apparatus Bushing Leakage Distance (circuit breakers, bushings, transformer bushings, etc.)	92 in. creep (equivalent to 650 kV BIL)

The engineer must determine the ratings based on installation, operating conditions, and contamination levels.

Nominal Voltage

Other factors which may affect equipment voltage ratings

- **Operating conditions**
- **Application**

Nominal Voltage

Operating Condition Considerations

- **Generation**
- **Utility voltage swings**
- **Transient overvoltage conditions**
- **VAR support**

Application Considerations

- **Switching of cap banks or reactors**
- **Out-of phase switching**
- **Higher short-circuit ratings**

Continuous Current

An agreement on max continuous rating of equipment is essential at the beginning of a project.

Radial Feed

- Equipment rated for max load (plus contingency)
- Equipment rated to include future growth

Main-Tie-Main

- Each main rated for 100% load of associated bus
- Each main rated for 100% load of both buses

Continuous Current

We refer to equipment and main breaker, but really all the equipment should be considered:

- **Transformer**
- **Bus**
- **Cables**
- **Raceway**
- **CTs / Metering**

Continuous Current

Transformer Aging

MINERAL-OIL-IMMERSED TRANSFORMERS IEEE Std C57.91-1995

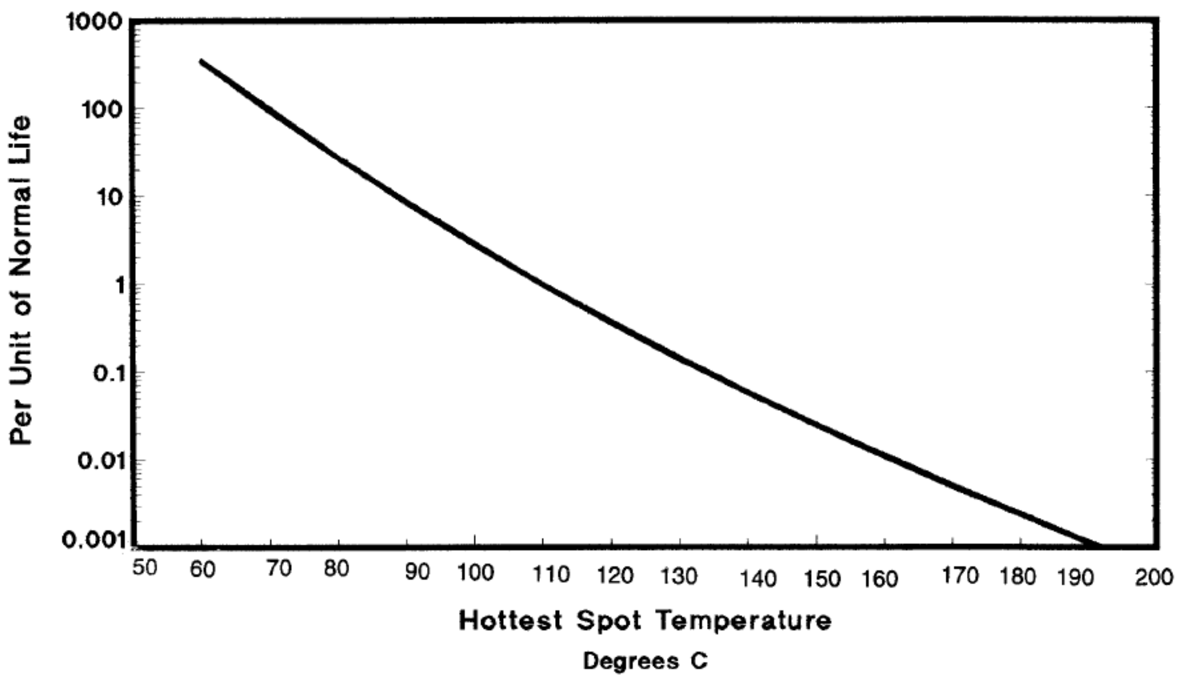


Figure 1—Transformer insulation life

Continuous Current

Transformer Aging

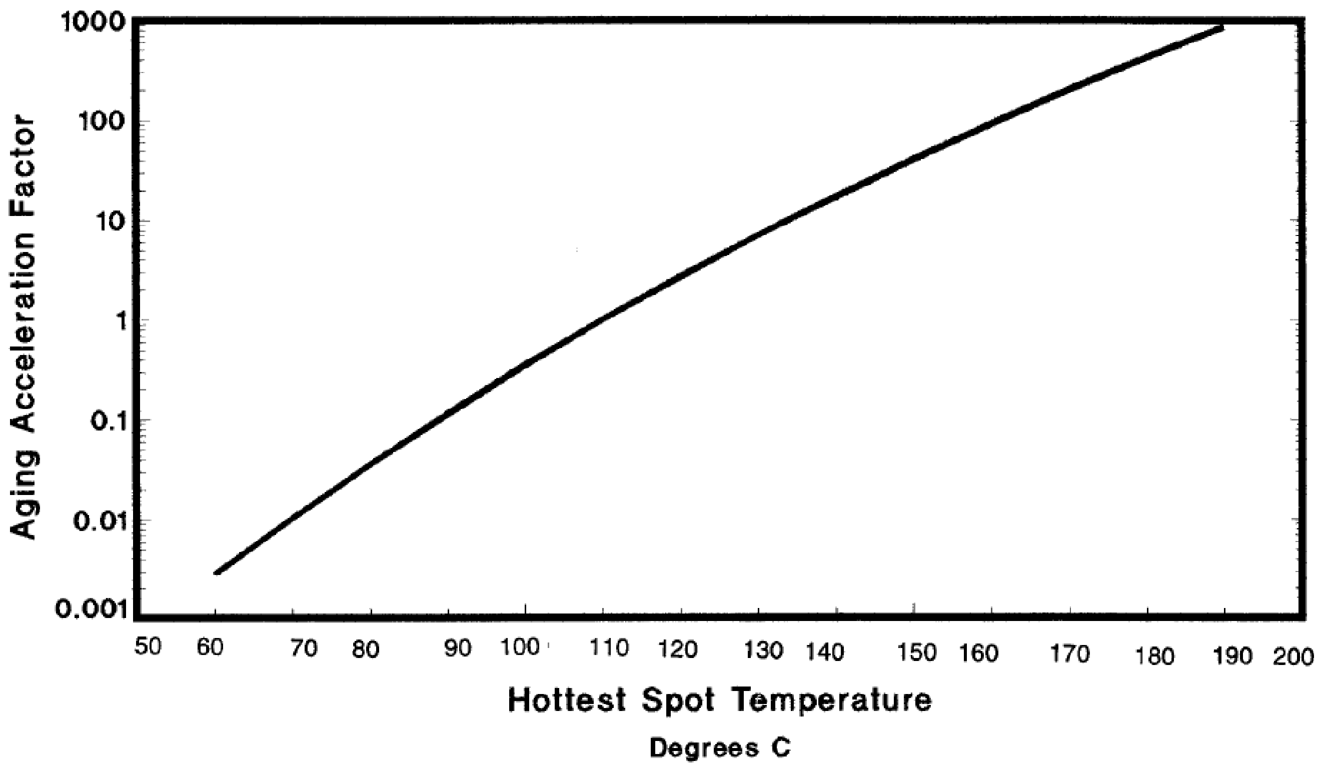


Figure 2—Aging acceleration factor (relative to 110 °C)

Continuous Current

<u>Transformer Aging</u>

Expected transformer life = 180,000 hours = 20 yrs

As seen from previous slides, the maximum winding hotspot of a transformer has a direct relationship on the transformer insulation life.

Generally speaking, a transformer rated 30 MVA ONAN is the same size as a transformer rated 30/40/50 MVA ONAN/ONAF/ONAF.

The difference is that the latter transformer includes two stages of fans that cool the oil.

Continuous Current

A common practice for sizing transformers

<u>Example:</u>

Arrangement: Main-Tie-Main

Max Plant Load = 45 MVA

Max Load per Bus = 22.5 MVA

Each Transformer sized at 30/40/50 MVA ONAN/ONAF/ONAF

Under normal conditions, the transformer will be operating under the base rating. If one transformer is removed from service, the remaining transformer will be operating at 45 MVA (90% of max rating).

Continuous Current

As an EPC (with a fixed price contract) the difference in sizing for 50% vs 100% is huge.

Using $25/kVA:

15/20/25 MVA transformer will cost $375,000

30/40/50 MVA transformer will cost $750,000

For two transformers, you are looking at

$750k vs. $1.5M….just for the transformers!

Add to this breakers, bus, cables, etc.

…but the availability is increased since the entire load can be serviced by one transformer

Short Circuit

ANSI Short circuit ratings differ between equipment.

Make sure that S.C. calculation method matches the method used for rating of equipment.

MV and HV Breakers

- **Sym. RMS Interrupting**

  (based on operating time; typically 3 or 5 cycles)

- **Asym. RMS or Peak Mom. (within first half cycle)**
  - **Both are based on X/R**

LV Breakers

- **Sym. RMS (within the first half-cycle)**
  - **Based on X/R**

Short Circuit

LV MCC

•Sym. RMS (within the first half-cycle)

- **Per UL 845, unless specified otherwise, MCCs are tested at the rated short-circuit for a time duration no less than 3 cycles**
- **Based on X/R**

It is very important to understand that when specifying standard UL 845 LV MCC which is MLO, the upstream breaker feeding the MCC must have an <u>instantaneous trip</u> element.

Note: a common position on this is that the fault is typically on the load side of the feeder breaker, which is supplied with an instantaneous trip unit.

Short Circuit

Segregated and Non-Segregated Bus Duct

IEEE C37.23

Note that SC rating (1/2 cycle withstand) is the asymmetrical RMS total current (including the DC offset)

Table 2.B— Segregated- and Nonsegregated-Phase Bus Rated Short-Circuit Withstand Current* (kA asymmetrical) 167 ms Duration

Nominal Voltage (kV)	Nonsegregated	Segregated
0.635 ac and all dc	75; 100; 150	—
4.76	39; 58; 78	—
13.8	37; 58; 77	—
14.4	—	60; 80; 100
23.0	32; 56; 64	60; 80; 100
34.5	32; 56; 64	60; 80; 100

Short Circuit

Disconnect Switches

IEEE C37.32

Short Time Withstand:

Symmetrical RMS at 3 seconds

Withstand:

Asymmetrical RMS or Peak (at ½ cycle)

Short Circuit

Disconnect Switch Catalog Data

Peak

RATINGS					
Maximum Voltage Rating (kV)	72.5	123	145	170	245
BIL (kV)	350	550	650	750	900
Rated Power Frequency	60 Hz				
Continuous Current	1200 A	2000 A - 3000 A		3000 A - 5000 A	
Short-Time Symmetrical Withstand (3 Sec)	38 kA RMS	63 kA RMS		80 kA RMS	
Peak Withstand	99 kA	164 kA		208 kA	
Ambient Temperature Rating	-40ºC to +50º Standard -50ºC Optional				

Asymmetrical RMS

RATINGS				
CATALOG NO.	kV	BIL kV	AMPS	MOM. kA
HH6V-00706	7.5	95	600	40
HH6V-00712	7.5	95	1200	61
HH6V-00720	7.5	95	2000	100
HH6V-01506	15	110	600	40
HH6V-01512	15	110	1200	61
HH6V-01520	15	110	2000	100
HH6V-02306	23	150	600	40
HH6V-02312	23	150	1200	61
HH6V-02320	23	150	2000	100
HH6V-03406	34.5	200	600	40
HH6V-03412	34.5	200	1200	61
HH6V-03420	34.5	200	2000	100
HH6V-04606	46	250	600	40
HH6V-04612	46	250	1200	61
HH6V-04620	46	250	2000	100
HH6V-06912	69	350	1200	61
HH6V-06920	69	350	2000	100

Maximum Voltage (kV)	Current Ampere Cont.	Current Ampere MOM X 100	BIL kV
72 5	1200	61	350
	2000	100	
121	1200	61	550
	2000	100	
145	1200	61	650
	2000	100	
169	1200	61	700
	2000	100	
230	1200	61	900
	2000	100	
230	1200	61	1050
	2000	100	

Special Operating Conditions

Ensure that special operating conditions are in the spec.

- **Seismic**
- **Ambient temperature**
- **Humidity**
- **Contamination (coast line, cooling towers, process, etc)**
- **Voltage range**
- **Altitude**
- **Outdoor (solar radiation gain, IEEE C37.24)**

Special Applications

Ensure that application is specified

- **Step-up vs Step-down transformer**
- **Generator (out of phase sync, VAR support)**
- **Voltage range / support**
- **Capacitor / Reactor switching**
- **Line switching**
- **Transient overvoltage conditions**

Special Considerations

Some special considerations include

- **Arc flash hazard analysis (now a requirement)**
- **System stability**
- **Maintenance capability**
- **Redundancy**

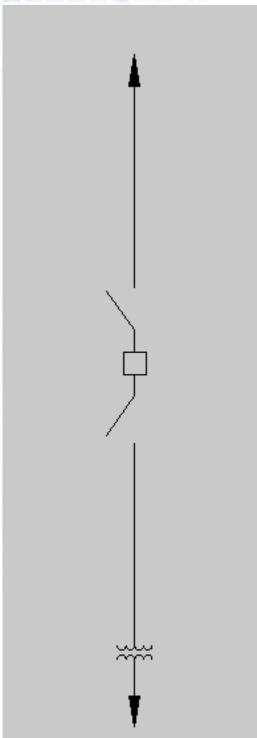
HV System Configuration

For high-voltage systems, you typically have more flexibility when it comes to system configuration/arrangement.

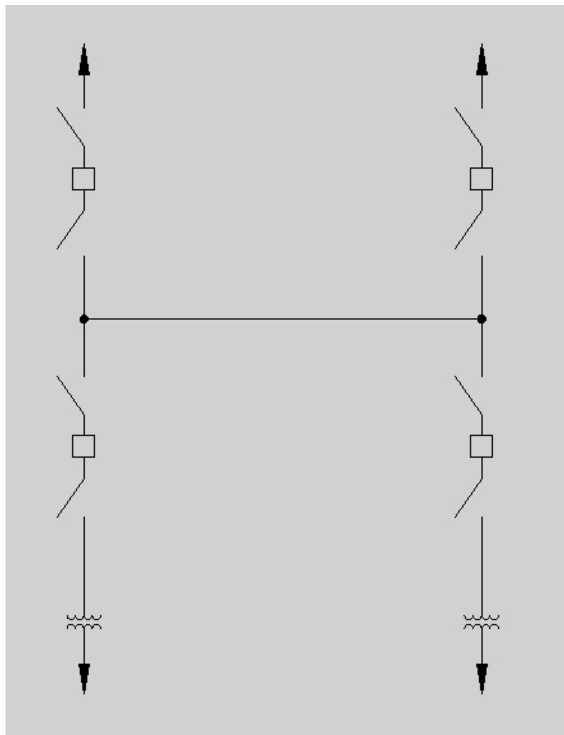
- **RADIAL FEED (TAP SUB)**
- **SINGLE BUS**
- **SINGLE BUS WITH TIE BREAKER**
- **MAIN AND TRANSFER BUS**
- **RING BUS**
- **BREAKER AND A HALF**
- **DOUBLE BREAKER / DOUBLE BUS**

HV System Configuration

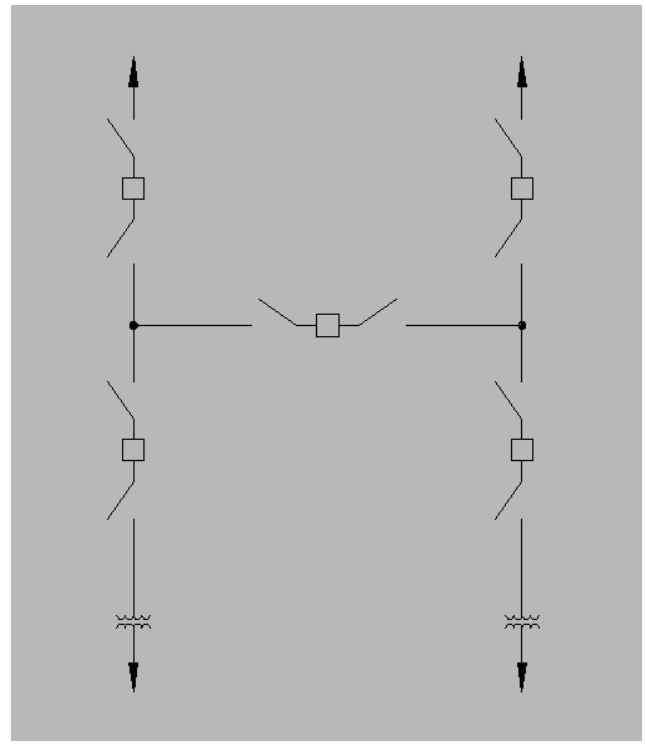
Radial Feed



Single Bus

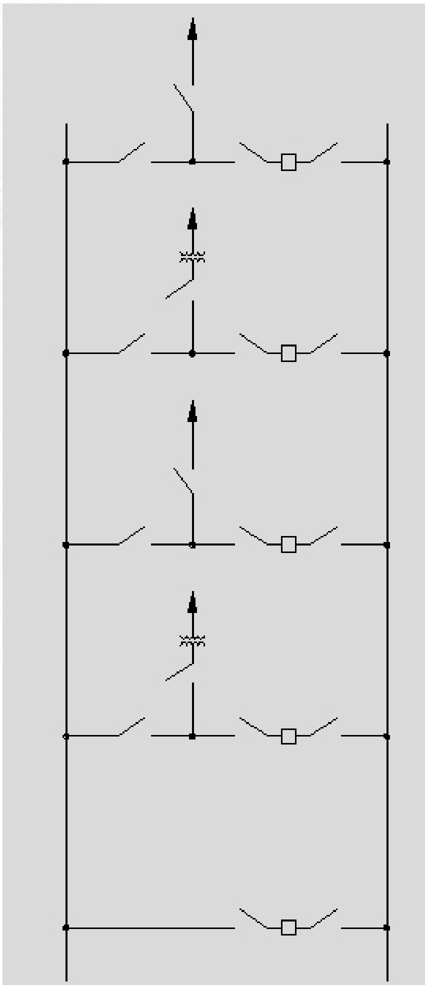


Single Bus w/ Tie

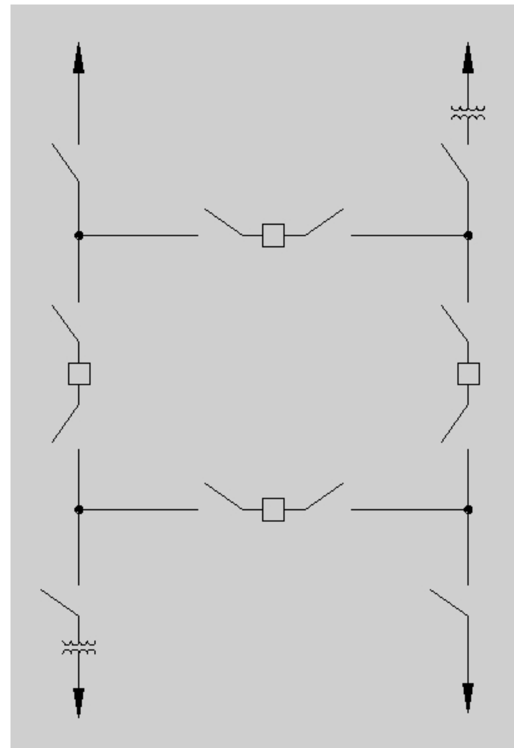


HV System Configuration

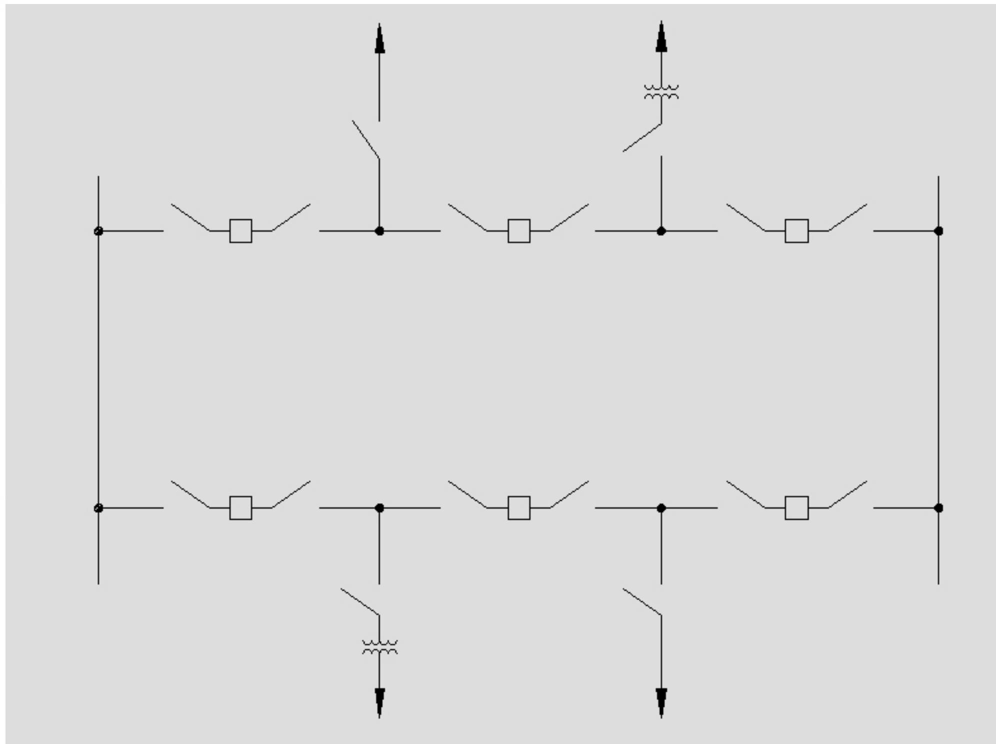
Main Bus and Transfer Bus



Ring Bus



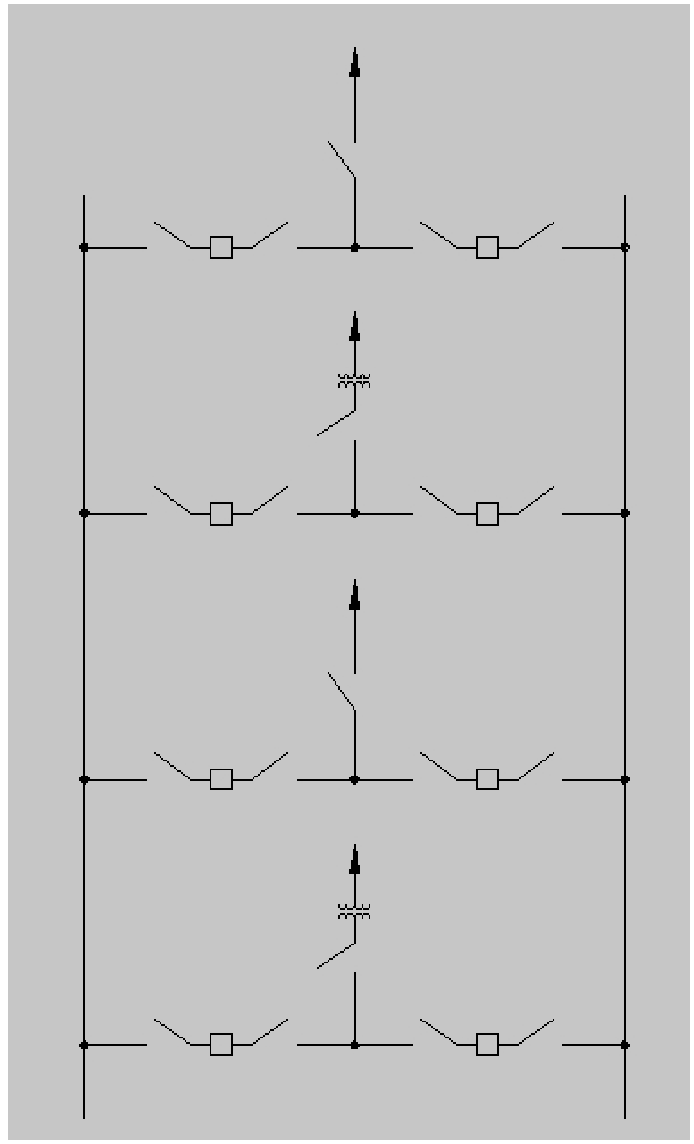
HV System Configuration



Breaker and a Half

HV System Configuration

Double Breaker / Double Bus



HV System Configuration

Outdoor AIS Installations

Configuration	Relative Cost Comparison
Single Bus	100%
Sectionalized Bus	122%
Main and Transfer Bus	143%
Ring Bus	114%
Breaker-and-a-Half	158%
Double Breaker-Double Bus	214%

Reference: "Reliability of Substation Configurations", Daniel Nack, Iowa State University, 2005

HV System Configuration

λ = ANNUAL FAIL RATE

r = ANNUAL OUTAGE TIME

U = AVG. OUTAGE TIME

a. Single bus
b. Sectionalized single bus
c. Breaker-and-a-half
d. Double breaker-double bus
e. Ring bus

Table 3: Substation Reliability Indices (Ignoring Line Failure)

Configuration	λ (/yr)	r (min)	U (min/yr)
a	0.0489	72.15	3.53
b	0.0453	71.95	3.26
c	0.00301	184.56	0.56
d	0.00567	124.216	0.70
e	0.0174	81.88	1.42

Table 4: Substation Reliability Indices (Including Line Failures)

Configuration	λ (/yr)	r (min)	U (min/yr)
a	0.0549	80.50	4.42
b	0.0459	76.35	3.50
c	0.00356	175.76	0.63
d	0.00572	125.14	0.72
e	0.0235	92.20	2.17

Reference: "Reliability of Substation Configurations", Daniel Nack, Iowa State University, 2005

LV & MV System Configurations

For LV and MV systems, the configuration options are typically limited to

- **Radial Feed**
- **Dual Main, Single Bus**
- **Main-Tie-Main (N.O. Tie Breaker)**
- **Main-Tie-Main (N.C. Tie Breaker)**

Arrester Voltage Ratings

System Voltage (kV rms)		Recommended Arrester Rating (MCOV) kV rms	
Nominal	Maximum	Three-Wire or Four-Wire Wye Solidly Grounded Neutral	Delta and Ungrounded Wye
2.4	2.52	3 (2.55)	3 (2.55)
4.16	4.37	3 (2.55)	6 (5.10)
4.8	5.04	—	6 (5.10)
6.9	7.25	6 (5.10)	9 (7.65)
8.32	8.74	6 (5.10)	9 (7.65) 10 (8.40)
12.0	12.6	9 (7.65) 10 (8.40)	12 (10.2) 15 (12.7)
12.47	13.1	9 (7.65) 10 (8.40)	15 (12.7) 18 (15.3)
13.2	13.9	10 (8.40) 12 (10.2)	15 (12.7) —
13.8	14.5	10 (8.40) 12 (10.2)	15 (12.7) 18 (15.3)
20.78	21.8	15 (12.7) 21 (17.0)	24 (19.5) 27 (22.0)
22.86	24.0	18 (15.3) 21 (17.0)	24 (19.5) 27 (22.0)
24.9	26.2	18 (15.3) 21 (17.0)	24 (19.5) 27 (22.0)
34.5	36.2	27 (22.0) 30 (24.4)	36 (29.0) 39 (31.5)
46.0	48.3	36 (29.0) 39 (31.5)	48 (39.0) —
69.0	72.5	54 (42.0) 60 (48.0)	72 (57.0) —
115	121	90 (70.0) 96 (76.0)	108 (84.0) —
138	145	108 (84.0) 120 (98.0)	132 (106) 144 (115)
161	169	120 (98.0) 132 (106) 144 (115)	144 (115) 168 (131) —
230	242	172 (140) 180 (144) 192 (152)	228 (180) 240 (190) —

System grounding is a critical factor in the selection of arrester voltage ratings. Typical data provided by arrester manufacturer is shown in the table.

Cable Insulation Ratings

System grounding is a critical factor in the selection of cable insulation ratings. UL 1072 "Standard for Medium-Voltage power Cables" provides the following guidance.

Cable Insulation Ratings

Table 310.104(E) Thickness of Insulation for Shielded Solid Dielectric Insulated Conductors Rated 2001 to 35,000 Volts

Conductor Size (AWG or kcmil)	2001–5000 Volts		5001–8000 Volts						8001–15,000 Volts						15,001–25,000 Volts					
	100 Percent Insulation Level [1]		100 Percent Insulation Level [1]		133 Percent Insulation Level [2]		173 Percent Insulation Level[3]		100 Percent Insulation Level[1]		133 Percent Insulation Level[2]		173 Percent Insulation Level[3]		100 Percent Insulation Level[1]		133 Percent Insulation Level[2]		173 Percent Insulation Level [3]	
	mm	mils	mm	mils	mm	mils	mm	mils	mm	mils	mm	mils	mm	mils	mm	mils	mm	mils	mm	mils
8	2.29	90	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
6–4	2.29	90	2.92	115	3.56	140	4.45	175	—	—	—	—	—	—	—	—	—	—	—	—
2	2.29	90	2.92	115	3.56	140	4.45	175	4.45	175	5.59	220	6.60	260	—	—	—	—	—	—
1	2.29	90	2.92	115	3.56	140	4.45	175	4.45	175	5.59	220	6.60	260	6.60	260	8.13	320	10.67	420
1/0–2000	2.29	90	2.92	115	3.56	140	4.45	175	4.45	175	5.59	220	6.60	260	6.60	260	8.13	320	10.67	420

Conductor Size (AWG or kcmil)	25,001–28,000 volts						28,001–35,000 volts					
	100 Percent Insulation Level[1]		133 Percent Insulation Level [2]		173 Percent Insulation Level[3]		100 Percent Insulation Level[1]		133 Percent Insulation Level[2]		173 Percent Insulation Level[3]	
	mm	mils	mm	mils	mm	mils	mm	mils	mm	mils	mm	mils
1	7.11	280	8.76	345	11.30	445	—	—	—	—	—	—
1/0–2000	7.11	280	8.76	345	11.30	445	8.76	345	10.67	420	14.73	580

Cable Insulation Ratings

[1] **100 Percent Insulation Level.** Cables in this category shall be permitted to be applied where the system is provided with relay protection such that ground faults will be cleared as rapidly as possible but, in any case, within 1 minute. While these cables are applicable to the great majority of cable installations that are on grounded systems, they shall be permitted to be used also on other systems for which the application of cables is acceptable, provided the above clearing requirements are met in completely de-energizing the faulted section.

[2] **133 Percent Insulation Level.** This insulation level corresponds to that formerly designated for ungrounded systems. Cables in this category shall be permitted to be applied in situations where the clearing time requirements of the 100 percent level category cannot be met and yet there is adequate assurance that the faulted section will be de-energized in a time not exceeding 1 hour. Also, they shall be permitted to be used in 100 percent insulation level applications where additional insulation is desirable.

[3] **173 Percent Insulation Level.** Cables in this category shall be permitted to be applied under all of the following conditions:

(1) In industrial establishments where the conditions of maintenance and supervision ensure that only qualified persons service the installation

(2) Where the fault clearing time requirements of the 133 percent level category cannot be met

(3) Where an orderly shutdown is essential to protect equipment and personnel

(4) There is adequate assurance that the faulted section will be de-energized in an orderly shutdown

Also, cables with this insulation thickness shall be permitted to be used in 100 or 133 percent insulation level applications where additional insulation strength is desirable.

Cable Insulation Ratings

Industry standard is to use 133% insulation for both solidly grounded systems as well as low-resistance grounded systems (LRG).

173% insulation is typically applied for high-resistance grounded systems (HRG)

Note: NEC and OSHA requires cables operating over 2000 V to be shielded.

Other Equipment

Other electrical equipment which may require special consideration when selecting voltage ratings include:

- **Capacitor banks**
- **Reactors**
- **Filters**

When specifying nominal voltage of this equipment higher than operating voltage, be careful to de-rate the power rating by a factor of $(V_{nom}/V_{operate})^2$

Project Constraints

Project constraints typically come down the following:

- **Cost**
- **Reliability / Availability**

These two factors are directly proportional

Project Constraints

As methods are identified to cut cost, the result is typically lower reliability / availability

As methods are identified to improve reliability and availability, the result is typically higher cost.

For this reason, it is critical that these parameters are spelled out clearly in the RFQ and the EPC proposal.

Design Key Documents

Efforts to obtain client acceptance of the One Line Diagram and Physical Plan are critical to ensure a smooth project.

<u>Ideally</u>, these two documents would be developed by the Client or the EPC during the contract negotiation process….

Unfortunately, this is not always the case.

Design Key Documents

Developing a detailed one line (i.e. tripping logic, interlocking schemes, identification of interposing/auxiliary trippping devices, etc) is typically not required, as this effort requires a significant amount of resources.

The Client may not always have such resources, while the EPC may not want to spend such resources until the EPC is certain that he will be awarded the project.

Design Key Documents

Once a one line diagram is finalized and approved by the Client, it serves as a road map for the project.

The next step is creating a physical plan drawing which identifies the boundary of the project.

This could be an outdoor substation layout drawing, or a switchgear building drawing layout, or a combination with cable routing plans.

Design Key Documents

Client approval of the one line diagram and the physical plan drawings, will for the most part define the project parameters.

Equipment Specifications

Improperly specified equipment can seriously impact project cost and schedule.

Once an order is placed for major pieces of apparatus, supplying the vendors with revisions to the specifications typically results in higher costs and impact to schedule.

Equipment Specifications

Equipment specifications should be provided by the Client with the RFQ or by EPC in the proposal.

This sets a basis for the pricing and schedule.

Equipment Specifications

When writing equipment specifications, try to eliminate duplicating requirements.

It seems that both Clients and EPCs develop standards with the idea that the more pages it has, the more accurate it is. This is typically not the case.

In most cases, the opposite it true.

Equipment Specifications

Examples of specifications that lead to confusion:

Oil Immersed Transformer

Applicable Standards: ANSI/IEEE C57.12.00, C57.12.90

- **Routine and design tests, as listed in ANSI/IEEE C57.12.00, shall be made in accordance with ANSI/IEEE C57.12.90. No load losses and excitation current shall be measured at 90%, 100% and 110% of rated voltage.**
- **Switching impulse, phase-to-ground and insulation power factor, as listed in ANSI/IEEE C57.12.00, shall be made in accordance with ANSI/IEEE C57.12.90**

Why are only specific tests listed…does this mean that the other tests listed in C57.12.90 are not required?

Equipment Specifications

Examples of specifications that lead to confusion:

Oil Immersed Transformer

Applicable Standards: ANSI/IEEE C57.12, IEC 60076

Contradictions between standards specifically testing tolerances. This typically allows the manufacturer to select the less stringent requirement which provides a lower cost.

Equipment Specifications

Examples of specifications that lead to confusion:

Medium Voltage Breakers

Applicable Standards: ANSI/IEEE C37.06, IEC 56

Significant differences in the way that ratings are defined. This typically allows the manufacturer to select the less stringent requirement which provides a lower cost, and this provides you with a piece of equipment that probably does not meet your requirements.

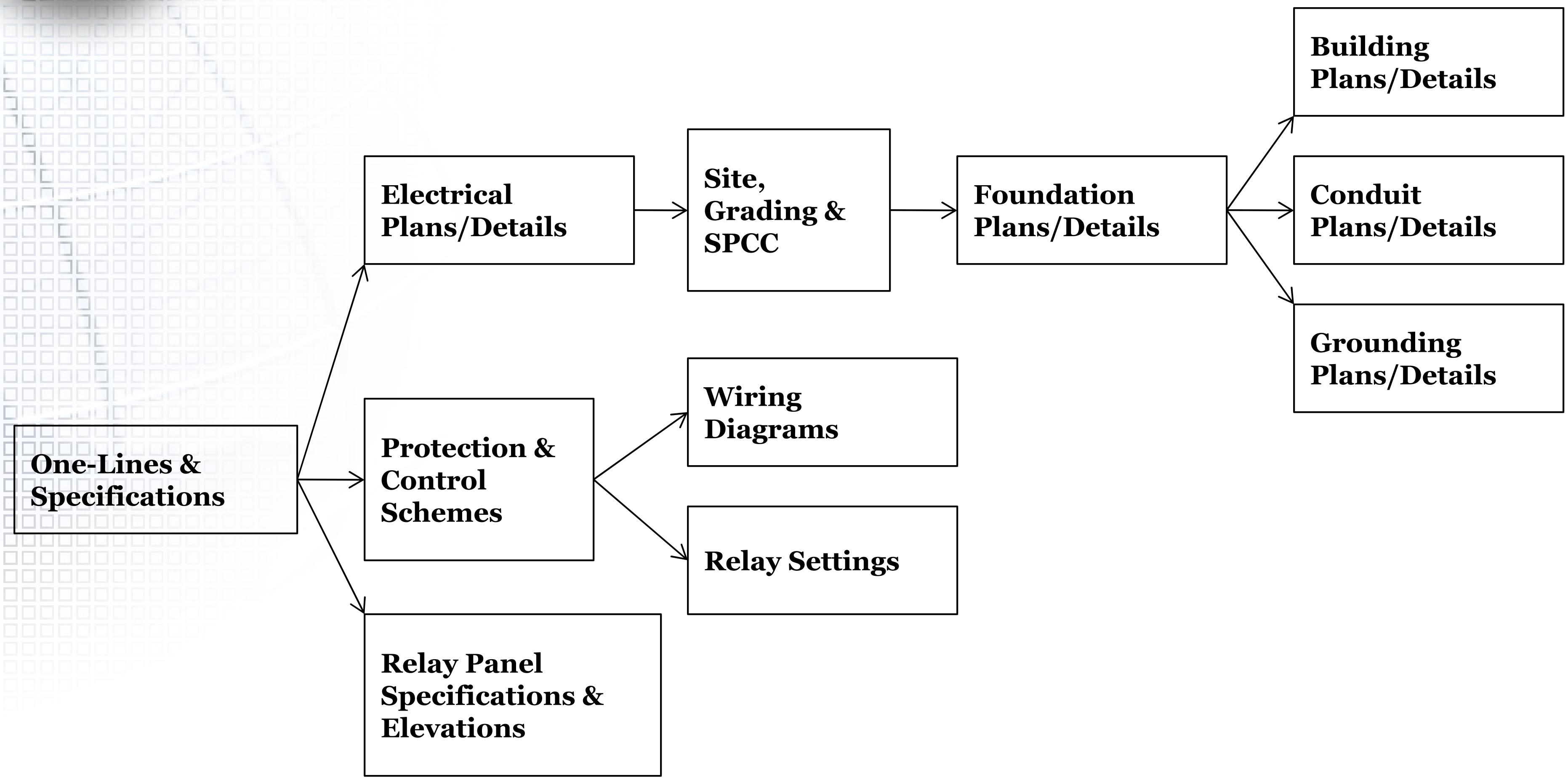
Equipment Specifications

Suggestions for writing specifications:

- Typically a smaller spec is better and provides more comparable quotations
- If you reference an applicable specification, there is no need to quote portions of this specification.
- List specifications that are applicable. Listing too many specifications may result in contradictions that allow the manufacturer to select the specification that provides a lower price.
- Avoid mixing ANSI/IEEE and IEC…unless there is a specific reason for doing so. It is very important that the ratings are associated with the correct standard.

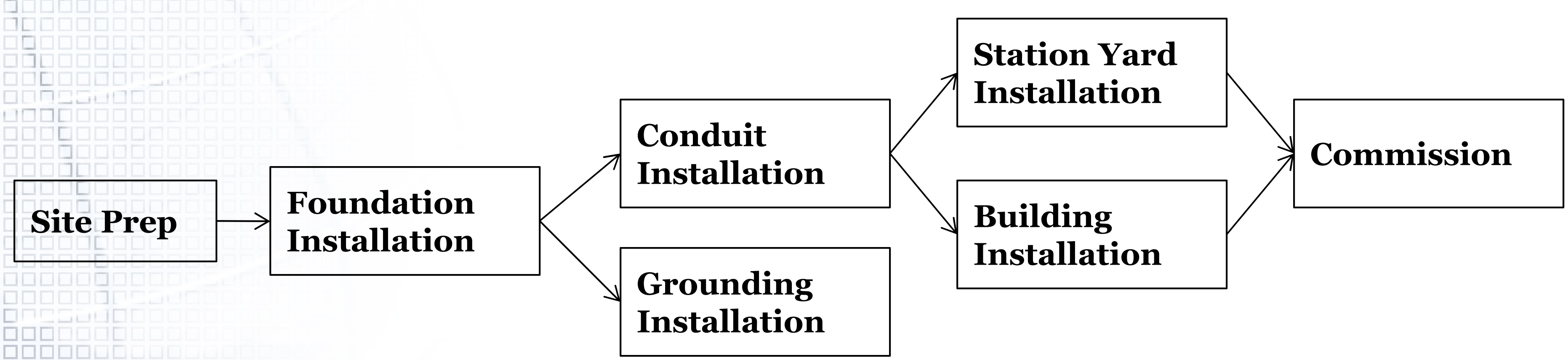
Engineering Process

Example for outdoor high-voltage substation



Construction Process

Example for outdoor high-voltage substation



Questions ?