Project Engineering Requirements - Pt 2

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Opening Joke

Q. How do Electrical Engineers meditate?

A. They contemplate $V = IR$

Ohmmmmmmmmmmmmmmmmmmmmmmmmmm...
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.
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

- 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

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

*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
Example #3
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, obtain an accurate load list.
- 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, **obtain an accurate load list.**
• Determine future growth requirements
• Determine capacity requirements
• Determine reliability requirements
Service

Radial System

Pros

• Less Expensive
• Smaller footprint
• Simpler control/protection schemes

Cons

o Less reliable
o Less flexible for maintenance
Service

Radial System

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

Cons
- Less reliable
- Less flexible for maintenance
Service

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

Pros

• Higher operation flexibility
• Higher maintenance flexibility
• Higher reliability

Cons

• More complex control/protection sch.
• 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

- Solidly grounded
- Low resistance ground (LRG)
- High resistance ground (HRG)
System Grounding

Solidly grounded

Pros

• 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

Cons

• 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)

Pros
- 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

Cons
- 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
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

Short-Circuit Model
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
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
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

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

<table>
<thead>
<tr>
<th>Line No.</th>
<th>Rated Maximum Voltage kV, rms</th>
<th>Power Frequency</th>
<th>1 Minute Dry kV, rms</th>
<th>10 Second Wet kV, rms</th>
<th>Full Wave (2)(6) Withstand kV, Peak</th>
<th>2 μsec Chopped Wave Withstand kV, Peak</th>
<th>Switching Impulse Withstand Voltage Terminal to Ground With Breaker Open kV, Peak</th>
<th>Withstand Voltage Terminal to Terminal on One Phase with Circuit Breaker Open kV, Peak</th>
<th>Minimum Creepage Distance of External Insulation to Ground mm</th>
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<td>2640</td>
<td>1425</td>
<td>1500</td>
<td>12000</td>
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</tbody>
</table>

**NOTES**

(1) For circuit breakers applied in gas insulated substations, see Table 5.
(2) 1.2 x 50 μseconds 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 distance 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 125 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 Outdoor Equipment

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

<table>
<thead>
<tr>
<th>Line No.</th>
<th>Rated Voltage (kV)</th>
<th>Impulse 1.2 x 50 μs Wave Crest</th>
<th>60 Hz Wave, Wet, 10 sec.</th>
<th>Minimum Metal-to-Metal Distance Between Rigidly Supported Energized Conductors, Inches</th>
<th>Recommended Ground Clearance, Inches</th>
<th>Recommended Minimum Ground Clearance, Inches</th>
<th>Recommended Phase Spacing, Center to Center, Inches</th>
<th>Bus Supports, Vertical Brk. Disc. Switches Power Fuses, Non-expulsion Types</th>
<th>Bus Supports, Vertical Brk. Disc. Switches Power Fuses, Non-expulsion Types</th>
<th>Minimum Clearance Between Overhead Conductor and Ground for Personal Safety, Feet</th>
<th>Recommended Withstand S.S. Crest kV</th>
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<td>292</td>
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</table>

Note—For insulator data, refer to ANSI C29.6 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 1-72.131-6 (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.
Class I Power Transformers shall include power transformers with high-voltage windings of 69 kV and below.
Class II power transformers shall include power transformers with high-voltage windings from 115 kV through 765 kV.

### Table 6—Dielectric insulation levels for Class II power transformers

<table>
<thead>
<tr>
<th>Nominal system voltage (kV)</th>
<th>Basic lightning impulse insulation level (BIL) (kV crest)</th>
<th>Chopped wave level (kV crest)</th>
<th>Switching impulse level (BIL) (kV crest)</th>
<th>Induced-voltage test (phase to ground)</th>
<th>Applied-voltage test level (kV rms)</th>
</tr>
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### Nominal Voltage

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<tr>
<th>Application</th>
<th>Nominal system voltage (kV rms)</th>
<th>Maximum system voltage (from ANSI C84-1-1995) (kV rms)</th>
<th>Basic lightning impulse insulation levels (BIL) in common use (kV crest)</th>
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<td>8.7</td>
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<td>75</td>
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<td>345.0</td>
<td>362.0</td>
<td>1175</td>
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<td>500.0</td>
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<td>1675</td>
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<tr>
<td></td>
<td>765.0</td>
<td>800.0</td>
<td>2050</td>
</tr>
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**NOTES**

# Nominal Voltage

## HV Bushings

<table>
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<th></th>
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<td>38.0</td>
<td>200</td>
<td>22</td>
<td>27</td>
<td>35</td>
<td>42</td>
<td>Light</td>
<td>28mm/kV</td>
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<tr>
<td>46</td>
<td>48.0</td>
<td>250</td>
<td>29</td>
<td>37</td>
<td>46</td>
<td>56</td>
<td>Medium</td>
<td>35mm/kV</td>
</tr>
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<td>69</td>
<td>72.5</td>
<td>350</td>
<td>44</td>
<td>55</td>
<td>69</td>
<td>85</td>
<td>Heavy</td>
<td>44mm/kV</td>
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<td>550</td>
<td>73</td>
<td>91</td>
<td>115</td>
<td>141</td>
<td>Extra Heavy</td>
<td>54mm/kV</td>
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<tr>
<td>138</td>
<td>146.0</td>
<td>650</td>
<td>88</td>
<td>110</td>
<td>138</td>
<td>169</td>
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<td>750</td>
<td>102</td>
<td>128</td>
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<td>220</td>
<td>274</td>
<td>345</td>
<td>423</td>
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<td>550.0</td>
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<td>318</td>
<td>399</td>
<td>500</td>
<td>614</td>
<td></td>
<td></td>
</tr>
<tr>
<td>765</td>
<td>800.0</td>
<td>2050</td>
<td>487</td>
<td>609</td>
<td>765</td>
<td>939</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**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

<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Bus and Switch Insulator Leakage Distance</td>
<td>132 in. creep (equivalent to 750 kV BIL or extra creep 650 kV BIL)</td>
</tr>
<tr>
<td>Apparatus Bushing Leakage Distance (circuit breakers, bushings, transformer bushings, etc.)</td>
<td>92 in. creep (equivalent to 650 kV BIL)</td>
</tr>
</tbody>
</table>

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

Figure 1—Transformer insulation life
Continuous Current

Transformer Aging

![Graph showing aging acceleration factor vs. hottest spot temperature in degrees Celsius.](image)

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

Transformer Aging

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

Example:

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 instantaneous trip 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>
<thead>
<tr>
<th>Nominal Voltage (kV)</th>
<th>Nonsegregated</th>
<th>Segregated</th>
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<td>0.635 ac and all dc</td>
<td>75; 100; 150</td>
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<tr>
<td>4.76</td>
<td>39; 58; 78</td>
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<td>13.8</td>
<td>37; 58; 77</td>
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<td>14.4</td>
<td>—</td>
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<td>23.0</td>
<td>32; 56; 64</td>
<td>60; 80; 100</td>
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<td>34.5</td>
<td>32; 56; 64</td>
<td>60; 80; 100</td>
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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

Asymmetrical RMS

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<th>BIL kV</th>
<th>AMPS</th>
<th>MOM. kA</th>
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<th>BIL kV</th>
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</tr>
<tr>
<td>2000</td>
<td>100</td>
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</tr>
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</table>
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

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

<table>
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<tr>
<th>Configuration</th>
<th>Relative Cost Comparison</th>
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<tbody>
<tr>
<td>Single Bus</td>
<td>100%</td>
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<tr>
<td>Sectionalized Bus</td>
<td>122%</td>
</tr>
<tr>
<td>Main and Transfer Bus</td>
<td>143%</td>
</tr>
<tr>
<td>Ring Bus</td>
<td>114%</td>
</tr>
<tr>
<td>Breaker-and-a-Half</td>
<td>158%</td>
</tr>
<tr>
<td>Double Breaker-Double Bus</td>
<td>214%</td>
</tr>
</tbody>
</table>

Reference: “Reliability of Substation Configurations”, Daniel Nack, Iowa State University, 2005
HV System Configuration

$\lambda = \text{ANNUAL FAIL RATE}$

$r = \text{ANNUAL OUTAGE TIME}$

$U = \text{AVG. OUTAGE TIME}$

### Table 3: Substation Reliability Indices (Ignoring Line Failure)

<table>
<thead>
<tr>
<th>Configuration</th>
<th>$\lambda$ (/yr)</th>
<th>$r$ (min)</th>
<th>$U$ (min/yr)</th>
</tr>
</thead>
<tbody>
<tr>
<td>a</td>
<td>0.0489</td>
<td>72.15</td>
<td>3.53</td>
</tr>
<tr>
<td>b</td>
<td>0.0453</td>
<td>71.95</td>
<td>3.26</td>
</tr>
<tr>
<td>c</td>
<td>0.00301</td>
<td>184.56</td>
<td>0.56</td>
</tr>
<tr>
<td>d</td>
<td>0.00567</td>
<td>124.216</td>
<td>0.70</td>
</tr>
<tr>
<td>e</td>
<td>0.0174</td>
<td>81.88</td>
<td>1.42</td>
</tr>
</tbody>
</table>

### Table 4: Substation Reliability Indices (Including Line Failures)

<table>
<thead>
<tr>
<th>Configuration</th>
<th>$\lambda$ (/yr)</th>
<th>$r$ (min)</th>
<th>$U$ (min/yr)</th>
</tr>
</thead>
<tbody>
<tr>
<td>a</td>
<td>0.0549</td>
<td>80.50</td>
<td>4.42</td>
</tr>
<tr>
<td>b</td>
<td>0.0459</td>
<td>76.35</td>
<td>3.50</td>
</tr>
<tr>
<td>c</td>
<td>0.00356</td>
<td>175.76</td>
<td>0.63</td>
</tr>
<tr>
<td>d</td>
<td>0.00572</td>
<td>125.14</td>
<td>0.72</td>
</tr>
<tr>
<td>e</td>
<td>0.0235</td>
<td>92.20</td>
<td>2.17</td>
</tr>
</tbody>
</table>

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

<table>
<thead>
<tr>
<th>System Voltage (kV rms)</th>
<th>Recommended Arrester Rating (MCOV) kV rms</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Three-Wire or Four-Wire Wye Solid Grounded Neutral</td>
</tr>
<tr>
<td>Nominal</td>
<td>Maximum</td>
</tr>
<tr>
<td>2.4</td>
<td>2.52</td>
</tr>
<tr>
<td>4.16</td>
<td>4.37</td>
</tr>
<tr>
<td>4.8</td>
<td>5.04</td>
</tr>
<tr>
<td>6.9</td>
<td>7.25</td>
</tr>
<tr>
<td>8.32</td>
<td>8.74</td>
</tr>
<tr>
<td>12.0</td>
<td>12.6</td>
</tr>
<tr>
<td>12.47</td>
<td>13.1</td>
</tr>
<tr>
<td>13.2</td>
<td>13.9</td>
</tr>
<tr>
<td>13.8</td>
<td>14.5</td>
</tr>
<tr>
<td>20.78</td>
<td>21.8</td>
</tr>
<tr>
<td>22.86</td>
<td>24.0</td>
</tr>
<tr>
<td>24.9</td>
<td>26.2</td>
</tr>
<tr>
<td>34.5</td>
<td>36.2</td>
</tr>
<tr>
<td>46.0</td>
<td>48.3</td>
</tr>
<tr>
<td>69.0</td>
<td>72.5</td>
</tr>
<tr>
<td>115</td>
<td>121</td>
</tr>
<tr>
<td>138</td>
<td>145</td>
</tr>
<tr>
<td>161</td>
<td>169</td>
</tr>
<tr>
<td>230</td>
<td>242</td>
</tr>
</tbody>
</table>
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

<table>
<thead>
<tr>
<th>Conductor Size (AWG or kcmil)</th>
<th>2001–5000 Volts</th>
<th>5001–8000 Volts</th>
<th>8001–15,000 Volts</th>
<th>15,001–25,000 Volts</th>
<th>25,001–28,000 Volts</th>
<th>28,001–35,000 Volts</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>100 Percent Insulation Level 1</td>
<td>100 Percent Insulation Level 2</td>
<td>100 Percent Insulation Level 3</td>
<td>133 Percent Insulation Level 1</td>
<td>133 Percent Insulation Level 2</td>
<td>133 Percent Insulation Level 3</td>
</tr>
<tr>
<td>mm mils</td>
<td>mm mils</td>
<td>mm mils</td>
<td>mm mils</td>
<td>mm mils</td>
<td>mm mils</td>
<td>mm mils</td>
</tr>
<tr>
<td>8</td>
<td>2.29 90</td>
<td>2.92 115</td>
<td>3.56 140</td>
<td>4.45 175</td>
<td>4.45 175</td>
<td>5.59 220</td>
</tr>
<tr>
<td>6-4</td>
<td>2.29 90</td>
<td>2.92 115</td>
<td>3.56 140</td>
<td>4.45 175</td>
<td>4.45 175</td>
<td>5.59 220</td>
</tr>
<tr>
<td>2</td>
<td>2.29 90</td>
<td>2.92 115</td>
<td>3.56 140</td>
<td>4.45 175</td>
<td>4.45 175</td>
<td>5.59 220</td>
</tr>
<tr>
<td>1</td>
<td>2.29 90</td>
<td>2.92 115</td>
<td>3.56 140</td>
<td>4.45 175</td>
<td>4.45 175</td>
<td>5.59 220</td>
</tr>
<tr>
<td>1/0–2000</td>
<td>2.29 90</td>
<td>2.92 115</td>
<td>3.56 140</td>
<td>4.45 175</td>
<td>4.45 175</td>
<td>5.59 220</td>
</tr>
</tbody>
</table>

72
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 \((\frac{V_{\text{nom}}}{V_{\text{operate}}})^2\)
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.
Efforts to obtain client acceptance of the One Line Diagram and Physical Plan are critical to ensure a smooth project.

Ideally, 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 tripping 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.
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 is 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

- Site Prep
- Foundation Installation
- Conduit Installation
- Grounding Installation
- Station Yard Installation
- Building Installation
- Commission
Questions ?