Basic Guides: Electric Substation Design

Colegio de Ingenieros y Agrimensores de Puerto Rico
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Objective

The seminar’s objective is to provide a basic knowledge of the process of designing an electrical substation.
Electrical Substation

An assembly of equipment in an electric system through which electrical energy is passed for generation, transmission, distribution, interconnection, transformation, conversion or switching.
Basic Concepts
Electrical Substation Design

Substation Types:
Functions

Generator step-up
Transmission Center
Distribution
Generator Step-Up
Transmission Center
230/115/38 KV Transmission Center
230/115 KV Transmission Center
Distribution Substation
Industrial Substation
Industrial Substation
Basic Concepts
Substation Types

Substation Types:
Insulating Medium
Air Insulated
Gas Insulated
Air Insulated (AIS)
GIS Substation
GIS Substation
GIS Substation
Substation Project
Basic Concepts

Process starts with a need
System deficiency is identified
System Deficiencies.doc
System Studies.doc
Devise a project plan
Project scope is documented
An estimate is developed and approved
Formal plans and drawings are developed
Records
Drawings
Material list and specifications
Scope

Description including references to other elements
Single-line diagrams
Estimates including soft and hard costs
System restrictions
Time constraints
Operational restrictions
Team

Diseño Sub-w\Copy of Industrial Complex B Scope.doc
General Design Procedure

System deficiencies are defined
Project scope
Preliminary design
Preliminary design approval
Final Design
Final Design approval
Establish Project Time Table
Basic Documents

Site information as permits, surveys, geological surveys, equipment specifications, restrictions, and legal contracts

Construction drawings

Supplier list
## Basic/Elements/ Drawings

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<tr>
<th>Cover sheet</th>
<th>Structure details</th>
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<tr>
<td>Drawing list</td>
<td>Conduits, racks &amp; raceways</td>
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<td>Single line diagram (S)</td>
<td>Cable plans</td>
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<td>Protection Single line</td>
<td>Control building</td>
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<tr>
<td>Three line diagram</td>
<td>Station service AC-DC</td>
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<tr>
<td>Site grading/civil</td>
<td>Cable list</td>
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<tr>
<td>Grounding and Fence</td>
<td>Schematics AC-DC</td>
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<td>Foundation</td>
<td>Control panel wiring</td>
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<tr>
<td>Equipment layout</td>
<td>Equipment/breakers-</td>
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<td>Line feed cables</td>
<td>transformers/ wiring</td>
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<tr>
<td></td>
<td>Communication</td>
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<td></td>
<td>Facilities integration</td>
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# Drawings

<table>
<thead>
<tr>
<th>Single Line Diagram</th>
<th>Three Line Diagram</th>
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<tr>
<td>Is the station reference</td>
<td>Three phase line diagram</td>
</tr>
<tr>
<td>Presents orientation &amp; interconnections of equipment</td>
<td>Define Phasing</td>
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<tr>
<td>Presents switching &amp; functional relay information</td>
<td>Circuit breaker pole numbers</td>
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<td></td>
<td>Disconnect switches</td>
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<td></td>
<td>CT / VT connections &amp; ratio</td>
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<tr>
<td></td>
<td>Cables</td>
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<td></td>
<td>Transformer information &amp; connections</td>
</tr>
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<td></td>
<td>Arresters</td>
</tr>
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</table>
Drawings

AC Schematics
Is a document to establish current CT and voltage VT circuits interconnections with relays and metering

DC Schematics
Is a document to establish relay, control and circuit interruption interconnections
Cover Sheet

Drawing List
Survey & Site
Site

Diseño Sub-w\VIEQ Electrical Site .pdf
Single Line

Diagram
Single Line Diagram

Diseño Sub-w\Single line-1a.pdf
Equipment Layout

General System Layout

Diseño Sub-w\VIEQ Subst Profile 1.pdf
Aerial Photograph V.pdf
Grounding & Fence
Fence Grounding Detail

- **Fence Post**
- **Gate**
- **Burndy #4 GAR 2026 Connector**
- **Burndy #BD-12 Flex Copper Braid**
- **Install Cyclone Fence Inside Concrete Base**
- **Burndy #GG18-1 Connector**
- **Burndy #GAR-2026 Connector**
- **#4/0 AWG Stranded Bare Copper Wire (Typical)**

**Gate Note:**
For double gates use same connection for each gate.
Grounding

Diseño Sub-w\VIEQ Grounding 1.pdf
Diseño Sub-w\SVC Grounding 2.pdf
Three Line Diagram
Three Line Diagram Example

Diseño Sub-w\LMM AC CT VT.pdf
Line Feed Example

Diseño Sub-w\SVC Primary Dist.pdf
VERY IMPORTANT NOTE:
115 KV LINE ROUTE IS APPROXIMATE AND ESTIMATED FROM INFORMATION OBTAINED FROM CONTRACTOR AND FIELD INFORMATION FROM PRE-P.A. Tie-in information is not developed from a formal survey.

LEGEND:
- Existing underground feeder feed points
- Existing distribution underground lines, voltages as indicated on drawings
- Existing 3/4 MV aerial lines
- Existing 12/7 and 16/9 MV aerial lines

NEW UNDERGROUND 115 KV LINE CONSIDER THREE NETS OF 2 x 800 MV ALUM CONDUCTORS, 300 or 350 kV AND 300 or 350 kV for switching at the end of the 115 to 34.5 kV substation.

YELLOW WARNING RIBBON PERIODICALLY LINING ELECTRICAL TRENCHES AND ATTACHMENTS TO TERMINATOR STRUCTURE AT 34.5 KV SWITCH YARD TO INDICATE THE LOCATION OF UNDERGROUND CABLES.

ELECTRICAL SUB PLAN
SCALE: 1:200

Sheets of
Cable Study

Ampacity Cable Studies

Report-Cable-Sub-DIS.pdf
Panel & Control

Wiring
Preliminary Design

Preliminary Information Required

Is a new site or existing?

If existing, get the last drawings
What are the design standards
Description of existing property
Planning study
Industry expansion plan
First Visit to the Site

Observe all site advantages and constraints
Site restrictions (urban regulations)
Check for future expansion constraints
How lines and load circuits will be brought to the site and exit out
Access to the site (how to move heavy equipment)
# First Visit to the Site

## Power Line Supply
- Line Voltage
- Consider how to maintain the substation in service without one, or two lines out of service
- Overhead or underground
  - Restrictions for line construction, regulations
- Emergency Generator integration

## Load Circuits
- Line voltage
- Consider how to enter a building or exit the station
- Overhead or underground
  - See future expansion plans & design accordingly
First Visit to the Site

Is the site has a good construction and maintenance access?
If existing substation, does it allows for outages?
Does it provides for public and workers safety?

Observe drainage patterns
Flat terrain or hillside
Run off patterns

What are the aesthetics requirements?
Check for potential zoning, environmental or other problems
Verify local or government special regulations
Post First Visit to Site

- Update project scope & get approval if required
- Update estimate if required
- Submit amended permits if required
- Adjust any design criteria if required
- Issue instructions for long lead equipment and site studies
<table>
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<th>Time Frame</th>
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<td>Substation Transformers</td>
<td>10 - 16 months</td>
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<tr>
<td>Circuit Breakers</td>
<td>4 – 8 months</td>
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<tr>
<td>High Voltage Switches</td>
<td>4 – 8 months</td>
</tr>
<tr>
<td>Control &amp; Protection Panel</td>
<td>4 – 8 months</td>
</tr>
<tr>
<td>High Voltage GIS Equipment</td>
<td>8 – 12 months</td>
</tr>
<tr>
<td>Medium Voltage GIS</td>
<td>8 – 10 months</td>
</tr>
</tbody>
</table>
Developed Project Time Table

- Expected Service Date
- Permits
- Equipment Procurement (transformers, breakers, etc. lead time)
- Power supplier requirements (PREPA and others)
- Client operations input
- Get the approval:
  - SLD drawing
  - Site Layout
  - Detailed design
  - Construction
  - Commissioning and as-built
RUS Bulletin 1724E

Substation Design Summary

SUB-SJ007.pdf
## Bus Arrangements

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<tr>
<th>Reliability</th>
<th>Optimum Bus configuration</th>
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<tr>
<td>Cost of configuration</td>
<td>Outage costs</td>
</tr>
<tr>
<td>Available space</td>
<td>Type of bus or customer</td>
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<tr>
<td>Basic configurations</td>
<td>Maintenance cost</td>
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<tr>
<td>Single bus</td>
<td>System security</td>
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<tr>
<td>Single bus with tie breaker</td>
<td>Load characteristics</td>
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<tr>
<td>Main &amp; transfer bus</td>
<td>Failures effect in the system</td>
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<tr>
<td>Ring bus</td>
<td>Location of the bus</td>
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<tr>
<td>Breaker &amp; a half</td>
<td></td>
</tr>
<tr>
<td>Double bus</td>
<td></td>
</tr>
</tbody>
</table>
## Bus Arrangements

<table>
<thead>
<tr>
<th>Cost of configuration</th>
<th>Cost</th>
<th>Space</th>
</tr>
</thead>
<tbody>
<tr>
<td>Single bus</td>
<td>$1.00 P.U.</td>
<td>1.0</td>
</tr>
<tr>
<td>Single bus with tie breaker</td>
<td>$1.22 P.U.</td>
<td>1.2</td>
</tr>
<tr>
<td>Main &amp; transfer bus</td>
<td>$1.38 P.U.</td>
<td>1.7</td>
</tr>
<tr>
<td>Ring bus</td>
<td>$1.15 P.U.</td>
<td>1.2</td>
</tr>
<tr>
<td>Breaker &amp; a half</td>
<td>$1.63 P.U.</td>
<td>2.0</td>
</tr>
<tr>
<td>Double bus Double breaker</td>
<td>$2.06 P.U.</td>
<td>3.0</td>
</tr>
</tbody>
</table>
Surge Arresters

Functions:

- Limit transient surge voltages below the insulation breakdown of the equipment

- Provide transient voltage protection while connected to the power operating voltage
Surge Arrester Selection

All arresters use Zinc Oxide valves (MOV)
For selecting you will need:
  - Power operating voltage rating
  - Energy dissipation capability
  - Type or arrester class
  - Insulation coordination study
**EXLIM - P**

Station Metal Oxide Surge Arrester

The arrester meets the following performance criteria:

- **Energy Capability (kJ/kV of rating):**
  - 1-Shot (Single Impulse): 7.0
  - Design performance rating: 4 msec. duration
  - 3-Shot (Rated Test Energy): 6.8
  - Multiple shots over 1 min.

**Protective Level @ 10 kA:**
- 2.30 (per unit of voltage rating)
- Pressure Relief Class: 80 kA

### Electrical Characteristics

<table>
<thead>
<tr>
<th>Voltage Rating kWh</th>
<th>MCRO Rating kV</th>
<th>TOV ≤ kV</th>
<th>Switching Surge @ 1.5 kA</th>
<th>Maximum Discharge Voltage kV-Crest</th>
</tr>
</thead>
<tbody>
<tr>
<td>54</td>
<td>4 kW</td>
<td>64.5</td>
<td>103</td>
<td>101</td>
</tr>
<tr>
<td>60</td>
<td>4 kW</td>
<td>71.7</td>
<td>113</td>
<td>111</td>
</tr>
<tr>
<td>72</td>
<td>5 kW</td>
<td>86.0</td>
<td>136</td>
<td>134</td>
</tr>
<tr>
<td>90</td>
<td>70</td>
<td>107.8</td>
<td>170</td>
<td>167</td>
</tr>
<tr>
<td>96</td>
<td>76</td>
<td>114.7</td>
<td>181</td>
<td>178</td>
</tr>
<tr>
<td>108</td>
<td>84</td>
<td>129.1</td>
<td>204</td>
<td>200</td>
</tr>
<tr>
<td>110</td>
<td>98</td>
<td>131.5</td>
<td>207</td>
<td>204</td>
</tr>
<tr>
<td>132</td>
<td>106</td>
<td>157.7</td>
<td>257</td>
<td>245</td>
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<tr>
<td>144</td>
<td>115</td>
<td>172.1</td>
<td>281</td>
<td>267</td>
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<tr>
<td>168</td>
<td>131</td>
<td>200.8</td>
<td>327</td>
<td>312</td>
</tr>
<tr>
<td>172</td>
<td>140</td>
<td>205.5</td>
<td>335</td>
<td>319</td>
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<td>180</td>
<td>144</td>
<td>215.1</td>
<td>350</td>
<td>333</td>
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<tr>
<td>192</td>
<td>152</td>
<td>229.4</td>
<td>373</td>
<td>356</td>
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<td>228</td>
<td>180</td>
<td>272.5</td>
<td>444</td>
<td>423</td>
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<tr>
<td>240</td>
<td>190</td>
<td>286.8</td>
<td>466</td>
<td>444</td>
</tr>
<tr>
<td>258</td>
<td>209</td>
<td>308.3</td>
<td>508</td>
<td>478</td>
</tr>
<tr>
<td>300</td>
<td>243</td>
<td>358.5</td>
<td>590</td>
<td>555</td>
</tr>
<tr>
<td>312</td>
<td>245</td>
<td>372.8</td>
<td>614</td>
<td>578</td>
</tr>
<tr>
<td>336</td>
<td>272</td>
<td>401.5</td>
<td>661</td>
<td>622</td>
</tr>
<tr>
<td>360</td>
<td>293</td>
<td>430.2</td>
<td>708</td>
<td>667</td>
</tr>
</tbody>
</table>

Notes:
- © Temporary overvoltage with no prior energy surge.
- * Switching surge with a time to actual crest of 45 to 60 μs. 500A switching surge current wave for ratings 54-132 kV; 1000A for ratings 144-240 kV; 2000A for ratings 256-500 kV.
- 3 Equivalent front-of-wave producing a voltage crest in 0.50 μs. Protective level is maximum discharge voltage for 10 kA impulse current wave.
Transformers

Some of the Standards applied

IEEE STD C57.12.2000
ANSI STD C57.12.10-1997
IEEE STD C57.12.90-1999
IEEE STD C57.12.01-2000
IEEE STD C57.98-1993
IEEE STD C57.91-1995
IEEE PC 57.119 (Draft 14.0) 2001
Transformers

Rating
Self cooled ONAN oil natural, air natural circulation
Forced Air Rating ONAF oil natural, air forced circulation
Forced Oil Rating OFAF oil forced, air forced circulation

Rating
Transformers 2.5-10 MVA
One 125% stage cooling
Transformers >10 MVA
Two cooling stages
133% ONAN
166% ONAN
Continuous loading with oil hot spot less than 110 degree C
Short term loading 180 degree C
Transformers

Oil Preservation
Sealed tank
Inert Gas
   Nitrogen blanket over oil
Modified Conservator
   Main tank is filled of oil
      from a conservator tank

Winding connections
Delta-Wye
NLT, LTC location?
Wye –Delta
NLT, LTC location?
Delta –Delta
NLT, LTC location?
Three winding transformers
NLT, LTC-location
Breakers

Definition:
Is an automatically operated electromechanical device designed to protect an electrical circuit from damage caused by a short circuit or an overload.
Breakers Type

There are different classifications

- Interrupting medium
  - Air blasting
  - Oil (high & low volume)
  - Vacuum (medium voltage)
  - Gas SF6 (high voltage)
  - Magnetic Air (distribution)
- Tank
  - Dead tank
  - Live tank

Ratings – ANSI C37.06

- Rated voltage
- Insulation level
- Continuous current
- Interrupting current at rated voltage
- Transient recovery voltage
- Rated interrupting time
- Permissible trip delay
Disconnecting Switches

Types

Station
Transmission
Distribution
Low voltage
Switches
Station Power, Batteries Chargers

AC Power
- Two sources, emergency generator with transfer switch
- Transformer cooling system
- Transformer load tap changer
- Transformer cabinet heaters
- Circuit breakers stored energy mechanism
- Circuit breakers cabinet heaters
- Building & Outdoor yard lights
- Battery chargers & outlets
- Building mechanical system
- Building A/C

DC Service
- Two battery banks
- Two DC distribution panel
- One circuit per breaker from each panel (combine)
- For relay panel, one circuit from each panel
- Two circuit per transformer

Use IEEE Std 485 for sizing lead acid batteries
Cables

High voltage cables
Follow PREPA regulations and buy cables from approved manufacturers
Shielded cable
   TR-Cross-linked Polyethylene
   Ethylene Propylene Rubber
   EPR

Low voltage Cables
(600V)
Copper cable is more reliable
Multiconductor, color code cable is preferred
Practice is:
   PT circuits  #12 AWG CU
   CT circuits  #10 or #8 AWG CU
   Control Circuits  #14 AWG CU
   SCADA alarms  #18 AWG CU
Protection

Relays are devices that are connected throughout the electric power system to detect an undesirable conditions and start an action to minimize damages to the system.
Protection

Protection philosophy requires a balance between redundancy and cost.

The goal is to protect the system with the simplest design.

The more complex the protection scheme the more probability for bad operations.
Substation Layout

Single Line Diagram

Check:

Numbers of breakers, disconnect switches, transformers, auxiliaries, protective devices, lines and other equipment.
Short circuit and current capacity of equipment, bus and other equipment
Compliance with project’s scope and requirements
Number of feeders and load circuits
That all equipment fit within substation lot and complies with standards
Substation Layout

Finalize design requirements
   Outdoor
      High, low profile or GIS?
   Indoor
      GIS or metal clad?
System protection and power company requirements
Overhead feeders and load circuits?
   If overhead check clearances
Underground feeder and load circuits?
   Cables or Gas Insulated Lines or Bus (GIL, GIB)
Substation Layout

Outdoor Substation

Check:
  Compliance with all technical requirements
  All energize elements comply with the required clearances

Clearances
  Verify compliance with the last requirements of the National Electrical Safety Code or PREPA
  Diseño Sub-w\Copy of SVC Subst Profile 2.pdf
  Diseño Sub-w\Copy of SVC Subst Profile 3.pdf

If using outdoor metal clad substation: is protected from vehicle traffic?
If using underground lines: are the manholes accessible?
Substation Layout

Indoor Substation

Check:

- Compliance with all technical requirements
- Is the metal clad follow the NFPA Arc Flash guides?
- For maintenance clearances

GIS substation are considered safe and complies with all recommended guides

[GIS-PDF\General-Layout-GIS.pdf]
Substation Design
References

ANSI C37 series – Protection and Control Equipment
ANSI C57 Series – Transformers
IEEE Standard 80- Substation Grounding
NEMA Standards – Electric Equipment Construction
National Electrical Safety Code
Rural Utilities Service Bulletin 1724E-300
(www.usda.gov/rus/electric/bulletin.htm)
PREPA - Manual para el Diseño y Construcción de Mallas Conectadas a Tierra de Subestaciones y Equipos
PREPA -Reglamento Complementario al Código Eléctrico Nacional
Questions?
Thank You
Substation Design An Introduction

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