Primary and Secondary Electrical Distribution Systems

Critical Facilities Round Table
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Utility Considerations

- Capacity
- Voltage and Sources
- Size of Metering Equipment
- Relaying Requirements
- Station Batteries
Utility Metering

• Requirements Dictated by the Utility
• EUSERC (as a reference)
  – 15 kV: 48”W x 72” to 96”D
  – 21 kV: 60”W x 96”D
  – 38 kV: 72”W x 129”D
115 kV Substation Service

(Approximately 80’ by 75’)

Section B–B
Types of Systems

• Radial
• Primary-Selective Radial
• Loop-Primary Selective
• Secondary Selective
• Sparing Transformer
• Spot Network
Simple Radial System

• Simple, least costly
• Easy to coordinate
• No idle parts
Radial System

Figure 1.1-1. Simple Radial System
Primary and Secondary Radial

Figure 1.1-2. Primary and Secondary Simple Radial System
Loop Primary – Radial Secondary
Loop Switching – Substation Transformer

Figure 1.1-4. Secondary Unit Substation Loop Switching
Loop Switching – Pad Mount Transformer

Figure 1.1-5. Pad-Mounted Transformer Loop Switching
Primary Selective Radial System

- Duplex or selector switch
- Spare primary incoming circuit
- Duration of outage from cable failure limited
Primary Selective – Secondary Radial

Figure 1.1-7. Basic Primary Selective — Radial Secondary System
Duplex Selector Switch

Figure 1.1-8. Duplex Fused Switch in Two Structures
Selector Switch – Single Structure

Figure 1.1-9. Fused Selector Switch in One Structure
Secondary Selective System

• Normally operated as two electrically independent substations with tie breaker open
• Failure of either primary circuit affects only one bus
• Service restored by opening dead bus main and closing tie
• Operation can be made automatic
• Transformers not paralleled so fault currents similar to radial
Two-Source Primary – Secondary Selective

Figure 1.1-10. Two-Source Primary — Secondary Selective System
Sparing Transformer System

• Alternative to Double-Ended Substations
• Single Common Backup Transformer
• Service restored by opening dead bus main and closing tie
• Operation can be made automatic
• Transformers not paralleled so fault currents similar to radial
• Location of substations limited (must be clustered)
Sparing Transformer

Figure 1.1-11. Sparing Transformer System
Spot Network

• Transformers paralleled on the secondary side
• Uses network protectors
• If primary voltage fails, associated protector automatically opens
• Other protector remains closed
• No “dead time” on bus, even momentarily
• Upon voltage restoration automatically synchronizes and re-closes
• Improved voltage regulation
• Secondary fault current increased
Spot Network

Figure 1.1-12. Three-Source Spot Network
Primary Equipment

- Air Terminal Chamber
- Metal-Clad Switchgear
  Circuit Breaker and Relays
- Metal-Enclosed Switchgear
  Switch and Fuse
- Others (Reclosers and Interrupters)
Metal-Clad Switchgear

- Defined in ANSI C37.20.2 as metal enclosed power switchgear
- Removable (draw-out) type switching and interrupting devices
- Connect and disconnect position
- Major parts of the switchgear enclosed by grounded metal barriers for compartmentalization
- Automatic shutters that cover primary stabs or studs
- All primary bus conductors and connections covered with insulation material throughout
Protective Relays
(ANSI Device Numbers)

27 - Undervoltage
47 - Phase sequence
49 - Thermal overload
50 - Instantaneous
51 - Time overcurrent
59 - Overvoltage
63 - Sudden pressure
67 - Directional overcurrent
86 - Lockout
87 - Differential
Metal-Enclosed Interrupter Switchgear

- Defined in ANSI C37.20.3 as metal-enclosed power switchgear
- Interrupter switches
- Power fuses (current limiting or non-current limiting)
- Bare bus and connections
- Instrument transformers
- Control wiring and accessory devices
Power Fuse Coordination

Expulsion
  Inverse-time
  Easier to coordinate

Current Limiting
  Steep straight line
  More difficult to coordinate
Pad Mounted Transformer
Switching and Fusing

- LBOR Switch
- Oil Interruption
- Rated 200, 300, 400 A
- $I_{sc} = 12 \text{ kA}$
- Current Limiting and Expulsion Fuses
- Limited Sizes
Transformers

Liquid Filled Substation Transformer

Dry Type Substation Transformer

Typical Pad-Mounted Transformer

Cast Coil Substation Transformer
Unit Substation Transformers

- 112.5 through 20,000 kVA
- Maximum 69 kV Primary
- Maximum 34.5 kV Secondary
- Bushings wall mounted
- Part of a substation lineup
- Can be custom designed to meet custom dimensions
Padmount Transformers

- Up to 5,000 kVA
- Maximum 34.5 kV Primary
- Maximum 600 V Secondary
- Weather resistant high and low voltage compartments
- Tamper-resistant Design
- No Fan Cooling Available
Network Transformers

- 300-2500 kVA
- Maximum 34.5 kV Primary
- Maximum 600 V Secondary
- Used in areas of high load density
- Designed for use in a secondary network system in either subway or vault applications.
Dry Versus Liquid Transformers

- **Dry**
  - No fluid to spill or burn
  - Cost is higher than oil
  - Resistant to moisture and chemical contamination
  - Minimum maintenance
  - UL Listing is available

- **Liquid**
  - Lowest purchase price
  - Hermetically sealed tank for harsh environments
  - Lowest losses per purchase dollar
  - Best balance of design properties- dielectric, thermal, and cost
  - UL Listing is available
Liquid Filled Technology Benefits

- Lowest Purchase Cost
- Lowest Loss Per Purchase Dollar
- Ability to operate in adverse conditions
- Excellent Dielectric Properties
  - Smaller Footprint
  - Better losses
- Options available for “Safety-Related” and “Environmentally Sensitive Applications”
Dry Type Technology Benefits

- Environmentally Safe
- Non-flammable
- Minimal Maintenance
- Coordination Flexibility
- Higher Fan Cooled Rating
Comparison of Transformer Costs

Liquid Filled Transformers
- Mineral Oil (Outdoor) 1.00
- Vegetable Oil (Indoor/Outdoor) 1.20
- Silicone (Indoor/Outdoor) 1.35
- Pad Mounted – 5% Less than Substation Design

Dry Type Transformers
- Vacuum Pressure Impregnated 1.25
- Vacuum Pressure Imp. - Epoxy 1.35
- Cast Coil 1.55 to 2.0
- Lower Temperature Rise – 15% to 35%
- Outdoor – Add 20%
Loss Evaluation

\[ I^2R \text{ Losses} = \text{Total Losses (TL)} - \text{No Load Losses (NL)} \]

\[ I^2R \text{ Losses} \text{ are proportional to the Load Factor Squared} \]

Load Factor = Actual Load kVA/Rated Base kVA

Operating Losses = No Load Losses + \[ I^2R \text{ Losses at the appropriate Load Factor} \]
Loss Evaluation Example

Losses in watts for a 1000 kVA oil-filled transformer:
1,800 watts no load losses
15,100 watts full load losses
Load losses are approximately 13,300 watts (15,100 – 1,800)

At 0% load: 1,800 watts

At 50% load: 1,800 watts + (13,300)(.5)^2 = 1,800 watts + 3,325 watts = 5,125 watts

At 100% load: 1,800 watts + 13,300 watts = 15,100 watts

At 110% load: 1,800 watts + (13,300)(1.1)^2 = 1,800 watts + 16,093 watts = 17,893 watts
Auxiliary Fan Cooling

- Liquid filled transformers
  Fan cooling - 15% (750 kVA to 2000 kVA)
  Fan cooling - 25% (2500 kVA and above)

- Dry type transformers
  Fan cooling - 33% (All ratings)
Environment

• Maximum altitude 1000 m (3300 feet)
  Rating reduced 0.3% to 0.5% for each 100 m (330 feet) above that altitude

• Indoor and outdoor designs available

• Ambient
  30 degree C (86 degree F) average over 24 hours
  40 degree C (104 degree F) maximum
Transformers - Liquid Filled

- Insulation systems (Oil, Silicone, Vegetable Oil)
- Temperature rise
  - 55 degree C
  - 65 degree C
- Efficiency - 99%
- Overload capacity - ANSI C37.92
- Auxiliary devices
  - Temperature gauge
  - Liquid level gauge
  - Pressure vacuum gauge
  - Sudden pressure relay
  - Pressure relief device
Transformers - Dry type

- Insulation systems
  - Varnish
  - Polyester
  - Silicone
  - Epoxy
- Design types
  - Dip and bake
  - VPI
  - Cast coil
- Insulation classes
  - Class H 220 degree C
  - Class F 185 degree C
  - Class B 150 degree C
Transformers - Dry Type

• Temperature rise
  150 degree C
  115 degree C
  100 degree C (epoxy)
  80 degree C

• Efficiency
  97% to 98% (typical)
  99% (low temperature rise)

• Overload capacity - ANSI C57.96

• Auxiliary devices
  Temperature gauge
Secondary Neutral Grounding

• Solid Grounding
• Impedance Grounding
  Low resistance
  High resistance
  Reactance
Secondary Equipment

- Air terminal chamber
- Busway
- Low voltage switchboard
  Molded Case Circuit breakers
- Metal-Enclosed Switchgear
  Low voltage Power circuit breakers
Low-Voltage Switchboards (UL891) Versus Metal-Enclosed Switchgear (UL1558)
Paralleling Switchgear

Figure 42.3-4. Typical Electrical System with EGP3 Assembly and ATS Units (3-Generator Sources)
Low-Voltage Switchboards (UL891) 
Versus 
Metal-Enclosed Switchgear (UL1558)

- Molded Case Circuit Breakers (UL489)
- Insulated Case Circuit Breakers (UL489)
- Power Circuit Breakers (UL1066)
- Front Access or Rear Access
- Drawout or Fixed Mounted
- Manually or Electrically Operated
Low-Voltage Circuit Breaker Types

Molded Case Circuit Breakers
- Tested in accordance with UL489 & Nema AB-1
- Open Air Test - Rated @ 80% (Optional 100%)
- Over Toggle Mechanism
- Sealed Case - Not Maintainable
- Applied in Switchboards/Panelboards

Insulated Case Circuit Breakers
- Tested in accordance with UL489 & Nema AB-1
- Open Air Test - Rated @ 80% or 100%
- 2-Step Stored Energy Mechanism
- Sealed Case - Not Fully Maintainable
- Applied in Switchboards

Power Circuit Breakers
- Tested in accordance with UL1066 & ANSI C37
- Tested in the Enclosure - Rated @ 100%
- 2-Step Stored Energy Mechanism
- Open Access - Fully Maintainable
- Applied in Metal-Enclosed Draw-out Swgr
Low-Voltage Circuit Breaker Typical Ratings

Molded Case Circuit Breakers
- Frame Size: 100 through 3000 ampere
- Interrupting: 10/35/65/100 kA @ 480 Volts
- Limiters Available: 200 kAIC
- Instantaneous: 10-13X Frame Rating @ various X/R

Insulated Case Circuit Breakers
- Frame Size: 400 (800) through 5000 ampere
- Interrupting: 65/85/100 kA @ 480 Volts
- Limiters Not Normally Available
- Inst./Short Time: 25/35/65 kA @ various X/R

Power Circuit Breakers
- Frame Size: 800 through 5000 ampere
- Interrupting: 65/85/100 kA @ 600 Volts
- Limiters Available: 200 kAIC
- Short Time: 35/65/85/100 kA @ X/R of 6.6
TCC with Power Circuit Breakers

**PCB 2400 amp**
- 480V, Microprocessor Trip, LS
- Frame size: 3200 A
- Sensor: 2400
- LTPU: 1.0 f(S) = 2400 amp
- STPU: 5.0 f(s) = 12000 amp
- LTD: 7.00 sec.
- STD: .3 sec.
- No Instantaneous Trip

**PCB 800 amp**
- 480V, Microprocessor Trip, LS
- Frame size: 800 A
- Sensor: 800
- LTPU: 1.00 f(S) = 800 amp
- STPU: 5.0 f(s) = 4000 amp
- LTD: 7.00 sec.
- STD: .1 sec.
- No Instantaneous Trip

**MCCB 200 amp**
- 480V, Microprocessor Trip, LSI
- Frame size: 250 A
- Trip: 200 A
- Inst. PU: 10.0*T = 2000 A

**MCCB 50 amp**
- 480V, Thermal-Magnetic Trip
- Frame size: 100 A
- Trip: 50 A
- Inst. PU: Non adjustable
Maintenance - MCCBs and ICCBs

- Enclosed design requires little maintenance
- Terminal connections and trip units tightened to the proper torque values
- Inspect conductors
- Visually inspect and operate periodically
- Replacement parts are not available
- Repair, refurbishment, or remanufacture not recommended - replace damaged breakers
Maintenance - PCBs

- Designed to be serviced
- Replacement parts are available (contacts, pole assemblies, arc chutes)
- Inspection and maintenance program is recommended
- Keep it dry, keep it clean, keep it tight
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