"UPS Distribution Systems and UPS Fundamentals In The Petrochemical Industry"

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Tutorial Topics

- **Introduction** (general, historical perspective)
- **Purpose of a UPS**
- **UPS system** (types, configurations, trends, redundancy, hardware and operation)
- **Battery selection**
- **Magnetic components used in UPS systems** (ferroresonant, isolation and constant voltage transformers, reactors)
- **UPS system application** (system design and integration with the selection of distribution and protection equipment in UPS primary and secondary networks)
- **Review load types and design application considerations**
- **Power system analysis and harmonic considerations for typical applications**
- **System acceptance** (testing, commissioning, performance verification and maintenance)
Introduction
General

- UPS systems installed in petrochemical facilities provide uninterruptible power to process control, standby and other critical equipment. Accepted design, installation, verification and maintenance assures power is continuously available. This intensive half-day tutorial provides the needed background to better understand UPS distribution systems and UPS applications in petrochemical industry applications.
**Introduction**

**Historical Perspective**

- UPS Distribution Systems Are Copied From One Project To The Next
  - Industry practice
  - “This is the way we have always done it”
  - Time-Current Curves not produced
  - Internal protective device not considered
  - System selectivity not reviewed
Historical Perspective

- UPS Systems Supply Critical Process Loads
  - DCS & PLC’s
  - Critical Process Alarm Systems
  - SIS Systems
  - APC & Custody Transfer Systems
  - Process Analyzers
  - Gas Detection Systems
  - Fire Protection Systems
  - Critical Telephone Circuits
  - Emergency Lighting
  - Custom Load and Driver Control Systems
What is the Purpose of a Uninterruptible Power System (UPS)?
Purpose of a Uninterruptible Power System (UPS)?

- It is a modular unit or assembly of components that provide quality and continuity of AC power for a specific manufacturing unit or units
  - Note: The MAJORITY of instruments, process measurement, and process control devices rely on the UPS for electrical energy.

- In many instances, a UPS provides AC power to process equipment that is deemed “MISSION CRITICAL”
  - Safety
  - Environmental
  - Reliability & Operational Cost
Critical Equipment

- Not all instruments and control devices are critical
- If the LOSS of an instrument or control system creates a hazardous process condition, can cause an environmental incident, or trips a processing unit, it is typically deemed a CRITICAL device or system.
  - Examples
    - Process Measurement Devices
      - Transmitters and Switches used in process control
    - Basic Process Control Systems (BPCS)
      - DCS, PLC’s etc.
    - SIS Systems
- Non-critical Instruments
  - Examples
    - Process Measurement Devices that are for indication only
    - BPCS for non-critical control

Purpose of a Uninterruptible Power System (UPS)?
Purpose of a Uninterruptible Power System (UPS)?

Critical Power System

- Complex
  - Multiple Power Supplies –
    - Can be 120 VAC powered 24 VDC sources
  - UPS System
  - Batteries
  - Distribution
  - Short Circuit Protection

- Typical Power Source – Motor Control Center (MCC)
  - Thermal-Magnetic Breaker
  - Single Transformer
  - Typically Double-Ended without Automatic Switching
  - Separate Power Sources for increased reliability
    - (i.e. Separate Feeders from Separate Transformers up through the Main Substation)
Critical Power System Expectations

- Provides Reliable Power
- Maintains Critical Loads During Abnormal Situations
  - Disturbances such as sags, swells, surges
  - Short Circuits
  - Maintenance can be provided online

Purpose of a Uninterruptible Power System (UPS)?
What is a UPS?
Management and Operations Believe it is:
- Unreliable Power System
- Trips process units during maintenance
- Unavailable Power System
- System that has unlimited capacity
- OR ALL OF THE ABOVE!
What is a UPS?

UPS Actual Consists of...

- UPS – Components
  - Rectifier/Charger
  - Inverter
    - Ferro & PWM Technologies
  - Alternate Input
  - Static Switch
  - Manual Bypass Switch
  - Battery

![Diagram of UPS system](image.png)

*Grounding electrode per NEC Article 250*
Rectifier/Charger

- Full-wave controlled rectifier for changing AC to DC
- Typically it is a phase-controlled, silicone controlled rectifier circuit combined with a voltage regulator
  - Provides voltage and current control of its DC output
- Feeds the battery system
- Feeds the UPS inverter
- Appropriately Sized
  - Sized for load and to charge the battery
Inverter

- The inverter converts a DC waveform (supplied by the Rectifier/Charger/Battery) into an AC waveform
- Output will be supplied to either the load terminals or the input of the static transfer switch (depends of system configuration)

There are two different technologies to accomplish this:

- Ferroresonant
  - Norm for many years
  - Larger System
  - Commutated square wave bridge with an oscillator and filtering components
- PWM (Pulse Width Modulation)
  - Utilizes solid-state power electronic devices
  - Minimum parts count and reduced magnetic element size
What is a UPS?
Ferroresonant Transformer
What is a UPS?

UPS System

Cyberex
What is a UPS?

UPS System

SCI
What is a UPS?

Alternate Source

- Alternate Source
  - Redundant Power to UPS system
  - Inverter synchronizes to Alternate Source
    - Waveforms are in sync (eliminates transfer issues)
  - Power Source During the Following:
    - Inverter fails
    - Normal Power Source is lost
      - And battery system is discharged
    - Short-circuit or overload conditions
  - Provides BYPASS power for off-line maintenance of the Rectifier and Inverter
Manual Bypass

- Permits the power to flow from the alternate source to the load by bypassing the Inverter and Static Switch
- Permits UPS isolation
- Permits maintenance to be performed on the UPS components
- Permits start-up and shut-down of the system
- Can be internally or externally mounted
What is a UPS?

Alternate Source & Manual Bypass Switch (MBS)
What is a UPS?

Manual Bypass Switch (MBS)
What is a UPS?

- Static Switch
  - FAST acting
  - Typically can transfer within ¼ cycle (4 milliseconds)
  - Is supposed to transfer output power from the Inverter to the Alternate Source without any power dips or sags
  - Transfer normally at the zero-wave crossing due to waveform monitoring
What is a UPS?

Input Circuit Breakers
What is a UPS?

Meters and Mimic Panel
What is a UPS?

Procedures

START-UP PROCEDURE

- PRESS PRECHARGE PUSHBUTTON UNTIL PRECHARGE LIGHT IS ON.
- CLOSE BATTERY INPUT BREAKER.
- CLOSE AC INPUT BREAKER.
- CLOSE BYPASS SOURCE AC INPUT BREAKER.
- VERIFY STATIC SWITCH IS IN BYPASS TO LOAD POSITION AND TRANSFER MANUAL BYPASS SWITCH TO THE NORMAL OPERATION POSITION.
- PRESS INVERTER TO LOAD PUSHBUTTON.

SHUT-DOWN PROCEDURE

- PRESS BYPASS TO LOAD PUSHBUTTON.
- TRANSFER MANUAL BYPASS SWITCH TO THE BYPASS TO LOAD POSITION.
- OPEN BYPASS SOURCE AC INPUT BREAKER.
- OPEN BATTERY INPUT BREAKER.
- OPEN AC INPUT BREAKER.
UPS SYSTEMS
UPS Systems

Topics Covered

- System Types
- Hardware Components / Block Diagram
- Configurations
- Redundancy
- Applicable To Petrochemical Industry
• **System Types (from energy storage perspective)**
  - **Static (chemical energy)**
    - High Efficiency, High EMI / THD pollution
    - High Reliability and Availability
    - Most popular
    - Poor performance with non-linear/non-balanced loads
    - High Cost to achieve very high reliability
  - **Rotary (kinetic energy)**
    - More reliable than Static UPS
    - Availability lower from Static UPS
    - Large size
    - Electro-mechanical i.e. involved maintenance
    - Desirable for high power and/or non-linear/non-balanced load applications
    - High transient overload capabilities
    - High efficiency, Low EMI / THD pollution
  - **Hybrids (of static, rotary and engines) (mixture of energy sources)**
System Types (from switching perspective)

- Dual Conversion
  - On-Line UPS
  - Off-Line UPS
- Single Conversion
  - Line-Interactive UPS
UPS Systems

Static – On-line

- Static, On-Line UPS
• Static, Off-Line UPS #1
• Static, Off-Line UPS #2
• Static, Line-Interactive UPS #1
UPS Systems

Static – Line Interactive

- Static, Line-Interactive UPS #2
UPS Systems
Rotary

- Rotary UPS

![Rotary UPS Diagram]
Hybrid, Static-Rotary UPS
UPS Systems

Trends in Industrial Systems

- Most Popular Industrial Systems Configuration
  - On-Line
  - Technology
    - Ferroresonant
    - PWM
    - Magnetic / PWM Hybrid / Active Filter / PFC Rectifier
  - Power
    - 1-phase (< 5-10kVA)
    - 3-phase (>15kVA)
  - Galvanic Isolation
  - Redundancy
    - 2x100% or 3x100%
    - Feed-Through
• 2x100% or 3x100% with load sharing
UPS Systems

Redundancy

- 2x100% with load sharing, with galvanic isolation
● Limitations
  – Difficult to Replace
  – All Output Power Runs Through MBS
  – Not all components can be PM’d or Repaired
UPS Systems
Alternate UPS Configuration of the same Company

- Second Tap off Alternate Source Can Backfeed into Distribution Panel
- Controversial
- Allows for Isolating any Component or Replacing Entire UPS System without Total Outage
Alternate UPS Configuration of Another Company

- Second Tap off Alternate Source feed into segregated Distribution Panel
- Allows for Isolating any Component or Replacing Entire UPS System without Total Outage

UPS Systems

480V Distribution Sources (segregated from main substation)

- Input Circuit Breaker
- UPS System
- Alt Source Input
- MBS
- Output Circuit Breaker
- UPS System Custom Distribution Panel (Dual Mains w/ independent branch circuits)
UPS Systems

Redundancy

- Feed-through, concept
UPS Systems

Redundancy

- Feed-through, Examples
BATTERY SELECTION FOR UPS SYSTEM
Battery Selection For UPS System

Topics Covered

- Battery
- Battery Basics (definitions, technology, reaction, construction, sizing and capacity)
- Battery Comparison
- Other Considerations
- Maintenance
- Derating
- Standards
- Hydrogen Emission Generation
Battery Selection For UPS System

Battery

In general, storage of electrical energy requires its conversion into another form of energy. A Battery is a device that uses chemical compounds as the storage medium. During discharge, a chemical process occurs that generates energy, which can be drawn from the battery in the form of an electric current at a certain voltage.
Battery Selection For UPS System

Battery Systems
Battery Selection For UPS System

Battery Systems
Battery Selection For UPS System

Battery Systems
Battery Selection For UPS System

Battery Basics - Definitions

- Voltage - Force which puts electrons into motion
- Nominal Battery Voltage – Voltage measured at the battery terminal which represents the average voltage over a discharge period
- End of Discharge Voltage (Cut-off Voltage) – Voltage at which the battery discharge is terminated
- Maximum System DC System Voltage – Maximum voltage which can be tolerated by the loads
- Minimum System DC Voltage – Minimum Voltage at which the loads will continue to operate
- Nominal System Voltage – Arbitrary equipment rating which has been standardized by NEC (12, 24, 36, 48, 70, 110, 220, 240, 360 or 480V)
Battery Selection For UPS System

Battery Basics - Technology

- Nickel Cadmium Battery Discharge Profile

![Graph showing nickel cadmium battery discharge profile with cell voltage (V) on the y-axis and capacity %C5 (Ah) on the x-axis. The graph includes markers for 1.14 V/cell and 1.00 V/cell, and labels for 'After constant current recharge' and 'After constant potential recharge.' The graph indicates a 0.2 C discharge.]
- Nickel Cadmium Battery Discharge Profile
Battery Selection For UPS System

Battery Basics - Technology

● Deep Discharge –
  – Lead Acid Battery cycle life is limited to less than 150 deep discharge cycles (The more you discharge the battery the quicker it will reach the end of life)
  – Discharge below 1.8 volts per cell can permanently damage lead acid batteries
    ● Battery will sulfate causing higher internal resistance and lower capacity
    ● Severe deep discharge for extended periods of time can cause internal short circuit failure
  – For short durations, the end of discharge voltage may be as follows, if the discharge is followed by an immediate recharge:

<table>
<thead>
<tr>
<th>END OF DISCHARGE VOLTAGE</th>
<th>DISCHARGE RATE</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.65</td>
<td>1 HOUR OR LESS</td>
</tr>
<tr>
<td>1.70</td>
<td>3 HOUR OR LESS</td>
</tr>
<tr>
<td>1.75</td>
<td>5 HOUR OR LESS</td>
</tr>
<tr>
<td>1.80</td>
<td>8 HOUR OR LESS</td>
</tr>
</tbody>
</table>
Proper Sizing and Cell Selection (Most Important Voltages Required)

- Maximum System DC Voltage – (Determines the maximum number of cells that can be equalize charged without damage to loads)
- Minimum System DC Voltage – (Determines the end of discharge voltage)

Both of the Following Equations Must be True

\[
Max.DCVolts \geq \frac{\text{# of cells}}{\text{EqualizeVolts / cell}}
\]

\[
Min.DCVolts = \frac{\text{# of cells}}{\text{End of Discharge Volts / cell}}
\]
Battery Selection For UPS System

Battery Basics - Definitions

- Float Charging Voltage – Normal float charging voltage maintains a steady float charge to keep the battery fully charged
- Equalize Charging Voltage – Elevated charging voltage used to fast charge the battery or as a maintenance remedy
- Boost Charge – Charging elevated above an equalize charge for reviving a battery after manufacture, storage or abuse
Battery Selection For UPS System

Battery Basics - Capacity

- Capacity – Measure of the usable energy that can be discharged from a battery (typically the larger the battery – the more active material to create energy)

- Capacity is a Function of:
  - Temperature
  - Discharge Rate
  - Voltage Window
  - Battery Age
  - State of Charge

Note: The slower the battery discharge, the more usable energy can be extracted from the battery
Battery Selection For UPS System

Battery Basics - Capacity

- Capacity varies by end of discharge voltage:

<table>
<thead>
<tr>
<th>Cell</th>
<th>Type</th>
<th>8</th>
<th>5</th>
<th>60</th>
<th>5</th>
<th>1</th>
<th>1</th>
</tr>
</thead>
<tbody>
<tr>
<td>SBM231</td>
<td>29.1</td>
<td>46.2</td>
<td>173</td>
<td>427</td>
<td>595</td>
<td>840</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Cell</th>
<th>Type</th>
<th>8</th>
<th>5</th>
<th>60</th>
<th>5</th>
<th>1</th>
<th>1</th>
</tr>
</thead>
<tbody>
<tr>
<td>SBM231</td>
<td>27.7</td>
<td>43.4</td>
<td>105</td>
<td>228</td>
<td>319</td>
<td>422</td>
<td></td>
</tr>
</tbody>
</table>

- Amps X the time period, the more capacity is extracted to the lower end voltage:
  - 1.00 EODV: at 60 seconds
    \[1 \text{ min} \times 1 \text{ hr} / 60 \text{ min}] \times 595 \text{ amps} = 9.92 \text{ Ahrs} 
  - 1.14 EODV: at 60 seconds
    \[1 \text{ min} \times 1 \text{ hr} / 60 \text{ min}] \times 319 \text{ amps} = 5.32 \text{ Ahrs}
Battery Selection For UPS System

Battery Basics - Capacity

- Nickel Cadmium Battery Discharge Profile

![Graph showing Nickel Cadmium Battery Discharge Profile]
Battery Basics - Capacity

- **Nickel Cadmium**
  - Deep Discharges **DO NOT** Affect Performance and **DO NOT** Cause Permanent Damage to NICADS
  - Allows Long Term Open Circuit Storage
  - Nickel Cadmium Offer the Most Deep Cycles (Full Charge and Discharges) of any Technology Available:

<table>
<thead>
<tr>
<th>TECHNOLOGY</th>
<th># OF CYCLES *</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sintered/PBE NICAD</td>
<td>&gt; 2000</td>
</tr>
<tr>
<td>Pocket Plate NICAD</td>
<td>&gt; 1500</td>
</tr>
<tr>
<td>Flooded Plate Calcium</td>
<td>approx. 50 TO 150</td>
</tr>
<tr>
<td>Flooded Plate Antimony</td>
<td>600-800</td>
</tr>
<tr>
<td>Flooded Plate Selenium</td>
<td>600-800</td>
</tr>
<tr>
<td>Flooded Plante'</td>
<td>600-800</td>
</tr>
<tr>
<td>Valve Regulate Lead Acid</td>
<td>approx. 50 TO 150</td>
</tr>
</tbody>
</table>

* TO 80% DEPTH OF DISCHARGE
Battery Selection For UPS System

Battery Basics - Capacity

- Capacity varies by rate of discharge: Using the SBM231 again, more usable energy is extracted at slower discharges.

- 1.00 EODV at 60 seconds:

  \[
  \left[1 \text{ min} \times 1 \text{ hr} / 60 \text{ min}\right] \times 595 \text{ amps} = 9.92 \text{ Ahrs}
  \]

- 1.00 EODV at 8 hours:

  \[
  [8 \text{ hr}] \times 29.1 \text{ amps} = 232.8 \text{ Ahrs}
  \]
Battery Construction

- Battery Components
  - Case or Jar
  - Each Jar Typically has 3-4 Cells
  - Electrolyte
  - Grid or Current Collector
  - Active Material
  - Separator
Battery Basics - Reaction

- Lead Acid Chemical Reaction

Discharge:
\[ \text{PbO}_2 + \text{Pb} + 2\text{H}_2\text{SO}_4 \rightarrow 2\text{PbSO}_4 + 2\text{H}_2\text{O} \]

Charge:

Diagram:

- Positive
- Negative
NiCad Chemical Reaction

Discharge:

\[ 2\text{NiOOH} + \text{Cd} + 2\text{H}_2\text{O} \rightarrow 2\text{Ni(OH)}_2 + \text{Cd(OH)}_2 \]

Charge:

\[ \text{Ni(OH)}_2 + \text{Cd(OH)}_2 \rightarrow 2\text{NiOOH} + \text{Cd} + 2\text{H}_2\text{O} \]
Battery Basics – Lead Acid Construction

● Electrode Construction Types:
  - Planté - Pure lead casting (Single piece unit)
  - Gauntlet - Lead Alloy tubular splines with [pasted active material
  - Fauré - Pasted active material on lead alloy rectilinear (Current collector)

● Two part construction
  - Active Material (generates charge and discharge electrons)
  - Current collector (grid)
Battery Selection For UPS System

Battery Basics – Lead Acid Construction

- Plate construction

- Planté Plate
- Grid Plate
- Tubular Plate
Electrode Materials of Construction:

- Pure Lead
- Lead Selenium
- Lead Antimony
- Lead Calcium (Ag, Sn, Zn, Mg…)

Alloys in the lead current collector offer NO technical advantage

Used to reduce manufacturing costs by making electrodes easier to mass produce
Battery Selection For UPS System

Battery Basics – Lead Acid Construction

- Pure Lead: Best Electrical Performance, Least Maintenance
- Lead Selenium: Poorest Electrical Performance
- Lead Antimony: Highest Maintenance
- Lead Calcium: Poorest Electrical Performance, Highest Maintenance
Battery Selection For UPS System

Battery Basics – Lead Acid Construction

- Pure Lead
  - Most Reliable
  - Highest Cost

- Lead Selenium
  - + Plate Poisoning

- Lead Antimony
  - + Plate Growth

- Lead Calcium
  - Least Reliable
  - Lowest Cost
Battery Selection For UPS System

Battery Basics – Nickel Cadmium Construction

- Plastic Bonded Electrode
  - Powdered active material
  - Plastic bonded to perforated steel strip
  - Withstand extreme temperatures

- Sintered Plate Electrode
  - Powdered nickel material
  - Sintered onto perforated steel strip
  - Impregnated with active material

- Pocket Plate Electrode
  - Powdered active material
  - Suspended in perforated steel envelope

- Fiber Plate Electrode
  - Metallic sponge nickel
  - Impregnated active materials
Battery Basics – Nickel Cadmium Construction

- Plastic Bonded Electrode  Best Cycle Life  Best Reliability
- Sintered Plate Electrode
- Pocket Plate Electrode
- Fiber Plate Electrode  Poorest Cycle Life  Least Reliability

NOTE: Fiber plates are not recommended for continuous float charge because they are prone to hotspots and can short circuit on float charge and cycling.
Battery Selection For UPS System

Battery Basics – Nickel Cadmium Construction

• Plate construction

Sintered Plate
Pocket Plate
Fiber Plate
### Battery Basics – Technology Comparison

<table>
<thead>
<tr>
<th>Battery Type</th>
<th>Nickel Cadmium</th>
<th>Lead Acid</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Electrolyte</strong></td>
<td>Potassium Hydroxide</td>
<td>Sulfuric Acid</td>
</tr>
<tr>
<td><strong>Symbol</strong></td>
<td>KOH</td>
<td>H2SO4</td>
</tr>
<tr>
<td><strong>Specific Gravity</strong></td>
<td>1.2</td>
<td>1.215, 1.21, 1.24, 1.25, 1.30 *</td>
</tr>
<tr>
<td><strong>Electrolyte</strong></td>
<td>Inert to all internal components</td>
<td>Reacts with every internal element</td>
</tr>
<tr>
<td><strong>Advantages/Disadvantages</strong></td>
<td>Does not change properties with state of charge</td>
<td>Changes properties with state of charge</td>
</tr>
<tr>
<td><strong>Battery System</strong></td>
<td>Chemically and physically strong</td>
<td>Chemically and physically weaker</td>
</tr>
<tr>
<td><strong>Advantages/Disadvantages</strong></td>
<td>Minimum maintenance regardless of temperature</td>
<td>More maintenance required</td>
</tr>
<tr>
<td></td>
<td>More resistant to temperature extremes</td>
<td>Sensitive to temperature extremes</td>
</tr>
<tr>
<td></td>
<td>More resistant to electrical abuses</td>
<td>Less reliable</td>
</tr>
</tbody>
</table>

* different plate technologies have different SG's
Battery Selection For UPS System

Battery Basics – Other Considerations

- Despite all of the advances in power electronics associated with UPS systems
  - Battery remains the key component in determining system reliability
  - Battery chemistry has not changed much over the years

- Batteries have a finite age
  - They are expensive
  - Their life is shorter than the manufacturer warrants
  - Require a tremendous amount of maintenance

- One weak cell can yield the complete battery string useless

- While design and installation are critical, the key to a reliable UPS system is BATTERY MAINTENANCE
  - Includes: connection maintenance, internal diagnostics and checking for leaking post seals
Battery Selection For UPS System

Battery Basics – Other Considerations

- Battery sizing is based on the time and load power required
  - Refer to IEEE 485 and 1184 for more details
- UPS batteries must be matched to the application
- Choice of battery design depends on the environment, maintenance and application
- Maintain approximately 77 deg F for longer battery life
  - every + 15 deg F cuts life in half
  - Colder is not necessarily better because CAPACITY is REDUCED
- New battery assemblies should be certified prior to UPS commissioning
  - Refer to IEEE 450 for commissioning details
Battery Selection For UPS System

Battery Basics – Other Considerations

- Care should be taken when storing batteries prior to putting in service after manufacturer date
  - Lead Antimony – refreshing charge for every 3 months of storage
  - Lead Calcium – refreshing charge for every 6 months of storage
  - VRLA storage times vary based on storage temperature (refer to manufacturer)
  - FAILURE TO GIVE A REFRESHING CHARGE before the end of the recommended storage interval may result in plate sulfation which will adversely affect battery capacity
Float adjustment

Float current demand in specification apply when the electrolyte temperature is 77°F (25°C). The value will double for every 15°F (8°C) of temperature rise. If temperature drops, the current value will be halved for every 15°F (8°C) decrease. Some battery float current demand will increase with aging.
Battery Selection For UPS System

Battery Basics – Maintenance

● Float characteristics

## Battery Selection For UPS System

### Battery Basics – Maintenance

#### Proper Float Charging
- Maximizes battery life
- Maximizes battery capacity
- Reduces battery maintenance

<table>
<thead>
<tr>
<th>Battery Type</th>
<th>Recommended Float Voltage Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lead Selenium / Low Antimony Alloy Type:</td>
<td>2.15 to 2.25 volts per cell</td>
</tr>
<tr>
<td>(Specific gravity 1.24)</td>
<td></td>
</tr>
<tr>
<td>Lead Antimony Types:</td>
<td>2.15 to 2.17 volts per cell</td>
</tr>
<tr>
<td>(Specific gravity 1.215)</td>
<td></td>
</tr>
<tr>
<td>Lead Calcium Flooded Types:</td>
<td>2.17 to 2.25 volts per cell</td>
</tr>
<tr>
<td>(Specific gravity 1.215)</td>
<td></td>
</tr>
<tr>
<td>Lead Calcium Flooded Types:</td>
<td>2.23 to 2.33 volts per cell</td>
</tr>
<tr>
<td>(Specific gravity 1.250)</td>
<td></td>
</tr>
<tr>
<td>Lead Calcium Flooded Types:</td>
<td>2.28 to 2.37 volts per cell</td>
</tr>
<tr>
<td>(Specific gravity 1.30)</td>
<td></td>
</tr>
<tr>
<td>Pure Lead Plante' Types:</td>
<td>2.15 to 2.25 volts per cell</td>
</tr>
<tr>
<td>(Specific gravity 1.210)</td>
<td></td>
</tr>
<tr>
<td>Lead Calcium Valve Regulated Types:</td>
<td>2.27 @ 20 deg C volts per cell</td>
</tr>
<tr>
<td></td>
<td>(-2.4 mv per deg C rise over 20 deg C)</td>
</tr>
</tbody>
</table>
### Battery Selection For UPS System

#### Battery Basics – Maintenance

- **Initial Charge**
  - Recommended voltages and time periods

<table>
<thead>
<tr>
<th>Cell Volts</th>
<th>Lead Calcium Types</th>
<th>Lead Antimony Types</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Time-Hrs. 1.215 S.G.</td>
<td>Time-Hrs. 1.250 S.G.</td>
</tr>
<tr>
<td>2.24</td>
<td>444</td>
<td>-</td>
</tr>
<tr>
<td>2.27</td>
<td>333</td>
<td>-</td>
</tr>
<tr>
<td>2.30</td>
<td>210</td>
<td>-</td>
</tr>
<tr>
<td>2.33</td>
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<td>2.36</td>
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<td>235</td>
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<td>2.39</td>
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<tr>
<td>2.42</td>
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<td>2.45</td>
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<td>2.48</td>
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<td>55</td>
</tr>
<tr>
<td>2.50</td>
<td>32</td>
<td>44</td>
</tr>
</tbody>
</table>

**NOTE:** Time periods listed in Tables are for cell temperatures from 70 deg F to 90 deg F. For temperatures 55 deg F to 69 deg F double the number of hours. For temperatures 40 deg F to 54 deg F use four times the number of hours.
Battery Selection For UPS System

Battery Basics – Maintenance

● Float Voltage – Float voltage can be a misleading test
  – While voltage readings of individual cells are important
  – The sum of voltages of all the batteries MUST equal the output of the charger (resistive losses excluded)
  – Normal reading does not necessarily indicate the condition of the cell
  – An abnormal reading requires further investigation

● Specific Gravity Readings
  – Sulfate is part of the electrochemical process
    ● Discharged State - some of the sulfate migrates to the plates and the acid is reduced in specific gravity
    ● Fully Charged State – sulfate is in the acid and the specific gravity is normal
  – The difficulty in interpreting specific gravity readings is adjusting for cell and ambient temperatures
Battery Basics – Maintenance

- **Float Current Readings** – Float current results from the difference in potential from the batteries' self-discharge rates (batteries are always in a self-discharge rate) and the chargers attempt to keep the batteries fully charged.

- **Ripple Current Readings** – Ripple current is a byproduct of the conversion process of converting AC into DC by the rectifier circuit of the charger.
  - Filters in the charger reduce the effects of ripple current.
  - Over time, these circuit components degrade and ripple current increases.
  - An increase in ripple current greater than about 5A RMS for every 100Ah of battery capacity (5%) leads to increased temperature and shortened battery life.
  - If ripple current exceeds this amount, repair or replace charger (First place to look is aging electrolytic filter capacitors).
Battery Selection For UPS System

Battery Basics – Maintenance

- Temperature – Effects of temperature extremes in both cell (internal) and ambient (external) conditions impact battery life
  - Typical battery systems are designed for 20 years @ 77 deg F
  - 15 deg F increase in temperature cuts battery life in half
  - Increased temperature causes faster positive grid corrosion as well as other failure modes

- Discharge Current and Time – Online monitoring systems use discharge current and time calculations to determine ampere-hours removed and replaced
  - Presumably the benefit allows one to calculate battery capacity
  - Currently, the only sure way to determine true capacity is a load test
Battery Basics – Maintenance

- **Intercell Connection Resistance**
  - One of the more important parameters to test
  - More than 50% of battery bank failures are related to loose or corroded intercell connectors
  - If resistance measurement exceeds the lower end of the µohm range the connection is inadequate

- **Capacity (load test)** – Only true method of determining the battery systems actual capacity
  - The test has limited predictive value depending on how frequently it is performed (each load test subtracts from the life expectancy of the battery system)
  - Most manufacturers recommend capacity tests every 3 to 5 years

- **Impedance** – Internal impedance tests measure the capability of a cell to deliver current
  - Components of impedance (resistive and capacitive reactance) correlate to capacity
  - Although the correlation is not 100% it is an excellent way to find weak batteries
  - Impedance is inversely proportional to capacity
Battery Selection For UPS System

Battery Basics – Maintenance

- As impedance increases, battery capacity decreases
- Batteries do not have to be offline to test internal impedance

End Voltage vs. Impedance

![Graph showing End Voltage vs. Impedance with data points]

<table>
<thead>
<tr>
<th>Cell Number</th>
<th>Z</th>
<th>Vdc</th>
</tr>
</thead>
<tbody>
<tr>
<td>11</td>
<td>0.3</td>
<td>2.0</td>
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<td>18</td>
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<tr>
<td>22</td>
<td>0.7</td>
<td>1.9</td>
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<td>23</td>
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<td>9</td>
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<td>1.9</td>
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<td>7</td>
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<td>1.8</td>
</tr>
<tr>
<td>19</td>
<td>0.9</td>
<td>1.8</td>
</tr>
</tbody>
</table>

Data Points
Battery Basics – Maintenance

- Battery Aging and End of Life

- Nicads experience a gradual loss of capacity of about 1% per year.
- Lead Acid batteries demonstrate a drastic drop in capacity as they approach end of life.
Derating Factors:
- For MIN ambient temperature
- For MAX ambient temperature
- Float current
- For rate of discharge
- For aging
- For design margin
- Maximum DC voltage (load tolerance)
- Minimum DC voltage tolerance (operating voltage)
- % capacity recharge with time
Derating with ambient temperature
Battery Selection For UPS System

Battery Basics – Derating

- Derating rate of discharge and design margin

Typical discharge characteristics
(equal weight same discharge conditions)
Battery Basics – Derating

- Derating rate of discharge and design margin

Battery Selection For UPS System

Battery Basics – Derating

- Derating internal resistance change

Battery Basics – Derating

- Discharge available capacity available with ambient temperature change
Battery Selection For UPS System

Battery Basics – Standards

- Specification and Sizing:
  - IEEE 485 – Recommended Practice for Sizing Lead-Acid Batteries for Stationary Applications
  - IEEE 1115 – Recommended Practice for Sizing Nickel-Cadmium Batteries for Stationary Applications
  - IEEE 1184 – Guide for the Selection and Sizing of Batteries for Uninterruptible Power Supplies
  - IEEE 1106 – Recommended Practice for Installation, Maintenance, Testing, and Replacement of Vented Ni-Cad Batteries for Stationary Applications
Hydrogen Gas Evolution Calculation

\[ V_{H2}(I_F, \text{CapAhr}, K, N, C_{Type}) = I_F \frac{\text{CapAhr}}{100} \cdot K \cdot N \cdot C_{Type} \]

**Where:**

- \( V_{H2} \) - Volume of evolved hydrogen per hour
- \( I_F \) - Float current per 100Ahr of installed battery bank capacity in [A] and temperature compensated
- \( \text{CapAhr} \) - Installed battery bank capacity in [Ahr]
- \( K \) - Maximum hydrogen evolution rate constant dependent on plate type:
  - \( K_{\text{Antimony_US}} = 2.67 \times 10^{-4} \text{ ft}^3/\text{A} \)
  - \( K_{\text{Antimony_SI}} = 7.56 \times 10^{-6} \text{ m}^3/\text{A} \)
  - \( K_{\text{Lead_US}} = 1.474 \times 10^{-2} \text{ ft}^3/\text{A} \)
- \( N \) - Number of cells in battery bank
- \( C_{Type} \) - Constant dependent on battery construction:
  - \( C_{\text{Flooded}} = 1.00 \)
  - \( C_{\text{GNB_AbsolyteIIP}} = 0.01 \)
### Battery Selection For UPS System

**Battery Basics – Hydrogen**

- **Hydrogen Emission Generation**

---

#### Example:

**Application:** Instrumentation UPS  
**Battery Type:** GNB Absolyte IIP #3-100A23 (sealed), Lead-Acid type  
- Float voltage per cell @77 °C: 2.25V  
- Float current \( I_F = 50 \text{mA} \)

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>( \text{Cap}_{Ah} )</td>
<td>1100 ( \text{A} \cdot \text{hr} )</td>
</tr>
<tr>
<td>( N )</td>
<td>60</td>
</tr>
<tr>
<td>( K_{Lead_US} )</td>
<td>0.01474 ( \text{ft}^3 / \text{A} )</td>
</tr>
<tr>
<td>( C_{GNB_AbsolyteIIP} )</td>
<td>0.01</td>
</tr>
</tbody>
</table>
• Hydrogen Emission Generation

\[ V_{\text{Hydrogen\ Released\ 1hr}} := V_{\text{H2}}(I_F, C_{\text{Ahr}}, K_{\text{Lead\ US}}, N, C_{\text{GNB\ AbsolyteIIP}}) \]

\[ V_{\text{Hydrogen\ Released\ 1hr}} = 0.004864 \text{ ft}^3 \]

Total volume of hydrogen released during charging in 8-hour period is

\[ V_{\text{Total}} := 8 \cdot V_{\text{Hydrogen\ Released\ 1hr}} \]

\[ V_{\text{Total}} = 0.038914 \text{ ft}^3 \]

\[ \text{Vol}_{\text{Battery\ Room}} := 10 \cdot \text{ft} \cdot 10 \cdot \text{ft} \cdot 10 \cdot \text{ft} \]

\[ \text{Vol}_{\text{Battery\ Room}} = 1000 \text{ ft}^3 \]

\[ \text{Vol}_{\%} := \frac{V_{\text{Total}}}{\text{Vol}_{\text{Battery\ Room}}} \]

\[ \text{Vol}_{\%} = 0.003891 \% \]
What does this mean?

Need to verify with standards and local jurisdiction

- API RP500, Section 6.3.2.1 (2nd Ed. Nov 1997)
  - (below 25% of LFL - Low Flammable Limit)

Or

- NEC 2005, Art 500, Table 5.1

Or

- Local jurisdiction requirements
In the example, the hydrogen concentration in the battery room for 8-hour period is much less than 25% of LFL allowable requirement for adequate ventilation requirement per API RP500.

- The NFPA 497, Table 2-1 lists Hydrogen LFL=4%.
- The API RP500 required 24% of LFL=4% calculates to 1%
- Calculated $H_2$ concentration the room is 0.00391%
- If flooded batteries were used, $H_2$ concentration would be 0.391%
MAGNETIC COMPONENTS
(used in UPS System)
Magnetic Components Overview

- Hysteresis Influence on Performance
- Transformer
- Isolation Transformer
- Ferroresonant Transformer / Constant Voltage Transformer
- Reactor / Multi-winding Reactor / Combinational Filter
Magnetic Component

Hysteresis Influence

- Hysteresis Influence on Performance

\[ L = \frac{\psi}{i} \]

\[ L = \frac{d\psi}{di} \]
Magnetic Components

Hysteresis Influence

- Hysteresis Influence on Performance
  - Magnetic Losses, Regulation and Inrush Current

\[ P_{Cu} = I^2 * R \]
\[ P_{Fe} = P_{eddy} + P_{hist} \]
\[ P_{Fe} = \pi * d^2 * (f * B_{max})^2 \]
\[ P_{hist} = 2 * f * B_{max} * H_c \]

\[ \gamma = \frac{U(\text{no-load}) - U(\text{full-load})}{U(\text{full-load})} * 100\% \]
\[ \gamma \approx \frac{P_{cu}}{P_{load}} * 100\% \]

\[ \text{Im} = \frac{H_0(l)}{0.4 * \pi * N} \]
Magnetic Components
Transformer

- Transformer

\[ n = \frac{N_s}{N_p} = 1 \]
Magnetic Components

Transformer - Construction

- Construction

(laminations)

Laminated iron core

Primary winding
(many turns)

Secondary winding
(few turns)
Isolation Transformer
Magnetic Components

**Transformer CVT & Ferroresonant**

- **Constant Voltage Transformer (CVT) / Ferroresonant Transformer**
  - **Advantages:**
    - Constant voltage output for variation in input voltage
    - Blocks harmonics from saturation in the CVT (tank circuit) and from input and output of the CVT
    - “Ride through” ability (prime reason to use in UPS systems)
  - **Disadvantages**
    - Low efficiency
    - Intolerant to frequency changes
Magnetic Components

Transformer CVT & Ferroresonant

- Constant Voltage Transformer (CVT) / Ferroresonant Transformer
Magnetic Components

Transformer CVT & Ferroresonant Transformer

- Constant Voltage Transformer (CVT) / Ferroresonant Transformer
Magnetic Components

Transformer CVT & Ferroresonant Transformer

- Constant Voltage Transformer (CVT) / Ferroresonant Transformer
Magnetic Components
Reactor & Filters

- Reactor, Multi-Winding Reactor, Combinational Filters
  - Increase input impedance
  - Provide di/dt smoothing component
  - Part of LC filters
  - Part of specialized filters with different in and parameters (Harmonic Mitigating Transformer)
UPS SYSTEM APPLICATION
UPS System Application

Overview

- System Components
- System Design and Integration Consideration
- Distribution and Protection Component Selection
- Additional Design Consideration:
  - Load Types
  - Static Switch Operation
UPS System Application

System Components

- System Components
  - UPS Package:
    Components discussed previously in the presentation
  - Primary network:
    Components connected to UPS System upstream of UPS as seen from load perspective
  - Secondary network:
    Components connected to UPS System downstream of UPS as seen from load perspective
System Design and Integration Consideration

- General
- Reliability
  - UPS System
  - Primary network
  - Secondary Network
  - Enhancement
- Special Considerations
  - Application Location (Onshore, Offshore, Overseas etc.)
  - Unusual requirements
- Voltage, Power and Energy Flow effects on system design
- Specification
UPS System Application

General

- General:
  - System design and space planning
  - Installation and environment
  - Maintenance and operation
UPS System Application

General

- General:
  - System design and space planning
    - UPS system primary purpose
    - Operating Hours
    - Type (see previous chapters)
    - Capacity (centralized, local)
    - Battery (see previous chapters)
    - Systems
    - Expansion provisions
    - Cost
UPS System Application

General

- **General:**
  - Installation and environment
    - Loading / Offloading conditions
    - Space (installation, operation and maintenance)
    - Installation practices
    - Environment (temperature, humidity, hazardous classification etc.)
    - System heat rejection vs. environmental conditions
    - System heat rejection vs. backup/battery operation
General:

- Maintenance and operation
  - Monitoring (on-line) (voltages, currents, temperature, battery etc.)
  - Preventive maintenance (off-line)
  - Operation Autonomy
  - System Settings
  - Connecting components checking
Reliability:
- UPS System
- Primary network
- Secondary Network
- Enhancement
Reliability:

- UPS System (from vendor)

Note:
MTBF, MTTR do not include batteries, interconnecting cables outside of enclosure and internal operating software
Reliability:

- Primary network
  - Reliability Indices:

\[
SAIFI = \frac{\text{Total number of customer interruptions}}{\text{Total number of customers served}}
\]

(about 2/year)

\[
SAIDI = \frac{\text{Sum of all customer interruption durations}}{\text{Total number of customers served}}
\]

(from 0.5 to 5 hrs/year)

\[
CAIDI = \frac{SAIFI}{SAIDI}
\]

\[
ASAI = \frac{\text{Customer hours service availability}}{\text{Customer hours service demanded}}
\]
UPS System Application

Reliability

- Reliability:
  - Primary network
    - Parameters Influencing Indices
      - Location
      - Routing
      - Environmental Exposure
      - Voltage
      - Supply configuration
    - Improving
      - Identifying reliability “driving” elements
      - Evaluation
Reliability:
  - Secondary Network
    - Indices not applicable
      - How fast can be repaired
      - Plant running or not
      - Etc.
    - Parameters Influencing Reliability
      - Location
      - Routing
      - Environmental, process, and other exposures
      - Voltage
      - Supply configuration
      - Maintenance
UPS System Application

Reliability

- Reliability:
  - Enhancement
    - How much reliability is needed (0.9999….)
    - System approach
    - Redundancy
      - Complete – primary, secondary and UPS system
      - Most fragile components
      - Enhanced monitoring
System Design and Integration Consideration

- Special Considerations
  - Application Location
    - Onshore (petrochemical, pipeline, control room etc.)
    - Offshore (process, NAV lights, COMMs, control etc.)
    - Overseas (process, control room, special etc.)
  - Unusual requirements
    - i.e. “bump-less transfer time” no voltage dip etc.
UPS System Application

System Design & Integration

- System Design and Integration Consideration
  - Voltage, Power and Energy Flow

- UPS Load Flow - Link
UPS System Application

System Design & Integration

- System Design and Integration Consideration
  - Specification List – (Minimum Requirement Level)
    - Location of equipment
    - Application and block diagram
    - Type Equipment
    - Primary and secondary network
    - Grounding
    - Input Power ratings and quality
    - Type of Load
    - Output power – rating and quality
    - Battery and battery charger (options)
    - Service condition
    - Monitoring requirements
    - Monitoring Interface
    - Installation requirements
    - Provision for future expansion (load sharing, sensing Inrush current capability)
    - Maximum input THD
    - Maximum load THD
    - Amps and PF from load
    - Overload capacity and for how long
    - Steady state voltage regulation
Not all UPS Systems are the Same!

- **UPS Systems**
  - Commercial Grade
    - Typical utilized in IT applications
  - Lack flexibility and robustness
    - Tend to utilize PWM
    - Static switches are rarely power transistors
      - Utilize contactors
  - Typically use sealed batteries
UPS System Application

Sizing Principles

● UPS System Sizing Principles
  – Size for expected loads plus margin for growth
  – Size batteries at full load for a minimum of 30 minutes
  – Size normal power source for load for load requirements + 25%
    ● DO NOT use the typical 125% of UPS KVA
  – Typically 1-phase below 50kVA and 3-phase above
UPS System Limitations

- Batteries will eventually discharge
- UPS is a complex system
  - Will not last forever
  - Requires periodic maintenance
  - Human error
UPS System Application

Distribution System

- Distribution Panels
  - What should I use? Breaker or a Fuse

**Breaker:**
- Can reset a breaker
- Breakers are current limiting

**Fuse:**
- Fuse has to be found
- Fuses are current limiting
  - Fuses may clear faster

SO……What should be used Breaker or a Fuse?

- Will be covered in mover detail later in the presentation
UPS System Application
Fuse Panel

- Fused Panel
UPS System Application

Fuse Panel
UPS System Application

Breaker Panel
One Company’s Instrument Power System

- UPS Power Panel
- Critical Power Panel
- 24 VDC Power Supply
- Dual Input DCS Power Supply
- 24 VDC
- Field Devices

UPS System Application
Another Company’s Instrument Power System

UPS System Application

Fed from UPS

Fed from Alternate Source

Custom UPS & Alternate Source Distribution Panel

24 VDC Power Supply *

24 VDC Power Supply *

24 VDC Distribution

To Field Devices

*One or more power supplies as needed.
Another Company’s Instrument Power System – Complete View

UPS System Application

480V Distribution Sources (segregated from main substation)

Input Circuit Breaker

Rectifier

Inverter

Static Switch

MBS

Output Circuit Breaker

Custom UPS & Alternate Source Distribution Panel

Battery Set

Alt Source Xfmr

Alt Source Input

To Field Devices

Typical Dual Input Power Supply

24 VDC Power Supply *

24 VDC Power Supply *

24 VDC Distribution

* One or more power supplies as needed.
REVIEW LOAD TYPES AND DESIGN APPLICATION CONSIDERATIONS
Review Load Types & Design Application Considerations

Overview

- Load Types in Secondary Distribution System (RC linear, RL non-liner with high THD, Regenerative)
- ITI (CBEMA) Curve
- Benchmarks For DCS, PLC and Critical Instrumentation
- Short-Circuit Output Magnitude and The Alternate Source
- Single-Phase or Three-Phase UPS Output Voltage
- Protecting The UPS Static Switch
- Molded Case Circuit Breakers Versus Fuses
- UPS System Loads
- Example / Application:
  - 120V UPS Distribution System Selectivity Example
  - 240V UPS / 480V Distribution System Selectivity Example
- Application Guideline Summary
Load Types in Secondary Distribution System

Load Types

- Load Types from UPS and static switch operation perspective
  - RL linear
  - RC linear
  - RL non-liner with high THD
  - Regenerative
Load Types in Secondary Distribution System

RL Linear Loads

- RL linear loads
  - Static power supplies
  - Distribution transformers
  - Long feeders with RL loads

- Inverter: operates in design operating range
- Static Switch: detection time and transfer time intervals increase due to the additional inductance
Load Types in Secondary Distribution System

RC Linear Loads

- RC linear loads
  - Any load connected to long cable (transmission line)

- Inverter: operates out of design operating range; need verification with vendor capabilities and stability

- Static Switch: detection time and transfer time intervals increase due to the additional “line” capacitance; in case capacitance is so large that influence system voltage, commutation could be unstable and/or long delay causing non-bump-less transfer
Load Types in Secondary Distribution System

RL Linear Loads

- RL non-linear loads with high THD
  - Switching power supplies (PC, PLC, DCS etc.)
  - Emergency lights

Assure THD is in operating spec of UPS

- Inverter: operates in design operating range
- Static Switch: detection time and transfer time intervals will increase/decrease due to the voltage distortion and sensing capabilities of UPS circuitry.
Regenerative loads:
- Regeneration is power produced by load that has high inertia or is driven by some other force mechanical or chemical load.

Assure vendor is aware about special requirement of this type of load. UPS components will be damaged.

- Inverter: not design for 2Q / 4Q operation
- Static Switch: detection time and transfer time intervals will increase due to the additional “line” capacitance; in case capacitance is so large that influence system voltage, commutation could be unstable and/or long delay causing non-bump-less transfer
What Is The ITI (CBEMA) Curve?
What Is The ITI Curve?

- Information Technology Industry (ITI) Council
- Provides Input Voltage vs. Time Restrictions
- Describes Steady-State And Transient Voltage Limits

ITI Curve

ITI (CBEMA) CURVE
(Revised 2000)
What Is The ITI Curve?

- New ITI Curve
  - Refined for modern electronic equipment
  - Curve applies to 120Vrms, 60Hz nominal equipment
  - Engineer is responsible for application at other voltages and frequencies
  - ITI curve describes seven types of events:
    - Not considered: Line Voltage Swell, Low-Frequency Decaying, Ringwave, High-Frequency Impulse, Voltage Sags
    - Dropout
    - No damage region
    - Prohibited region
● Dropout
  - A voltage includes both severe RMS voltage sags and complete interruptions of the applied voltage, followed by immediate re-application of the nominal voltage
  - This transient typically results from the occurrence and subsequent clearing of faults in the AC distribution system
  - THE INTERRUPTION MAY LAST UP TO 20 MILLISECONDS; FAULTS MUST BE SENSED AND INTERRUPTED QUICKLY
No Damage Region
- Events in this region include sags and dropouts (which are less than the lower limit of the steady state tolerance range)
- The normal functional state of the Information Technology Equipment (ITE) is not typically expected during these conditions (no damage to the ITE should result)
What Is The ITI Curve?

- **Prohibited Region**
  - This region includes any surge or swell (which exceeds the upper limit of the envelope)
  - If the ITE is subjected to such conditions, damage to the ITE may result
ITI Curve

Issues And Compliance

- **ITI Curve is the Benchmark**
  - Fast System Fault Interruption
  - Voltage Restoration

- **Concerns**
  - UPS Inverters Typically Supply Limited Fault Current
  - Depend On The Alternate Source To Provide Fault Current
  - Short-Circuit Sensing
  - Fast Fault Interruption

- **Compliance With the ITI Curve During Fault Conditions**
  - Requires Fast Transfer to the Static Switch
  - Requires Fast Interrupting Protective Devices
  - *Maintains Operation of Critical Computer Business Equipment During Normal and Abnormal System Conditions*
Equipment Benchmarks
Industry Recognized Voltage Dropout/Restoration Data
- Equipment sample for operating facility
- Data may not represent your facility
- Determine if process equipment will operate without interruption

Table Shows Typical UPS Loads
- Some of the data is minimum hold-up time with zero volts
- Others show the minimum threshold voltage at which they shutdown
Sample From Typical Petrochemical Facility

<table>
<thead>
<tr>
<th>Reference Number</th>
<th>Equipment Description</th>
<th>Minimum “Hold-Up” Time</th>
<th>Minimum Threshold Voltage</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>DCS Mfg. #1</td>
<td>17 ms</td>
<td>0 Vrms</td>
</tr>
<tr>
<td>2</td>
<td>DCS Mfg. #1</td>
<td>20 ms</td>
<td>0 Vrms</td>
</tr>
<tr>
<td>3</td>
<td>DCS Mfg. #1</td>
<td>40 ms</td>
<td>0 Vrms</td>
</tr>
<tr>
<td>4</td>
<td>DCS Mfg. #1</td>
<td>25 ms</td>
<td>0 Vrms</td>
</tr>
<tr>
<td>5</td>
<td>DCS Mfg. #2</td>
<td>40 ms</td>
<td>0 Vrms</td>
</tr>
<tr>
<td>6</td>
<td>DCS Mfg. #2</td>
<td>40 ms</td>
<td>0 Vrms</td>
</tr>
<tr>
<td>7</td>
<td>DCS Mfg. #3</td>
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<td>0 Vrms</td>
</tr>
<tr>
<td>8</td>
<td>DCS Mfg. #3</td>
<td>20 ms</td>
<td>0 Vrms</td>
</tr>
<tr>
<td>9</td>
<td>PLC Mfg. #1</td>
<td>20 ms</td>
<td>0 Vrms</td>
</tr>
<tr>
<td>10</td>
<td>PLC Mfg. #1</td>
<td>5 ms</td>
<td>0 Vrms</td>
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<tr>
<td>11</td>
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<td>20 ms</td>
<td>0 Vrms</td>
</tr>
<tr>
<td>12</td>
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<tr>
<td>13</td>
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<td>97 Vrms</td>
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<td>14</td>
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<td>0 Vrms</td>
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<td>18</td>
<td>Other Mfg. #2</td>
<td>0 ms</td>
<td>88 Vrms</td>
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<td>19</td>
<td>Other Mfg. #3</td>
<td>0 ms</td>
<td>95 Vrms</td>
</tr>
<tr>
<td>20</td>
<td>Other Mfg. #4</td>
<td>0 ms *</td>
<td>102 Vrms</td>
</tr>
<tr>
<td>21</td>
<td>Other Mfg. #5</td>
<td>0 ms *</td>
<td>95 Vrms</td>
</tr>
<tr>
<td>22</td>
<td>Other Mfg. #6</td>
<td>0 ms *</td>
<td>95 Vrms</td>
</tr>
<tr>
<td>23</td>
<td>Relay #1</td>
<td>30 ms</td>
<td>0 Vrms</td>
</tr>
<tr>
<td>24</td>
<td>Relay #2</td>
<td>10 ms</td>
<td>0 Vrms</td>
</tr>
</tbody>
</table>

* 0 ms below threshold without battery backup

Industry Data

Equipment Benchmarks

ITI (CBEMA) CURVE (Revised 2000)

- Static switch transition signal occurred at time 0 ms
- The worst scenario, 1/2 cycle UPS transfer time
- Ideal UPS to by-pass power voltage switching curve
- Equipment #13, 17, 18, 19, 20, 21, 22
- Equipment #1, 10, 14, 24

Percent of Nominal Voltage (RMS or Peak Equivalent)

Duration in Cycles (c) and Seconds (s)
Regulated and non-regulated dc voltages for a personal computer, during voltage sag

Equipment Benchmarks

General Data

- Voltage tolerance curves for personal computers – USA market/tests

Equipment Benchmarks

General Data

- Voltage tolerance curves for personal computers – Japanese market/tests

General Data

Equipment Benchmarks

- Voltage tolerance curves for PLCs

- Voltage tolerance curves for various process control equipment
  1 – common process controller
  2 – more complicated process controller
  3 – PLC
  4 – PLC newer version of 3
  5 – AC control relay
  6 – AC control relay for more important applications
    (same mfg as 5)
  7 – AC contactor

General Data

- Voltage tolerance curves for high-pressure sodium lamps

Equipment Benchmarks

General Data

- Ride-through duration for an interruption of power supply

General purpose relays

- 90° point of wave
- 0° point of wave

Motor starters

Contactors

Duration in 60-Hz cycles

Equipment Benchmarks

General Data

- Voltage magnitude for dropout for a 5-cycle voltage sag

Short-Circuit Output Magnitude And The Alternate Source
What Is UPS Inverter Short-Circuit Current Magnitude?

- Pulse Width Modulated (PWM)
  - Typically 1.5 times the full load current for 1/4 cycle
- Ferroresonant
  - Can supply a maximum of 5 times full load amps for 1/4 cycle
    (Energy Stored In The Output Filter)
- Both Technologies Are Very Limited In Supporting Short-Circuit Conditions
Short-Circuit Output Magnitude And The Alternate Source

How Are The UPS Distribution System Faults Interrupted?

- **UPS Inverter**
  - UPS short-circuit current insufficient for downstream protective device sensing and interruption
  - UPS senses the sudden rapid voltage reduction and within 1/2 cycle transfers to alternate source

- **Alternate Source**
  - Alternate source has significantly greater short-circuit capability
  - Increased fault current is usually adequate for protective devices to interrupt the fault
Short-Circuit Output Magnitude And The Alternate Source

Issues

- **Static Switch Alternate Source Issues**
  - Closure into a short-circuit is a severe condition
  - Must be adequately rated
  - Must be protected for this severe condition
  - Assumes the alternate source is available

- **UPS Specifications Should Include:**
  - Short-circuit available from the alternate source
    (UPS manufacturer can supply equipment adequate for the fault conditions)
Dilemma & Solution

- **Dilemma**
  - Making the transfer and interrupting the short-circuit current within the following:
    - Voltage/time limits of the ITI curve for ITE
    - “Hold-up” time of DCS, PLC, and critical equipment

- **Solution**
  - Quick transfer (within 1/8 to 1/3 cycle)
    - Only part of the sequence
    - Fast interrupting devices are required
Single-Phase
Or
Three Phase
UPS Output Voltage?
Inverter Output Selection
- Most plant critical loads are single-phase
- Single-phase UPS provides more fault current than a three-phase UPS
- Relatively large kVA rated UPS systems are readily available in single-phase output configuration

30kVA Example
- 120V single-phase UPS vs. 208Y/120V three-phase UPS
- Single-phase UPS fault current is 3 times the 3-phase UPS line-to-ground fault current
Protecting The UPS Static Switch
Why Does The UPS Static Switch Requires Protection?

- Why Is An Internal Fuse Or Circuit Breaker Used To Protect The Static Switch?
  - For 1 to 5 cycles, a typical static transfer switch has a short-circuit rating of 10 times the full load switch rating
  - The alternate source short-circuit could exceed the static switch withstand capability
  - Hence, an internal solid-state fuse or circuit breaker typically protect the static transfer switch
Protecting The UPS Static Switch

Static Switch Protection

- **Static Switch With No Protection**
  - UPS manufacturer should be asked to confirm the validity of the design during *USER DEFINED* high magnitude short-circuit current conditions

- **UPS Integral Protective Devices**
  - To plot UPS internal protective devices on TCC’s
    - The purchase order specification requires:
      - Short-circuit withstand data
      - Coordination curve data
Protecting The UPS Static Switch

Static Switch Operation

- Static Switch Operation
  - Switching is performed for one or more conditions:
    - Overcurrent > 150% of nominal current*
    - Undervoltage < 80% of nominal voltage*
    - Overvoltage > 110% of nominal voltage*
    - Inverter Fault*

* - Manufacturer may not provide function and/or value of threshold could change
Molded Case Circuit Breakers vs. Fuses
Electrical System Design

Molded Case Circuit-Breakers vs. Fuses

Electric System Design

- Electrical Design Practices
  - MCCB’s are typically used in indoor panelboards for plant switchgear rooms and offices
  - Industry practice uses circuit breakers in UPS distribution systems

- UPS Manufacturers
  - Recommend downstream fast-acting, current-limiting fuses with 1/2 cycle clearing time
Molded Case Circuit-Breakers vs. Fuses

Breaker Fundamentals

- Molded Case Circuit Breaker (MCCB) Interrupting Time
  - 1.1 cycles for 100A frame
  - 1.5 cycles for 225A-4000A frame
- 100A MCCB interrupting time
  - 1.1 cycles breaker interruption
  - 0.25 cycles static switch transfer time
  - 1.35 cycles total time
  - Marginally exceeds the ITI guidelines for maintaining power to critical instrumentation
  - This may result in a plant shutdown
Molded Case Circuit-Breakers vs. Fuses

Fuse Selectivity

TYPICAL SELECTIVITY SCHEDULE FOR LOW VOLTAGE FUSES
Exact ratios vary with ampere ratings, system voltage, and short-circuit current.

<table>
<thead>
<tr>
<th>Line side</th>
<th>Load side</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Class L Fuse 601-6000 A</td>
</tr>
<tr>
<td>Class L Fuse 601-6000 A</td>
<td>2:1</td>
</tr>
<tr>
<td>Class K1 Fuse 0-600 A</td>
<td>2:1</td>
</tr>
<tr>
<td>Class J Fuse 0-600 A</td>
<td>3:1</td>
</tr>
<tr>
<td>Class K5 Time-Delay Current Limiting Fuse 0-600 A</td>
<td>1.5:1</td>
</tr>
<tr>
<td>Class J Time-Delay Fuse 0-600 A</td>
<td>1.5:1</td>
</tr>
</tbody>
</table>

NOTE – For illustration only; from [9]. Refer to fuse manufacturer for specific and up-to-date data.
Equipment Benchmarks

General Data

- Sensitivity of PLCs processors and I/O

Molded Case Circuit-Breakers vs. Fuses

Breaker Fundamentals

- Authors Opinion
  - Based on the collected data
  - Modern MCCB’s operate faster than clearing times below and may provide fault clearing in less than 1.0 cycle vs.
    - 1.1 cycles for 100A frame
    - 1.5 cycles for 225A-4000A frame
UPS System Loads
Design Consideration

During the Project UPS Design Phase
- Sized for the anticipated loads
- Plus a nominal margin for future additions
- Try not to procure before all UPS loads are identified and kW requirements are known
Very Important To Evaluate All UPS Loads

- Segregate UPS loads from general purpose loads
- Compressor control panels should be thoroughly reviewed
- Compressor panels may include lighting, instrumentation, PLC, and space heater
- Lighting and space heater should be powered from a general purpose AC panel, **NOT UPS SYSTEM**
- Confirm control room “creature comfort” loads (under desk space heaters, coffee pots, microwaves etc.) are not connected to UPS power outlets or feeder circuits
- Educate operation and maintenance personnel
Future Load Additions

- To Avoid Overloading The UPS
  - Review both existing and new UPS loads
  - Review panel loading
  - Review UPS loading
  - All personnel should know the impact of adding loads to UPS
POWER SYSTEM ANALYSIS APPLICABLE TO UPS SYSTEMS DESIGN
Analysis for typical application of UPS systems:

- Load flow (AC/DC/AC and AC/AC), system regulation, power flow and power requirements
- Short circuit (primary and secondary system - LG, LL, LLG, 3PH, DC system) VERIFY VOLTGAES DURING FAULTS IN THE SYSTEM
- Vendor proposed system review (internal fuses, circuit breakers etc.)
- Coordination study (fuse/breaker selection)
- Battery capacity
- Battery hydrogen evolution (if applicable)
- Arc Flash
Additional analysis for special application of UPS systems:

- Harmonic flow (inverter and loads, charger/rectifier and primary network)
- Passive/Active Filters application
- Switching
- System modeling
- Reliability modeling
- EMF/RF modeling
Tools

- No special tools are required for most of the typical applications
Helpful tools for applications

- Standard Software (1PH, 3PH, LF-AC/DC, SC-AC/DC, Harmonic Flow, Filters, battery charge/discharge, arc-flash, reliability)
  - SKM
  - ETAP
- Hand calcs (LF-AC/DC, SC-AC/DC, Filters, battery charge/discharge, arc-flash)
  - Excel
  - MathCad
- Special Software (Harmonic Flow, passive/active filters, switching, control strategy, reliability)
  - MathCad
  - SPICE
  - Matlab
  - EMTP type
Examples:

- SC calculations for 120VAC secondary system
- SC calculations for 480VAC secondary system
Examples
Examples

• 120V UPS Distribution System Selectivity Example:
  • Phase 1
  • Phase 2
  • Phase 2A

• 240V UPS / 480V Distribution System Selectivity Example
Fig. 2. Example 120VAC UPS Distribution System

NOTE:
1) Fault locations are abbreviated, such as, FPH1A_. The following defines the parts of this brief descriptor.
"F" Fault.
"PH1" Phase 1.
"A" Fault location on the one line diagram.
"_" Fault source.
"P" PWM.
"F" Ferroresonant.
"ALT" Alternate Source.
2) Refer to Appendices for TCC's.
All Loads in the Control Room

PHASE 1

NOTE: BP1 AND L1 ARE IN ADJACENT MCC CUBICLES. OTHERWISE, PANEL L1 REQUIRES AN INCOMING MAIN BREAKER

120VAC PANEL L1

120VAC PANEL R1

120VAC PANEL R1

LOAD

UPS
30KVA
120V
1-PHASE

480 V MCC
NORMAL

480 V MCC
ALTERNATE

125A

30KVA
480-120V
1-PHASE

350A

PANELBOARD BP1

100A 100A 100A

2-1/C #2
100FT

FPH1A_
50A
15A

2-1/C #14
25FT

FPH1B_
50A
15A

FPH1C_
Loads Located Greater than 1000 feet

- UPS 30KVA 120V 1-PHASE
- 480 V MCC NORMAL
- 480 V MCC ALTERNATE
- 30KVA 480-120V 1-PHASE
- 350A
- 125A
- 100A 100A 100A
- 350A
- 15A
- 20A
- 100A
- T1
- 10KVA 120-480V
- 2-1/C #1/0 1000FT
- 100A
- 10A
- 100A
- 120VAC PANEL R2
- FPH1C
- INSTR. SKID
- 2 x 2-1/C #500KCMIL 1000FT
- T2
- 10KVA 480-120V
- 2-1/C #6 150FT
- 100A
- 15A
- 20A
- 10A
- FPH2A
- T1
- 100A
- 120VAC PANEL AR2
- INSTR. SKID
- 2-1/C #6 150FT
- 10A
- FPH2A
120V UPS Distribution System
Selectivity Example – Phase 1

<table>
<thead>
<tr>
<th>Fault Location</th>
<th>PWM Isc</th>
<th>&quot;Ferro&quot; Isc</th>
<th>Alt. Source Isc</th>
</tr>
</thead>
<tbody>
<tr>
<td>FPH1A_</td>
<td>375A</td>
<td>1250A</td>
<td>11549A</td>
</tr>
<tr>
<td>FPH1B_</td>
<td>360A</td>
<td>1047A</td>
<td>2493A</td>
</tr>
<tr>
<td>FPH1C_</td>
<td>310A</td>
<td>535A</td>
<td>601A</td>
</tr>
</tbody>
</table>

**Diagram:**
- Panelboard BP1
- 120VAC Panel L1
- 2-1/C #2 100FT
- 2-1/C #14 25FT
- Panel L1 50A
- FPH1A_
- FPH1B_
- FPH1C_
- Load

**Current in Ampères**
- Time in Seconds
- Current Scale x10^1

**Reference:**
- Ref. Voltage: 120
120V UPS Distribution System
Selectivity Example – Phase 1

<table>
<thead>
<tr>
<th>Fault Location</th>
<th>PWM</th>
<th>&quot;Ferro&quot;</th>
<th>Alt. Source</th>
</tr>
</thead>
<tbody>
<tr>
<td>FPH1A_</td>
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<td>1047A</td>
<td>2493A</td>
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<tr>
<td>FPH1C_</td>
<td>310A</td>
<td>535A</td>
<td>601A</td>
</tr>
</tbody>
</table>

**120V UPS Distribution System 120V UPS Distribution System**

**Selectivity Example**

**Phase 1**

**Diagram:**
- **Panelboard BP1**
- **100A**
- **15A**
- **20A**
- **50A**
- **15A**
- **120VAC PANEL L1**
- **120VAC PANEL R1**
- **FPH1A_**
- **FPH1B_**
- **FPH1C_**
- **LOAD**
- **2-1/C #14 25FT**
- **2-1/C #2 100FT**
120V UPS Distribution System
Selectivity Example – Phase 1

Fault | PWM | “Ferro” | Alt. Source
--- | --- | --- | ---
FPH1A | 375A | 1250A | 11549A
FPH1B | 360A | 1047A | 2493A
FPH1C | 310A | 535A | 601A
120V UPS Distribution System
Selectivity Example – Phase 2

<table>
<thead>
<tr>
<th>Fault Location</th>
<th>Isc</th>
<th>“Ferro” Isc</th>
<th>Alt. Source Isc</th>
</tr>
</thead>
<tbody>
<tr>
<td>FPH2A</td>
<td>325A</td>
<td>817A</td>
<td>1812A</td>
</tr>
<tr>
<td>FPH2B</td>
<td>282A</td>
<td>500A</td>
<td>615A</td>
</tr>
</tbody>
</table>

**Diagram Details:**
- **Current in Amperes:**
  - **TIME IN SECONDS**
  - **CURRENT IN AMPERES**
- **Fault Location:**
  - SSW_350A_Bkr
  - BP1_100A_FDRR
  - R2_15A_FDR
  - R2_100A_MAIN
  - MCC_125A_FDR
- **Wire Details:**
  - 2 x 2-1/C #500KCMIL 1000FT
  - 100A
  - 10A FPH2B_
  - 120VAC PANEL R2
  - INSTR. SKID
  - 2-1/C #6 150FT
  - 100A FPH2A_
  - 10A
120V UPS Distribution System
Selectivity Example – Phase 2

<table>
<thead>
<tr>
<th>Fault Location</th>
<th>PWM Isc</th>
<th>“Ferro” Isc</th>
<th>Alt. Source Isc</th>
</tr>
</thead>
<tbody>
<tr>
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<tr>
<td>FPH2B</td>
<td>282A</td>
<td>500A</td>
<td>615A</td>
</tr>
</tbody>
</table>

**Diagram:**
- PANELBOARD BP1
- 100A
- 2 x 2-1/C #500KCmil 1000FT
- 100A FPH2A 15A
- 20A
- 10A FPH2B
- 120VAC PANEL R2
- INSTR. SKID

**Graph:**
- Current in Amperes
- Time in Seconds
- Ref. Voltage: 120 Current Scale x10^4
120V UPS Distribution System
Selectivity Example – Phase 2A

<table>
<thead>
<tr>
<th>Fault Location</th>
<th>PWM Isc</th>
<th>“Ferro” Isc</th>
<th>Alt. Source Isc</th>
</tr>
</thead>
<tbody>
<tr>
<td>FPH2A1_</td>
<td>86A</td>
<td>243A</td>
<td>765A</td>
</tr>
<tr>
<td>FPH2A2_</td>
<td>58A</td>
<td>88A</td>
<td>103A</td>
</tr>
<tr>
<td>FPH2A3_</td>
<td>219A</td>
<td>327A</td>
<td>382A</td>
</tr>
<tr>
<td>FPH2A4_</td>
<td>186A</td>
<td>244A</td>
<td>265A</td>
</tr>
</tbody>
</table>

Current in Amperes

Time in Seconds

Ph2A_MCCB.tcc Ref. Voltage: 120 Current Scale x10^4
**120V UPS Distribution System**

**Selectivity Example – Phase 2A**

<table>
<thead>
<tr>
<th>Fault Location</th>
<th>Isc</th>
<th>“Ferro” Isc</th>
<th>Alt. Source Isc</th>
</tr>
</thead>
<tbody>
<tr>
<td>FPH2A1_</td>
<td>86A</td>
<td>243A</td>
<td>765A</td>
</tr>
<tr>
<td>FPH2A2_</td>
<td>58A</td>
<td>89A</td>
<td>103A</td>
</tr>
<tr>
<td>FPH2A3_</td>
<td>219A</td>
<td>327A</td>
<td>382A</td>
</tr>
<tr>
<td>FPH2A4_</td>
<td>186A</td>
<td>244A</td>
<td>265A</td>
</tr>
</tbody>
</table>

**Diagram Description**

Current in Amperes

Time in Seconds

Panelboard BP1

100A Terminal

10kVA Transformer
120-480V

2-1/C #1/0 Terminal 1000FT

2-1/C #6 Terminal 150FT

FPH2A1

FPH2A2

FPH2A3

FPH2A4

120VAC Panel AR2

Instr. SKID
Fig. 3. Example 240VAC UPS/480V Distribution System Oneline Diagram With Traditional Circuit Breaker Protection

NOTES:
1) Fault locations are abbreviated, such as, FPH1A_. The following defines the parts of this brief descriptor.
   "F" Fault.
   "1,2,3,4" Fault location on the one line diagram.
   "_" Fault source.

2) Refer to Appendices for TCC's.
240V/480V UPS Distribution System
240V UPS / 480V Distribution
System Selectivity Example

<table>
<thead>
<tr>
<th>Fault Location</th>
<th>PWM Isc</th>
<th>“Ferro” Isc</th>
<th>Alt. Source Isc</th>
</tr>
</thead>
<tbody>
<tr>
<td>F1_</td>
<td>148A</td>
<td>437A</td>
<td>1259A</td>
</tr>
<tr>
<td>F2_</td>
<td>144A</td>
<td>384A</td>
<td>675A</td>
</tr>
<tr>
<td>F3_</td>
<td>508A</td>
<td>1123A</td>
<td>1725A</td>
</tr>
<tr>
<td>F4_</td>
<td>416A</td>
<td>622A</td>
<td>682A</td>
</tr>
</tbody>
</table>

[Graph showing current in amperes and time in seconds]

480V_FUSED.tcc Ref. Voltage: 480 Current Scale x10^0
Application Guideline
Summary
Points Covered

- Application Guideline
  - Intended as a starting point
  - Include additional information
    - Fundamentals
    - Changes
    - Lessons learned
    - Exceptions
Application Guideline Summary

UPS Distribution System General Protection

Application Guideline Summary

1. To avoid overloading UPS systems, review UPS loads
2. Segregate panel loads with critical process loads on UPS
3. Perform short-circuit duty check with Alt. Source supply
4. ITI curve is the benchmark for computer business equipment
5. Review critical loads voltage limits with system conditions
6. Review UPS static switch timing/triggering parameters
7. When applicable, specify 1-phase UPS systems
   Redundant power supply applications may require 3-phase UPS
8. Transfer to the Alt. Source may not be required with “ferro” inverters, because generally have a greater initial (1/4-1 cycle) fault current.


10. Adequate fault current may minimize Static Sw. Alt. Source transfer.

11. Confirm UPS internal fuse/circuit breaker configuration. Confirm the Alt. Source fault does not exceed the UPS interrupt rating.

12. With UPS internal, single-element CL fuses, include in the project spec factory fault testing with upstream and downstream dual-element fuses.

13. Fuse sizes should be minimized, i.e., less than typical 15A fuses.
14. For selectivity, use fuse selectivity ratio tables from the same manufacturer since fuse selectivity tables are obtained by test.

15. Specify a 480V MCC fused switch for the feeder cable powering the Alternate Source isolation transformer.

16. To assure adequate fault clearing current to remote skid panels, increased cable sizes may be required.

17. To increase Alt. Source short-circuit current, the Alt. Source isolation transformer kVA rating may be increased.

18. Use shielded, isolation type Alternate Source transformer. Only use ferroresonant transformers after thorough investigation.

19. For enhanced system reliability, the Alternate Source should be powered from a separate upstream source (not the same MCC).
SYSTEM ACCEPTANCE
● **System acceptance**
  - Factory Acceptance Testing (FAT)
  - Commissioning
  - Performance verification
  - Maintenance
There is no standard for specification of UPS system and testing in ANSI world

Testing and acceptance parameters:
- Client specification
- Vendor internal QA plan
- Fusion of multitude different specifications
Useful specification:

- UL 1778 - Standard for Uninterruptible Power Supply Equipment
- CSA C22/2 NO.17.1 - Commercial and Industrial Power Supplies
- NEMA PE-1 - Uninterruptible Power Systems Standard
- NEMA PE-5 – Utility Type Battery Chargers
- IEC 62040 Uninterruptible Power Systems (UPS)
  - Part 1: General and safety requirements
  - Part 2: Electromagnetic Compatibility (EMC) Requirements
  - Part 3: Method of Specifying the Performance and Test Requirements
- ANSI C62.41, Category A & B - Recommended practice on surge voltages in low voltage power circuits
- FCC Rules and Regulations 47, Part 15, Class A - Certified compliance
- IEEE Std. 650 – Standard for qualification of class 1E static battery
Factory Acceptance Testing (FAT)
- Industry testing
- Vendor internal QC procedures
- Client specification
Factory Acceptance Testing (FAT) – Minimum Recommended

- “Ring-out” connection test (verification of proper operation)
- Dielectric withstand test
- Auxiliary device test
- Alarms test (hardwired and networked)
- No-Load test
- Auto-transfer switch operation and synchronization test
- By-pass Transfer switch and synchronization test
- 25%, 50%, 75%, 100% Load test (AC input power operation) and operating temperature
- Efficiency test
- Overload capability test
- 100% Load test (DC battery operation)
- Current division test for redundant configurations
- Battery test
- Battery discharge test (stored energy time)
- Battery charge test (energy restore time)
- Frequency stability test
- Operation test: (AC input power loss test, AC input power return test, Redundancy test (if applicable for N+1 applications), Transfer test)
- Output voltage unbalance
- Unbalance load test (3-ph units)
- Harmonic component
- Audible noise (0%, 25%, 50%, 75%, 100% loading)
- System autonomy operation test
- Short circuit capability test

NOTE: ALL VALUES TO BE RECORDED, AUDITED BY 3RD PARTY INSPECTOR AND PROVIDED TO END-USER AS RECORD AND COMPARISON AT THE SITE INSTALLATION.
Commissioning:

- Assure that FAT testing was performed
- NETA specification as a guide
- Specific application additional requirements i.e. special voltage tolerance for dynamic loading, leading power factor, very low power factor etc.
- Compare specific values from FAT and site installation i.e. bolted resistance, battery resistance, insulation resistance etc.
- Battery charge and discharge test after installation at site
- VERYFY AND RECORD ALL SETTING PARAMETERS for hardware and software
- Separately commission all distribution primary and secondary system per NETA guidelines
Performance Verification

- **Performance verification**
  - Periodic testing
    - Battery test
    - Autonomy of operation
    - Operation test: (AC input power loss test, AC input power return test, Redundancy test (if applicable for N+1 applications), Transfer test)
  - Grounding operation
    - DC ground detection
    - AC ground detection
  - Thermographic scan
  - On-line monitoring:
    - Battery status
    - UPS controller status
Maintenance

- Every month:
  - Check and record meter readings.
  - Check indicating lights.

- Every year:
  - Perform Manufacturer’s recommended service.

- Every T/A:
  - Function Check operation by simulating loss of normal source and loss of inverter source.

- At 5/10yr intervals:
  - Perform manufacturer’s recommended component change out.
Industry Needs

- There is a need to revise / update existing UPS system standards (IEEE Std. 944-1986, IEEE Std. 446-1995 etc.) or create a new standard for the industry.
  - Standard needs current information in the following:
    - Construction, system architecture, topology etc.
    - Principle of operation and conversion
    - Sizing, redundancy, energy storage
    - Static and transient performance
    - Protection and selectivity
    - Acceptance testing, commissioning, and maintenance
- "Lessons Learned"
  - Industry needs to provide feedback to evaluate and apply solutions with the application of UPS systems for critical process loads
Application Comments

- Ferroresonant UPS Systems Have Additional Limitations:
  - Some UPS systems with output ferroresonant transformers could overheat during very light load or unloaded condition
  - Overloaded ferroresonance transformer tend to collapse output voltage

- Static Transfer Switch Timing Performance
  - Dependence on:
    - Impedance (cables, installation, transformers etc.) between voltage sources and switch inputs. Also, impedance of the distribution system connected to the switch output
    - Voltage detection logic (detection time)
  - Changes with:
    - Type of loads connected (RL, RC, RLC, regenerative)
    - Type of fault (L-G, L-L etc.) and angle when fault occurred
Resources & References
IEEE 485 – Recommended Practice for Sizing Lead-Acid Batteries for Stationary Applications
IEEE 1115 – Recommended Practice for Sizing Nickel- Cadmium Batteries for Stationary Applications
IEEE 1184 – Guide for the Selection and Sizing of Batteries for Uninterruptible Power Supplies
IEEE 1106 – Recommended Practice for Installation, Maintenance, Testing, and Replacement of Vented Ni-Cad Batteries for stationary Applications
NEMA PE-1 – Uninterruptible Power Systems
IEEE 450 – Recommended Practice for Maintenance, Testing and Replacement of Large Lead Storage Batteries…
IEEE 1188 – Recommended Practice for Maintenance, Testing, and Replacement of VRLA Batteries… (Sealed Type)
Battery Manufacturer Literature
- T.A. Short, “Distribution Reliability and power Quality”, 2006
Thank you

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Abstract - Typical petroleum and chemical industry UPS (uninterruptible power supply) distribution systems [1] are reviewed for interrupting device selectivity during short-circuit conditions. When selectivity is not achieved, alternative solutions are proposed. Distribution system selectivity comparisons are performed for standard circuit breaker panelboards, fuse panelboards and custom panelboards utilizing hydraulic-magnetic circuit breakers. When remote panels are implemented, application considerations include oversizing feeder cables or using step-up/step-down transformers. To determine the “ride through” response of individual operating plant UPS loads, the voltage depression time during UPS distribution system fault clearing is compared with the load “ride through” capability. General guidelines are provided for improved UPS distribution system performance.

Index Terms – Selectivity, UPS, ITI curve, Information Technology Equipment (ITE), Alternate Source, "hold-up" time, distributed control system (DCS), programmable logic controller (PLC), motor control center (MCC), molded case circuit breaker (MCCB), time-current curve (TCC), low-voltage (LV), Safety Interlock System (SIS), pulse width modulated (PWM), and true, online, double-conversion UPS.

Key Terms - In this paper, the term selectivity describes the performance of cascaded circuit breakers and fuses. Selectivity is achieved when the breaker or fuse nearest the fault isolates the fault, and no other device interruption occurs.

I. INTRODUCTION

Historically, UPS distribution systems have been copied from one project to the next. Within this industry, the practice or paradigm has been "This is the way we've always done it". Typically, time-current curves have not been produced to determine if the UPS distribution system is selective, or if a downstream 120 V panelboard feeder fault may trip the upstream main breaker. It has not been industry practice to review the time-current relationship of 120 V UPS systems, including the Alternate Source power supply at the 480 V MCC. This is somewhat ironic because the UPS system powers critical process loads, such as, DCS, PLC, critical process alarms, safety interlock and/or shutdown systems, advanced process control computers, custody transfer flowmeters, process stream analyzers, gas detection systems, fire protection systems, critical telephone circuits, emergency lighting, etc.

When time-current curves are produced, the importance of quickly restoring voltage to non-faulted critical equipment may not be paramount, and the restoration benchmarks, the ITI curve [2] for computer business equipment and manufacturer specific data for DCS, PLC, and critical instrumentation, may not be reviewed. Also, UPS internal current-limiting fuses or circuit breakers may be unintentionally omitted from the time-current curve plots or considerations.

The following discussions highlight some UPS distribution concerns needed to improve critical system performance during short-circuit transient conditions. Two typical system configurations provide the basis for the salient points described in the paper discussions.

This paper considers true, online, double-conversion UPS systems [1]. Standby Power Systems and offline UPS systems are beyond the scope of this paper. Redundant UPS inverter output configurations with two inverters are not considered in this paper.

The time-current curves short-circuit fault currents are based on bolted faults for maximum fault current flow. Arcing and non-bolted faults are not considered for the discussions of this paper. Impedances for some relatively short length cables are not considered.

II. ITI (CBEMA) CURVE

The Computer and Business Equipment Manufacturers Association (CBEMA) is now known as Information Technology Industry Council. Previously, CBEMA provided an input voltage versus time curve describing steady-state and transient voltage limits for continued operation of electronic equipment [2].

The new ITI curve (Fig. 1) is refined for modern electronic equipment performance. The curve applies to 120 Vrms, 60 Hz nominal equipment. When other nominal voltages and frequencies are used, it is the application engineer's responsibility to apply the ITI curve.

Although the ITI curve describes seven types of events, only Dropout, No Damage Region, and Prohibited Region are discussed. The following are per ITI definition:

1) Dropout - A voltage includes both severe RMS voltage sags and complete interruptions of the applied voltage, followed by immediate re-application of the nominal voltage. The interruption may last up to 20 ms. This transient typically results from the
occurrence and subsequent clearing of faults in the AC distribution system.

2) No Damage Region - Events in this region include sags and dropouts which are more severe than those specified in the preceding paragraphs, and continuously applied voltages, which are less than the lower limit of the steady-state tolerance range. The normal functional state of the ITE is not typically expected during these conditions, but no damage to the ITE should result.

3) Prohibited Region - This region includes any surge or swell, which exceeds the upper limit of the envelope. If ITE is subjected to such conditions, damage to the ITE may result.

According to ITI, dropout includes both severe RMS voltage depressions and complete voltage interruption followed by immediate voltage re-application. Per Fig. 1 the maximum voltage interruption time is 20 ms; this means faults must be sensed and interrupted very quickly. However, UPS inverters typically supply limited fault current, and depend on the Alternate Source to provide sufficient fault current for short-circuit sensing and fast fault interruption. Therefore, the ITI curve is the benchmark for fast system fault interruption and voltage restoration of computer business equipment.

Compliance with the ITI curve guideline maintains operation of critical computer business equipment during normal and abnormal system conditions. Compliance with the ITI curve during fault conditions is dependent on fast transfer to the Static Switch and fast interrupting protective devices.

### III. BENCHMARKS for DCS, PLC, and CRITICAL INSTRUMENTATION

The authors are not familiar with industry recognized voltage dropout versus voltage restoration tabulations; hence, data was obtained from an actual operating facility. Table I shows typical critical process control and protection equipment powered by a UPS and indicates minimum “hold-up” time with 0 volts. Table I data is used to determine if fast fault clearing could result in process equipment operating without interruption during UPS distribution system short-circuit conditions. Seven devices had 0 ms “hold-up” time and 95 to 102 Vrms minimum threshold voltage (79% to 85% of rated voltage); however, the “hold-up” time of these devices was significantly increased by procuring the devices with an optional battery backup. Table I is compiled from a very small equipment sample, and this data may not represent the specific equipment characteristics in other operating facilities. Application engineers should obtain data from specific facilities for comparison with the findings of this paper.

<table>
<thead>
<tr>
<th>Equipment Description</th>
<th>Minimum &quot;Hold-Up&quot; Time</th>
<th>Minimum Threshold Voltage</th>
</tr>
</thead>
<tbody>
<tr>
<td>DCS Mfg. #1</td>
<td>17 ms</td>
<td>0 Vrms</td>
</tr>
<tr>
<td>DCS Mfg. #1</td>
<td>20 ms</td>
<td>0 Vrms</td>
</tr>
<tr>
<td>DCS Mfg. #1</td>
<td>40 ms</td>
<td>0 Vrms</td>
</tr>
<tr>
<td>DCS Mfg. #1</td>
<td>25 ms</td>
<td>0 Vrms</td>
</tr>
<tr>
<td>DCS Mfg. #2</td>
<td>40 ms</td>
<td>0 Vrms</td>
</tr>
<tr>
<td>DCS Mfg. #2</td>
<td>40 ms</td>
<td>0 Vrms</td>
</tr>
<tr>
<td>DCS Mfg. #3</td>
<td>40 ms</td>
<td>0 Vrms</td>
</tr>
<tr>
<td>DCS Mfg. #3</td>
<td>20 ms</td>
<td>0 Vrms</td>
</tr>
<tr>
<td>PLC Mfg. #1</td>
<td>20 ms</td>
<td>0 Vrms</td>
</tr>
<tr>
<td>PLC Mfg. #1</td>
<td>5 ms</td>
<td>0 Vrms</td>
</tr>
<tr>
<td>PLC Mfg. #1</td>
<td>20 ms</td>
<td>0 Vrms</td>
</tr>
<tr>
<td>PLC Mfg. #1</td>
<td>20 ms</td>
<td>0 Vrms</td>
</tr>
<tr>
<td>PLC Mfg. #2</td>
<td>8.33 ms</td>
<td>0 Vrms</td>
</tr>
<tr>
<td>PLC Mfg. #3</td>
<td>40 ms</td>
<td>0 Vrms</td>
</tr>
<tr>
<td>PLC Mfg. #3</td>
<td>21 ms</td>
<td>0 Vrms</td>
</tr>
<tr>
<td>Other Mfg. #1</td>
<td>0 ms</td>
<td>90 Vrms</td>
</tr>
<tr>
<td>Other Mfg. #2</td>
<td>0 ms</td>
<td>88 Vrms</td>
</tr>
<tr>
<td>Other Mfg. #3</td>
<td>0 ms</td>
<td>95 Vrms</td>
</tr>
<tr>
<td>Other Mfg. #4</td>
<td>0 ms *</td>
<td>102 Vrms</td>
</tr>
<tr>
<td>Other Mfg. #5</td>
<td>0 ms *</td>
<td>95 Vrms</td>
</tr>
<tr>
<td>Other Mfg. #6</td>
<td>0 ms *</td>
<td>95 Vrms</td>
</tr>
<tr>
<td>Relay #1</td>
<td>30 ms</td>
<td>0 Vrms</td>
</tr>
<tr>
<td>Relay #1</td>
<td>10 ms</td>
<td>0 Vrms</td>
</tr>
</tbody>
</table>

* 0 ms below threshold w/o battery backup
IV. SHORT-CIRCUIT OUTPUT MAGNITUDE AND THE ALTERNATE SOURCE

What is the UPS inverter short-circuit magnitude? True, online, double-conversion pulse width modulated (PWM) and Ferroresonant are modern UPS types typically used in the petro-chemical and refining industries. The PWM type typically provides a short-circuit magnitude of approximately 1.5 times full load current for 0.25 cycles. Typically, the Ferroresonant type can supply a maximum short-circuit current of 5 times full load current for approximately 0.25 to 1.0 cycles because of the energy stored in the output transformer secondary tuned circuit; however, the output transformer is the ferroresonant, regulating type and inherently limits “long-time” fault current to 150% to 200% of rated current.

It is obvious both technologies are very limited in supporting short-circuit tripping conditions. Hence, UPS short-circuit current support may be insufficient for downstream protective device sensing and fast interruption. So how are UPS distribution system faults interrupted?

When a fault occurs, the UPS senses the sudden rapid current increase or voltage reduction, and within 0.5 cycles the Static Switch transfers from the inverter to the Alternate Source. The Alternate Source has significantly greater short-circuit capability, and the increased fault current is usually adequate for protective device fault interruption. However, Static Switch closure into a short-circuit is a severe condition, and the Static Switch must be adequately rated and protected for this condition. Of course, this interrupting method assumes the Alternate Source is available.

The dilemma is making the transfer, interrupting the short-circuit current and restoring the depressed voltage within the voltage/time limits of the ITI curve for ITE and “hold-up” time of DCS, PLC, and other critical instrumentation. Transfer to the Alternate Source occurs in 0.125 to 0.5 cycles after the voltage depression or current increase exceeds setpoint limits. Although transfer sensing and operation varies, UPS manufacturers generally maintain bus voltage within the ITI voltage/time curve (Fig. 1) and the DCS, PLC, and critical instrumentation benchmarks of Table I. The application engineer should investigate static switch timing and triggering parameters to confirm transfer operation. Quick transfer operation is only part of the sequence; fast interrupting devices are also required.

When compared to the UPS short-circuit output current, the Alternate Source provides significant fault current. Hence, the UPS specification should include the short-circuit available from the Alternate Source, so the UPS manufacturer can supply equipment adequate for the fault conditions.

Providing adequate Alternate Source short-circuit tripping current is a significant concern. Increasing the Alternate Source isolation transformer kVA rating (while maintaining the same impedance and X/R ratio) increases the short-circuit tripping current. Hence, oversizing the Alternate Source isolation transformer should be considered. This recommendation applies to both isolation transformers and ferroresonant transformers.

The UPS Alternate Source power is typically provided by a shielded, isolation transformer which suppresses noise and ground interference. Occasionally, in special applications, a ferroresonant, regulating transformer may be considered for the UPS Alternate Source power supply. Ferroresonant, regulating transformers can reduce harmonics and regulate secondary voltage; however, during fault conditions, transformer secondary short-circuit current may be significantly limited [3]. Hence, using ferroresonant transformers as the Alternate Source transformer should be confirmed with the UPS application engineer for correct application.

If the UPS distribution system tripping current is sufficiently limited, the short-circuit current may not be adequate for protective device fast fault interruption. Although, a UPS with a ferroresonant output transformer can initially provide significantly more short-circuit current than a comparable PWM UPS, the ferroresonant output up is quickly limited by the inherent ferroresonant transformer characteristics [4]. During remote or high-impedance faults, UPS output current is minimally increased, therefore, the UPS ferroresonant transformer current limiting characteristic could result in a non-transfer to the Alternate Source. When ferroresonant, regulating transformers are considered, the UPS distribution long-time system fault conditions should be thoroughly reviewed by the application engineer to confirm short-circuit tripping current is adequate for protective device sensing and interruption.

For enhanced system reliability, the Alternate Source should be powered from a separate upstream source. As a minimum, input power to the UPS Normal Source and Alternate Source should not be supplied from the same 480 V MCC [5].

V. SINGLE-PHASE OR THREE-PHASE UPS OUTPUT VOLTAGE

Section IV. indicates the significance of adequate fault current being supplied by the source. UPS maximum fault current can be increased by proper selection. Since typical plant UPS loads are single-phase, it would be consistent to provide a single-phase UPS. A single-phase UPS provides more fault current than a three phase UPS [6]. As an example, comparing a 30kVA, 120V single-phase UPS with a 30kVA, 208Y/120V three-phase, the single-phase UPS fault current is three times the three-phase UPS line-to-ground fault current. Relatively large kVA rated UPS systems are readily available in single-phase output configuration.

Some critical DCS, PLC and SIS systems have redundant power supply requirements. Ideally, these loads should be powered by two separate UPS systems. However, if only one UPS system is provided, a three-phase UPS system could be considered, enabling the redundant power supplies to be powered by different phases. With a three-phase configuration, a line-to-ground fault depresses the voltage on only one phase, and the loss of both power supply inputs should not occur. If a three-phase isolation transformer is provided in the Alternate Source, short-circuit current can be increased by oversizing the transformer kVA rating without an increase in transformer impedance or X/R.

VI. PROTECTING THE UPS STATIC SWITCH

Have you wondered why there is an internal fuse or circuit breaker directly preceding both incoming sides of the Static Switch? For 1 to 5 cycles, a typical Static Switch has a short-circuit rating of 10 times the full load switch rating. Because the Alternate Source short-circuit available could exceed the Static Switch withstand capability, an internal solid-state fuse or circuit breaker typically protect the Static Switch. If the Static Switch is not protected, the UPS manufacturer should be
asked to confirm the validity of the design during high magnitude current conditions defined by the application engineer. 

To plot UPS Static Switch internal protective devices on TCC’s the purchase order specification should require short-circuit withstand and coordination curve data for all integral UPS protective devices.

VII. MOLDED CASE CIRCUIT BREAKERS VERSUS FUSES

Because of electrical design standardization, plant switchgear rooms and offices typically use molded case circuit breakers in indoor panelboards. Although fuses are recommended, it has been an industrial practice to use circuit breakers in UPS distribution systems. Simply stated, it is a case of “This is the way we have always done it”. It is ironic because UPS manufacturers recommend downstream fast-acting, current-limiting fuses with 0.50 cycle clearing time [7].

According to Table II [8], panelboard breaker clearing times are 1.1 cycles (100A frame size) to 1.5 cycles (225A-4000A frame size). If a 100A MCCB interrupts the fault, 1.35 cycles (1.1 cycles breaker interruption plus 0.25 cycles) Static Switch transfer time, may be required, marginally exceeding the ITI guidelines for maintaining power to critical instrumentation. This may result in a plant shutdown.

<table>
<thead>
<tr>
<th>MCCBs</th>
<th>Frame Size</th>
<th>100 A</th>
<th>225-4000 A</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Instantaneous, cycles</td>
<td>1.1</td>
<td>1.5</td>
</tr>
</tbody>
</table>

VIII. UPS SYSTEM LOADS

Typically, UPS system loads consist of the DCS, PLC’s, critical process instruments, fire and gas alarm panels, safety shutdown systems, process equipment control panels (boiler controls, compressor controls, etc.) and other critical electrical loads.

During the project design phase, the UPS is sized for the anticipated UPS loads plus a nominal margin for future additions. Occasionally, the UPS is sized and procured before all UPS loads are identified and KW requirements are known. Hence, it is very important to anticipate UPS loads.

It is also important to evaluate the UPS loads. As an example, a compressor control panel should be thoroughly reviewed to segregate UPS loads from general purpose loads. Although the compressor panel may include lighting, instrumentation, PLC and a space heater, the lighting and space heater should be powered from a general purpose AC panel, not a UPS distribution panel.

During plant operations, special attention should be provided to confirm control room “Creature Comfort” loads, such as, under desk space heaters, coffee pots, microwaves, etc., are not connected to local UPS power outlets or feeder circuits. To avoid overloading the UPS, it is imperative operations reviews both existing and new UPS loads on a proactive basis, to ensure extraneous loads have not been added. Educating operation and maintenance personnel to recognize proper UPS loads is essential to minimize this recurring concern.

IX. 120V UPS DISTRIBUTION SYSTEM SELECTIVITY EXAMPLE (Fig. 2)

The 120 V UPS distribution system example is selected to illustrate an initial facility system configuration and loading (Phase 1), and a modified system configuration for future (or unplanned) loads (Phase 2 and Alternate Phase 2). A 30 kVA UPS powers the initial Phase 1 loads, and panel BP1 breakers provide the flexibility of adding future Phase 2 and Alternate Phase 2 UPS distribution panels without system interruption. BP1 and panel L1 are adjacent in the same 480V MCC. If panel L1 is located “out of sight” of BP1, then panel L1 requires an incoming main breaker. Compliance with NFPA 70, 2002 [9], Articles 408 and 240.92 should be confirmed.

Phase 2 shows the addition of a future UPS panel R2, 1000 feet from panel BP1. An Alternate Phase 2 configuration illustrates the option of powering remote panel AR2 via step-up and step-down transformers instead of cable routed at 120 V. Using cable at 120 V to connect BP1 to future panel R2 may initially be more costly than installing a new local UPS. However, additional training and continuing maintenance of the local UPS are not required, particularly if a different UPS manufacturer is selected. This decision may also depend on the available funding for capital projects compared to the maintenance budget.

The Appendices discussions describe interrupting device response when UPS short-circuit current is sufficient for the Static Switch transfer to the Alternate Source. Because UPS system design varies, the application engineer must determine if the Static Switch transfer is inhibited during low-magnitude short-circuit fault conditions, such as, remote faults or high-impedance faults. In the Appendices examples, transfer voltage parameters may be marginal for limited fault conditions; however, transfer to the Alternate Source is assumed in the discussions. In actual application, the transfer threshold must be evaluated.

The Phase 1, Phase 2, and Alternate Phase 2 appendices discussions (Appendices A. through G.) typically show a lack of selectivity when molded case or hydraulic-magnetic circuit breakers are installed. Selectivity is improved by replacing the circuit breakers with fuses selected according to the manufacturers fuse selectivity ratio table guidelines (see Table III).

The Appendices provide detailed discussions for the time-current curve plots. As a minimum, a cursory review of each Appendix should be performed to obtain a general concept of the salient points. Fuse time-current curve plots for Phase 2 and Alternate Phase 2 are not provided and are an exercise for the application engineer to investigate.
TABLE III
TYPICAL SELECTIVITY SCHEDULE\textsuperscript{a} FOR LOW VOLTAGE FUSES

<table>
<thead>
<tr>
<th>Line side</th>
<th>Load side</th>
</tr>
</thead>
<tbody>
<tr>
<td>Class L fuse 601-6000 A</td>
<td>Class K1 fuse 0-600 A</td>
</tr>
<tr>
<td>2:1</td>
<td>2:1</td>
</tr>
<tr>
<td>Class K1 fuse 0-600 A</td>
<td>2:1</td>
</tr>
<tr>
<td>Class J fuse 0-600 A</td>
<td>3:1</td>
</tr>
<tr>
<td>Class K5 current-limiting fuse 0-600 A</td>
<td>1.5:1</td>
</tr>
<tr>
<td>Class J time-delay fuse 0-600 A</td>
<td>1.5:1</td>
</tr>
</tbody>
</table>

\textsuperscript{a} Exact ratios vary with amperage ratings, system voltage, and short-circuit current.

X. 240V UPS/480V DISTRIBUTION SYSTEM
SELECTIVITY EXAMPLE (Fig. 3)

A 480V UPS distribution system is included to illustrate interrupting device response when one UPS system powers multiple panels at remote locations. The results are similar to Section IX. with the specifics discussed in detail in Appendices H and I. The time-current curve plot with hydraulic-magnetic breakers is not included and is an exercise for the application engineer to investigate. The interrupting device response is expected to be similar to the results of Appendices B and E.

PB#1 main breaker (or fuse) provides minimal system protection, and it could be replaced with a disconnect switch. Compliance with NFPA 70, 2002 [9], Articles 408 and 240.92 should be confirmed. Obviously, if a main lug only panelboard is installed it should be sized to match upstream protection.

Making these panelboard and MCC fuse changes and coordinating with the UPS manufacturer improves system selectivity for devices downstream of the Alternate Source transformer secondary. This approach provides fast fault clearing, enhancing plant safety and reliability.

Unlike circuit breakers, which require a time-current curve graphical plot, fuse selectivity is performed by prudent selection, according to fuse manufacturer selectivity tables. Table II is an example from [10], and indicates selectivity sizing ratios that vary from 1.5:1 to 8:1. Hence, it is important to perform adequate analysis during the fuse selection process. Typical ratios may be 2:1 or 3:1; however, the application engineer must select appropriate fuses for the specific application. Refer to Appendix I, for examples of fuse selectivity ratio selection.

XI. APPLICATION GUIDELINE SUMMARY

Table IV. is provided as a convenience to summarize some of the salient points discussed in this paper and is intended as a starting point for performing UPS distribution system design. As this topic develops, application engineers are expected to modify Table IV, to include additional fundamentals, changes, lessons learned, and exceptions. Sharing this data via the internet would help application engineers to design safer and more reliable UPS distribution systems.

XII. CONCLUSIONS

Application engineers must thoroughly understand critical UPS distribution system design. By having a better understanding of UPS load and system protective devices, system response is better understood and system limitations are known early in the project. Time-current curves should be produced as the graphical argument for confirming selectivity between protective devices. When selectivity is achieved by test from a fuse or circuit breaker manufacturer, an explanation should be provided.

It is important to understanding and classify voltage depression and voltage restoration times and the degree of selectivity achieved between protective devices. This defines process loads that are protected from prolonged voltage collapse during fault conditions, and enhances petrochemical plant process reliability and safety for operators, engineers and office personnel. The findings of this paper indicate that fuses may enable DCS, some PLC’s, protective relays, and critical instrumentation to operate continuously during UPS distribution system faults. Because a very limited sample of operating equipment is included in this paper, it is imperative that a separate analysis is performed by each application engineer for the specific plant process equipment.

This paper provides general guideline topics for consideration during UPS distribution system design and implementation. The authors have made assumptions for the equipment, devices, and UPS systems considered in the UPS distribution system examples of Figs. 2 and 3, and corresponding appendices. These assumptions may not be applicable for each specific application. For example, one such assumption is that system fault conditions result in UPS system output current and voltage exceeding static switch transfer setpoints (or threshold), hence, the static switch will transfer to the alternate source and increased fault tripping current will occur. This may not be true for all UPS systems and UPS distribution systems when limited fault conditions exist. Consequently, each UPS and UPS distribution system must be thoroughly evaluated for the specific equipment, devices, and configuration implemented.
XIII. ACKNOWLEDGMENTS

The authors thank Michael Alford and Craig Mouton for their helpful suggestions.

XIV. REFERENCES


XV. VITAE

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TABLE IV.
GENERAL APPLICATION GUIDELINE SUMMARY

UPS Distribution System
General Protection Application Guideline Summary

1. To avoid overloading UPS systems, the UPS loads should be reviewed when additional UPS loads are anticipated.

2. Segregate panel loads. Connect non-UPS loads to General Purpose panels. Connect critical process loads to UPS distribution system panels.

3. Panelboard and circuit breaker or fuse ratings should be compared with the short-circuit current supplied by the Alternate Source.

4. Use the ITI curve as a benchmark for computer business equipment operation during both steady-state and transient conditions.

5. Review DCS, PLC, protection relays, and critical instrumentation loads voltage drop/voltage restoration limits to confirm the installed equipment can tolerate, without interruption, UPS system short-circuit transients.

6. To confirm successful transfer operation, UPS static switch timing and triggering parameters should be reviewed.

7. When applicable, single-phase UPS systems should be specified, because single-phase UPS systems provide more short-circuit current than equivalent kVA three-phase systems. However, when critical systems require redundant DCS, PLC, and SIS power supplies and only one UPS system is provided, a three-phase UPS system configuration may be considered.

8. Ferroresonant type inverters generally have a greater initial short-circuit current contribution during the first 0.25 to 1.0 cycles. This may assist in downstream fuse interruption, and transfer to the Alternate Source may not be required.

9. UPS manufacturers recommend fast-acting current-limiting fuses for the UPS distribution system because fast fault current interruption is provided. Consequently, instrument panels should be the fuse type, not the circuit breaker type.

10. If adequate fault current is available and can be sensed by the fuse, fast-acting fuses may minimize Static Switch transfer to the Alternate Source.

11. UPS internal fuse/circuit breaker configurations vary, and the specifics must be confirmed with each manufacturer. Also, the manufacturer should confirm the Alternate Source fault magnitude does not exceed the UPS Alternate Source rating capabilities.

12. When the UPS internal fuses are the single-element current-limiting type, factory fault testing in combination with upstream and downstream dual-element fuses may be required to determine if the internal fuse is selective with the dual-element fuses. This contingency should be included in the UPS specification.

13. Fuse sizes should be minimized. As an example, if a 3 A fuse is adequate a 15 A fuse should not be used.

14. Typically, fuse selectivity is achieved by using a fuse selectivity ratio tables. Fuses should be from the same manufacturer since the fuse selectivity tables are obtained by test.

15. When single-phase UPS systems are implemented, the 480V MCC data sheet shall specify a single-phase or three-phase fused switch for the feeder cable powering the Alternate Source isolation transformer.

16. When 120 V remote skid-mounted loads are powered from UPS system instrument panels provide special attention to the reduced fault current magnitude. Increased cable sizes may be required to assure selective fault clearing for a local instrument panel, avoiding an extended voltage collapse and loss of panel loads.

17. To increase Alternate Source short-circuit current, the Alternate Source step-down isolation transformer kVA rating could be increased without increasing impedance and X/R parameters.

18. The Alternate Source transformer should be the shielded, isolation type. Because of the current-limiting characteristics, ferroresonant transformers should be used in the Alternate Source only after thorough investigation.

19. For enhanced system reliability, the Alternate Source should be powered from a separate upstream source. As a minimum, the UPS Normal Source input power and Alternate Source should not be supplied from the same 480 V MCC.
NOTE:
1) Fault locations are abbreviated, such as, FPH1A_. The following defines the parts of this brief descriptor.
"F" Fault.
"PH" Phase.
"A" Fault location on the one line diagram.
"_" Fault source.
"P" PWM.
"F" Ferroresonant.
"ALT" Alternate Source.
2) Refer to Appendixes for TCC's.

Fig. 2. Example 120VAC UPS Distribution System
Fig. 3. Example 240VAC UPS/480V Distribution System One-line Diagram with Traditional Circuit Breaker Protection

NOTE:
1) Fault locations are abbreviated, such as, FPH1A_. The following defines the parts of this brief descriptor.

"F" Fault.
"1,2,3,4" Fault location on the one line diagram.
"_" Fault source.

2) Refer to Appendices for TCC's.
APPENDIX A
Time-Current Curve and Discussion for Fig. 2. Phase 1, Example 120V UPS Distribution

Fig. A-1. Time-Current Curve for Fig. 2. Phase 1 Feeder with Molded Case Circuit Breakers
APPENDIX A
Time-Current Curve and Discussion for Fig. 2, Phase 1, Example 120V UPS Distribution

I. Fault Source - PWM UPS

A. Fault Point FPH1CP:
   1) Fault current is sufficient to trip Panel R1, 15 A breaker.
   2) Refer to III. A.

B. Fault Point FPH1BP:
   1) Fault current is not sufficient to trip 50 A breakers at Panel R1 and Panel L1.
   2) Refer to III. B.

C. Fault Point FPH1AP:
   1) Fault current is not sufficient to trip Panel L1, 50 A feeder breaker.
   2) Refer to III. C.

II. Fault Source - Ferroresonant UPS

A. Fault Point FPH1CF:
   1) Fault current is sufficient to trip Panel R1, 15 A breaker.
   2) Panel R1, 50 A main breaker may trip.
   3) Panel L1, 50 A feeder breaker may trip.
   4) Refer to III. A.

B. Fault Point FPH1BF:
   1) Fault current is sufficient to trip Panel R1, 15 A breaker, Panel R1, 50 A main breaker, Panel L1, 50 A feeder breaker and Panel BP1, 100 A feeder breaker.

II. Fault Source - Ferroresonant UPS

A. Fault Point FPH1CF:
   1) Fault current is sufficient to trip Panel R1, 15 A breaker.
   2) Panel R1, 50 A main breaker may trip.
   3) Panel L1, 50 A feeder breaker may trip.
   4) Refer to III. A.

B. Fault Point FPH1BF:
   1) Fault current is sufficient to trip Panel R1, 15 A breaker, Panel R1, 50 A main breaker, Panel L1, 50 A feeder breaker and Panel BP1, 100 A feeder breaker.

II. Fault Source - Ferroresonant UPS

A. Fault Point FPH1CF:
   1) Fault current is sufficient to trip Panel R1, 15 A breaker.
   2) Panel R1, 50 A main breaker may trip.
   3) Panel L1, 50 A feeder breaker may trip.
   4) Refer to III. A.

B. Fault Point FPH1BF:
   1) Fault current is sufficient to trip Panel R1, 15 A breaker, Panel R1, 50 A main breaker, Panel L1, 50 A feeder breaker and Panel BP1, 100 A feeder breaker.

II. Fault Source - Ferroresonant UPS

A. Fault Point FPH1CF:
   1) Fault current is sufficient to trip Panel R1, 15 A breaker.
   2) Panel R1, 50 A main breaker may trip.
   3) Panel L1, 50 A feeder breaker may trip.
   4) Refer to III. A.

B. Fault Point FPH1BF:
   1) Fault current is sufficient to trip Panel R1, 15 A breaker, Panel R1, 50 A main breaker, Panel L1, 50 A feeder breaker and Panel BP1, 100 A feeder breaker.
APPENDIX B

Time-Current Curve and Discussion for Fig. 2. Phase 1, Example 120V UPS Distribution System with Hydraulic-Magnetic Circuit Breaker Interrupting Devices

Fig. B-1. Time-Current Curve for the Fig. 2. Phase 1 Feeder with Hydraulic–Magnetic Circuit Breakers
APPENDIX B
Time-Current Curve and Discussion for Fig. 2. Phase 1, Example 120V UPS Distribution System with Hydraulic-Magnetic Circuit Breaker Interrupting Devices

Fig. B-1 time-current curve shows the Fig. A-1 MCCB’s replaced with hydraulic-magnetic circuit breakers.

I. Fault Source - PWM UPS

A. Fault Point FPH1CP:
   1) Fault current is sufficient to trip Panel R1, 15 A feeder breaker.
   2) Fault current may trip Panel R1, 50 A main breaker.
   3) Fault current may trip Panel L1, 50 A feeder breaker.
   4) Refer to III. A.

B. Fault Point FPH1BP:
   1) Fault current may trip Panel R1, 50 A main breaker.
   2) Fault current may trip Panel R1, 50 A feeder breaker.
   3) Refer to III. B.

C. Fault Point FPH1AP:
   1) Fault current is sufficient to trip Panel L1, 50 A feeder breaker.
   2) Fault current is sufficient to trip Panel BP1, 100 A feeder breaker.
   3) Refer to III. C.

II. Fault Source - Ferroresonant UPS

A. Fault Point FPH1CF:
   1) Fault current is sufficient to trip Panel R1, 15 A feeder breaker, Panel R1, 50 A main breaker, and Panel L1, 50 A feeder breaker.

B. Fault Point FPH1BF:
   1) Fault current is sufficient to trip Panel R1, 50 A main breaker, Panel L1, 50 A feeder breaker, and Panel BP1, 100 A feeder breaker.
   2) Refer to III. B.

C. Fault Point FPH1AF:
   1) Fault current is sufficient to trip Panel L1, 50 A feeder breaker and Panel BP1, 100 A feeder breaker.
   2) Refer to III. C.

If the fault is not interrupted before the Static Switch transfers to the Alternate Source, the following occurs.

III. Fault Source - UPS Alternate Source

A. Fault Point FPH1CALT:
   1) Panel R1, 15 A feeder breaker trips.
   2) Panel R1, 50 A main breaker trips.
   3) Panel L1, 50 A feeder breaker trips.

B. Fault Point FPH1BALT:
   1) Panel R1, 50 A main breaker trips.
   2) Panel L1, 50 A feeder breaker trips.
   3) Panel BP1, 100 A feeder breaker trips.

C. Fault Point FPH1AALT:
   1) Panel L1, 50 A breaker trips.
   2) Panel BP1, 100 A main breaker trips.
   3) UPS internal 350 A breaker trips.
   4) 480 V MCC, 125 A UPS feeder breaker trips.
   5) The 11,549 A short-circuit contribution at Panel L1 exceeds the rating of the typical 120 V, 10 kA panelboard.
APPENDIX C
Time-Current Curve and Discussion for Fig. 2. Phase 1, Example 120V UPS Distribution System with Fuse Interrupting Devices

Fig. C-1. Time-Current Curve for the Fig. 2. Phase 1 Feeder with Fuses
APPENDIX C
Time-Current Curve and Discussion for Fig. 2. Phase 1, Example 120V UPS Distribution System with Fuse Interrupting Devices

I. Discussion

1) To achieve selectivity in Appendices A and B examples, the MCCB’s should be replaced with fuses at the following locations:
   a) Panel R1,
   b) Panel L1,
   c) Panel BP1,
   d) UPS 350 A internal fuse, and
   e) 480 V MCC Alternate Source UPS feeder.
2) Fig. C-1 shows the lack of selectivity when the 480 V MCC Alternate Source feeder breaker is not replaced with fuses.
3) Fuses should be selected from the fuse selectivity ratios table(s) from one manufacturer.
4) Fuse selectivity tables are by test. Using cascaded fuses from different manufacturers may not be selective because the fuses have not been tested as a system.
5) When fuse systems are implemented according to fuse selectivity ratio tables, time-current curves are not necessary because the fuse manufacturer has confirmed selectivity by test.
6) When fuses and circuit breakers are cascaded throughout the UPS distribution system, selectivity cannot be confirmed. Hence, the UPS manufacturer could be requested to replace the circuit breaker protecting the Static Switch with a dual-element fuse. The replacement fuse should be from the same manufacturer as the other UPS distribution system fuses. This may impact UPS certification standards and warranty; consequently, the end-user must obtain warranty complicity from the UPS manufacturer to include this matter.
7) If the UPS manufacturer provides a single-element (short-circuit only protection) current-limiting fuse, testing of the single-element current-limiting fuse with downstream and upstream dual-element (overload and short-circuit protection) fuses is typically necessary to confirm selectivity between devices. Testing is required for single-element and dual-element fuses because fuse selectivity tables are typically based on dual-element fuses. This approach is applicable, even if the same fuse manufacturer supplies the dual-element and single-element fuses. The UPS specification should include a statement requesting a separate line item price for dual-element/single-element fuse testing with the end-user providing the fault current parameters.
APPENDIX D
Time-Current Curve and Discussion for Fig. 2. Phase 2, Example 120V UPS Distribution System with Molded Case Circuit Breaker Interrupting Devices

Fig. D-1. Time-Current Curve for the Fig. 2. Phase 1 Feeder with Molded Case Circuit Breakers
APPENDIX D
Time-Current Curve and Discussion for Fig. 2. Phase 2, Example 120V UPS Distribution System with Molded Case Circuit Breaker Interrupting Devices

I. Fault Source - PWM UPS

A. Fault Point FPH2BP:
   1) Fault current is sufficient to trip Instrument Skid Panel, 10 A breaker and Panel R2, 15 A feeder breaker.
   2) Refer to III. A.

B. Fault Point FPH2AP:
   1) Fault current is sufficient to trip Panel R2, 15 A feeder breaker.
   2) Refer to III. B.

C. Fault Point Panel R2, 100 A Main Load Terminals:
   1) Fault current is sufficient to trip Panel R2, 100 A main breaker and Panel BP1, 100 A feeder breaker.
   2) Refer to III. C.

D. Fault Point Panel BP1, 100 A Feeder Breaker Load Terminal to Panel R2:
   1) Fault current is not sufficient to trip BP1, 100 A breaker.
   2) Refer to III. D.

II. Fault Source – Ferroresonant UPS

A. Fault Point FPH2BF:
   1) Same comments as I. A.

B. Fault Point FPH2AF:
   1) Fault current is sufficient to trip Panel R2, 15 A feeder breaker, Panel R2, 100 A main breaker, and Panel BP1, 100A feeder breaker to Panel R2.
   2) Refer to III. C.

C. Fault Point Panel R2, 100 A Main Breaker Load Terminals:
   1) Fault current is sufficient to trip Panel R2, 100 A main breaker and Panel BP1, 100 A feeder breaker
   2) Refer to III. C.

D. Fault Point Panel BP1, 100 A Feeder Breaker Load Terminal to Panel R2:
   1) Fault current is sufficient to trip BP1, 100 A breaker.
   2) Refer to III. D.

If the fault is not interrupted before the Static Switch transfers to the Alternate Source, the following occurs.

III. Fault Source – UPS Alternate Source

A. Fault Point FPH2BALT:
   1) Instrument Skid Panel, 10A breaker trips.
   2) Panel R2, 15A feeder breaker trips.

B. Fault Point FPH2AALT:
   1) Panel R2, 15A feeder breaker trips.
   2) Panel R2, 100A main breaker trips.
   3) Panel BP1, 100A feeder breaker trips.

C. Fault Point Panel R2, 100A Main Load Terminals:
   1) Panel R2, 100 A main breaker trips.
   2) Panel BP1, 100 A feeder breaker to Panel R2 trips.

D. Fault Point Panel BP1, 100A Feeder Load Terminal to Panel R2:
   1) Panel BP1, 100A feeder breaker trips.
   2) UPS internal 350A breaker trips.
   3) 480 V MCC, 125A UPS feeder breaker trips.
   4) The 11,549 A short-circuit contribution at Panel L1 exceeds the rating of the typical 120 V, 10 kA panelboard.
APPENDIX E
Time-Current Curve and Discussion for Fig. 2. Phase 2, Example 120V UPS Distribution System with Hydraulic-Magnetic Circuit Breaker Interrupting Devices

Fig. E-1. Time-Current Curve for the Fig. 2. Phase 2 Feeder with Hydraulic Magnetic Circuit Breakers
APPENDIX E
Time-Current Curve and Discussion for Fig. 2. Phase 2, Example 120V UPS Distribution System with Hydraulic-Magnetic Circuit Breaker Interrupting Devices

Fig. E-1 time-current curve shows the Fig. D-1 MCCB’s replaced with hydraulic-magnetic circuit breakers.

I. Fault Source - PWM UPS

A. Fault Point FPH2BP:
   1) Fault current is sufficient to trip Instrument Skid Panel, 10 A breaker and Panel R2, 15 A feeder breaker.
   2) Refer to III. A.

B. Fault Point FPH2AP:
   1) Fault current is sufficient to trip Panel R2, 15 A feeder breaker.
   2) Refer to III. B.

C. Fault Point Panel R2, 100 A Main Breaker Load Terminals:
   1) Fault current is sufficient to trip Panel R2, 100 A main breaker and Panel BP1, 100 A feeder breaker after a prolonged delay.
   2) Refer to III. C.

D. Fault Point Panel BP1, 100 A Feeder Load Terminal to Panel R2:
   1) Fault current is sufficient to trip BP1, 100 A feeder breaker to Panel R2 after a prolonged delay.
   2) Refer to III. D.

II. Fault Source – Ferroresonant UPS

A. Fault Point FPH2BF:
   1) Same comments as I. A.

B. Fault Point FPH2AF:
   1) Fault current is sufficient to trip Panel R2, 15 A feeder breaker.
   2) Fault current is sufficient to trip Panel R2, 100 A main breaker.

C. Fault Point Panel R2, 100A Main Load Terminals:
   1) Fault current is sufficient to trip Panel R2, 100 A main breaker and Panel BP1, 100A feeder breaker to Panel R2 after a prolonged delay.
   2) Refer to III. C.

D. Fault Point Panel BP1, 100 A Feeder Breaker Load Terminal to Panel R2:
   1) Fault current is sufficient to trip Panel R2, 100 A main breaker.
   2) Fault current is sufficient to trip BP1, 100 A breaker.

If the fault is not interrupted before the Static Switch transfers to the Alternate Source, the following occurs.

III. Fault Source – UPS Alternate Source

A. Fault Point FPH2BALT:
   1) Instrument Skid Panel, 10 A breaker trips.
   2) Panel R2, 15 A feeder breaker trips.

B. Fault Point FPH2AALT:
   1) Panel R2, 15 A feeder breaker trips.
   2) Panel R2, 100 A main breaker trips.
   3) Panel BP1, 100 A feeder breaker trips.

C. Fault Point Panel R2, 100 A Main Breaker Load Terminals:
   1) Panel R2, 100 A main breaker trips.
   2) Panel BP1, 100 A feeder breaker to Panel R2 may trip.

D. Fault Point Panel BP1, 100 A Feeder Breaker Load Terminal to Panel R2:
   1) Panel BP1, 100 A feeder breaker trips.
   2) UPS internal 350 A breaker trips.
   3) 480 V MCC, 125 A UPS feeder breaker trips.
   4) The 11,549 A short-circuit contribution at Panel L1 exceeds the rating of the typical 120 V, 10 kA panelboard.
APPENDIX F
Time-Current Curve and Discussion for Fig. 2. Alternate Phase 2, Example 120V UPS Distribution System with Molded Case Circuit Breaker Interrupting Devices

Fig. F-1. Time-Current Curve for the Fig. 2. Alternate Phase 2 Feeder with Molded Case Circuit Breakers
APPENDIX F
Time-Current Curve and Discussion for Fig. 2. Alternate Phase 2, Example 120V UPS
Distribution System with Molded Case Circuit Breaker Interrupting Devices

Alternate Phase 2 is an alternate to the Phase 2 system. The 1000 feet of 2-1/8 #500 kcmil per phase cable is replaced with two 10 kVA, 120 V-480 V, single-phase transformers and 1000 feet of 2-1/8 #1/0 cable.

I. Fault Source - PWM UPS

A. Fault Point FPH2A4P:
   1) Fault current is sufficient to trip Instrument Skid Panel, 10A breaker and Panel AR2, 15 A feeder breaker after a prolonged delay.
   2) Refer to III. A.

B. Fault Point FPH2A3P:
   1) Fault current is sufficient to trip Panel AR2, 15 A feeder breaker.
   2) Refer to III. B.

C. Fault Point Panel AR2, 100 A Main Load Terminals:
   1) Fault current is sufficient to trip Panel R2, 100 A main breaker after a prolonged delay.
   2) Refer to III. C.

D. Fault Point FPH2A2P:
   1) Fault current is sufficient to trip Panel BP1, 100 A feeder breaker after a prolonged delay.
   2) Refer to III. D.

E. Fault Point FPH2A1P:
   1) Fault current is not sufficient to trip Panel BP1, 100 A breaker after a prolonged delay.
   2) Refer to III. E.

F. Fault Point Panel BP1, 100 A Feeder Breaker Load Terminal to Panel AR2:
   1) Fault current is sufficient to trip BP1, 100 A breaker.
   2) Refer to III. F.

If the fault is not interrupted before the Static Switch transfers to the Alternate Source, the following occurs.

II. Fault Source – Ferroresonant UPS

A. Fault Point FPH2A4F:
   1) Fault current is sufficient to trip Instrument Skid Panel, 10 A breaker and Panel AR2, 15 A feeder breaker.
   2) Refer to III. A.

B. Fault Point FPH2A3F:
   1) Fault current is sufficient to trip Panel AR2, 15 A feeder breaker.
   2) Refer to III. B.

C. Fault Point Panel AR2, 100 A Main Load Terminals:
   1) Panel AR2, 100 A main breaker trips after a prolonged delay.
   2) Panel BP1, 100 A feeder breaker to Panel AR2 trips after a prolonged delay.

D. Fault Point FPH2A2F:
   1) Fault current is sufficient to trip Panel BP1, 100 A feeder breaker after a prolonged delay.
   2) Refer to III. D.

E. Fault Point FPH2A1F:
   1) Fault current is sufficient to trip Panel BP1, 100 A breaker.
   2) Refer to III. E.

F. Fault Point Panel BP1, 100 A Feeder Breaker Load Terminal to Panel AR2:
   1) Fault current is sufficient to trip BP1, 100 A breaker.
   2) UPS internal 350 A breaker trips.
   3) 480 V MCC, 125 A UPS feeder breaker trips.
   4) The 11,549 A short-circuit contribution at Panel L1 exceeds the rating of the typical 120 V, 10 kA panelboard.

III. Fault Source – UPS Alternate Source

A. Fault Point FPH2A4ALT:
   1) Instrument Skid Panel, 10 A breaker trips.
   2) Panel AR2, 15 A feeder breaker trips.

B. Fault Point FPH2A3ALT:
   1) Panel AR2, 15 A feeder breaker trips.

C. Fault Point Panel AR2, 100 A Main Load Terminals:
   1) Panel AR2, 100 A main breaker trips after a prolonged delay.
   2) Panel BP1, 100 A feeder breaker to Panel AR2 trips after a prolonged delay.

D. Fault Point FPH2A2ALT:
   1) Panel BP1, 100 A feeder breaker trips.

E. Fault Point FPH2A1ALT:
   1) Refer to III. D.

F. Fault Point Panel BP1, 100 A Feeder Breaker Load Terminal to Panel AR2:
   1) Panel BP1, 100 A feeder breaker trips.
   2) UPS internal 350 A breaker trips.
   3) 480 V MCC, 125 A UPS feeder breaker trips.
   4) The 11,549 A short-circuit contribution at Panel L1 exceeds the rating of the typical 120 V, 10 kA panelboard.
APPENDIX G
Time-Current Curve and Discussion for Fig. 2. Alternate Phase 2, Example 120V UPS Distribution System with Hydraulic-Magnetic Circuit Breaker Interrupting Devices

Fig. G-1. Time-Current Curve for the Fig. 2. Alternate Phase 2 Feeder with Hydraulic-Magnetic Circuit Breakers
APPENDIX G
Time-Current Curve and Discussion for Fig. 2. Alternate Phase 2, Example 120V UPS Distribution System with Hydraulic-Magnetic Circuit Breaker Interrupting Devices

Alternate Phase 2 is an alternate to the Phase 2 system. The 1000 feet of 2-1/c#500 kcmil per phase cable is replaced with two 10 kVA, 120 V-480 V, single-phase transformers and 1000 feet of 2-1/c#1/0 cable.

I. Fault Source - PWM UPS

A. Fault Point FPH2A4P:
1) Fault current is sufficient to trip Instrument Skid Panel, 10 A breaker and Panel AR2, 15 A feeder breaker.
2) Refer to III. A.

B. Fault Point FPH2A3P:
1) Fault current is sufficient to trip Panel AR2, 15 A feeder breaker.
2) Refer to III. B.

C. Fault Point Panel AR2, 100 A Main Load Terminals:
1) Fault current is sufficient to trip Panel AR2, 100 A main breaker and Panel BP1, 100 A feeder breaker after a prolonged delay.
2) Refer to III. C.

D. Fault Point FPH2A2P:
1) Fault current is sufficient to trip Panel BP1, 100 A feeder breaker after a prolonged delay.
2) Refer to III. D.

E. Fault Point FPH2A1P:
1) Fault current is sufficient to trip Panel BP1, 100 A breaker after prolonged delay.
2) Refer to III. E.

F. Fault Point Panel BP1, 100 A Feeder Load Terminal to Panel AR2:
1) Fault current is sufficient to trip BP1, 100 A breaker, UPS internal 350 A breaker, and 480 V MCC, 125 A UPS feeder breaker after a prolonged delay.
2) Refer to III. F.

II. Fault Source – Ferroresonant UPS

A. Fault Point FPH2A4F:
1) Same comments as I. A.

B. Fault Point FPH2A3F:
1) Same comments as I. B.

C. Fault Point Panel AR2, 100 A Main Load Terminals:
1) Same comments as I. C.

D. Fault Point FPH2A2F:
1) Same comments as I. D.

E. Fault Point FPH2A1F:
1) Fault current is sufficient to trip Panel BP1, 100 A breaker, UPS internal 350 A breaker, and 480 V MCC, 125 A UPS feeder breaker after a prolonged delay.
2) Refer to III. E.

F. Fault Point Panel BP1, 100 A Feeder Breaker Load Terminal to Panel AR2:
1) Fault current is sufficient to trip Panel BP1, 100 A breaker, UPS internal 350 A breaker, and 480 V MCC, 125 A UPS feeder breaker.
2) Refer to III. F.

If the fault is not interrupted before the Static Switch transfers to the Alternate Source, the following occurs.

III. Fault Source – UPS Alternate Source

A. Fault Point FPH2A4ALT:
1) Instrument Skid Panel, 10 A breaker trips.
2) Panel AR2, 15 A breaker trips.

B. Fault Point FPH2A3ALT:
1) Panel AR2, 15 A breaker trips.

C. Fault Point Panel AR2, 100 A Load Terminals:
1) Panel AR2, 100 A breaker trips after a prolonged delay.
2) Panel BP1, 100 A feeder breaker to Panel AR2 trips after a prolonged delay.

D. Fault Point FPH2A2ALT:
1) Panel BP1, 100 A breaker trips after a prolonged delay.

E. Fault Point FPH2A1ALT:
1) Panel BP1, 100 A breaker trips after a prolonged delay.

F. Fault Point Panel BP1, 100 A Feeder Breaker Load Terminal to Panel AR:
1) Panel BP1, 100 A breaker trips.
2) UPS internal 350 A breaker trips.
3) 480 V MCC, 125 A UPS breaker trips.
4) The 11,549 A short-circuit contribution at Panel L1 exceeds the rating of the typical 120 V, 10 kA panelboard.
APPENDIX H
Time-Current Curve and Discussion for Fig. 3. Example 240 V UPS / 480 V Distribution System with Molded Case Circuit Breaker Interrupting Devices

Fig. H-1. Time-Current Curve for Fig. 3. With Molded Case Circuit Breakers
APPENDIX H
Time-Current Curve and Discussion for Fig. 3. Example 240 V UPS / 480 V Distribution System with Molded Case Circuit Breaker Interrupting Devices

I. Fault Source - PWM UPS

A. Fault Point F4P:
   1) Fault current is sufficient to trip Instrument Skid Panel, 10 A breaker and Panel PB#1, 15 A feeder breaker.
   2) Refer to III. A.

B. Fault Point F3P:
   1) Fault current is sufficient to trip Panel PB#1, 15 A feeder breaker.
   2) Refer to III. B.

C. Fault Point F2P:
   1) Fault current is sufficient to trip Panel PB#2, 30 A feeder breaker after a prolonged delay.
   2) Refer to III. C.

D. Fault Point F1P:
   1) Same comments as I. C.

II. Fault Source - Ferroresonant UPS

A. Fault Point F4F:
   1) Fault current is sufficient to trip Instrument Skid Panel, 10 A breaker, and Panel PB#1, 15 A feeder breaker.
   2) Refer to III. A.

B. Fault Point F3F:
   1) Fault current is sufficient to trip Panelboard PB#1, 15 A feeder breaker after a prolonged delay.
   2) Refer to III. B.

C. Fault Point F2F:
   1) Fault current is sufficient to trip Panel PB#2, 30 A feeder breaker and PB#1, 125 A main breaker.
   2) Refer to III. C.

D. Fault Point F1F:
   1) Same comments as II. C.

II. Fault Source - Alternate Source

A. Fault Point F4ALT:
   1) Instrument Skid 10 A breaker trips.
   2) Power PP#1, 15 A feeder breaker trips.

B. Fault Point F3ALT:
   1) Panel PB#1, 15 A feeder breaker trips.
   2) Panel PB#1, 125 A main breaker trips.
   3) Panel PB#2, 30 A feeder breaker trips.

C. Fault Point F2ALT:
   1) Panel PB#2, 30 A feeder breaker trips.
   2) Panel PB#2, 150 A main breaker trips.
   3) 480 V, 150 A MCC feeder breaker trips.

If the fault is not interrupted before the Static Switch transfers to the Alternate Source, the following occurs.

III. Fault Source - Alternate Source

A. Fault Point F4ALT:
   1) Instrument Skid 10 A breaker trips.
   2) Power PP#1, 15 A feeder breaker trips.

B. Fault Point F3ALT:
   1) Panel PB#1, 15 A feeder breaker trips.
   2) Panel PB#1, 125 A main breaker trips.
   3) Panel PB#2, 30 A feeder breaker trips.

C. Fault Point F2ALT:
   1) Panel PB#2, 30 A feeder breaker trips.
   2) Panel PB#2, 150 A main breaker trips.
   3) 480 V, 150 A MCC feeder breaker trips.
APPENDIX I
Time-Current Curve and Discussion for Fig. 3. Example 240 V UPS / 480 V Distribution System with Fuse Interrupting Devices

Fig. I-1. Time-Current Curve for Fig. 3, with Fuses
APPENDIX I
Time-Current Curve and Discussion for Fig. 3. Example 240 V UPS / 480 V Distribution System with Fuse Interrupting Devices

I. Discussion for Short-Circuit Contribution from PWM UPS

1) For a general discussion, refer to Appendix C.

2) To enhance protective device selectivity concerns of Appendices H, the MCCB’s should be replaced with fuses at the following locations:
   a) Panel PP#1,
   b) Panel PB#1,
   c) Panel PB#2, and
   d) 480V MCC Alternate Source UPS feeder.

3) In Fig. I-1, the 10 A skid fuse and the PB#1, 15 A fuse are selective during high-magnitude faults only if a 1.5:1 ratio is achieved. It is obvious the PB#1, 15A feeder fuse and the PB#1, 125 A main fuse are selective because an 8.3:1 ratio (125 A/15 A) is achieved.

4) The PB#1, 125 A fuse and the upstream PB#2, 30A feeder fuse are not selective, because the selectivity ratio is 125 A/(30A x 4) = 125 A/120 = 1.04, which is less than a minimum 1.5:1 selectivity ratio.
1.0 PRELIMINARIES

Base quantities:

\[
S_b := 30000 \\
U_{b_{120}} := 120 \\
U_{b_{480}} := 480 \\
\left(\frac{U_{b_{120}}}{1000}\right)^2 \\
Z_{b_{120}} := \frac{S_b \cdot U_{b_{120}}}{10^6} \\
Z_{b_{120}} = 0.48
\]

A) Equations and Data

Data from NEC Table 9, ohms/1000ft

<table>
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<tr>
<th>Diameter</th>
<th>Z_{metalic_cond}</th>
<th>Z_{nonmetalic_cond}</th>
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<tr>
<td>&quot;1/2&quot;</td>
<td>3.1 + j·0.073</td>
<td>3.1 + j·0.58</td>
</tr>
<tr>
<td>&quot;1/8&quot;</td>
<td>3.06 + j·0.068</td>
<td>2.0 + j·0.054</td>
</tr>
<tr>
<td>&quot;1/4&quot;</td>
<td>1.2 + j·0.063</td>
<td>1.2 + j·0.050</td>
</tr>
<tr>
<td>&quot;1/8&quot;</td>
<td>0.78 + j·0.065</td>
<td>0.78 + j·0.052</td>
</tr>
<tr>
<td>&quot;1/16&quot;</td>
<td>0.49 + j·0.064</td>
<td>0.49 + j·0.051</td>
</tr>
<tr>
<td>&quot;2/5&quot;</td>
<td>0.31 + j·0.060</td>
<td>0.31 + j·0.048</td>
</tr>
<tr>
<td>&quot;2/10&quot;</td>
<td>0.20 + j·0.057</td>
<td>0.20 + j·0.045</td>
</tr>
<tr>
<td>&quot;1/16&quot;</td>
<td>0.16 + j·0.057</td>
<td>0.16 + j·0.046</td>
</tr>
</tbody>
</table>

Z_{cable} :=

<table>
<thead>
<tr>
<th>Diameter</th>
<th>Z_{cable}</th>
</tr>
</thead>
<tbody>
<tr>
<td>&quot;1/2&quot;</td>
<td>0.12 + j·0.055</td>
</tr>
<tr>
<td>&quot;1/4&quot;</td>
<td>0.10 + j·0.054</td>
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<tr>
<td>&quot;1/8&quot;</td>
<td>0.063 + j·0.051</td>
</tr>
<tr>
<td>&quot;2/5&quot;</td>
<td>0.054 + j·0.052</td>
</tr>
<tr>
<td>&quot;2/10&quot;</td>
<td>0.045 + j·0.051</td>
</tr>
<tr>
<td>&quot;2/20&quot;</td>
<td>0.039 + j·0.050</td>
</tr>
<tr>
<td>&quot;2/30&quot;</td>
<td>0.035 + j·0.049</td>
</tr>
<tr>
<td>&quot;2/40&quot;</td>
<td>0.029 + j·0.048</td>
</tr>
<tr>
<td>&quot;2/50&quot;</td>
<td>0.021 + j·0.048</td>
</tr>
<tr>
<td>&quot;2/60&quot;</td>
<td>0.018 + j·0.046</td>
</tr>
</tbody>
</table>
PWM Inverter Equivalent Impedance

\[ S_{UPS} := 30000 \]

\[ U_n := 120 \]

\[ I_{n\_PWM\_UPS} := \frac{S_{UPS}}{U_n} \quad I_{n\_PWM\_UPS} = 250 \]

\[ K_{SC\_PWM} := 1.5 \]

\[ I_{SC\_PWM\_UPS} := K_{SC\_PWM} \cdot I_{n\_PWM\_UPS} \quad I_{SC\_PWM\_UPS} = 375 \]

\[ S_{SC\_PWM\_UPS} := I_{SC\_PWM\_UPS} \cdot U_n \quad S_{SC\_PWM\_UPS} = 45000 \]

\[ X_{pu\_PWM\_UPS} := \frac{S_b}{S_{SC\_PWM\_UPS}} \quad X_{pu\_PWM\_UPS} = 0.666667 \]

\[ Z_{pu\_PWM\_UPS} := j \cdot X_{pu\_PWM\_UPS} \quad Z_{pu\_PWM\_UPS} = 0.666667i \]
PWM Ferro Equivalent Impedance

\[ S_{\text{UPS}} := 30000 \]

\[ U_n := 120 \]

\[ I_{n, \text{FERRO_UPS}} := \frac{S_{\text{UPS}}}{U_n} \quad I_{n, \text{FERRO_UPS}} = 250 \]

\[ K_{\text{SC_FERRO}} := 5 \]

\[ I_{\text{SC_FERRO_UPS}} := K_{\text{SC_FERRO}} I_{n, \text{FERRO_UPS}} \quad I_{\text{SC_FERRO_UPS}} = 1250 \]

\[ S_{\text{SC_FERRO_UPS}} := I_{\text{SC_FERRO_UPS}} U_n \quad S_{\text{SC_FERRO_UPS}} = 150000 \]

\[ X_{pu, \text{FERRO_UPS}} := \frac{S_b}{S_{\text{SC_FERRO_UPS}}} \quad X_{pu, \text{FERRO_UPS}} = 0.2 \]

\[ Z_{pu, \text{FERRO_UPS}} := j \cdot X_{pu, \text{FERRO_UPS}} \quad Z_{pu, \text{FERRO_UPS}} = 0.2i \]

Alternate Source Equivalent Impedance

\[ I_{3\text{ph_SC}} := 50000 \]

\[ K_{3\text{ph_1ph}} := \frac{\sqrt{3}}{2} \quad K_{3\text{ph_1ph}} = 0.866025 \]

\[ X_{R, \text{ALT_SRC}} := 6 \]

\[ I_{1\text{ph_SC}} := I_{3\text{ph_SC}} K_{3\text{ph_1ph}} \quad I_{1\text{ph_SC}} = 43301.27 \]

\[ S_{\text{SC_ALT_SRC}} := \sqrt{3} U_{b, 480} I_{1\text{ph_SC}} \quad S_{\text{SC_ALT_SRC}} = 36 \times 10^6 \]

\[ Z_{pu, \text{SC_ALT_SRC}} := \frac{S_b}{S_{\text{SC_ALT_SRC}}} \quad Z_{pu, \text{SC_ALT_SRC}} = 0.000833 \]

\[ Z_{pu, \text{SC_ALT_SRC}} := 2Z' \left( X_{R, \text{ALT_SRC}}, Z_{pu, \text{SC_ALT_SRC}} \right) \]

\[ Z_{pu, \text{SC_ALT_SRC}} = 0.000274 + 0.001644i \]
Cables:

\[ Z_{c(2')} = 0.2 + 0.057i \]
\[ Z_{pu_2} := 2 \cdot Z_{c(2')} \cdot \left( \frac{100}{1000} \right) \cdot \frac{1}{Z_{b(120)}} \quad Z_{pu_2} = 0.083333 + 0.02375i \]
\[ Z_{c(14')} = 3.1 + 0.073i \]
\[ Z_{pu_{14}} := 2 \cdot Z_{c(14')} \cdot \left( \frac{25}{1000} \right) \cdot \frac{1}{Z_{b(120)}} \quad Z_{pu_{14}} = 0.322917 + 0.007604i \]
\[ Z_{c(8')} = 0.78 + 0.065i \]
\[ Z_{pu_8} := 2 \cdot Z_{c(8')} \cdot \left( \frac{150}{1000} \right) \cdot \frac{1}{Z_{b(120)}} \quad Z_{pu_8} = 0.4875 + 0.040625i \]
\[ Z_{c(500')} = 0.029 + 0.048i \]
\[ Z_{pu_{500}} := 2 \cdot Z_{c(500')} \cdot \left( \frac{1000}{1000} \right) \cdot \frac{1}{Z_{b(120)}} \quad Z_{pu_{500}} = 0.120833 + 0.2i \]
\[ Z_{c(1/0')} = 0.12 + 0.055i \]
\[ Z_{pu_{1/0}} := 2 \cdot Z_{c(1/0')} \cdot \left( \frac{1000}{1000} \right) \cdot \frac{1}{Z_{b(120)}} \quad Z_{pu_{1/0}} = 0.5 + 0.229167i \]
\[ Z_{c(6')} = 0.49 + 0.064i \]
\[ Z_{pu_6} := 2 \cdot Z_{c(6')} \cdot \left( \frac{150}{1000} \right) \cdot \frac{1}{Z_{b(120)}} \quad Z_{pu_6} = 0.30625 + 0.04i \]

Transformers:

\[ S_{nT30kva} := 30000 \]
\[ Z_{T30kva} := 0.02 \quad X_{R_{T30kva}} := 3 \]
\[ Z_{pu_{T30kva}} := Z \left( X_{R_{T30kva}}, Z_{T30kva} \right) \left( \frac{S_b}{S_{nT30kva}} \right) \]
\[ Z_{pu_{T30kva}} = 0.006325 + 0.018974i \]
\[ S_{nT10kva} := 10000 \]
\[ Z_{T10kva} := 0.02 \quad X_{R_{T10kva}} := 3 \]
\[ Z_{pu\text{T10kva}} := Z(\frac{S_b}{Z_{pu\text{T10kva}}}) \]
\[ Z_{pu\text{T10kva}} = 0.018974 + 0.056921i \]

### 2.1. SHORT CIRCUIT CALCS (PHASE 1 - PWM)

\[ Z_{FPH1AP} := Z_{pu\text{PWM_UPS}} \]
\[ \text{Isc}_{FPH1AP} := \frac{S_b}{Z_{FPH1AP} \cdot U_{b\_120}} \]
\[ \text{Isc}_{FPH1AP} = -375i \]
\[ \text{Isc}_{FPH1AP} = 375 \]

\[ Z_{FPH1BP} := Z_{pu\text{PWM_UPS}} + Z_{pu\_2} \]
\[ \text{Isc}_{FPH1BP} := \frac{S_b}{Z_{FPH1BP} \cdot U_{b\_120}} \]
\[ \text{Isc}_{FPH1BP} = 43.077933 - 356.900672i \]
\[ \text{Isc}_{FPH1BP} = 359.491026 \]

\[ Z_{FPH1CP} := Z_{pu\text{PWM_UPS}} + Z_{pu\_2} + Z_{pu\_14} \]
\[ \text{Isc}_{FPH1CP} := \frac{S_b}{Z_{FPH1CP} \cdot U_{b\_120}} \]
\[ \text{Isc}_{FPH1CP} = 155.705714 - 267.534356i \]
\[ \text{Isc}_{FPH1CP} = 309.546282 \]

### 2.2. SHORT CIRCUIT CALCS (PHASE 2 - PWM)

\[ Z_{FPH2AP} := Z_{pu\text{PWM_UPS}} + \frac{1}{2} Z_{pu\_500} \]
\[ \text{Isc}_{FPH2AP} := \frac{S_b}{Z_{FPH2AP} \cdot U_{b\_120}} \]
\[ \text{Isc}_{FPH2AP} = 25.538473 - 324.074414i \]
\[ \text{Isc}_{FPH2AP} = 325.079128 \]
2.3. SHORT CIRCUIT CALCS (PHASE 2 ALT - PWM)

\[ Z_{FPH2A1P} := Z_{puPWM_UPS} + Z_{puT10kva} \]

\[ \text{Isc}_{FPH2A1P} := \frac{S_b}{Z_{FPH2A1P}U_{b_480}} \]

\[ \text{Isc}_{FPH2A1P} = 2.263343 - 86.315811i \]

\[ \boxed{\text{Isc}_{FPH2A1P} = 86.34548} \]

\[ \text{Isc}_{FPH2A1P_{120}} = \frac{480}{120} \cdot |\text{Isc}_{FPH2A1P}| \]

\[ \boxed{\text{Isc}_{FPH2A1P_{120}} = 345.381921} \]

\[ Z_{FPH2A2P} := Z_{puPWM_UPS} + Z_{puT10kva} + Z_{pu1_0} \]

\[ \text{Isc}_{FPH2A2P} := \frac{S_b}{Z_{FPH2A2P}U_{b_480}} \]

\[ \text{Isc}_{FPH2A2P} = 27.556331 - 50.589106i \]

\[ \boxed{\text{Isc}_{FPH2A2P} = 57.60737} \]

\[ \text{Isc}_{FPH2A2P_{120}} = \frac{480}{120} \cdot |\text{Isc}_{FPH2A2P}| \]

\[ \boxed{\text{Isc}_{FPH2A2P_{120}} = 230.429478} \]

\[ Z_{FPH2A3P} := Z_{puPWM_UPS} + Z_{puT10kva} + Z_{pu1_0} + Z_{puT10kva} \]

\[ \text{Isc}_{FPH2A3P} := \frac{S_b}{Z_{FPH2A3P}U_{b_120}} \]

\[ \text{Isc}_{FPH2A3P} = 102.753351 - 192.858143i \]

\[ \boxed{\text{Isc}_{FPH2A3P} = 218.523487} \]
\[ Z_{FPH2A4P} := Z_{puPWM_UPS} + Z_{puT10kva} + Z_{pu1_0} + Z_{puT10kva} + Z_{pu6} \]

\[ Z_{FPH2A4P} = 0.844197 + 1.049675i \]

\[ I_{scFPH2A4P} := \frac{S_b}{Z_{FPH2A4P} U_b_{120}} \]

\[ I_{scFPH2A4P} = 116.313472 - 144.624222i \]

\[ |I_{scFPH2A4P}| = 185.593613 \]

**3.1. SHORT CIRCUIT CALCS (PHASE 1 - FERRO)**

\[ Z_{FPH1AF} := Z_{puFERRO_UPS} \]

\[ Z_{FPH1AF} = 0.2i \]

\[ I_{scFPH1AF} := \frac{S_b}{Z_{FPH1AF} U_b_{120}} \]

\[ I_{scFPH1AF} = -1250i \]

\[ |I_{scFPH1AF}| = 1250 \]

\[ Z_{FPH1BF} := Z_{puFERRO_UPS} + Z_{pu2} \]

\[ Z_{FPH1BF} = 0.083333 + 0.22375i \]

\[ I_{scFPH1BF} := \frac{S_b}{Z_{FPH1BF} U_b_{120}} \]

\[ I_{scFPH1BF} = 365.442536 - 981.213208i \]

\[ |I_{scFPH1BF}| = 1047.05664 \]

\[ Z_{FPH1CF} := Z_{puFERRO_UPS} + Z_{pu2} + Z_{pu14} \]

\[ Z_{FPH1CF} = 0.40625 + 0.231354i \]

\[ I_{scFPH1CF} := \frac{S_b}{Z_{FPH1CF} U_b_{120}} \]

\[ I_{scFPH1CF} = 464.681223 - 264.629999i \]

\[ |I_{scFPH1CF}| = 534.750106 \]

**3.2. SHORT CIRCUIT CALCS (PHASE 2 - FERRO)**

\[ Z_{FPH2AF} := Z_{puFERRO_UPS} + \frac{1}{2} Z_{pu500} \]

\[ Z_{FPH2AF} = 0.060417 + 0.3i \]
\[ \text{Isc}_{FPH2AF} := \frac{S_b}{Z_{FPH2AF} U_b_{120}} \]
\[ \text{Isc}_{FPH2AF} = 161.282847 - 800.85276i \]
\[ \text{Isc}_{FPH2BF} := \frac{S_b}{Z_{FPH2BF} U_b_{120}} \]
\[ \text{Isc}_{FPH2BF} = 366.601493 - 339.939566i \]

**3.3. SHORT CIRCUIT CALCS (PHASE 2 ALT - FERRO)**

\[ Z_{FPH2A1F} := Z_{pu \text{FERRO\_UPS}} + Z_{pu T10kva} \]
\[ Z_{FPH2A1F} = 0.018974 + 0.256921i \]
\[ \text{Isc}_{FPH2A1F} = 17.867752 - 241.945905i \]
\[ \text{Isc}_{FPH2A1F} = 242.604776 \]
\[ \text{Isc}_{FPH2A1F_{120}} := \frac{480}{120} \left| \text{Isc}_{FPH2A1F} \right| \]
\[ \text{Isc}_{FPH2A1F_{120}} = 970.419104 \]

\[ Z_{FPH2A2F} := Z_{pu \text{FERRO\_UPS}} + Z_{pu T10kva} + Z_{pu T10kva} \]
\[ Z_{FPH2A2F} = 0.518974 + 0.486088i \]
\[ \text{Isc}_{FPH2A2F} = 64.151304 - 60.086204i \]
\[ \text{Isc}_{FPH2A2F} = 87.896199 \]
\[ \text{Isc}_{FPH2A2F_{120}} := \frac{480}{120} \left| \text{Isc}_{FPH2A2F} \right| \]
\[ \text{Isc}_{FPH2A2F_{120}} = 351.584794 \]

\[ Z_{FPH2A3F} := Z_{pu \text{FERRO\_UPS}} + Z_{pu T10kva} + Z_{pu T10kva} + Z_{pu T10kva} \]
\[ Z_{FPH2A3F} = 0.537947 + 0.543009i \]
\[ \text{Isc}_{\text{FPH2A3F}} := \frac{S_b}{Z_{\text{FPH2A3F}} \cdot U_{b_{120}}} \]
\[ \text{Isc}_{\text{FPH2A3F}} = 230.188813 - 232.354567i \]
\[ \boxed{\text{Isc}_{\text{FPH2A3F}} = 327.071145} \]
\[ Z_{\text{FPH2A4F}} := Z_{\text{puFERRO_UPS}} + Z_{\text{puT10kva}} + Z_{\text{pu10kva}} + Z_{\text{pu6}} \]
\[ Z_{\text{FPH2A4F}} = 0.844197 + 0.583009i \]
\[ \text{Isc}_{\text{FPH2A4F}} := \frac{S_b}{Z_{\text{FPH2A4F}} \cdot U_{b_{120}}} \]
\[ \text{Isc}_{\text{FPH2A4F}} = 200.508932 - 138.47289i \]
\[ \boxed{\text{Isc}_{\text{FPH2A4F}} = 243.677191} \]

4.1. SHORT CIRCUIT CALCS (PHASE 1 - ALT SOURCE)

\[ Z_{\text{FPH1AA}} := Z_{\text{puSC_ALT_SRC}} + Z_{\text{puT30kva}} \]
\[ Z_{\text{FPH1AA}} = 0.006599 + 0.020618i \]
\[ \text{Isc}_{\text{FPH1AA}} := \frac{S_b}{Z_{\text{FPH1AA}} \cdot U_{b_{120}}} \]
\[ \text{Isc}_{\text{FPH1AA}} = 3520.139957 - 10998.930699i \]
\[ \boxed{\text{Isc}_{\text{FPH1AA}} = 11548.500415} \]
\[ Z_{\text{FPH1BA}} := Z_{\text{puSC_ALT_SRC}} + Z_{\text{puT30kva}} + Z_{\text{pu2}} \]
\[ Z_{\text{FPH1BA}} = 0.089932 + 0.044368i \]
\[ \text{Isc}_{\text{FPH1BA}} := \frac{S_b}{Z_{\text{FPH1BA}} \cdot U_{b_{120}}} \]
\[ \text{Isc}_{\text{FPH1BA}} = 2235.724982 - 1102.988939i \]
\[ \boxed{\text{Isc}_{\text{FPH1BA}} = 2493.00036} \]

\[ Z_{\text{FPH1CA}} := Z_{\text{puSC_ALT_SRC}} + Z_{\text{puT30kva}} + Z_{\text{pu2}} + Z_{\text{pu14}} \]
\[ Z_{\text{FPH1CA}} = 0.412849 + 0.051972i \]
\[ \text{Isc}_{\text{FPH1CA}} := \frac{S_b}{Z_{\text{FPH1CA}} \cdot U_{b_{120}}} \]
\[ \text{Isc}_{\text{FPH1CA}} = 596.102338 - 75.040895i \]
\[ \boxed{\text{Isc}_{\text{FPH1CA}} = 600.807068} \]
4.2. SHORT CIRCUIT CALCS (PHASE 2 - ALT SOURCE)

\[ Z_{FPH2AA} := \frac{S_b}{Z_{FPH2AA} \cdot U_{b_{120}}} \]

\[ \text{IscFPH2AA} := \frac{S_b}{Z_{FPH2AA} \cdot U_{b_{120}}} \]

\[ \text{IscFPH2AA} = 879.942513 - 1583.768623i \]

\[ \left| \text{IscFPH2AA} \right| = 1811.800727 \]

\[ Z_{FPH2BA} := \frac{S_b}{Z_{FPH2BA} \cdot U_{b_{120}}} \]

\[ \text{IscFPH2BA} := \frac{S_b}{Z_{FPH2BA} \cdot U_{b_{120}}} \]

\[ \text{IscFPH2BA} = 565.125389 - 243.175925i \]

\[ \left| \text{IscFPH2BA} \right| = 615.224541 \]

4.3. SHORT CIRCUIT CALCS (PHASE 2 ALT - ALT SOURCE)

\[ Z_{FPH2A1A} := \frac{S_b}{Z_{FPH2A1A} \cdot U_{b_{480}}} \]

\[ \text{IscFPH2A1A} := \frac{S_b}{Z_{FPH2A1A} \cdot U_{b_{480}}} \]

\[ \text{IscFPH2A1A} = 239.757017 - 726.977813i \]

\[ \left| \text{IscFPH2A1A} \right| = 765.493415 \]

\[ \text{IscFPH2A1A}_{120} := \frac{480}{120} \left| \text{IscFPH2A1A} \right| \]

\[ \left| \text{IscFPH2A1A}_{120} \right| = 3061.973659 \]

\[ Z_{FPH2A2A} := \frac{S_b}{Z_{FPH2A2A} \cdot U_{b_{480}}} \]

\[ \text{IscFPH2A2A} := \frac{S_b}{Z_{FPH2A2A} \cdot U_{b_{480}}} \]

\[ \text{IscFPH2A2A} = 88.708529 - 51.767154i \]

\[ \left| \text{IscFPH2A2A} \right| = 102.708526 \]
\[ V_{d}(A,Z,\text{ckt},L) := A : Z : \text{ckt} : \frac{L}{1000} \]

Voltage drop from R1 to load:

\[ |V_{d}(8,Zc(\"14\"),2,25)| = 1.240344 \quad [\text{V}] \quad \frac{|V_{d}(8,Zc(\"14\"),2,25)|}{120} \cdot 100 = 1.03362 \quad [%] \]

Voltage drop from L1 panel to R1 panel:

\[ |V_{d}(40,Zc(\"2\"),2,100)| = 1.663712 \quad [\text{V}] \quad \frac{|V_{d}(40,Zc(\"2\"),2,100)|}{120} \cdot 100 = 1.38642 \quad [%] \]
Voltage drop from BP1 panel to skid:

\[
\begin{align*}
Vd(40, Zc(2^\prime), 2, 100) & \quad \text{...} = 2.904055 \text{ V} \\
+ Vd(8, Zc(14^\prime), 2, 25) & \quad \text{...} + \frac{Vd(8, Zc(14^\prime), 2, 25)}{120} \cdot 100 = 2.420046 \% \\
\end{align*}
\]

Is this assumed that between UPS and BP1 and L1 panels there is no Vd?

Voltage drop for 480V alternate connection:

\[
\begin{align*}
Vd(40, Zc(2^\prime), 2, 100) & \quad \text{...} = 4.824055 \text{ V} \\
+ Vd(8, Zc(14^\prime), 2, 25) & \quad \text{...} + \frac{Vd(8, Zc(14^\prime), 2, 25)}{120} \cdot 100 = 4.020046 \%
+ 200 \times Zpu_{T30kva} \cdot Z_{b_120} \\
\end{align*}
\]

5.2. VOLTAGE DROP CALCS (PWM/FERRO - PHASE 2)

\[
Vd(A, Z, ckt, L) := A \cdot Z \cdot ckt \cdot \frac{L}{1000}
\]

Voltage drop from R2 to skid

\[
\begin{align*}
Vd(8, Zc(6^\prime), 2, 150) & \quad = 1.185989 \text{ V} \\
\frac{Vd(8, Zc(6^\prime), 2, 150)}{120} \cdot 100 = 0.988324 \%
\end{align*}
\]

Voltage drop from BP1 panel to R2 panel:

\[
\begin{align*}
Vd\left(40, \frac{1}{2} Zc(500^\prime), 2, 500\right) & \quad = 1.121606 \text{ V} \\
\frac{Vd\left(40, \frac{1}{2} Zc(500^\prime), 2, 500\right)}{120} \cdot 100 = 0.934672 \\
\end{align*}
\]

Voltage drop from BP1 panel to skid:
System layout need to be redesigned i.e. R2 panel load changed, UPS location and/or qty of conductors.

Voltage drop for 480V alternate connection:

$$\left| V_d \left( 40, \frac{1}{2} Z_c \left( \frac{500}{2}, 2, 1000 \right) \right) \right| \quad \cdots \quad 3.429201 \quad \text{[V]}$$

$$\left| V_d \left( 8, Z_c \left( 6 \right), 2, 150 \right) \right| \quad \cdots \quad 5.349201 \quad \text{[V]}$$

$$\left| V_d \left( 40, \frac{1}{2} Z_c \left( \frac{500}{2}, 2, 1000 \right) \right) \right| \quad \cdots \quad 4.457667 \quad \%$$

5.3. VOLTAGE DROP CALCS (PWM/FERRO - 2ALT)

$$V_d(A,Z,ckt,L) := A \cdot Z \cdot \text{ckt} \cdot \frac{L}{1000}$$

$A$ - current in conductor

$Z$ - impedance of conductor in ohms/1000ft

$ckt$ - circuit configuration (1 - 3ph; 2 - single phase)

$L$ - conductor length one way

Voltage drop from AR2 to skid

$$\left| V_d \left( 8, Z_c \left( 6 \right), 2, 150 \right) \right| = 1.185989 \quad \text{[V]}$$

$$\left| V_d \left( 8, Z_c \left( 6 \right), 2, 150 \right) \right| \cdot \frac{100}{120} = 0.988324 \quad \%$$

Voltage drop from BP1 panel to skid:

Assumption: T1 and T2 taps are at $TAP_{POS} := -2.5\%$.

$$\left| V_d \left( 40, \frac{120}{480}, Z_c \left( \frac{1}{0} \right), 2, 1000 \right) \right| \cdots \quad 3.130064 \quad \text{[V]}$$

$$\left| V_d \left( 8, Z_c \left( 6 \right), 2, 150 \right) \right| + \frac{TAP_{POS}}{100} \cdot \frac{120}{100} \cdot \frac{120}{100} \cdot \frac{120}{100} = 2.608387 \quad \%$$

System layout need to be redesigned i.e. AR2 panel load changed, UPS location and/or qty of conductors.
Voltage drop for 480V alternate connection:

\[
\begin{align*}
\frac{V_d}{480} \left( \frac{120}{Zc(1/0), 2, 1000} \right) + 2 \left[ 40-Zpu_{T10kva}Z_{b\_120} \right] + \\
\left( V_d(8, Zc(6), 2, 150) \right) + \frac{TAP\_POS}{100} \cdot 120 + \\
\left( 200-Zpu_{T30kva}Z_{b\_120} \right) \\
\end{align*}
\]

\[
\begin{align*}
\frac{V_d}{480} \left( \frac{120}{Zc(1/0), 2, 1000} \right) + 2 \left[ 40-Zpu_{T10kva}Z_{b\_120} \right] + \\
\left( V_d(8, Zc(6), 2, 150) \right) \cdot 100 + TAP\_POS + \frac{200-Zpu_{T30kva}Z_{b\_120}}{120} \cdot 100 = 4.208387 \\
\end{align*}
\]

6. VOLTAGE AT UPS STATIC SWITCH DURING FAULTS.

Voltage at % of nominal voltage at the switch

\[
\begin{align*}
Usc_{FPH1AP} & := \frac{0}{Zpu_{PWM\_UPS}} \cdot 100 & |Usc_{FPH1AP}| = 0 \\
Usc_{FPH1BP} & := \frac{Zpu_2}{Zpu_{PWM\_UPS} + Zpu_2} \cdot 100 & |Usc_{FPH1BP}| = 12.460195 \\
Usc_{FPH1CP} & := \frac{Zpu_2 + Zpu_{14}}{Zpu_{PWM\_UPS} + Zpu_2 + Zpu_{14}} \cdot 100 & |Usc_{FPH1CP}| = 50.450863 \\
Usc_{FPH2AP} & := \frac{\frac{1}{2}Zpu_{500}}{Zpu_{PWM\_UPS} + \frac{1}{2}Zpu_{500}} \cdot 100 & |Usc_{FPH2AP}| = 15.192112 \\
Usc_{FPH2BP} & := \frac{\frac{1}{2}Zpu_{500} + Zpu_{6}}{Zpu_{PWM\_UPS} + \frac{1}{2}Zpu_{500} + Zpu_{6}} \cdot 100 & |Usc_{FPH2BP}| = 44.294027 \\
Usc_{FPH2AP} & := \frac{Zpu_{T10kva}}{Zpu_{PWM\_UPS} + Zpu_{T10kva}} \cdot 100 & |Usc_{FPH2AP}| = 8.289166 \\
Usc_{FPH2BP} & := \frac{Zpu_{T10kva} + Zpu_{1\_0}}{Zpu_{PWM\_UPS} + Zpu_{T10kva} + Zpu_{1\_0}} \cdot 100 & |Usc_{FPH2BP}| = 54.621397 \\
\end{align*}
\]
\[
\text{UscFPH2A3P} := \frac{Z_{pu \cdot T10kva} + Z_{pu1 \cdot 0} + Z_{pu \cdot T10kva}}{Z_{pu \cdot PWM \cdot UPS} + Z_{pu \cdot T10kva} + Z_{pu1 \cdot 0} + Z_{pu \cdot T10kva}} \cdot 100 \\
|\text{UscFPH2A3P}| = 55.767076
\]

\[
\text{UscFPH2A4P} := \frac{Z_{pu \cdot T10kva} + Z_{pu1 \cdot 0} + Z_{pu \cdot T10kva} + Z_{pu6}}{Z_{pu \cdot PWM \cdot UPS} + Z_{pu \cdot T10kva} + Z_{pu1 \cdot 0} + Z_{pu \cdot T10kva} + Z_{pu6}} \cdot 100 \\
|\text{UscFPH2A4P}| = 68.819544
\]

\[
\text{UscFPH1AF} := \frac{0}{Z_{pu \cdot FERRO \cdot UPS}} \cdot 100 \\
|\text{UscFPH1AF}| = 0
\]

\[
\text{UscFPH1BF} := \frac{Z_{pu2}}{Z_{pu \cdot FERRO \cdot UPS} + Z_{pu2}} \cdot 100 \\
|\text{UscFPH1BF}| = 36.291671
\]

\[
\text{UscFPH1CF} := \frac{Z_{pu2} + Z_{pu14}}{Z_{pu \cdot FERRO \cdot UPS} + Z_{pu2} + Z_{pu14}} \cdot 100 \\
|\text{UscFPH1CF}| = 87.155316
\]

\[
\text{UscFPH2AF} := \frac{\frac{1}{2} Z_{pu500}}{Z_{pu \cdot FERRO \cdot UPS} + \frac{1}{2} Z_{pu500}} \cdot 100 \\
|\text{UscFPH2AF}| = 38.178142
\]

\[
\text{UscFPH2AF} := \frac{\frac{1}{2} Z_{pu500} + Z_{pu6}}{Z_{pu \cdot FERRO \cdot UPS} + \frac{1}{2} Z_{pu500} + Z_{pu6}} \cdot 100 \\
|\text{UscFPH2AF}| = 78.490016
\]

\[
\text{UscFPH2A1F} := \frac{Z_{pu \cdot T10kva}}{Z_{pu \cdot FERRO \cdot UPS} + Z_{pu \cdot T10kva}} \cdot 100 \\
|\text{UscFPH2A1F}| = 23.290058
\]

\[
\text{UscFPH2A2F} := \frac{Z_{pu \cdot T10kva} + Z_{pu1 \cdot 0}}{Z_{pu \cdot FERRO \cdot UPS} + Z_{pu \cdot T10kva} + Z_{pu1 \cdot 0}} \cdot 100 \\
|\text{UscFPH2A2F}| = 83.34026
\]

\[
\text{UscFPH2A3F} := \frac{Z_{pu \cdot T10kva} + Z_{pu1 \cdot 0} + Z_{pu \cdot T10kva}}{Z_{pu \cdot FERRO \cdot UPS} + Z_{pu \cdot T10kva} + Z_{pu1 \cdot 0} + Z_{pu \cdot T10kva}} \cdot 100 \\
|\text{UscFPH2A3F}| = 83.468379
\]

\[
\text{UscFPH2A4F} := \frac{Z_{pu \cdot T10kva} + Z_{pu1 \cdot 0} + Z_{pu \cdot T10kva} + Z_{pu6}}{Z_{pu \cdot FERRO \cdot UPS} + Z_{pu \cdot T10kva} + Z_{pu1 \cdot 0} + Z_{pu \cdot T10kva} + Z_{pu6}} \cdot 100 \\
|\text{UscFPH2A4F}| = 90.357383
\]
### 7. S/C CURRENTS MATRIX

<table>
<thead>
<tr>
<th>PWM</th>
<th>FERRO</th>
<th>ALT SOURCE</th>
</tr>
</thead>
<tbody>
<tr>
<td>$</td>
<td>I_{SCFPH1A1P}</td>
<td>= 375</td>
</tr>
<tr>
<td>$</td>
<td>I_{SCFPH1BP}</td>
<td>= 359</td>
</tr>
<tr>
<td>$</td>
<td>I_{SCFPH1CP}</td>
<td>= 310</td>
</tr>
<tr>
<td>$</td>
<td>I_{SCFPH2AP}</td>
<td>= 325</td>
</tr>
<tr>
<td>$</td>
<td>I_{SCFPH2BP}</td>
<td>= 282</td>
</tr>
<tr>
<td>$</td>
<td>I_{SCFPH2A1P}</td>
<td>= 86</td>
</tr>
<tr>
<td>$</td>
<td>I_{SCFPH2A2P}</td>
<td>= 58</td>
</tr>
<tr>
<td>$</td>
<td>I_{SCFPH2A3P}</td>
<td>= 219</td>
</tr>
<tr>
<td>$</td>
<td>I_{SCFPH2A4P}</td>
<td>= 186</td>
</tr>
</tbody>
</table>
480V CALCS REVISED

1.0 PRELIMINARIES

Base quantities:

\[ S_b := 50000 \]

\[ U_{b_{120}} := 120 \]

\[ U_{b_{480}} := 480 \]

\[ Z_{b_{120}} := \frac{\left( \frac{U_{b_{120}}}{1000} \right)^2}{S_b \times 10^6} \]

\[ Z_{b_{120}} = 0.288 \]

\[ Z_{b_{480}} := \frac{\left( \frac{U_{b_{480}}}{1000} \right)^2}{S_b \times 10^6} \]

\[ Z_{b_{480}} = 4.608 \]

A) Equations and Data

Data from NEC Table 9, ohms/1000ft

<table>
<thead>
<tr>
<th>Size</th>
<th>Zmetalic_cond</th>
<th>Znonmetalic_cond</th>
</tr>
</thead>
<tbody>
<tr>
<td>&quot;14&quot;</td>
<td>3.1 + j0.073</td>
<td>3.1 + j0.58</td>
</tr>
<tr>
<td>&quot;12&quot;</td>
<td>2.0 + j0.068</td>
<td>2.0 + j0.054</td>
</tr>
<tr>
<td>&quot;10&quot;</td>
<td>1.2 + j0.063</td>
<td>1.2 + j0.050</td>
</tr>
<tr>
<td>&quot;8&quot;</td>
<td>0.78 + j0.065</td>
<td>0.78 + j0.052</td>
</tr>
<tr>
<td>&quot;6&quot;</td>
<td>0.49 + j0.064</td>
<td>0.49 + j0.051</td>
</tr>
<tr>
<td>&quot;4&quot;</td>
<td>0.31 + j0.060</td>
<td>0.31 + j0.048</td>
</tr>
<tr>
<td>&quot;2&quot;</td>
<td>0.20 + j0.057</td>
<td>0.20 + j0.045</td>
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<tr>
<td>&quot;1&quot;</td>
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<td>0.16 + j0.046</td>
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<tr>
<td>&quot;1/0&quot;</td>
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<td>0.13 + j0.044</td>
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<tr>
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<td>0.057 + j0.041</td>
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<tr>
<td>&quot;300&quot;</td>
<td>0.045 + j0.051</td>
<td>0.049 + j0.041</td>
</tr>
<tr>
<td>&quot;350&quot;</td>
<td>0.039 + j0.050</td>
<td>0.043 + j0.040</td>
</tr>
<tr>
<td>&quot;400&quot;</td>
<td>0.035 + j0.049</td>
<td>0.038 + j0.040</td>
</tr>
<tr>
<td>&quot;500&quot;</td>
<td>0.029 + j0.048</td>
<td>0.032 + j0.039</td>
</tr>
<tr>
<td>&quot;750&quot;</td>
<td>0.021 + j0.048</td>
<td>0.024 + j0.038</td>
</tr>
<tr>
<td>&quot;1000&quot;</td>
<td>0.018 + j0.046</td>
<td>0.019 + j0.037</td>
</tr>
</tbody>
</table>
\[ Zc(a) := \begin{cases} 
    i \leftarrow 0 \\
    K \leftarrow 0 \\
    I \leftarrow \text{rows}(Z\text{cable}) - 1 \\
    \text{for } i \in 0..(I) \\
    (K \leftarrow Z\text{cable}_{i,i}) \text{ if } Z\text{cable}_{i,0} = a \\
    -1 \text{ otherwise} \\
\end{cases} \]

\[ Z(XR, Z) := \begin{aligned}
    R &\leftarrow \frac{1}{Z} \\
    X &\leftarrow \frac{XR}{\left(1 + XR^2\right)^2} \\
    Z &\leftarrow R + jX
\end{aligned} \]

\[ Vd(A, Z, ckt, L) := A \cdot Z \cdot ckt \cdot \frac{L}{1000} \]

PWM Inverter Equivalent Impedance

\[ S_{\text{UPS}} := 50000 \]
\[ U_n := 240 \]
\[ I_{n\_PWM\_UPS} := \frac{S_{\text{UPS}}}{U_n} \]
\[ I_{n\_PWM\_UPS} = \frac{50000}{240} = 208.333333 \]

\[ K_{\text{SC\_PWM}} := 1.5 \]

\[ I_{\text{SC\_PWM\_UPS}} := K_{\text{SC\_PWM}} \cdot I_{n\_PWM\_UPS} \]
\[ I_{\text{SC\_PWM\_UPS}} = 1.5 \cdot 208.333333 = 312.5 \]

\[ S_{\text{SC\_PWM\_UPS}} := I_{\text{SC\_PWM\_UPS}} \cdot U_n \]
\[ S_{\text{SC\_PWM\_UPS}} = 312.5 \cdot 240 = 75000 \]

\[ X_{\text{pu\_PWM\_UPS}} := \frac{S_b}{S_{\text{SC\_PWM\_UPS}}} \]
\[ X_{\text{pu\_PWM\_UPS}} = \frac{312.5}{75000} = 0.04166667 \]
\[ Z_{pu}^{PWM\_UPS} := j X_{pu}^{PWM\_UPS} \]

**PWM Ferro Equivalent Impedance**

\[ S_{UPS} := 50000 \]
\[ U_n := 240 \]
\[ I_{n\_FERRO\_UPS} := \frac{S_{UPS}}{U_n} \]
\[ I_{n\_FERRO\_UPS} = 208.333333 \]
\[ K_{SC\_FERRO} := 5 \]
\[ I_{SC\_FERRO\_UPS} := K_{SC\_FERRO} I_{n\_FERRO\_UPS} \]
\[ I_{SC\_FERRO\_UPS} = 1041.66667 \]
\[ S_{SC\_FERRO\_UPS} := I_{SC\_FERRO\_UPS} U_n \]
\[ S_{SC\_FERRO\_UPS} = 250000 \]
\[ X_{pu\_FERRO\_UPS} := \frac{S_b}{S_{SC\_FERRO\_UPS}} \]
\[ X_{pu\_FERRO\_UPS} = 0.2 \]
\[ Z_{pu\_FERRO\_UPS} := j X_{pu\_FERRO\_UPS} \]
\[ Z_{pu\_FERRO\_UPS} = 0.2i \]

**Alternate Source Equivalent Impedance**

\[ I_{3ph\_SC} := 50000 \]
\[ K_{3ph\_1ph} := \frac{\sqrt{3}}{2} \]
\[ K_{3ph\_1ph} = 0.866025 \]
\[ X_{R\_ALT\_SRC} := 6 \]
\[ I_{1ph\_SC} := I_{3ph\_SC} K_{3ph\_1ph} \]
\[ I_{1ph\_SC} = 43301.27 \]
\[ S_{SC\_ALT\_SRC} := \sqrt{3} U_b^{480} I_{1ph\_SC} \]
\[ S_{SC\_ALT\_SRC} = 36 \times 10^6 \]
\[ Z_{pu\_SC\_ALT\_SRC} := \frac{S_b}{S_{SC\_ALT\_SRC}} \]
\[ Z_{pu\_SC\_ALT\_SRC} = 0.001389 \]
\[ Z_{pu\_SC\_ALT\_SRC} := \text{Z}(X_{R\_ALT\_SRC}, Z_{pu\_SC\_ALT\_SRC}) \]
\[ Z_{pu\_SC\_ALT\_SRC} = 0.000457 + 0.00274i \]

**Cables:**

\[ Z_c(“8”) = 0.78 + 0.065i \]
\[ Z_{pu\_8} := 2 Z_c(“8”) \left( \frac{300}{1000} \right) \frac{1}{Z_b^{480}} \]
\[ Z_{pu\_8} = 0.101563 + 0.008464i \]
Zc("10") = 1.2 + 0.063i

\[ Z_{pu10} := 2Zc("10") \cdot \left( \frac{50}{1000} \right) \cdot \frac{1}{Z_{b\_120}} \]
\[ Z_{pu10} = 0.416667 + 0.021875i \]

Transformers:

\[ S_{n\_T50kva} := 50000 \]
\[ Z_{T50kva} := 0.04 \quad X_{R\_T50kva} := 3 \]
\[ Z_{pu\_T50kva} := Z(X_{R\_T50kva}, Z_{T50kva}) \cdot \left( \frac{S_{b}}{S_{n\_T50kva}} \right) \]
\[ Z_{pu\_T50kva} = 0.012649 + 0.037947i \]
\[ S_{n\_T10kva} := 10000 \]
\[ Z_{T10kva} := 0.02 \quad X_{R\_T10kva} := 3 \]
\[ Z_{pu\_T10kva} := Z(X_{R\_T10kva}, Z_{T10kva}) \cdot \left( \frac{S_{b}}{S_{n\_T10kva}} \right) \]
\[ Z_{pu\_T10kva} = 0.031623 + 0.094868i \]

**2.1. SHORT CIRCUIT CALCS (PWM)**

\[ Z_{F1\_P} := Z_{pu\_PWM\_UPS} + Z_{pu\_T50kva} \]
\[ Z_{F1\_P} = 0.012649 + 0.704614i \]
\[ Isc_{F1\_P} := \frac{S_{b}}{Z_{F1\_P} \cdot U_{b\_480}} \]
\[ Isc_{F1\_P} = 2.653055 - 147.787453i \]
\[ |Isc_{F1\_P}| = 147.811264 \]

\[ Z_{F2\_P} := Z_{pu\_PWM\_UPS} + Z_{pu\_T50kva} + Z_{pu\_8} \]
\[ Z_{F2\_P} = 0.114212 + 0.713078i \]
\[ Isc_{F2\_P} := \frac{S_{b}}{Z_{F2\_P} \cdot U_{b\_480}} \]
\[ Isc_{F2\_P} = 22.812077 - 142.426674i \]
\[ |Isc_{F2\_P}| = 144.241979 \]
\[ Z_{F3P} := Z_{puPWM_UPS} + Z_{puT50kva} + Z_{pu8} + Z_{puT10kva} \]
\[ Z_{F3P} = 0.145834 + 0.807946i \]
\[ \text{Isc}_{F3P} := \frac{S_b}{Z_{F3P}U_{b_{-480}}} \]
\[ \text{Isc}_{F3P} = 22.537219 - 124.859807i \]
\[ |\text{Isc}_{F3P}| = 126.87749 \]
\[ \text{Isc}_{F3P\_120} := \frac{U_{b_{-480}}}{U_{b_{-120}}} \cdot \text{Isc}_{F3P} \]
\[ |\text{Isc}_{F3P\_120}| = 507.509962 \]
\[ Z_{F4P} := Z_{puPWM_UPS} + Z_{puT50kva} + Z_{pu8} \ldots \]
\[ + Z_{puT10kva} + Z_{pu10} \]
\[ Z_{F4P} = 0.562501 + 0.829821i \]
\[ \text{Isc}_{F4P} := \frac{S_b}{Z_{F4P}U_{b_{-480}}} \]
\[ \text{Isc}_{F4P} = 58.301761 - 86.00876i \]
\[ |\text{Isc}_{F4P}| = 103.9067 \]
\[ \text{Isc}_{F4P\_120} := \frac{U_{b_{-480}}}{U_{b_{-120}}} \cdot \text{Isc}_{F4P} \]
\[ |\text{Isc}_{F4P\_120}| = 415.626799 \]

**2.2. SHORT CIRCUIT CALCS (FERRO)**

\[ Z_{F1F} := Z_{puFERRO_UPS} + Z_{puT50kva} \]
\[ Z_{F1F} = 0.012649 + 0.237947i \]
\[ \text{Isc}_{F1F} := \frac{S_b}{Z_{F1F}U_{b_{-480}}} \]
\[ \text{Isc}_{F1F} = 23.206067 - 436.538329i \]
\[ |\text{Isc}_{F1F}| = 437.154702 \]
\[ Z_{F2F} := Z_{puFERRO_UPS} + Z_{puT50kva} + Z_{pu8} \]
\[ Z_{F2F} = 0.114212 + 0.246411i \]
\[ \text{Isc}_{F2F} := \frac{S_b}{Z_{F2F}U_{b,480}} \]

\[ \text{Isc}_{F2F} = 161.288255 - 347.978456i \]

\[ |\text{Isc}_{F2F}| = 383.539968 \]

\[ Z_{F3F} := Z_{pu,Ferro_UPS} + Z_{pu,T50kva} + Z_{pu_8} + Z_{pu,T10kva} \]

\[ Z_{F3F} = 0.145834 + 0.341279i \]

\[ \text{Isc}_{F3F} := \frac{S_b}{Z_{F3F}U_{b,480}} \]

\[ \text{Isc}_{F3F} = 110.288764 - 258.095927i \]

\[ |\text{Isc}_{F3F}| = 280.672619 \]

\[ \text{Isc}_{F3F}_{120} := \frac{U_{b,480}}{U_{b,120}}^{-\text{Isc}_{F3F}} \]

\[ |\text{Isc}_{F3F}_{120}| = 1122.690475 \]

\[ Z_{F4F} := Z_{pu,Ferro_UPS} + Z_{pu,T50kva} + Z_{pu_8} \ldots \]

\[ + Z_{pu,T10kva} + Z_{pu_{10}} \]

\[ Z_{F4F} = 0.562501 + 0.829821i \]

\[ \text{Isc}_{F4F} := \frac{S_b}{Z_{F4F}U_{b,480}} \]

\[ \text{Isc}_{F4F} = 130.705721 - 84.384432i \]

\[ |\text{Isc}_{F4F}| = 155.578654 \]

\[ \text{Isc}_{F4F}_{120} := \frac{U_{b,480}}{U_{b,120}}^{-\text{Isc}_{F4F}} \]

\[ |\text{Isc}_{F4F}_{120}| = 622.314618 \]

2.3. SHORT CIRCUIT CALCS (ALT)

\[ Z_{F1A} := Z_{pu,SC_ALT_SRC} + Z_{pu,T50kva} + Z_{pu,T50kva} \]

\[ Z_{F1A} = 0.025755 + 0.078635i \]

\[ \text{Isc}_{F1A} := \frac{S_b}{Z_{F1A}U_{b,480}} \]

\[ \text{Isc}_{F1A} = 391.837234 - 1196.354881i \]
$$[\text{Isc}_{F1A}] = 1258.888962$$

$$Z_{F2A} := Z_{pu\text{SC}_\text{ALT}_\text{SRC}} + Z_{pu\text{T}50kva} + Z_{pu\text{T}10kva} + Z_{pu8}$$

$$Z_{F2A} = 0.127317 + 0.087098i$$

$$\text{Isc}_{F2A} := \frac{S_b}{Z_{F2A}U_{b\_480}}$$

$$\text{Isc}_{F2A} = 557.33455 - 381.274165i$$

$$[\text{Isc}_{F2A}] = 675.271641$$

$$Z_{F3A} := Z_{pu\text{SC}_\text{ALT}_\text{SRC}} + Z_{pu\text{T}50kva} + Z_{pu\text{T}10kva} + Z_{pu8} + Z_{pu10}$$

$$Z_{F3A} = 0.15894 + 0.181967i$$

$$\text{Isc}_{F3A} := \frac{S_b}{Z_{F3A}U_{b\_480}}$$

$$\text{Isc}_{F3A} = 283.625017 - 324.715014i$$

$$[\text{Isc}_{F3A}] = 431.141497$$

$$\text{Isc}_{F3A\_120} := \frac{U_{b\_480}}{U_{b\_120}} \cdot \text{Isc}_{F3A}$$

$$[\text{Isc}_{F3A\_120}] = 1724.565989$$

$$Z_{F4A} := Z_{pu\text{SC}_\text{ALT}_\text{SRC}} + Z_{pu\text{T}50kva} + Z_{pu\text{T}10kva} + Z_{pu8} + Z_{pu10}$$

$$Z_{F4A} = 0.575607 + 0.203842i$$

$$\text{Isc}_{F4A} := \frac{S_b}{Z_{F4A}U_{b\_480}}$$

$$\text{Isc}_{F4A} = 160.802176 - 56.945398i$$

$$[\text{Isc}_{F4A}] = 170.587567$$

$$\text{Isc}_{F4A\_120} := \frac{U_{b\_480}}{U_{b\_120}} \cdot \text{Isc}_{F4A}$$

$$[\text{Isc}_{F4A\_120}] = 682.350268$$

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3.1. VOLTAGE DROP CALCS (PWM/FERRO/ALT)

\[ Vd(A,Z,ckt,L) := \frac{A \cdot Z \cdot ckt \cdot L}{1000} \]

Voltage drop from PB#1 to PP#1:

\[ |Vd(6,Zc(10"),2,50)| = 0.720992 \quad [V] \]

\[ \frac{|Vd(6,Zc(10"),2,50)|}{120} \cdot 100 = 0.600826 \quad [%] \]

Voltage drop from PB#2 panel to PB#1 panel:

\[ |Vd(12,Zc(8"),2,300)| ... = 11.165066 \quad [V] \]

\[ + \left| \frac{12 \cdot Zpu_{T10kva} \cdot Z_{b_{480}}}{480} \right| \cdot 100 = 2.326055 \quad [%] \]

Voltage drop from PB#2 to PP#1:

\[ N/A \]

Voltage drop from MCC to PP#1:

\[ N/A \]

4. VOLTAGE AT UPS STATIC SWITCH DURING FAULTS.

Voltage at % of nominal voltage at the switch

\[ Usc_{F1P} := \frac{Zpu_{T50kva}}{Zpu_{PWM_{UPS}} + Zpu_{T50kva}} \cdot 100 \]

\[ |Usc_{F1P}| = 5.675953 \]

\[ Usc_{F2P} := \frac{Zpu_{T50kva} + Zpu_8}{Zpu_{PWM_{UPS}} + Zpu_{T50kva} + Zpu_8} \cdot 100 \]

\[ |Usc_{F2P}| = 17.071035 \]
\[ \text{UsC}_{F3P} := \frac{Z_{pu}\text{T50kva} + Z_{pu}\text{8} + Z_{pu}\text{T10kva}}{Z_{pu}\text{PWM_UPS} + Z_{pu}\text{T50kva} + Z_{pu}\text{8} + Z_{pu}\text{T10kva}} \cdot 100 \]

\[ |\text{UsC}_{F3P}| = 24.731429 \]

\[ \text{UsC}_{F4P} := \frac{Z_{pu}\text{T50kva} + Z_{pu}\text{8} + Z_{pu}\text{T10kva} + Z_{pu}\text{10}}{Z_{pu}\text{PWM_UPS} + Z_{pu}\text{T50kva} + Z_{pu}\text{8} + Z_{pu}\text{T10kva} + Z_{pu}\text{10}} \cdot 100 \]

\[ |\text{UsC}_{F4P}| = 58.422316 \]

\[ \text{UsC}_{F1F} := \frac{Z_{pu}\text{T50kva}}{Z_{pu}\text{FERRO_UPS} + Z_{pu}\text{T50kva}} \cdot 100 \]

\[ |\text{UsC}_{F1F}| = 16.786741 \]

\[ \text{UsC}_{F2F} := \frac{Z_{pu}\text{T50kva} + Z_{pu}\text{8}}{Z_{pu}\text{FERRO_UPS} + Z_{pu}\text{T50kva} + Z_{pu}\text{8}} \cdot 100 \]

\[ |\text{UsC}_{F2F}| = 45.391947 \]

\[ \text{UsC}_{F3F} := \frac{Z_{pu}\text{T50kva} + Z_{pu}\text{8} + Z_{pu}\text{T10kva}}{Z_{pu}\text{FERRO_UPS} + Z_{pu}\text{T50kva} + Z_{pu}\text{8} + Z_{pu}\text{T10kva}} \cdot 100 \]

\[ |\text{UsC}_{F3F}| = 54.709744 \]

\[ \text{UsC}_{F4F} := \frac{Z_{pu}\text{T50kva} + Z_{pu}\text{8} + Z_{pu}\text{T10kva} + Z_{pu}\text{10}}{Z_{pu}\text{FERRO_UPS} + Z_{pu}\text{T50kva} + Z_{pu}\text{8} + Z_{pu}\text{T10kva} + Z_{pu}\text{10}} \cdot 100 \]

\[ |\text{UsC}_{F4F}| = 87.475257 \]