Effects of Voltage Sags on Industrial Equipment

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Voltage Sag Test Equipment: Porto-Sag
Versions of the Porto-Sag
Porto-Sag Software Interface
Utility/Equipment Interface: Voltage Sags

- Most Important Power Quality Variation Affecting Sensitive Equipment
- Characterized by Magnitude (here, 50% of Nominal) and Duration (here, 4 Cycles, 1 Cycle = 1/60 sec)
Example Equipment Tolerance Curve

Sag Rate Probabilities vs Equipment System Test

- Programmable Logic Controller, 78%
- 120 Vac DPDT Relay, 78%
- 24 Vdc Instrument Power Supply, 70%
- 0-5 events per site per year
- 5-10 events per site per year
- 10-15 events
- 15-20 events

Percent of Nominal Voltage %

Time (cycles)

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Voltage Sag Impacts on

• PCs
• Electronic Lighting
• Relays and Contactors and Motor Starters
• DC Power Supplies
• PLC Based Control Systems
• Variable Frequency Drives
Switch Mode Power Supply Voltage Sag Tolerance (100% Load)


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Dell Dimension 8250

Test Curves

% of Nominal Voltage

Duration (Seconds)

SEMI F47  ITC (Lower)  Test Results

0.0  0.5  1.0  1.5  2.0  2.5  3.0
Compaq Deskpro 2000

Test Curves

<table>
<thead>
<tr>
<th>% of Nominal Voltage</th>
<th>Duration (Seconds)</th>
</tr>
</thead>
<tbody>
<tr>
<td>SEMI F47</td>
<td>0.0</td>
</tr>
<tr>
<td>ITIC (Lower)</td>
<td>0.5</td>
</tr>
<tr>
<td>Test Results</td>
<td>1.0</td>
</tr>
<tr>
<td></td>
<td>1.5</td>
</tr>
<tr>
<td></td>
<td>2.0</td>
</tr>
<tr>
<td></td>
<td>2.5</td>
</tr>
<tr>
<td></td>
<td>3.0</td>
</tr>
</tbody>
</table>

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HP Netserver LP1000r
Impact on Lighting

PQ Issue:
Some HID metal halide lamp/ballast systems are prone to blackouts due to voltage sags from the normal operation of large electric loads. Restart times may take as long as 10-15 minutes.
Improving Immunity of Metal Halide Lamps

- Use magnetic-regulator ballast to increase metal halide lamp immunity to sags
- For critical lighting applications install non-HID lighting such as tungsten halogen or use UPS
- Isolate lighting systems from sag-causing loads
- Consider installing instant-restrike metal halide lamps
Susceptibility of HPS Lamps vs Age

Percent of Nominal Supply Voltage

- Non-Regulating Ballast
- Auto-Regulating Ballast
- Magnetic-Regulating Ballast

HPS Lamp Age (Hours of Use)

- New Lamp
- Old Lamp

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Relays, Contactors & Motor Starters

- **Relays**
  - Auxiliary device to switch control circuits, large starter coils and light loads

- **Contactors**
  - Electromagnetically operated switches that provide a safe and convenient means for connecting and interrupting power circuits

- **Starters**
  - Same function as contactors but also provides overload protection
Finding the Weakest Link

Main Contactor
2 cycles, 43%

EMO Relay
1 cycle, 52%

EMO Relay
0.5 cycles, 61%

Contactor
2 cycles, 49%

EMO Relay (next gen)
0.5 Cycles, 78%

EMO Relay
1 Cycle 45%

Not Shown:
EMO Relay 1 Cycle, 38%
What happens during a voltage sag down to 50% of nominal for 5 cycles?
Voltage Tolerance Curve: Small Contactor

What happens during a voltage sag down to 50% of nominal for 5 cycles?
Hard-Wired Motor Control Circuits

CR: AB 120V AC ‘Ice-Cube’ Relay
M: Cuttler Hammer Nema Size 1 Starter

Which Circuit is more susceptible to voltage sag?
Q1. What happens if the EMO relay or Main Contactor are extremely vulnerable to voltage sags?
Q2. What if the plant voltage is low?
Q3. What if the transformer rated output voltage does not match the relay and contactor?
Impact of MCR

Notes:
1.0 Digital Meter Jumpers must be set for 120VAC.

What happens when an operator hits the E-Stop?
Industrial Load Bank

Table 1. Tested Process Devices and Their Ratings

<table>
<thead>
<tr>
<th>Name</th>
<th>Voltage (V)</th>
<th>Size</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>CR1</td>
<td>120</td>
<td>10 A</td>
<td>DPDT Relay</td>
</tr>
<tr>
<td>CR2</td>
<td>120</td>
<td>10 A</td>
<td>DPDT Relay</td>
</tr>
<tr>
<td>CR3</td>
<td>24</td>
<td>10 A</td>
<td>DPDT Relay</td>
</tr>
<tr>
<td>CR4</td>
<td>24</td>
<td>5 A</td>
<td>DPDT Relay</td>
</tr>
<tr>
<td>MS1</td>
<td>120</td>
<td>2 HP @ 230 V</td>
<td>3-Pole Motor Starter</td>
</tr>
<tr>
<td>MS2</td>
<td>120</td>
<td>3 HP @ 230 V</td>
<td>3-Pole Motor Starter</td>
</tr>
<tr>
<td>MS3</td>
<td>120</td>
<td>3 HP @ 230 V</td>
<td>3-Pole Motor Starter</td>
</tr>
<tr>
<td>MS4</td>
<td>120</td>
<td>1.5 HP @ 230 V</td>
<td>3-Pole Motor Starter</td>
</tr>
<tr>
<td>MS5</td>
<td>120</td>
<td>30 HP @ 230 V</td>
<td>3-Pole Motor Starter</td>
</tr>
<tr>
<td>MC1</td>
<td>120</td>
<td>10 Amp</td>
<td>4-Pole Contactor</td>
</tr>
<tr>
<td>MC2</td>
<td>120</td>
<td>10 Amp</td>
<td>4-Pole Contactor</td>
</tr>
<tr>
<td>MC3</td>
<td>120</td>
<td>3 HP @ 230 V</td>
<td>3-Pole Contactor</td>
</tr>
<tr>
<td>MC4</td>
<td>24</td>
<td>7.5 HP @ 230 V</td>
<td>3-Pole Contactor</td>
</tr>
<tr>
<td>MC5</td>
<td>24</td>
<td>10 HP @ 230 V</td>
<td>3-Pole Contactor</td>
</tr>
<tr>
<td>MC6</td>
<td>24</td>
<td>7.5 HP @ 230 V</td>
<td>3-Pole Contactor</td>
</tr>
<tr>
<td>MC7</td>
<td>24</td>
<td>40 HP @ 230 V</td>
<td>3-Pole Contactor</td>
</tr>
<tr>
<td>PS1</td>
<td>120</td>
<td>60 W</td>
<td>PLC Power Supply</td>
</tr>
<tr>
<td>PS2</td>
<td>120</td>
<td>140 W</td>
<td>Instrument Power Supply</td>
</tr>
<tr>
<td>PS3</td>
<td>120</td>
<td>200 W</td>
<td>Computer Power Supply</td>
</tr>
<tr>
<td>PS4</td>
<td>120</td>
<td>500 W</td>
<td>Multi-Output Power Supply</td>
</tr>
<tr>
<td>PS5</td>
<td>120</td>
<td>40 W</td>
<td>Unregulated Power Supply</td>
</tr>
</tbody>
</table>
Composite Voltage Sag Ride-Through of General Purpose Relays

Figure 5. Composite Low-Voltage Tolerance of Relays
DC Power Supplies

- DC Power Supplies Used for
  - Instrumentation
  - Control Voltage
  - PC Power
  - PLC P/S Power
  - DC Relays, Contactors, Motor Starters

- PQ Performance Varies based on topology and loading
Switch Mode Power Supply Voltage Sag Tolerance (100% Load)


All Power Supplies At 100% Load.
Relative Power Supply Response at 100% Loading

Ride-Through for Single-Phase Voltage Sags

Curve Represents when DC output begins to deviate more than 5% from normal
Programmable Controllers
PLC Fundamentals Block Diagram

SYSTEM INPUTS

SYSTEM OUTPUTS

PROCESSOR

PLC MEMORY AND CONTROL PROGRAM

POWER SUPPLY

EXTERNAL POWER SOURCE
Arrangement of Remote I/O Racks

Master PLC

Remote I/O

- Programming Unit
- Motor
- Pushbutton
- Hopper
- Drum
- On/Off Control
- Sensor
AC Powered PLC Power Supply

From Typical PLC Literature:

“Each ac-input power supply generates a shutdown signal on the backplane whenever the ac line voltage drops below its lower voltage limit, and removes the shutdown signal when the line voltage comes back up to the lower voltage limit. This shutdown is necessary to ensure that only valid data is stored in memory.”

What that means to you:
- Oversensitive Power Supply
- Customer Process Shutdown due to voltage Sags

What can be done about this?
PLC System Wiring (Typical)
PLC Test Results – Response 1

PLC Shuts down based on incoming AC Voltage before Control System is affected.
PLC Test Results – Response 2

PLC Shuts down on based on power supply DC Bus Voltage.

What happens if PLC has fewer I/O Cards?
What happens if PLC has more I/O Cards?
Effect of Voltage Sags on Adjustable Speed Drives
AC PWM Drive

INPUT SECTION

ENERGY STORAGE SECTION

OUTPUT SECTION

Rectifier Diode Bridge

DC Bus Capacitor

IGBT Inverter

Source Voltage

DC Bus Voltage

Motor Input Voltage
Example Response of ASD to Short Interruption

A Two-Cycle Interruption

- ASD Input Voltage
- ASD DC Bus Voltage
- Motor Current
- Motor Speed

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Voltage Sag Impact on ASD

Drive Trips on Undervoltage
Example Drive 1

Test Curves

- SEMI F47
- ITIC (Lower)
- Single-Phase Sag Results

Two-Phase Sag Results
Three-Phase Sag Results

% of Nominal Voltage

Duration (Seconds)
Example Drive 2

Test Curves

- SEMI F47
- ITIC (Lower)
- Single-Phase Sag Test
- Two-Phase Sag Test
- Three-Phase Sag Test

% of Nominal Voltage

Duration (Seconds)

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Example Drive 3

Test Curves

- SEMI F47
- ITIC (Lower)
- 60 Hz (Speed) Test

45 Hz (Speed) Test
30 Hz (Speed) Test
15 Hz (Speed) Test

% of Nominal Voltage

Duration (Seconds)
Why Do ASDs Trip During Single-Phase Voltage Sags?

- VSI AC Drive During Normal Operating Conditions
  - (Van = 100%, Vbn = 100%, Vcn = 100%)
Why Do ASDs Trip During Single-Phase Voltage Sags?

- VSI AC Drive During a Single-Phase Sag
- \((V_{an} = 100\%, \ V_{bn} = 100\%, \ V_{cn} = 0\%)\)

![Graph showing DC Bus Voltage, Bridge Rectifier Output, and Trip Level over time.](image-url)
Line-Side and Motor-side Contactors
ASD Enable Signal

Contact on 120 V AC relay
Latched Start/Stop Control (3-Wire Control Scheme)
What About Your Plant?

Active Demo Using EPRI’s Power Quality Investigator Software
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