Electric Power Quality: Voltage Sags Momentary Interruptions

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Power Quality Events

- Voltage sags
- Outages/interruptions
- Voltage swells
- Capacitor switching transients
- Lightning
- Voltage notching
- Harmonic distortion
- Voltage flicker
- EMI/RFI
Power Quality Events

- Voltage sags
  10-90% of nominal
- Outages/interruptions
  < 10% of nominal
- Instantaneous
  ½ to 30 cycles (½ sec)
- Momentary
  ½ to 3 seconds
- Temporary
  3 seconds to 1 minute
- Sustained
  > 1 minute
Table 2 of IEEE Standard 1159-2009

IEEE Recommended Practice for Monitoring Electric Power Quality defines power quality events

<table>
<thead>
<tr>
<th>Categories</th>
<th>Typical spectral content</th>
<th>Typical duration</th>
<th>Typical voltage magnitude</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.0 Transients</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1.1 Impulsive</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1.1.1 Nanosecond</td>
<td>5 ns rise</td>
<td>&lt; 50 ns</td>
<td></td>
</tr>
<tr>
<td>1.1.2 Microsecond</td>
<td>1 μs rise</td>
<td>50 ns – 1 ms</td>
<td></td>
</tr>
<tr>
<td>1.1.3 Millisecond</td>
<td>0.1 ms rise</td>
<td>&gt; 1 ms</td>
<td></td>
</tr>
<tr>
<td>1.2 Oscillatory</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1.2.1 Low frequency</td>
<td>&lt; 5 kHz</td>
<td>0.3–50 ms</td>
<td>0.4 pu*</td>
</tr>
<tr>
<td>1.2.2 Medium frequency</td>
<td>5–500 kHz</td>
<td>20 μs</td>
<td>0.8 pu</td>
</tr>
<tr>
<td>1.2.3 High frequency</td>
<td>0.5–5 MHz</td>
<td>5 μs</td>
<td>0.4 pu</td>
</tr>
<tr>
<td>2.0 Short-duration root-mean-square (rms) variations</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2.1 Instantaneous</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2.1.1 Sag</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2.1.2 Swell</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2.2 Momentary</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2.2.1 Interruption</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2.2.2 Sag</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2.2.3 Swell</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2.3 Temporary</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2.3.1 Interruption</td>
<td>&gt;3 s – 1 min</td>
<td></td>
<td>0.1 pu</td>
</tr>
<tr>
<td>2.3.2 Sag</td>
<td>&gt;3 s – 1 min</td>
<td></td>
<td>0.1–0.9 pu</td>
</tr>
<tr>
<td>2.3.3 Swell</td>
<td>&gt;3 s – 1 min</td>
<td></td>
<td>1.1–1.2 pu</td>
</tr>
<tr>
<td>3.0 Long duration rms variations</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3.1 Interruption, sustained</td>
<td></td>
<td></td>
<td>0.0 pu</td>
</tr>
<tr>
<td>3.2 Undervoltages</td>
<td></td>
<td></td>
<td>0.8–0.9 pu</td>
</tr>
<tr>
<td>3.3 Overvoltages</td>
<td></td>
<td></td>
<td>1.1–1.2 pu</td>
</tr>
<tr>
<td>3.4 Current overload</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>4.0 Imbalance</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>4.1 Voltage</td>
<td></td>
<td></td>
<td>0.5–2%</td>
</tr>
<tr>
<td>4.2 Current</td>
<td></td>
<td></td>
<td>1.0–30%</td>
</tr>
<tr>
<td>5.0 Waveform distortion</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>5.1 DC offset</td>
<td></td>
<td></td>
<td>0–0.1%</td>
</tr>
<tr>
<td>5.2 Harmonics</td>
<td>0–9 kHz</td>
<td>steady state</td>
<td>0–20%</td>
</tr>
<tr>
<td>5.3 Interharmonics</td>
<td>0–9 kHz</td>
<td>steady state</td>
<td>0–2%</td>
</tr>
<tr>
<td>5.4 Notching</td>
<td></td>
<td>steady state</td>
<td>0–1%</td>
</tr>
<tr>
<td>5.5 Noise</td>
<td>broadband</td>
<td>steady state</td>
<td></td>
</tr>
<tr>
<td>6.0 Voltage fluctuations</td>
<td>&lt; 25 Hz</td>
<td>intermittent</td>
<td>0.1–7%</td>
</tr>
<tr>
<td>7.0 Power frequency variations</td>
<td>&lt; 10 s</td>
<td>± 0.10 Hz</td>
<td></td>
</tr>
</tbody>
</table>

NOTE—These terms and categories apply to power quality measurements and are not to be confused with similar terms defined in IEEE Std 1366™-2003 [B27] and other reliability-related standards, recommended practices, and guides.
Voltage Sags
also called voltage dips

- Voltage drops to between 10% and 90% of its normal value
  - 120 V: Between 12 V and 108 V
  - 480 V: Between 48 V and 432 V

- Voltage stays low for at least ½ cycle (0.008 seconds) to as long as 3 seconds
  - Less than ½ cycle is a transient
Momentary Interruptions

- Voltage drops to less than 10% of its normal value
  - 120 V: 0 – 12 V
  - 480 V: 0 – 48 V

- Voltage stays low for at least ½ cycle (0.008 seconds) to as long as 3 seconds
Who is causing voltage sags?

Georg Simon Ohm
(1789 – 1854)

\[ V = I \times R \]

Voltage (V) = Current (A) x Resistance (Ω)
Impedance for ac

\[ Z = \sqrt{R^2 + X^2} \text{ (ohms } \Omega) \]

Ohm’s Law

Voltage (volts) = Current (amps) x Impedance (ohms)

So voltage sags are a result of significant, intermittent increases in current or impedance
The cause of voltage sags: Impedance (resistance and inductance)
The cause of voltage sags: Impedance (resistance and inductance)
The cause of voltage sags: Impedance (resistance and inductance)
At the end of line 3:

- **460 V**
  - Breaker
    - Contact: 200 μΩ
    - Wire to lug: 100 μΩ

  - 0000 copper wire
    - 500'
    - Resistance: 0.025 Ω

  - 20 volts = 4.3%

- **440 V -4.3%**
  - Breaker
    - Contact: 200 μΩ
    - Wire to lug: 100 μΩ

Transformer 13.2 kV: 460 V

Motor
- 200 hp, 460 V
- Full load current: 221 A
Voltage drops are usually ok. What causes them to increase?

Georg Simon Ohm
(1789 – 1854)

\[ V = I \times Z \]

Voltage \((V)\) = Current \((A)\) x Impedance \((\Omega)\)
What causes impedance to increase?
460 V

Transformer
13.2 kV: 460 V

Breaker
Contact: 200 μΩ
Loose wire to lug: 0.2 Ω

0000 copper wire
500’
Resistance: 0.025 Ω

97 volts
= 21%

Motor
200 hp, 460 V
Full load current: 221 A

Breaker
Contact: 200 μΩ
Wire to lug: 100 μΩ

363 volts
-21%
**Motor**
- 200 hp, 460 V
- Full load current: 221 A
- Transformer: 13.2 kV: 460 V

**Breaker**
- Contact: 200 \( \mu \Omega \)
- Loose wire to lug: 0.2 \( \Omega \)
- Wire to lug: 100 \( \mu \Omega \)

**Heat at loose connection:** 9.9 kW
**Heat at good connection:** 5.0 W

**Resistance:**
- Breaker: 0.025 \( \Omega \)
- Loose wire: 0.2 \( \Omega \)

**Breaker Contact:**
- 200 mW
- Loose wire to lug: 0.2 mW
- Wire to lug: 100 mW

**363 volts**
- -21%
Finding bad connections:
Infrared Thermography
Infrared Thermography

- [http://www.flir.com/instruments/content/?id=64755](http://www.flir.com/instruments/content/?id=64755), TG165 Imaging IR Thermometer, $500
- [http://www.extech.com/cameras/](http://www.extech.com/cameras/) $1,000
What causes current to increase?

Georg Simon Ohm
(1789 – 1854)

\[ V = IZ \]

Voltage (V) = Current (A) \times Impedance (Ω)
What causes current to increase?

- Induction motor starting
  - 150-500% current until full speed
- Resistance heater starting
  - 150% current until hot
- Short circuits
# NEMA starting codes

<table>
<thead>
<tr>
<th>Letter Designation</th>
<th>KVA per Horsepower*</th>
<th>Letter Designation</th>
<th>KVA per Horsepower*</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>0.0 - 3.15</td>
<td>K</td>
<td>8.0 - 9.0</td>
</tr>
<tr>
<td>B</td>
<td>3.15 - 3.55</td>
<td>L</td>
<td>9.0 - 10.0</td>
</tr>
<tr>
<td>C</td>
<td>3.55 - 4.0</td>
<td>M</td>
<td>10.0 - 11.2</td>
</tr>
<tr>
<td>D</td>
<td>4.0 - 4.5</td>
<td>N</td>
<td>11.2 - 12.5</td>
</tr>
<tr>
<td>E</td>
<td>4.5 - 5.0</td>
<td>P</td>
<td>12.5 - 14.0</td>
</tr>
<tr>
<td>F</td>
<td>5.0 - 5.6</td>
<td>R</td>
<td>14.0 - 16.0</td>
</tr>
<tr>
<td>G</td>
<td>5.6 - 6.3</td>
<td>S</td>
<td>16.0 - 18.0</td>
</tr>
<tr>
<td>H</td>
<td>6.3 - 7.1</td>
<td>T</td>
<td>18.0 - 20.0</td>
</tr>
<tr>
<td>J</td>
<td>7.1 - 8.0</td>
<td>U</td>
<td>20.0 - 22.4</td>
</tr>
<tr>
<td></td>
<td></td>
<td>V</td>
<td>22.4 - &amp; up</td>
</tr>
</tbody>
</table>

NEMA V: 22.4 kVA/hp = 25 x full load current!
NEMA D: 4.5 kVA/hp = 5 x full load current
460 V

Transformer 13.2 kV: 460 V

0000 copper wire 500’
Resistance: 0.025 Ω

102 volts = 22%

Breaker Contact: 200 μΩ
Wire to lug: 100 μΩ

358 V -22%

Motor
200 hp, 460 V
Full load current: 221 A
NEMA D
Starting current: 1130 A

Breaker Contact: 200 μΩ
Wire to lug: 100 μΩ

460 V

Motor
200 hp, 460 V
Full load current: 221 A
NEMA D
Starting current: 1130 A
CBEMA curve
CBEMA curve

78%, ½ second = 8 cycles
Motor
200 hp, 460 V
Full load current: 223 A

Breaker Contact: 200 μΩ
Loose wire to lug: 0.2 Ω

460 volts

Breaker Contact: 200 μΩ
Wire to lug: 100 μΩ

363 volts

0000 copper wire
500’
Resistance: 0.025 Ω

97 volts = 21%

79%, duration unknown
CBEMA curve

79%, duration unknown
Induction motor soft starter

- 30 hp (460 V, 40 A)
  - [http://www.automationdirect.com](http://www.automationdirect.com)
- $450 for very basic
  - Start Time, Starting Voltage, Stop Time
- $890 for full featured
  - Programmable, fault history, communications for remote control,
- 30 hp motor $2,000 and up
- Variable frequency drive ($>5,000) will soft start
Short Circuits
**Phase A to ground fault at end of line 3**

<table>
<thead>
<tr>
<th>Substation</th>
<th>End of line 1</th>
<th>End of line 2</th>
<th>End of line 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>13.2 kV</td>
<td>Phase A: 8.8 kV</td>
<td>4.4 kV</td>
<td>0 kV</td>
</tr>
<tr>
<td>Phase B: 14.1 kV</td>
<td>15.0 kV</td>
<td>16.2 kV</td>
<td></td>
</tr>
<tr>
<td>+6.5%</td>
<td>+14%</td>
<td>+22.3%</td>
<td></td>
</tr>
</tbody>
</table>

6055 amps 6055 amps 6055 amps
Protection against short circuits
Protection against short circuits
Short circuits
utility system protection

substation
recloser
fuse
Short circuits
utility system protection

Reclosers and fuses cause momentary (or longer) interruptions

- Utility might disable first (fast) trip.
  - fewer momentary interruptions
  - longer sags
  - more sustained interruptions.
Short circuits and protective operations also happen during lightning.

Transmission and distribution lines should follow design guidelines to minimize strikes.
Voltage sags and momentary outages: Effects on equipment

- Usually a dc device
- Low voltage on dc bus
- Not enough energy stored in device to ride through low voltage
- Example: a spinning motor has significant energy stored in its rotating mass. Turn off the power for a few seconds, it keeps spinning.
- The same motor with a drive needs the drive to continue or resume operating.
Voltage sags and momentary outages: Effects on equipment

- Usually a dc device
- Low voltage on dc bus
- Not enough energy stored in device to ride through low voltage
- Example: an oven has significant energy stored in its thermal mass. Turn off the power for a few seconds, it stays hot.
- The same motor with a digital controller needs the controller to continue or resume operation.
Effects on equipment

- Usually a dc device
- Low voltage on dc bus
- Not enough energy stored in device to ride through low voltage
- Example: digital devices
  - PCs and any device controlled by a microprocessor or microcontroller
Digital devices I have known

- Spring winder
- CT scanner
- Gamma camera
- ECG
- Radio/TV transmitters
- Theater lighting
- Photo processing

- Battery manufacturing/charging
- Printing
- a/c testing
- Cash registers
- Industrial ovens
- Motor drives
If your equipment is malfunctioning, how do you know it’s voltage sags or momentary interruptions?

- Lights dim or go out
- A motor started
- There is a thunderstorm or wind

To confirm, you can measure
Measuring power quality
PMI Eagle 120

- Single phase 120 V
- $450
- www.powermonitors.com
- True RMS Voltage and Current
- IEEE 1453/IEC61000-4-15 Flicker
- Harmonics to the 51st
- Minimum/Maximum/Average Recording
- Real/Reactive/Apparent Power Recording
- Waveform capture
PMI Revolution

- Three phase up to 600 V
- $7,300 with current probes
- www.powermonitors.com

Added features:
- 1 Megahertz, 5 kV voltage transients
- USB/Ethernet/Bluetooth/Cell
Power Standards

- PQ1 Power Quality Relay
- 240 V
- www.powerstandards.com/PQ1.php
- $349
**Power Standards Lab**

**PQube**
- [www.powerstandards.com/PQube.php#pqube](http://www.powerstandards.com/PQube.php#pqube)
- $1,645 for voltage only
- 690 V, 50/60 Hz
- Voltage dips, swells, and interruptions - waveforms and RMS graphs
- Frequency events, impulse detection, time-triggered snapshots
- THD, TDD, Voltage and current unbalance, RMS Flicker
- Daily, weekly, monthly trends. Cumulative probability, histograms, and more.
Fluke

- 1750 3-Phase Power Quality Recorder
- en-us.fluke.com
- $14,000
- voltage and current
- 3 phases plus ground
- 5 MHz, 8000 V waveform
Fluke

- 435 Power Quality and Energy Analyzer
- en-us.fluke.com
- $8,000
- voltage and current
- 3 phases plus ground
Examples of sags and outages
RMS vs. time plot

Voltage

124

97

1 hour per division
Examples of sags and outages
RMS vs. time plot

Voltage

Time (1 s/division)
Examples of sags and outages
RMS vs. time plot

volts

0 1 2 3 4 5 6 7 8
time (seconds)
Examples of sags and outages
RMS vs. time plot

Voltage

10 minutes per division
Examples of sags and outages
Waveform Plot

Voltage (V)

Time

10 ms/division
Examples of sags and outages

Waveform Plot
Examples of sags and outages
Waveform Plot
Voltage and current waveform plots
RMS voltage and current plots
Examples of sags and outages
Text
Solutions

- Reprogram drives and PLCs
## Drive faults: page 8 of 9

<table>
<thead>
<tr>
<th>Digital Operator Display</th>
<th>Description</th>
<th>Cause</th>
<th>Corrective Action</th>
</tr>
</thead>
</table>
| **PF Input Pha Loss**    | **Input Phase Loss**  
Drive input power supply has an open phase or has a large imbalance of voltage. Detected when L8-05 = 1 (enabled). | Open phase on the input of the Drive. | Check the input voltage. |
<p>|                          | Loose terminal screws at R/L1, S/L2 or T/L3. | Tighten the terminal screws. |
|                          | Momentary power loss occurred. | Check the input voltage. |
|                          | Input voltage fluctuation too large. | Check the input voltage. |</p>
<table>
<thead>
<tr>
<th>UV1 DC Bus Undervolt</th>
<th>DC Bus Undervoltage</th>
<th>Low input voltage at R/L1, S/L2 and T/L3.</th>
<th>Check the input circuit and increase the input power to within specifications.</th>
</tr>
</thead>
<tbody>
<tr>
<td>208-240Vac: Default trip point is ≤ 190Vdc</td>
<td>480Vac: Default trip point is ≤ 380Vdc</td>
<td>Trip point is adjustable in L2-05. Detected when the DC bus voltage is ≤ L2-05.</td>
<td>The acceleration time is set too short.</td>
</tr>
<tr>
<td>Voltage fluctuation of the input power is too large.</td>
<td>Extend the time in C1-01 or other active accel settings used such as C1-03, C1-05, or C1-07 (time).</td>
<td>Check the input voltage.</td>
<td></td>
</tr>
</tbody>
</table>
**Drive alarms:**

**page 4 of 5**

<table>
<thead>
<tr>
<th>UV DC Bus Undervolt (Flashing)</th>
<th>DC Bus Undervoltage</th>
<th>Low input voltage was at R/L1, S/L2 and T/L3.</th>
<th>Check the input circuit and increase the input power to within specifications.</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>The DC bus voltage is ≤ L2-05. Default: 208-240Vac: Trip point is 190Vdc 480Vac: Trip point is 380Vdc Detected while Drive is in a stopped condition.</td>
<td>The acceleration time was set too short.</td>
<td>Extend the time in C1-01 or other active accel settings used such as C1-03, C1-05, or C1-07 (time).</td>
</tr>
<tr>
<td></td>
<td>Voltage fluctuation of the input power was too large.</td>
<td></td>
<td>Check the input voltage.</td>
</tr>
</tbody>
</table>
### Parameters:

**page 30 of 41**

<table>
<thead>
<tr>
<th>Parameter No.</th>
<th>Parameter Name</th>
<th>Description</th>
<th>Setting Range</th>
<th>Factory Setting</th>
</tr>
</thead>
<tbody>
<tr>
<td>L2-05</td>
<td>Undervoltage Detection Level PUV Det Level</td>
<td>Sets the Drive's DC Bus undervoltage trip level. If this is set lower than the factory setting, additional AC input reactance or DC bus reactance may be necessary. Consult the factory before changing this parameter setting.</td>
<td>150 to 210</td>
<td>190 Vdc (230V)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>300 to 420</td>
<td>380 Vdc (480V)</td>
</tr>
</tbody>
</table>


Power Loss Ridethru

- DC Bus Undervoltage Detection Level
  - Factory setting: 380 V for 460 V drive
  - Available settings: 300-420V
  - If this is set lower than the factory setting, additional AC input reactance or DC bus reactance may be necessary. Consult the factory before changing this parameter setting
Reactors for reduced dc bus voltage setting

480 V → ac reactor → drive
(can also be on the drive dc bus)

Reactors for reduced dc bus voltage setting

Low dc bus voltage

low ac V

Reactors limit current surge to recharge dc bus when ac voltage recovers
Voltage notching

- Caused by dc motor drives
- Causes other machines to behave strangely
- Also solved with series reactors on dc drive
### Parameters:

**Power Loss Ride thru**

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Description</th>
<th>Default Values</th>
</tr>
</thead>
<tbody>
<tr>
<td>L2-01</td>
<td>Momentary Power Loss Detection Selection Pwrl. Selection</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Enables and disables the momentary power loss function.</td>
<td>0 to 2</td>
</tr>
<tr>
<td></td>
<td>0: Disabled - Drive trips on (UV1) fault when power is lost.</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>1: Power Loss Ride Thru Time - Drive will restart if power returns</td>
<td></td>
</tr>
<tr>
<td></td>
<td>within the time set in L2-02.*</td>
<td></td>
</tr>
<tr>
<td></td>
<td>2: CPU Power Active - Drive will restart if power returns prior to</td>
<td></td>
</tr>
<tr>
<td></td>
<td>control power supply shut down.*</td>
<td></td>
</tr>
<tr>
<td></td>
<td>* In order for a restart to occur, the run command must be</td>
<td></td>
</tr>
<tr>
<td></td>
<td>maintained throughout the ride thru period.</td>
<td></td>
</tr>
<tr>
<td>L2-02</td>
<td>Momentary Power Loss Ride-thru Time Pwrl. Ridethru t</td>
<td>0.0 to 25.5sec</td>
</tr>
<tr>
<td></td>
<td>Sets the power loss ride-thru time. This value is dependent on the</td>
<td>Varies by kVA</td>
</tr>
<tr>
<td></td>
<td>capacity of the Drive. Only effective when L2-01 = 1.</td>
<td></td>
</tr>
<tr>
<td>L2-03</td>
<td>Momentary Power Loss Minimum Base Block Time Pwrl. Baseblock t</td>
<td>0.1 to 5.0sec</td>
</tr>
<tr>
<td></td>
<td>Sets the minimum time to wait to allow the residual motor voltage</td>
<td>Varies by kVA</td>
</tr>
<tr>
<td></td>
<td>to decay before the Drive output turns back on during power loss</td>
<td></td>
</tr>
<tr>
<td></td>
<td>ride thru. After a power loss, if L2-03 is greater than L2-02,</td>
<td></td>
</tr>
<tr>
<td></td>
<td>operation resumes after the time set in L2-03.</td>
<td></td>
</tr>
<tr>
<td>L2-04</td>
<td>Momentary Power Loss Voltage Recovery Ramp Time Pwrl. V/F Ramp t</td>
<td>0.0 to 5.0sec</td>
</tr>
<tr>
<td></td>
<td>Sets the time it takes the output voltage to return to the preset V/F</td>
<td>Varies by kVA</td>
</tr>
<tr>
<td></td>
<td>pattern after speed search (current detection mode) is complete.</td>
<td></td>
</tr>
<tr>
<td>L2-05</td>
<td>Undervoltage Detection Level PUV Det Level</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Sets the Drive's DC Bus undervoltage trip level. If this is set lower</td>
<td>150 to 210</td>
</tr>
<tr>
<td></td>
<td>than the factory setting, additional AC input reactance or DC bus</td>
<td>190 Vdc (230V)</td>
</tr>
<tr>
<td></td>
<td>reactance may be necessary. Consult the factory before changing</td>
<td>300 to 420</td>
</tr>
<tr>
<td></td>
<td>this parameter setting.</td>
<td>380 Vdc (480V)</td>
</tr>
<tr>
<td>L2-06</td>
<td>KEB Deceleration Rate KEB Decel Time</td>
<td>0.0 to 200.0</td>
</tr>
<tr>
<td></td>
<td>Sets the time required to decelerate to zero speed when a KEB command</td>
<td>0.0sec</td>
</tr>
<tr>
<td></td>
<td>is input from a multi-function input.</td>
<td></td>
</tr>
<tr>
<td>L2-07</td>
<td>Momentary Recovery Time UV Return Time</td>
<td>0.0 to 25.5</td>
</tr>
<tr>
<td></td>
<td>Set the time (in seconds) to accelerate to the set speed after</td>
<td>0.0sec</td>
</tr>
<tr>
<td></td>
<td>recovery from a momentary power loss. If setting = 0.0, then active</td>
<td></td>
</tr>
<tr>
<td></td>
<td>acceleration time is used instead.</td>
<td></td>
</tr>
<tr>
<td>L2-08</td>
<td>Frequency Reduction Gain at KEB Start KEB Frequency</td>
<td>0 to 300</td>
</tr>
<tr>
<td></td>
<td>Sets the percentage of output frequency reduction at the beginning</td>
<td>100%</td>
</tr>
<tr>
<td></td>
<td>of deceleration when a KEB command is input from multi-function input.</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Reduction = slip frequency before KEB operation × L2-08 × 2</td>
<td></td>
</tr>
</tbody>
</table>
Power Loss Ridethru

- Momentary Power Loss Detection Selection
  - Factory setting: disabled
  - Ridethru time up to 25 seconds or
  - Ridethru if CPU power is still active

- Momentary Power Loss Minimum Base Block Time
- Momentary Power Loss Voltage Recovery Ramp Time
- Momentary Recovery Time
Solutions

» Apply these to digital part of system only whenever possible:

- Uninterruptible power supplies
- Ferroresonant transformers
- Active series compensators
Solutions
Uninterruptible power supplies

- Sizes available: watts to MW
- Apply only to digital part of the load whenever possible
  - Keep it active, or gracefully shut down
- For large loads, ride through until backup generator starts
Uninterruptible Power Supplies

- Cost depends on
  - Power capacity (kW or A at V; what is it powering?)
  - Energy capacity (kWh, number and size of batteries; how long do you want it to run?)

- Examples from apc.com:
  - 2.7 kW, 7 hours: $1,450 - $2,050
  - 700 W, 1 hour, $310
  - 40 kW, 30 seconds, $38,100
Solutions
Ferroresonant Transformers

- Sola Constant Voltage Transformer
  - [www.emersonindustrial.com](http://www.emersonindustrial.com)
- Sizes available: 10 to 7500 VA
- Will not power inductive loads
  - Including induction motors
- Cost 30 VA: $356 to 7500 VA: $7,200
  - About $1/VA
- 1% output voltage regulation for input voltages between 80% and 110% of rated.
- Protects against temporary voltage sags and swells between 65% and 120% of rated
Solutions
Active Series Compensator

- 120 – 240 V single phase
- 1000 - 5000 VA
- www.measurlogic.com
Solutions
Active Series Compensator

![Diagram showing VDC support zone and voltage sag immunity](image)

- VDC support provides voltage sag immunity and extends the "no fault" equipment operation area.
- F47 Specification from 0.05 to 1 sec
- Sag duration sec range from 0.01 to 100

*Sag depth % Vsupply*
Ward Jewell
ward.jewell@wichita.edu