Voltage Dip Immunity of Equipment and Installations

TUTORIAL

Improving Process Immunity (Part 7)
Flow chart of Immunity

Objectives

PROCESS TO IMPROVE PROCESS IMMUNITY AGAINST VOLTAGE DIPS

SUPPLY PERFORMANCE - Get information about what voltages dips should be expected or are typical at PCC
Contact electrical utility and ask for assessment of the PCC in terms of how many voltage dips can be expected or are typical. Alternatively the customer can measure by himself at the PCC.
RESPONSIBILITY: Customer & electrical network operator
DELIVERABLE: Assessment of number, magnitude and length of voltage dips over one year

PROCESS PERFORMANCE REQUIREMENT
Assessment of the number of process trips a customer can tolerate in a typical year of production.
RESPONSIBILITY: Customer
SUPPORT: Third party consultants might help if no internal resource available
DELIVERABLE: Number of process trips a customer is willing to accept

PIT (PROCESS IMMUNITY TIME) - Process assessment to find the critical equipment
Here it is important to focus on the PROCESS itself and not on individual equipment as the process is the important part.
RESPONSIBILITY: Customer
SUPPORT: Third party consultants might help if no internal resource available
DELIVERABLE: List of critical path equipment AND the required performance criteria

PROCESS IMMUNITY REQUIREMENT
With the inputs form the supply performance and the process performance requirement the required voltage dip immunity curve for the process can be established.
RESPONSIBILITY: Customer
DELIVERABLE: Required voltage dip immunity curve for the process

EQUIPMENT PERFORMANCE REQUIREMENT
With the PIT, the required performance criteria (full operation, recovery, assist) and the required immunity curve for the process the assessment for each individual equipment from the critical path can be done. Remark: various combinations of voltage tolerance and performance criterion may work (e.g. equipment full operating during dip or restart if PIT is high).
RESPONSIBILITY: Customer
SUPPORT: Third party consultants might help if no internal resource available
DELIVERABLE: Required voltage dip immunity curve for the equipment

EQUIPMENT / MITIGATION SELECTION
Get information from equipment manufacturer on ride through capabilities of their equipment (and costs)
Get information about voltage dip mitigation devices (and their costs)
1 – Equipment commercially available? YES & buy if cheaper than mitigation AND cheaper than financial loss due to expected process trips
2 – Specify equipment with better ride through capabilities in bidding for new equipment & use catalogue of PQ Labels (includes voltage dip ride through requirement, performance criteria, and required tests to be performed) & buy if cheaper than mitigation AND cheaper than financial loss due to expected process trips
3 – buy voltage dip mitigation device if cheaper than financial loss due to expected process trips
Other possibility would also be to work with the electrical utility in order to improve the supply performance (e.g. due to power quality contracts) or to change the process performance requirement or the process itself (e.g. use other technology, or other location with better supply if possible)
Step 1 – Supply Performance

"Information on voltage dips expected or typical at PCC"

Power supply performance characteristics:
- Voltage Level
- Network configuration
- Transformers configurations
- Overhead Vs underground networks
- Length of adjacent network
- Vegetation
- Weather (lightning, wind, snow, ice, …)
- Pollution (salt, fire,…)
- Other loads
Step 1 – Supply Performance

WHERE ? ⇒ Voltage drop

HOW LONG ? ⇒ Network protection

Transformer

C.B. 1

C.B. 2

C.B. 3

C.B. 4
Step 1 – Supply Performance

Example - Voltage dips at a facility
Voltage dip in time

[Graph showing voltage dips over time with date and voltage axis]
# Step 1 – Supply Performance

## Events log example

<table>
<thead>
<tr>
<th>#</th>
<th>Date</th>
<th>Time</th>
<th>Type</th>
<th>Duration (seconds)</th>
<th>Min. Remaining voltage (%)</th>
<th>Depht ØA</th>
<th>Depht ØB</th>
<th>Depht ØC</th>
</tr>
</thead>
<tbody>
<tr>
<td>13</td>
<td>2002-05-27</td>
<td>18:06:00</td>
<td>I</td>
<td>0,217</td>
<td>63%</td>
<td>108,7 %</td>
<td>63 %</td>
<td>111,5 %</td>
</tr>
<tr>
<td>14</td>
<td>2002-05-31</td>
<td>12:14:52</td>
<td>II</td>
<td>0,320</td>
<td>87,3%</td>
<td>89%</td>
<td>87,3%</td>
<td>101,7%</td>
</tr>
<tr>
<td>15</td>
<td>2002-06-23</td>
<td>18:27:07</td>
<td>II</td>
<td>0,067</td>
<td>73,5%</td>
<td>73,5%</td>
<td>76,7%</td>
<td>98,5%</td>
</tr>
<tr>
<td>16</td>
<td>2002-07-02</td>
<td>17:01:18</td>
<td>I</td>
<td>0,025</td>
<td>83%</td>
<td>97,4%</td>
<td>83%</td>
<td>92,2%</td>
</tr>
<tr>
<td>17</td>
<td>2002-07-02</td>
<td>18:17:33</td>
<td>III</td>
<td>0,033</td>
<td>80,5%</td>
<td>80,7%</td>
<td>80,5%</td>
<td>85,5%</td>
</tr>
<tr>
<td>19</td>
<td>2002-07-05</td>
<td>11:16:51</td>
<td>I</td>
<td>0,008</td>
<td>86,5%</td>
<td>94,2%</td>
<td>97,7%</td>
<td>86,5%</td>
</tr>
<tr>
<td>20</td>
<td>2002-07-05</td>
<td>11:55:16</td>
<td>I</td>
<td>0,025</td>
<td>84,5%</td>
<td>92,3%</td>
<td>97,1%</td>
<td>84,5%</td>
</tr>
<tr>
<td>21</td>
<td>2002-07-05</td>
<td>16:30:40</td>
<td>II</td>
<td>0,100</td>
<td>82,1%</td>
<td>82,1%</td>
<td>96,1%</td>
<td>89,6%</td>
</tr>
<tr>
<td>28</td>
<td>2002-08-14</td>
<td>16:31:26</td>
<td>II</td>
<td>0,150</td>
<td>56,1%</td>
<td>56,1%</td>
<td>58,2%</td>
<td>85,6%</td>
</tr>
<tr>
<td>51</td>
<td>2003-06-09</td>
<td>9:51:01</td>
<td>III</td>
<td>0,192</td>
<td>46,6%</td>
<td>48,1%</td>
<td>48,4%</td>
<td>46,6%</td>
</tr>
</tbody>
</table>
Example - Voltage dips at a facility
Voltage dip on the worst phase cases

Voltage dips measured at a facility over a 1.5 year period
## Step 2 – Process Performance Requirement

"Assessment of the number of process trips a customer can tolerate in a year"

<table>
<thead>
<tr>
<th>#</th>
<th>Date</th>
<th>Time</th>
<th>Type</th>
<th>Duration (seconds)</th>
<th>Min. Remaining voltage (%)</th>
<th>Lost of load (minutes)</th>
<th>Cost (rubber &amp; plastics) minimum = 3$/kW[*] Based = 5 MW</th>
<th>Cost (semiconductor) minimum = 20$/kW[*] Based = 25 MW</th>
</tr>
</thead>
<tbody>
<tr>
<td>13</td>
<td>2002-05-27</td>
<td>18:06:00</td>
<td>I</td>
<td>0,217</td>
<td>63%</td>
<td>0</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>14</td>
<td>2002-05-31</td>
<td>12:14:52</td>
<td>II</td>
<td>0,320</td>
<td>87,3%</td>
<td>30</td>
<td>7 500 $</td>
<td>37 500 $</td>
</tr>
<tr>
<td>15</td>
<td>2002-06-23</td>
<td>18:27:07</td>
<td>II</td>
<td>0,067</td>
<td>73,5%</td>
<td>30</td>
<td>7 500 $</td>
<td>37 500 $</td>
</tr>
<tr>
<td>16</td>
<td>2002-07-02</td>
<td>17:01:18</td>
<td>I</td>
<td>0,025</td>
<td>83%</td>
<td>0</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>17</td>
<td>2002-07-02</td>
<td>18:17:33</td>
<td>III</td>
<td>0,033</td>
<td>80,5%</td>
<td>20</td>
<td>5 000 $</td>
<td>25 000 $</td>
</tr>
<tr>
<td>19</td>
<td>2002-07-05</td>
<td>11:16:51</td>
<td>I</td>
<td>0,008</td>
<td>86,5%</td>
<td>0</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>20</td>
<td>2002-07-05</td>
<td>11:55:16</td>
<td>I</td>
<td>0,025</td>
<td>84,5%</td>
<td>0</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>21</td>
<td>2002-07-05</td>
<td>16:30:40</td>
<td>II</td>
<td>0,100</td>
<td>82,1%</td>
<td>0</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>28</td>
<td>2002-08-14</td>
<td>16:31:26</td>
<td>II</td>
<td>0,150</td>
<td>56,1%</td>
<td>80</td>
<td>20 000$</td>
<td>100 000$</td>
</tr>
<tr>
<td>51</td>
<td>2003-06-09</td>
<td>9:51:01</td>
<td>III</td>
<td>0,192</td>
<td>46,6%</td>
<td>120</td>
<td>30 000$</td>
<td>150 000$</td>
</tr>
</tbody>
</table>

**Impact on process**

*ref.: [http://www.energypulse.net/centers/article/article_display.cfm?a_id=1890](http://www.energypulse.net/centers/article/article_display.cfm?a_id=1890)*
Step 2 – Process Performance Requirement

Voltage dips impact on the process (from the worst phase cases)

- Dips without lost of loads
- Dips with lost of loads

- Type III: cost 30,000 $US
- Type II: cost 12,500 $US
- Type II: cost 2,500 $US
- Interruption: cost 45,000 $US

* Duration (seconds) vs. Voltage (%)*
Step 3 – PIT (Process Immunity Time)

"Process assessment to find the critical equipments"

PIT definition:

"Time interval between the start of the voltage interruption and the moment the process parameter goes out of the allowed tolerance limit"
### Step 3 – PIT (Process Immunity Time)

<table>
<thead>
<tr>
<th>LEVEL 1</th>
<th>LEVEL 2</th>
<th>LEVEL 3</th>
<th>Process parameter</th>
<th>PIT</th>
<th>Priority</th>
<th>Action</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reactor</td>
<td>Cooling</td>
<td>DOL IM 1 (water)</td>
<td>Reactor cooling water temp</td>
<td>5s</td>
<td>4</td>
<td>Restart 1</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Oil pump</td>
<td>Oil pressure</td>
<td>1.5s</td>
<td>2</td>
<td>Crucial</td>
</tr>
<tr>
<td></td>
<td></td>
<td>DOL IM 2 – fan</td>
<td>Cooling of the water circuit</td>
<td>3min</td>
<td>7</td>
<td>Restart 3</td>
</tr>
<tr>
<td>Reaction</td>
<td></td>
<td>DOL IM 3 (feed)</td>
<td>Flow rate</td>
<td>30s</td>
<td>6</td>
<td>Restart 2</td>
</tr>
<tr>
<td></td>
<td></td>
<td>ASD 1 (mixer)</td>
<td>Reaction time</td>
<td>6s</td>
<td>5</td>
<td>Restart</td>
</tr>
<tr>
<td></td>
<td></td>
<td>ASD 2 (air)</td>
<td>% O₂</td>
<td>2s</td>
<td>3</td>
<td>Mitigate</td>
</tr>
<tr>
<td>Control</td>
<td></td>
<td>Temperature sensor</td>
<td>Reactor temperature</td>
<td>1 h</td>
<td>8</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Oxygen measurement</td>
<td>% O₂</td>
<td>1s</td>
<td>1</td>
<td>Mitigate</td>
</tr>
<tr>
<td></td>
<td></td>
<td>PLC with UPS</td>
<td></td>
<td>1 h</td>
<td>8</td>
<td></td>
</tr>
</tbody>
</table>

Listing of all process components such as:

Motor, drive, controls, PLC, sensors, lights, …
Step 4 – Process Immunity Requirement

"Determination of the appropriate immunity curve"

Type I & II Voltage dips

Voltage dips on the worst phase cases
Note: Only Type I & II curves are shown for simplification

Dips without lost of loads
Dips with lost of loads
Class A
Class B
Class C1
Class C2
Class D

Voltage (%) vs. Duration (seconds)
Step 4 – Process Immunity Requirement

Type III Voltage dips

Voltage dips on the worst phase cases
Note: Only Type III curves are shown for simplification

- Voltage (%):
  - Dips without lost of loads
  - Dips with lost of loads
  - Class A
  - Class B
  - Class C1
  - Class C2
  - Class D

- Duration (seconds):
  - 0,001
  - 0,010
  - 0,100
  - 1,000
  - 10,000
  - 100,000
Step 5 – Equipment Performance Requirement

"Determination of the appropriate immunity curve and performance criteria for each individual equipment"

<table>
<thead>
<tr>
<th>LEVEL 1</th>
<th>LEVEL 2</th>
<th>LEVEL 3</th>
<th>Process parameter</th>
<th>PIT</th>
<th>Priority</th>
<th>Action</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>DOL IM 1 (water)</td>
<td>Reactor cooling water temp</td>
<td>5s</td>
<td>4</td>
<td>Restart 1</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Immunity class</th>
<th>Voltage dip immunity label</th>
<th>Equipment performance criteria</th>
<th>Full operation</th>
<th>Self-recovery</th>
<th>Assisted-recovery</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>A</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>B</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>C1</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>C2</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>D</td>
<td>X</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Step 5 – Equipment Performance Requirement

"Determination of the appropriate immunity curve and performance criteria for each individual equipment"

<table>
<thead>
<tr>
<th>LEVEL 1</th>
<th>LEVEL 2</th>
<th>LEVEL 3</th>
<th>Process parameter</th>
<th>PIT</th>
<th>Priority</th>
<th>Action</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>Oil pump</td>
<td>Oil pressure</td>
<td>1,5s</td>
<td>2</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Voltage dip immunity label</th>
<th>Equipment performance criteria</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Full operation</td>
</tr>
<tr>
<td>Immunity class</td>
<td></td>
</tr>
<tr>
<td>A</td>
<td></td>
</tr>
<tr>
<td>B</td>
<td></td>
</tr>
<tr>
<td>C1</td>
<td></td>
</tr>
<tr>
<td>X</td>
<td></td>
</tr>
<tr>
<td>C2</td>
<td>X</td>
</tr>
<tr>
<td>D</td>
<td></td>
</tr>
</tbody>
</table>
**Step 5 – Equipment Performance Requirement**

**Economic for Rubber & Plastics industry**

### Conclusion:

- If no class ⇒ no change, no investment, 212 k$ of lost in 1,5 year
- If Class D ⇒ ~1/3 of saving on 212 k$
- If Class C2 ⇒ ~2/3 of saving on 212 k$
- Choice now depend on ROI (cost of equipment ?)

*Cost (rubber & plastics) minimum = 3$/kW [*]*

<table>
<thead>
<tr>
<th>Class</th>
<th>Total lost saving</th>
<th>If Class D used $</th>
<th>If Class C2 used $</th>
<th>If Class C1 used $</th>
<th>If Class B used $</th>
<th>If Class A used $</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total</td>
<td>212 500 $</td>
<td>135 000 $</td>
<td>90 000 $</td>
<td>75 000 $</td>
<td>75 000 $</td>
<td>45 000 $</td>
</tr>
<tr>
<td>saving</td>
<td>0 $</td>
<td>77 500 $</td>
<td>122 500 $</td>
<td>137 500 $</td>
<td>137 500 $</td>
<td>167 500 $</td>
</tr>
<tr>
<td>%</td>
<td>0,0%</td>
<td>36,5%</td>
<td>57,6%</td>
<td>64,7%</td>
<td>64,7%</td>
<td>78,8%</td>
</tr>
</tbody>
</table>
Step 6 – Equipment Selection

As proposed by CIGRE-CIRED-UIE Joint Working Group C4.1.10

Equipment Immunity Specification
Voltage dip immunity Class D

Class D curve for type I + II

Class D curve for type III

<table>
<thead>
<tr>
<th>Voltage dip immunity label</th>
<th>Full operation</th>
<th>Self-recovery</th>
<th>Assisted-recovery</th>
</tr>
</thead>
<tbody>
<tr>
<td>Immunity class</td>
<td>D</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Pass / Fail criteria

Testing Procedure Requirements

Testing for Type I and II voltage dip required:
- 80% for 3 seconds
- 70% for 500 milliseconds

Testing for Type III voltage dip required:
- 80% for 3 seconds
- 70% for 200 milliseconds

(Testing methods shall be according to IEC-61000-4-11 & IEC-61000-4-34)
Step 6 – Equipment Selection

As proposed by CIGRE-CIRED-UIE Joint Working Group C4.1.10

Equipment Immunity Specification
Voltage dip immunity Class C2

<table>
<thead>
<tr>
<th>Voltage dip immunity label</th>
<th>Pass / Fail criteria</th>
</tr>
</thead>
<tbody>
<tr>
<td>Immunity class</td>
<td>Full operation</td>
</tr>
<tr>
<td>C2</td>
<td></td>
</tr>
</tbody>
</table>

Testing Procedure Requirements

Testing for Type I and II voltage dip required:
- 90% for 3 seconds
- 70% for 500 milliseconds
- 50% for 200 milliseconds

Testing for Type III voltage dip required:
- 80% for 3 seconds
- 70% for 200 milliseconds

(Testing methods shall be according to IEC-61000-4-11 & IEC-61000-4-34)
Step 6 – Equipment Selection

As proposed by CIGRE-CIRED-UIE Joint Working Group C4:1:10

Equipment Immunity Specification
Voltage dip immunity Class C1

<table>
<thead>
<tr>
<th>Voltage dip immunity label</th>
<th>Pass / Fail criteria</th>
</tr>
</thead>
<tbody>
<tr>
<td>Immunity class</td>
<td>Full operation</td>
</tr>
<tr>
<td>C1</td>
<td>□</td>
</tr>
</tbody>
</table>

Testing Procedure Requirements

Testing for Type I and II voltage dip required:
- 90% for 3 seconds
- 70% for 500 milliseconds
- 40% for 200 milliseconds

Testing for Type III voltage dip required:
- 80% for 3 seconds
- 70% for 200 milliseconds

(Testing methods shall be according to IEC-61000-4-11 & IEC-61000-4-34)
Step 6 – Equipment Selection

As proposed by CIGRE-CIRED-UIE Joint Working Group C4.1.10

Equipment Immunity Specification
Voltage dip immunity Class B

Class B curve for type I + II

Class B curve for type III

<table>
<thead>
<tr>
<th>Voltage dip immunity label</th>
<th>Pass / Fail criteria</th>
</tr>
</thead>
<tbody>
<tr>
<td>Immunity class</td>
<td>Full operation</td>
</tr>
<tr>
<td>B</td>
<td>☐</td>
</tr>
</tbody>
</table>

Testing Procedure Requirements

Testing for Type I and II voltage dip required:
- 80% for 3 seconds
- 50% for 1 second
- 0% for 200 milliseconds
(Testing methods shall be according to IEC-61000-4-11 & IEC-61000-4-34)

Testing of Type III Voltage dip required:
- 80% for 3 seconds
- 50% for 1 second
- 0% for 100 milliseconds
Step 6 – Equipment Selection

Equipment Immunity Specification
Voltage dip immunity Class A

Class A curve for type I + II
Class A curve for type III

<table>
<thead>
<tr>
<th>Voltage dip immunity label</th>
<th>Pass / Fail criteria</th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Immunity class</td>
<td>Full operation</td>
<td>Self-recovery</td>
<td>Assisted-recovery</td>
<td></td>
</tr>
<tr>
<td>A</td>
<td>✗</td>
<td>✗</td>
<td>✗</td>
<td></td>
</tr>
</tbody>
</table>

Testing Procedure Requirements

Testing for Type I and II voltage dip required:
- 70% for 3 seconds
- 50% for 2 seconds
- 0% for 1 second
(Testing methods shall be according to IEC-61000-4-11 & IEC-61000-4-34)

Testing for Type III voltage dip required:
- 80% for 3 seconds
- 50% for 2 seconds
- 45% for 1 second
- 0% for 200 milliseconds
The report can be obtained in electronic format for free from: www.uie.org;
a hardcopy can be purchased from www.e-cigre.org