IEEE-IAS – Atlanta Chapter

Instrumentation & Controls Issues in Industrial Electrical Design

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Project Sales Engineer
Agenda

- Set the Stage
- Analog Signals
  - Surge Protection
  - Signal Conditioning
- Fieldbus Networks
Set the Stage

• I&C Design Engineer\Manager for 13 years at major consulting firm in the Water/Wastewater Treatment Industry
  – Developing P&IDs, control system network diagrams, basic panel layouts, instrumentation details, specifications for instruments, control systems and panel components

• Coordination with other design disciplines
  – Civil and process groups
  – Electrical – power requirements, network layouts, area classifications,
Agenda

- Set the Stage

- Analog Signals
  - Surge Protection
  - Signal Conditioning

- Fieldbus Networks
Analog Signals

- Water/Wastewater Industry
  - Pressure, Level, Flow, Temperature
  - Speed, Valve Position/Control
  - Chlorine Residual, Dissolved Oxygen, Nutrients, Suspended Solids, Conductivity, pH

- Analog Signals
  - 4-20 mA DC
  - Loop powered
  - 120 VAC powered devices

- Maintain high availability of signals through surge protection and/or signal conditioning
What is Surge Protection?

- Function of Surge Protective Device (SPD) is to divert transient voltage and current away from sensitive equipment, without interruption of the normal circuit operation.
What is Surge Protection?

**Working Principle of a Surge Protection Device**

- Normal Voltage ($t = T_s$)
- Surge protection device allows normal current flow to equipment
- Acts like a switch that is open under normal conditions
- Protected equipment
What is Surge Protection?

Surge protection devices are designed to protect electrical or electronic equipment from the effects of electrical surges. A surge is an abnormal, high or low, instantaneous voltage or current that occurs when a circuit is subjected to a transient event. Surge protection devices work by limiting the transient voltage and current that can reach the equipment. They do so by breaking the transient at the point of entry to the equipment, effectively blocking the surge. This is typically achieved through the use of lightning arrestors, varistors, or other types of energy absorption devices. Surge protection is critical in preventing damage to delicate electronic components that can occur when subjected to high voltage surges, such as those caused by lightning or electrical surges on the power grid.
Why Surge Protection?
## Source of disturbances

<table>
<thead>
<tr>
<th>LEMP</th>
<th>SEMP</th>
<th>ESD</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Lightning Electromagnetic Pulse</strong></td>
<td><strong>Switching Electromagnetic Pulse</strong></td>
<td><strong>Electrostatic Discharge</strong></td>
</tr>
<tr>
<td>Extremely high surge voltages</td>
<td>Switching of high-capacity machines</td>
<td>Discharge between bodies</td>
</tr>
<tr>
<td>Occur only rare as compared to other types</td>
<td>Short circuits in the power supply network</td>
<td>Generally not harmful to human beings</td>
</tr>
<tr>
<td></td>
<td>Occurrence of extremely high current changes</td>
<td></td>
</tr>
</tbody>
</table>
Lessons Learned – Surge Protection

- Proper selection of the surge protective devices
- Detailing where it is required and installation of components
- Understanding shield concepts and detailing shield connections
# Selecting the Right Surge Protection

<table>
<thead>
<tr>
<th>Suppressor diode</th>
<th>Varistor</th>
<th>Gas discharge tube (GDT)</th>
<th>Spark gap</th>
</tr>
</thead>
<tbody>
<tr>
<td><img src="image1.png" alt="Suppressor diode image" /></td>
<td><img src="image2.png" alt="Varistor image" /></td>
<td><img src="image3.png" alt="GDT image" /></td>
<td><img src="image4.png" alt="Spark gap image" /></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Voltage limiting behaviour</th>
<th>Voltage switching behaviour</th>
</tr>
</thead>
</table>
Selecting the Right Surge Protection

- Suppressor diode
- Varistor
- Gas-discharge tube
- Spark gap

Graph showing:
- Response time
- Discharge capability
Selecting the Right Surge Protection

Signal loops for Analog-Signals

Circuits with common reference for Binary-Signals

Different signal circuits requires adapted protection circuits!
Selecting the Right Surge Protection

- For isolated circuits
  - Low protection level between the lines
  - High protection level to ground

- For grounded circuits or circuits with common reference
  - Low protection level to reference (ground)
  - Higher protection level between the lines

Protection for analog signals

Protection for binary signals
Lessons Learned – Surge Protection

- Proper selection of the surge protective devices
- Detailing where it is required and installation of components
- Understanding shield concepts and detailing shield connections
Where to Place Surge Protection

- Power supply
- Data Communication
- Antenna
- Measurement and Control
- PLC

Diagram showing placement of surge protection components around a PLC.
Where to Place Surge Protection

To protect the complete system, surge protection on both sides of the cable is necessary!!!
Wiring is part of a good or bad installation
Lessons Learned – Surge Protection

- Proper selection of the surge protective devices
- Detailing where it is required and installation of components
- Understanding shield concepts and detailing shield connections
Shielding
Why is a shield needed?

Electromagnetic interferences

- Railway, e.g. 16.7 Hz
- 50 Hz, Power supply
- LW-Radio
- UKW-Radio
- Radar
- MW-Radio
- GSM 900 MHz
- CB-Radio
- Microwave
- Visible light
- UV-C

Wavelength $\lambda$

Frequency $f$

1 Hz, 10 Hz, 100 Hz, 1 kHz, 10 kHz, 100 kHz, 1 MHz, 10 MHz, 100 MHz, 1 GHz, 10 GHz, 100 GHz, 1 THz, 10 THz, 100 THz, 1 kTHz, 10 kTHz
Shielding
Grounding concepts and their behaviour

- Both ends grounded
  + protection against capacitive coupling
  + reducing inductive coupling
  - equalization currents on shield

\[ U = R \times I \]

\[ R_{\text{shield}} \ll R_{\text{ground}} \]
Shielding
Grounding concepts and their behaviour

- One end grounded
  + protection against capacitive coupling
  + no equalization currents on shield
  - not reducing inductive coupling
  - danger of spark over due lightning impact

![Diagram showing shielding concepts and their behaviour](image)
**Shielding**
Grounding concepts and their behaviour

- Double shielded
  - Inner shield one side grounded
  - Outer shield both sides grounded
  + protection against capacitive coupling
  + reducing inductive coupling
  + no equalization currents on inner shield
  - danger of spark over due lightning impact
    - caused by partial lightning currents on outer shield

Potential differences can lead to a spark over!
**Shield should be included to the surge protection concept!**
Shielding
Integrating in surge protecting concept

- Non-isolated system, both ends grounded, SPD on both ends
  - SPDs on both sides
  - Shield on both sides grounded
  - Equalization currents on shield
Shielding
Integrating in surge protecting concept

- Non-isolated system, one end grounded, SPD on both ends
  - SPDs on both sides
  - Better solution?
  - High voltage drop in ground possible
  - Diodes became conductive!
  - Equalization currents on line!

\[ R_{\text{wet pebbles}} = \frac{500 \Omega}{m} \]
\[ d = 25m \]
\[ I_{\text{ground}} = 1mA \]
\[ \Delta U = 25m \times 500 \frac{\Omega}{m} \times 1mA = 12.5V \]
Shielding
Integrating in surge protection concept

- Non-isolated system, one end grounded, SPD on both ends
  - SPD on both ends but slight difference in design
  - Indirect grounded!
  - No equalization currents
  - Partial lightning current on shield in case of lightning
Shielding
Integrating in surge protecting concept

- Non-isolated system, double shielded, SPD on both ends
  - SPD on both ends but slight difference in design
  - Indirect grounded!
  - No equalization currents
  - Partial lightning current on outer shield in case of lightning
Agenda

- Set the Stage

- Analog Signals
  - Surge Protection
  - Signal Conditioning

- Fieldbus Networks
Goals of Analog Signal Conditioning and Protection

- Improve Accuracy
- Increase Quality
- Reduce Installation Costs
- Reduce down time
- Safe Control
- Improve reliability
- Protect expensive equipment
Interface Analog

Why signal conditioners are used?

**Filtering**

**Amplifying**

**Converting**

**Isolating**
- High currents influencing the signal transmission
- Signal filtering and conversion to a current signal can help eliminate and avoid interferences
- **Low Pass limit filtering best < 50HZ**
Signal Amplification

Pressure transducer
\[ I_{\text{OUT}} = 4\ldots20\text{mA} \]
\[ R_{\text{LOAD}} = 300\ \Omega \]

Current loop with 3 devices
Total \( R_{\text{IN}} = 450\ \Omega \)

The total of the single resistances (450\(\Omega\)) is higher than the allowed load (300\(\Omega\))
Signal Amplification

Pressure transducer
\[ I_{\text{OUT}} = 4...20\text{mA} \]
\[ R_{\text{LOAD}} = 300 \ \Omega \]

Isolation amplifier
\[ R_{\text{LOAD}} = 500 \ \Omega \]

Current loop with 3 devices
Total \[ R_{\text{IN}} = 450 \ \Omega \]

The isolating amplifier **amplifies**, filters and isolates the measuring signal
Signal Amplification

Pressure transducer
\[ I_{\text{OUT}} = 4\ldots20\text{mA} \]
\[ R_{\text{LOAD}} = 300\ \Omega \]

Line > 1km
\[ R_{\text{Line}} = 20\ \Omega \]

Control / Periphery
\[ R_{\text{IN}} = 300\ \Omega \]

The total of the single resistances (320\Omega) is higher than the allowed load (300\Omega)
Signal Amplification

Pressure transducer
$I_{OUT} = 4...20mA$
$R_{LOAD} = 300 \, \Omega$

Isolation amplifier
$R_{IN} = 50 \, \Omega$
$R_{LOAD} = 500 \, \Omega$

Control / Periphery
$R_{IN} = 300 \, \Omega$

The isolation amplifier **amplifies**, filters and isolates the measuring signal.
INTERFACE Analog
Why signal conditioners are used?

Galvanic isolation

Diagram showing the use of signal conditioners to isolate potential loops and prevent ground current flow.
Signal Isolation

Types of Isolation

- **Optical Isolation**
  - Uses light emitting diodes
  - Higher resolution – Faster response times
  - Lower cost
  - More sensitive to static discharge and transients

- **Magnetic Isolation**
  - Uses transformer
  - More robust
  - Higher cost
Lessons Learned – Signal Conditioning

- Proper selection of the signal conditioning devices and interfacing with the control system

- Signal conditioners are not surge protective devices
INTERFACE Analog
Isolation technologies / active vs. passive

Sensor / Field transmitter

active

passive

Sensor / Field transmitter

3-Way Isolator

Active vs. passive

Isolation
Filtering
Conversion
Amplification

4...20 mA
0...20 mA
0...10 V
0...5 V
...

4...20 mA
0...20 mA
0...10 V
0...5 V
...

PLC / DCS

passive
INTERFACE Analog
Isolation technologies / active vs. active

Sensor / Field transmitter

active

passive

Analog IN

Loop Powered Isolator

Isolation
Filtering
Conversion
Signal Power

4...20 mA
0...20mA
0...10V
0...5V
...

passive

4...20 mA

PLC / DCS

active

4-wire

U_s
Lessons Learned – Signal Conditioning

- Proper selection of the signal conditioning devices and interfacing with the control system
- Signal conditioners are not surge protective devices
Interface Analog

Why signal conditioners are used?

Filtering

Amplifying

Converting

Isolating
Signal Conditioners/Isolators are NOT Surge Protective Devices

- Isolation/test voltage – 3 kV
- Not designed to handle high current, short duration surges
- If surge is needed, install SPD in front of isolator
Agenda

- Set the Stage

- Analog Signals
  - Surge Protection
  - Signal Conditioning

- Fieldbus Networks
What is Fieldbus?

- Fieldbus interconnects “field” equipment such as sensors, actuators and I/O to a control system on a single pair of wires
- Fieldbus Systems – IEC 61158-2 Specification
  - Fieldbus is an all-digital, serial, two-way communication system with a data rate of 31.25 kbit/s
    - Profibus PA & Foundation Fieldbus
    - Manchester II coding
Fieldbus Protocols
Foundation Fieldbus & Profibus PA

• **Foundation Fieldbus and Profibus PA are physically identical**
  – Twisted pair cables
  – Balanced power conditioning
  – Device Couplers
  – Two terminators required
  – 9 – 32 Vdc
  – 1900 Meter total segment length (120 meter spur length maximum)

**Primary Differences**

<table>
<thead>
<tr>
<th>Profibus PA</th>
<th>Foundation Fieldbus</th>
</tr>
</thead>
<tbody>
<tr>
<td>• Polling – Master/Slave</td>
<td>• Cyclic transmission – Publisher/Subscriber</td>
</tr>
<tr>
<td>• Bus Master</td>
<td>• Link Active Scheduler (LAS)</td>
</tr>
<tr>
<td>• Addressing instruments individually</td>
<td>• FF Devices automatically present on bus</td>
</tr>
<tr>
<td>• Device only communicates w/ master</td>
<td>• Peer to Peer communication possible</td>
</tr>
<tr>
<td>• Communication loss – fail safe</td>
<td>• Communication loss – backup LAS</td>
</tr>
</tbody>
</table>
Fieldbus Protocols
Foundation Fieldbus and Profibus PA

- **What does the signal look like?**
- **Manchester II coding is used for both protocols**
- **31.25 kbit/s means each bit has a period of 32 µs**
  - An ideal signal spends 50% of the time positive and 50% of the time negative
Foundation Fieldbus Topology

- 31.25 kb/s
- Powered Bus
- 9-32 Vdc
- Max length 1900 meters includes spurs
Profibus PATopology

- 31.25 kb/s
- Powered Bus
- 9-32 Vdc
- Max length 1900 meters includes spurs
Why Fieldbus?

- Saving IO cards
- Saving cables
- Saving cabinets
- Access to data
- Ease of planning / installation and startup
- Enabling fully digital communication
- Still being highly reliable
- ...

→ Saving money
Lessons Learned – Fieldbus Networks

- Understanding the process, process control timing, and number of devices per trunk

- Properly detailing network layout and wiring restrictions; making sure Electrical Contractor adheres to design

- Understanding shield concepts and detailing shield connections
Communication Structure

Token Passing Network

Macrocycle: The repetitious scheduling of the Function Block within all the devices on a segment. The LAS is responsible for scheduling of the segment macrocycle.

Token Passing Network
- For loops requiring 1s macrocycle time, limit segment to 12 devices including 3 valves maximum
- For loops requiring 0.5s macrocycle time, limit segment to 6 devices including 2 valves maximum
- For loops requiring 0.25s macrocycle time, limit segment to 3 devices including 1 valve maximum
Lessons Learned – Fieldbus Networks

- Understanding the process, process control timing, and number of devices per trunk

- Properly detailing network layout and wiring restrictions; making sure Electrical Contractor adheres to design

- Understanding shield concepts and detailing shield connections
# Fieldbus Wire Specification

## Cabling

<table>
<thead>
<tr>
<th>Cable Type and Description</th>
<th>Max Segment Length</th>
</tr>
</thead>
<tbody>
<tr>
<td>Type A: Multi or single-twisted-pair, individually shielded</td>
<td>1,900 (6,232)</td>
</tr>
<tr>
<td>Type B: Multi-twisted-pair, with an overall shield</td>
<td>1,200 (1,200)</td>
</tr>
<tr>
<td>Type C: Multi-twisted-pair, without shield</td>
<td>400 (1,312)</td>
</tr>
<tr>
<td>Type D: Multi-core, without twisted pairs, without a shield</td>
<td>200 (656)</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Total Devices</th>
<th>1 Device per Spur</th>
<th>2 Devices per Spur</th>
<th>3 Devices per Spur</th>
<th>4 Devices per Spur</th>
</tr>
</thead>
<tbody>
<tr>
<td>25-32</td>
<td>1 (3)</td>
<td>1 (3)</td>
<td>1 (3)</td>
<td>1 (3)</td>
</tr>
<tr>
<td>19 – 24</td>
<td>30 (98)</td>
<td>1 (3)</td>
<td>1 (3)</td>
<td>1 (3)</td>
</tr>
<tr>
<td>15 - 18</td>
<td>60 (197)</td>
<td>30 (3)</td>
<td>1 (3)</td>
<td>1 (3)</td>
</tr>
<tr>
<td>13 - 14</td>
<td>90 (295)</td>
<td>60 (197)</td>
<td>30 (98)</td>
<td>1 (3)</td>
</tr>
<tr>
<td>1 - 12</td>
<td>120 (394)</td>
<td>90 (295)</td>
<td>60 (197)</td>
<td>30 (98)</td>
</tr>
</tbody>
</table>

**Additional Specifications:**
- Attenuation
- Wire Resistance / Km
- Shield construction
- Wire-to-Shield capacitance
- Shield coverage
- Wire Twists per Meter
- Minimum Bend Radius
- Jacket Resistance
Fieldbus Terminator

- Exactly 2 terminators are required for each segment
- RC network creates a 50 Ohm equivalent load for the network
- Prevents signal reflections
- Signal level should be between 0.75V and 1.0V pp @ 50 Ohm

<table>
<thead>
<tr>
<th>Signal Amplitude</th>
<th>Status</th>
</tr>
</thead>
<tbody>
<tr>
<td>If peak-to-peak level is &gt; 1 V</td>
<td>Missing terminator</td>
</tr>
<tr>
<td>If peak-to-peak level is between 0.75 V and 1 V</td>
<td>Properly terminated</td>
</tr>
<tr>
<td>If peak-to-peak level is between 0.15 V and 0.75 V</td>
<td>Too many terminators</td>
</tr>
</tbody>
</table>
Fieldbus Cabling

- Minimize loops and maintain proper bend radius
Lessons Learned – Fieldbus Networks

- Understanding the process, process control timing, and number of devices per trunk

- Properly detailing network layout and wiring restrictions; making sure Electrical Contractor adheres to design

- Understanding shield concepts and detailing shield connections
Shield Grounding
Class A: Single Point Shielding
Shield Grounding
Class B: Multi Point Shielding
Shield Grounding
Class C: Shielding Using Isolated Device Couplers
Shield Grounding
Class D: Multi Point Shielding Using Capacitive Coupling
Summary

- Regardless, if it is analog or digital...control is only as good as the instrumentation and the signal

- Little more effort on the design details can alleviate a lot of field headaches
Questions?

W. Michael Sutton, PE, ISA CAP
Project Sales Engineer