Isolation in Industrial Motor Drives

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Agenda

• Brief introduction to isolation concepts and terminologies
• Isolation in motor drive systems
  – System architectures
  – Isolated gate drivers
  – Isolated delta-sigma modulators and amplifiers
  – Digital isolators
  – Isolated interfaces
• Isolation requirement per end equipment standard IEC 61800-5-1
  – Standard stipulations
  – Steps to pick the right isolators per IEC 61800-5-1
• Q&A
# Introduction to ISOLATION

## What is Isolation?

A means of transporting data & power between circuits with different ground references (functional isolation) or hazardous voltage levels (user safety) while preventing uncontrolled transient current from flowing in between the two.

## When to isolate?

- To protect from and safely withstand high voltage surges that would damage equipment or harm humans
- To tolerate large ground potential differences and disruptive ground loops in circuits that have high energy or are separated by large distance
- To communicate reliably with high side components in high-voltage motor/inverter drive systems, switches, and metrology applications

## Why Now?

- Industry’s move to the **next gen in Industrial Automation** and Control (Reliable links between Controllers/Sensors/Actuators)
- Need for step function **increase in Working Voltage and Energy Efficiency** in Motor Drives and Energy Storage/Delivery Systems

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## Industrial

- Sagging voltage in high energy circuits
- Safety concerns in hazardous environments

## Automotive & HEV

- Electrification of vehicles
- Energy management systems

## Server

- Data center infrastructure
- Power distribution units

## Communications

- Wireless networking
- Fiber optic connections
## Isolation Terminology

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Definition</th>
<th>Relevance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Basic Isolation</td>
<td>Isolation that can provide protection against high voltage as long as the barrier is intact.</td>
<td>Basic isolation must be coupled with another insulation barrier for safety isolation.</td>
</tr>
<tr>
<td>Reinforced Isolation</td>
<td>Isolation that is equivalent to two basic isolation barriers in series.</td>
<td>Reinforced isolation by itself is sufficient as a safety barrier against high voltage.</td>
</tr>
<tr>
<td>$V_{IOTM}$</td>
<td>The sinusoidal voltage isolator can tolerate for 60s (defined in $pk$)</td>
<td>Temporary overvoltage on supplies due to load changes, arcing etc.</td>
</tr>
<tr>
<td>$V_{ISO}$</td>
<td>The sinusoidal voltage isolator can tolerate for 60s (defined in $rms$)</td>
<td></td>
</tr>
<tr>
<td>$V_{ICRM}$</td>
<td>Maximum periodic voltage that the isolator has to handle on a continuous basis throughout its operating life (defined in $pk$)</td>
<td></td>
</tr>
<tr>
<td>$V_{IOWM}$</td>
<td>Maximum continuous working voltage that the isolator has to on a continuous basis throughout its operating life (defined in $rms$)</td>
<td></td>
</tr>
<tr>
<td>$V_{SURGE}$</td>
<td>Maximum peak voltage of the 1.2us/50us IEC-standard surge waveform that the isolator can handle.</td>
<td>Represents direct and indirect lightening strikes.</td>
</tr>
<tr>
<td>Creepage</td>
<td>Minimum distance from pins on side 1 to side 2 along the surface of the package</td>
<td>Limits working voltage due to degradation along package surface</td>
</tr>
<tr>
<td>Clearance</td>
<td>Minimum distance from pins on side 1 to side 2 through the air</td>
<td>Limits peak voltages and surge voltages due to air breakdown</td>
</tr>
<tr>
<td>CMTI</td>
<td>The maximum rate of change of ground potential difference (GND1-GND2) that the isolator can withstand without bit errors</td>
<td>Indicates robustness of isolator to ground noise.</td>
</tr>
</tbody>
</table>

System Block Diagram of Industrial Drive System
Isolated Gate Driver

- Combo solution of discrete digital isolator + gate driver. This solution is more popular for low power drive applications where IPMs are used.
- Isolated simple gate drivers with integrated isolation. This solution is more popular for low to medium power drive applications. In these applications, protections are implemented with dedicated current sensing.
- Isolated smart gate drivers with integrated isolation and protection features. This type of drivers are more for high power applications. The integrated protection features can protect both system and power devices in case of short circuit and over current conditions.
**System Block Diagram of Industrial Drive System**

- **Isolated current and voltage sensing**
  - LEM sensor + signal processing circuits.
  - Isolated amplifier + signal processing circuits.
  - Isolated delta-sigma modulator, which features best AC & DC performance at flexible data rate (depending on digital filter settings).
System Block Diagram of Industrial Drive System

- **Isolated Interface**
  - Combo solution of discrete digital isolator + interface protocol
  - Isolated CAN transceivers
  - Isolated RS485 transceivers
  - Isolated LVDS
  - …
System Block Diagram of Industrial Drive System

- **Isolated Interface**
  - Combo solution of discrete digital isolator + interface protocol
  - Isolated CAN transceivers
  - Isolated RS485 transceivers
  - Isolated LVDS
  - …

**Isolated signal + power**
Isolation in Motor Drive System – Case I

Gate-Driver with reinforced isolation

- Control Module
- Communication Bus RS-485, CAN, Ethernet
- Isolated Current and Voltage Sensing
- Isolated IGBT Gate Drivers
- Three-phase Diode Rectifier
- High Voltage Drive Inverter
- AC Motor Drive
- Encoder

Reinforced isolation
Isolation in Motor Drive System – Case II

**Gate-Driver with basic/functional isolation**

**Reinforced isolation**

**Basic/Functional isolation**
# The Isolation Standards Landscape

## Semiconductor Component Safety Standards

<table>
<thead>
<tr>
<th>Isolator type</th>
<th>International</th>
<th>Europe</th>
<th>U.S.</th>
<th>Canada</th>
<th>Germany</th>
</tr>
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<tbody>
<tr>
<td><strong>Organization</strong></td>
<td></td>
<td></td>
<td></td>
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</tr>
<tr>
<td>Magnetic/Capacitive Isolator Standards</td>
<td>IEC</td>
<td>CENELEC (EN)</td>
<td>UL</td>
<td>CSA</td>
<td>DIN/VDE</td>
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<tr>
<td>Component Acceptance Notice 5A</td>
<td>60747-17 (DRAFT)</td>
<td></td>
<td></td>
<td></td>
<td>VDE-0884-10/11</td>
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<tr>
<td>Optoisolator Standards</td>
<td>60747-5-5</td>
<td>60747-5-5</td>
<td>1577</td>
<td></td>
<td>Component Acceptance Notice 5A</td>
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</table>

## End Equipment Safety Standards

<table>
<thead>
<tr>
<th>Application</th>
<th>International</th>
<th>Europe</th>
<th>U.S.</th>
<th>Canada</th>
<th>Germany</th>
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<tr>
<td><strong>Organization</strong></td>
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<td></td>
<td></td>
<td></td>
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<tr>
<td>Reference Equipment standard for Low-Voltage Systems</td>
<td>60664-1</td>
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<tr>
<td>Industrial</td>
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<td>50178</td>
<td>508</td>
<td>14-M91</td>
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<td>60601</td>
<td>2601-1</td>
<td>601</td>
<td>750</td>
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<tr>
<td>Telecom</td>
<td>6095</td>
<td>0 60950/41003</td>
<td>1459</td>
<td>225</td>
<td>804</td>
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<tr>
<td>IT Equipment</td>
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<td>60950</td>
<td>60950</td>
<td>60950</td>
<td>60950</td>
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<tr>
<td>Household</td>
<td>60065</td>
<td>60065</td>
<td>8730-1</td>
<td></td>
<td>860</td>
</tr>
<tr>
<td>Motor Drives</td>
<td>61800-5-1</td>
<td></td>
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<td></td>
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<tr>
<td>Photo Voltaic Systems (Solar)</td>
<td>62109-1</td>
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<tr>
<td>Measurement and Control</td>
<td>61010-1</td>
<td>61010-1</td>
<td>1262</td>
<td>1010</td>
<td>0410/0411</td>
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<td>EM Immunity</td>
<td>61000-4-x</td>
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<td>EM Emission</td>
<td>CISPR22B</td>
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</table>

Customer systems **MUST** pass. TI isolators must enable.
IEC 61800-5-1: What it specifies

• IEC 61800-5-1 specifies the level of *insulation* required between high voltage and conductive parts/equipment surface, in terms of:
  – Working Voltage
  – Transient Overvoltage (corresponds to $V_{\text{IOTM}}$)
  – Surge Voltage (corresponds to $V_{\text{SURGE}}$)
  – Creepage
  – Clearance

• …. Depending On/Proportional to:
  – Basic, Double or Reinforced Isolation.
  – System Voltage (depends on supply voltage)
  – Working Voltage (corresponds to $V_{\text{IOTM}}$)
  – Overvoltage Category
  – Pollution degree
  – Material Group

• …. Tables to establish the above relationship.
IEC 61800-5-1: Definitions

• **System Voltage**
  - For **mains circuit**, the RMS value of the rated phase voltage
    - $V_{\text{ph-ph}}/\sqrt{3}$ for 3-phase system with neutral connected to earth.
    - $V_{\text{ph-ph}}$ for 3-phase system with one phase connected to earth.

• **Overvoltage Category** is:
  - IV for equipment connected permanently at origin of an installation (downstream of main distribution board).
  - III for equipment connected to supply in fixed installations (downstream of main distribution board)
  - II for equipment not permanently connected to supply, but connected through a plug.
Steps to choosing Isolators per IEC 61800-5-1

- **Step 1**: Identify Isolators, determine if basic or reinforced.
- **Step 2**: Determine System Voltage based on supply line voltage and earthing scheme.
  - Interpolation not allowed. Next defined System Voltage must be chosen.
- **Step 3**: Determine $V_{ISO}$ and $V_{SURGE}$ requirements from System Voltage.
  - For reinforced use $2 \times V_{ISO}$, and next level of $V_{SURGE}$.
- **Step 4**: Determine Clearance based on $V_{ISO}/V_{SURGE}$ levels determined in step 3.
  - For reinforced use $1.6 \times V_{ISO}$, and next level of $V_{SURGE}$.
  - Scaling factor required for altitudes > 2000m
- **Step 5**: Determine working voltage (both pk and rms) based on actual operating condition of isolator.
  - Depends on architecture, earthing, ringing, braking, regen etc.
- **Step 6**: Determine Creepage based on RMS values of working voltage expected.
  - Depends on material group (CTI) and pollution degree.
- **Step 7**: Choose isolator that meets $V_{ISO}$, $V_{SURGE}$, working voltage, creepage and clearance requirements obtained above.
**IEC 61800-5-1: Examples of isolation requirements**

<table>
<thead>
<tr>
<th>AC phase-phase Voltage (V&lt;sub&gt;RMS&lt;/sub&gt;) and Earthing Scheme</th>
<th>System Voltage (V&lt;sub&gt;RMS&lt;/sub&gt;) Per IEC 62109-1</th>
<th>Basic/Reinforced</th>
<th>Temporary Overvoltage (V&lt;sub&gt;RMS&lt;/sub&gt;/&lt;V&lt;sub&gt;PK&lt;/sub&gt;)</th>
<th>Impulse/Surge Voltage (V&lt;sub&gt;PK&lt;/sub&gt;)</th>
<th>Minimum Clearance (mm)</th>
<th>Working Voltage (V&lt;sub&gt;RMS&lt;/sub&gt;/&lt;V&lt;sub&gt;PK&lt;/sub&gt;)</th>
<th>Minimum Creepage (mm)</th>
<th>CTI I</th>
<th>CTI II</th>
<th>CTI III</th>
</tr>
</thead>
<tbody>
<tr>
<td>480 Neutral Earthed</td>
<td>277</td>
<td>300</td>
<td>Functional</td>
<td>NA</td>
<td>NA</td>
<td>0.1/0.2/0.8</td>
<td>480/678</td>
<td>2.5</td>
<td>3.6</td>
<td>5.0</td>
</tr>
<tr>
<td>480 Neutral Earthed</td>
<td>277</td>
<td>300</td>
<td>Basic</td>
<td>1500 / 2120</td>
<td>4000</td>
<td>3</td>
<td>480/678</td>
<td>2.5</td>
<td>3.6</td>
<td>5.0</td>
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<tr>
<td>480 Neutral Earthed</td>
<td>277</td>
<td>300</td>
<td>Reinforced</td>
<td>3000 / 4240</td>
<td>6000</td>
<td>5.5</td>
<td>480/678</td>
<td>5.0</td>
<td>7.2</td>
<td>10.0</td>
</tr>
<tr>
<td>690 Corner Earthed</td>
<td>690</td>
<td>1000</td>
<td>Functional</td>
<td>NA</td>
<td>NA</td>
<td>0.5/0.5/0.8</td>
<td>690/975</td>
<td>3.5</td>
<td>4.9</td>
<td>6.9</td>
</tr>
<tr>
<td>690 Corner Earthed</td>
<td>690</td>
<td>1000</td>
<td>Basic</td>
<td>2200 / 3110</td>
<td>8000</td>
<td>8.0</td>
<td>690/975</td>
<td>3.5</td>
<td>4.9</td>
<td>6.9</td>
</tr>
<tr>
<td>690 Corner Earthed</td>
<td>690</td>
<td>1000</td>
<td>Reinforced</td>
<td>4400 / 6220</td>
<td>12000</td>
<td>14</td>
<td>690/975</td>
<td>7.0</td>
<td>9.8</td>
<td>13.8</td>
</tr>
<tr>
<td>1000 Corner Earthed</td>
<td>1000</td>
<td>1000</td>
<td>Reinforced</td>
<td>4400 / 6220</td>
<td>12000</td>
<td>14</td>
<td>1000/1414</td>
<td>10.0</td>
<td>14.2</td>
<td>20.0</td>
</tr>
</tbody>
</table>

- Summary of requirements per IEC 61800-5-1 for a few example systems (Category III, pollution degree 2, altitude <2000 m)
- Isolators with more than 14.2mm creepage and clearance are required to support systems with system voltage up to 1000V<sub>RMS</sub>.
Trends of Industrial Motor Drives and Isolation Demanding

• More efficient and compact drives
  – Higher working voltage to reduce I2R loss
    • Isolators with higher working voltage and creepage and clearance.
  – SiC MOSFET to enable lower conduction and switching losses
    • Isolators with higher CMTI to support faster switching.
    • Isolators with lower prop delay to help reduce dead time.

• Smarter drives
  – More communication links to enable connected network
    • Higher data rate communication links including ISOLVDS.

• Reliable drives
  – More protection, fault diagnostic, and prognostic features
    • Isolated gate drivers with more protection features to help reduce system cost and reduce solution size.