Application Note

Understand Safety Requirement and Isolation Needs for High-Voltage Applications Part I: Distinguish Different Safety Standards and Understand Basic Principles of Safety Requirements

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ABSTRACT

Isolated components are widely used in high voltage (HV) applications to protect users from dangerous voltages. However, understanding the key considerations, such as isolation voltage, working voltage, clearance, creepage, certificate, and so forth, to select the appropriate isolated device can be confusing. This application note series helps engineers understand the safety requirements and isolation needs for HV applications, how to design the whole system isolation to satisfy the corresponding safety standards, and finally, how to select the right isolated devices. The series includes three parts, part I focuses on distinguishing the different safety standards and understanding the basic principles of the safety requirements. For the rest of the series, refer to *Part II: Key Considerations to Select ISO Devices and Demystify Clearance and Creepage Distance* and *Part III: Safety Regulation Design Examples of Solar and ESS System*.

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1 Introduction

Currently, in various HV power electronic applications, isolation is an extremely important part of the system design; applications include solar energy, energy storage systems, industrial automation, motor drives, medical equipment, power supplies, and hybrid electric vehicles. Selecting the correct isolator for safety protection is often confusing for designers. Designers must determine the most important items to consider—clearance, creepage, isolation voltage, working voltage, certificates, electrical engineering (EE) standards—and the proper isolated devices based on the product safety requirements.

To add clarity to this decision process, this application note focuses on the following:

- Clarifying the hierarchical relationships, types, and differences of the various safety standards
- Explaining the basic principles and specific safety requirements of the standards

This application note features an example of designing insulation for solar inverters and how this experience can apply to other HV applications.

Note

Isolation and insulation are often used interchangeably. Isolation refers to the separation between two systems or voltage levels, while insulation refers to the actual medium being used to do the separation. In this application note series, these terms are treated as having the same meaning.

2 Distinguish Different Safety Standards

The following list of datasheets serve as an example of devices with isolated components that meet different standards by different governing agencies:

- Digital isolator: *ISO644x General-Purpose, Basic and Reinforced, Quad-Channel Digital Isolators*
- Isolated gate driver: *UCC23513, 4A Source, 5-A Sink, 5.7kVRMS Opto-Compatible Single-Channel Isolated Gate Driver*

These documents include many different safety-related certifications on the first page, some of these certification standards are shown in the following list.

- Safety-related certifications:
  - DIN EN IEC 60747-17: *Semiconductor devices – Part 17: Magnetic and capacitive coupler for basic and reinforced insulation* (VDE 0884-17: *Part 17: Magnetic and capacitive couplers for basic insulation and enhanced insulation*)
  - UL 1577 Component Recognition Program: *Optical Isolators*
  - IEC 62368-1: *Audio/video, information and communication technology equipment – Part 1: Safety requirements*
  - IEC 61010-1: *Safety requirements for electrical equipment for measurement, control, and laboratory use – Part 1: General requirements*
  - IEC 60601-1: *Medical electrical equipment – ALL PARTS*
  - GB 4943.1: *Audio/video, information and communication technology equipment – Part 1: Safety requirements*

With so many various certificates and standards, feeling at the beginning of the decision-making process is common. Therefore, understanding these hierarchical relationships of the governing agencies and the types of safety standards, at the system level or component level, is important.

2.1 Hierarchical Relationships of Safety Standard Governing Agencies

Figure 2-1 shows the hierarchical relationships of the safety standards governing agencies.

- The first level.
  - International Electrotechnical Commission (IEC) is the recognized standardization institute in the power electronics industry. This standardization agency develops and publishes international electrical standards for different applications as general safety requirements.
- The second level.

  - Each country or region implements individual standards and interpretations, and can publish specific regional standards as a result. These regional standards are usually compatible with the first-level IEC standards. Of course, these governing bodies can generate a standard independently, without referring to the IEC standard.
- The third level.
  - The regional certification institute or agency that completes the corresponding testing and certificate issuance.

Examples of second-level governance agencies are:

- The USA/Canada safety standard (UL/CSA) of the Unites States and Canada
  - UL/CSA is the agency responsible for testing and certification of the safety standard
- Verband der Electrotechnical (VDE) of Germany
  - Technischer Ünderachievement (TÜV) and (VDE) are the agencies responsible for testing and certification of the safety standard
- Certification and Accreditation Administration of the People's Republic of China (CNCA) and Guojia Biaozhun (GB) of China
  - China Quality Certification Centre (CQC) is responsible for testing and certification of the safety standard

Power electronic products or systems sold or used in a country or region must meet the regional standards.

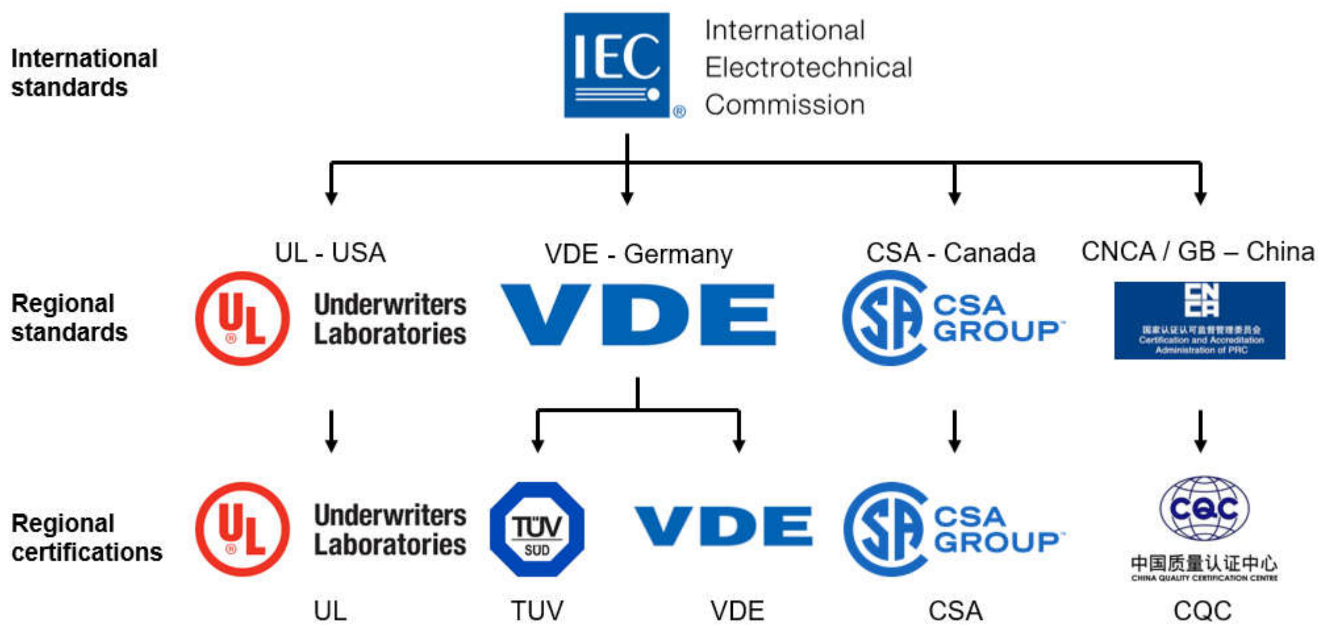

Figure 2-1. Hierarchical Relationships of the Safety Standard Governing Agencies

2.2 Types of Safety Standards

Different safety standards have different safety types. Depending on the target objective, these standards are generally categorized into three types:

- System and equipment standards
- Component standards
- Coordination and support standards

2.2.1 System and Equipment Standard

System and equipment standards are the controlling standards to regulate the safety of the system operation in the end equipment. This standard covers a variety of safety concerns, such as insulation, pressurized gases, and so forth. For example, the IEC 62477-1 standard is for power electronic converter systems and equipment, the IEC 62109-1 standard is for power converters used in photovoltaic power systems, the IEC 61010-1 standard is for medical equipment, and the IEC 60950 standard is for information technology equipment. System and equipment standards set performance levels (such as clearance and creepage) for specific conditions. Take a solar system for example, the IEC 62109-1 standard requires minimum clearance and creepage values that the design of the system must satisfy (such as an isolator, PCB, and other components related to high voltage). Therefore, the system and equipment standards also determine the specifications of the components based on the safety requirements of the system. Therefore, an evaluation of the system and equipment standards includes an evaluation of the related component standards.

2.2.2 Component Standards

Component standards aim to evaluate specific components that can be used in a variety of applications, which provide support across multiple IEC system standards. These standards define how to evaluate isolated performance, such as test methods, test conditions, sample size, and so forth. For example, the VDE 0884-5 standard (equivalent to IEC 60747-5-5) is for optocoupler isolators, the IEC 60747-17 standard (equivalent to VDE 0884-17) is for capacitive and inductive isolators, and the UL 1577 standard is for all isolators. Component manufacturers send devices to certificate institutes to have the certifying agency complete tests on the devices based on the standard methods and conditions. Afterward, the component manufacturer can demonstrate the resulting specifications in the datasheets. Users can select isolated components with appropriate specifications according to the system and equipment standards.

Note

The UL 1577 standard is the USA isolation standard. This standard is not considered congruent to the level-one IEC standard. Section 2.2.4 provides a detailed comparison of these two isolator component standards, the UL 1577 and IEC 60747-17 standard.

2.2.3 Coordination and Support Standards

Coordination and support standards aim to provide definitions, terminology, methods, or requirements that are applicable to other standards. For example, IEC 60664-1 is the standard for insulation coordination. The standard lists the factors that affect isolation performance in detail, such as operating voltage, overvoltage category (OVC), material contamination, comparative tracking index (CTI), and altitude. Based on these factors, the system and equipment standards can formulate clearance, creepage, and other isolation requirements under different conditions.

The relationship between these three types of safety standards are shown in Figure 2-2.

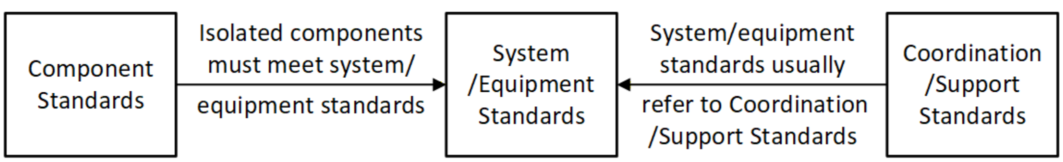

Figure 2-2. Relationships Between Different Types of Safety Standards

Note

Seeing other IEC standards for test methods is common, for example IEC 61000-4-x for ESD, EFT, surge, RF immunity, and so forth. These standards are not related to safety standards and are not discussed in this application note.

2.2.4 The UL 1577 Standard Versus the IEC 60747-17 (VDE 0884-17) Standard

Often, the UL 1577 and IEC 60747-17 (equivalent to VDE 0884-17) certificates are both listed in the insulation specifications of isolated devices. However, there are differences between these standards.

The UL 1577 standard is the certification required by the United States market, and the rating of the standard is based strictly on breakdown voltage. The UL1577 standard contains two parts:

- Qualification: Does destructive tests on lot samples and requires samples to withstand V_{ISO} for 60s
- Production: Does nondestructive production tests on every device, requires components to withstand 1.2 × V_{ISO} for 1s with no breakdown.

However, the UL 1577 standard has limitations. The standard is based on one-minute breakdown voltage, so the basis of the standard does not reflect isolators that can continuously operate at the isolation voltage, nor is this basis a measurement of transient voltage tolerance. Furthermore, only checking how much the isolation voltage can withstand is not adequate for all applications. In HV applications, partial discharge, as shown in Figure 2-3, is a major cause of insulation breakdown, and the UL 1577 standard does not test for partial discharge. If the dielectric of the isolators is poor, such as when tiny air bubbles or impurities exist, this outcome can lead to partial discharge, which reduces insulation strength. A partial discharge test is one of many important methods for verifying insulation reliability. The later-released IEC 60747-17 standard takes this testing a step further than the UL1577 standard.

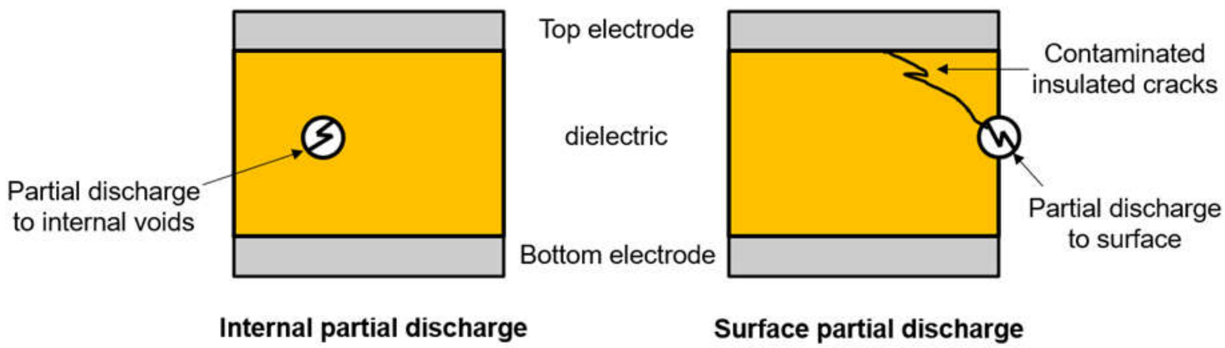

Figure 2-3. Partial Discharge

The IEC 60747-17 standard is primarily based on partial discharge rather than breakdown test. According to the contents of the standard, the standard identifies and tests more insulation voltage specifications, for example the long-term working voltage V_{IOWM}, transient voltage V_{IOTM}, surge voltage V_{IOSM}, and repetitive peak voltage V_{IORM}. A partial discharge test detects tiny imperfections that can potentially grow much larger. Test methods are shown in Figure 2-4.

Method a) is for random samples qualification, and applies V_{IOTM} on the samples for 60s to simulate the occurrence of a transient overvoltage, then drops to 1.6 times or 1.2 times of V_{IORM} for 10s to test the apparent charge q_{pd}.

Method b1) is for 100% production qualification and is completed on automatic test equipment (ATE), this test applies V_{IOTM} on the samples for 1s, then drops to 1.875 times or 1.5 times of V_{IORM} for 1s to test the apparent charge q_{pd}.

All methods require $q_{pd} \leq$ 5pC to screen qualified components.

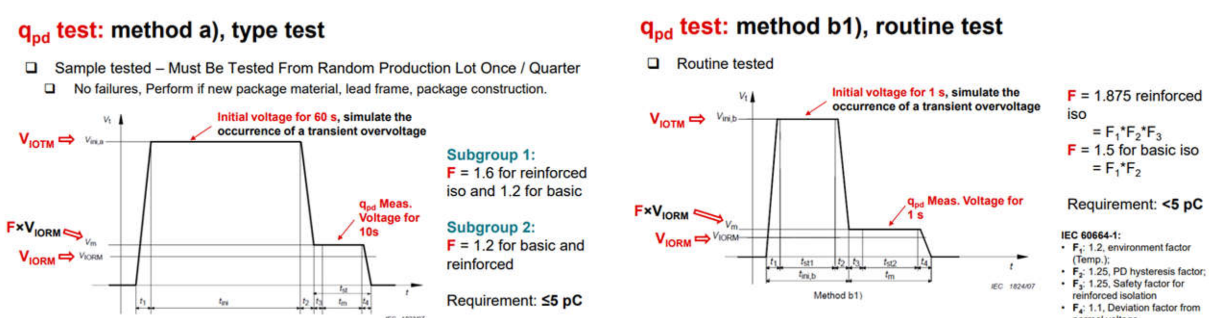

Figure 2-4. IEC 60747-17 (VDE 0884-17) Partial Discharge Tests

2.3 Example – Safety Standards in Solar and Energy Storage Systems (ESS)

Based on the previous discussion, engineers can now distinguish the relationships between the different standards governing and licensing agencies, the different standard types, and the different safety standards to match the standards to an actual system design and satisfy the relevant safety standard requirements. As an example, Figure 2-5 shows the relevant standards matched to solar systems and ESS.

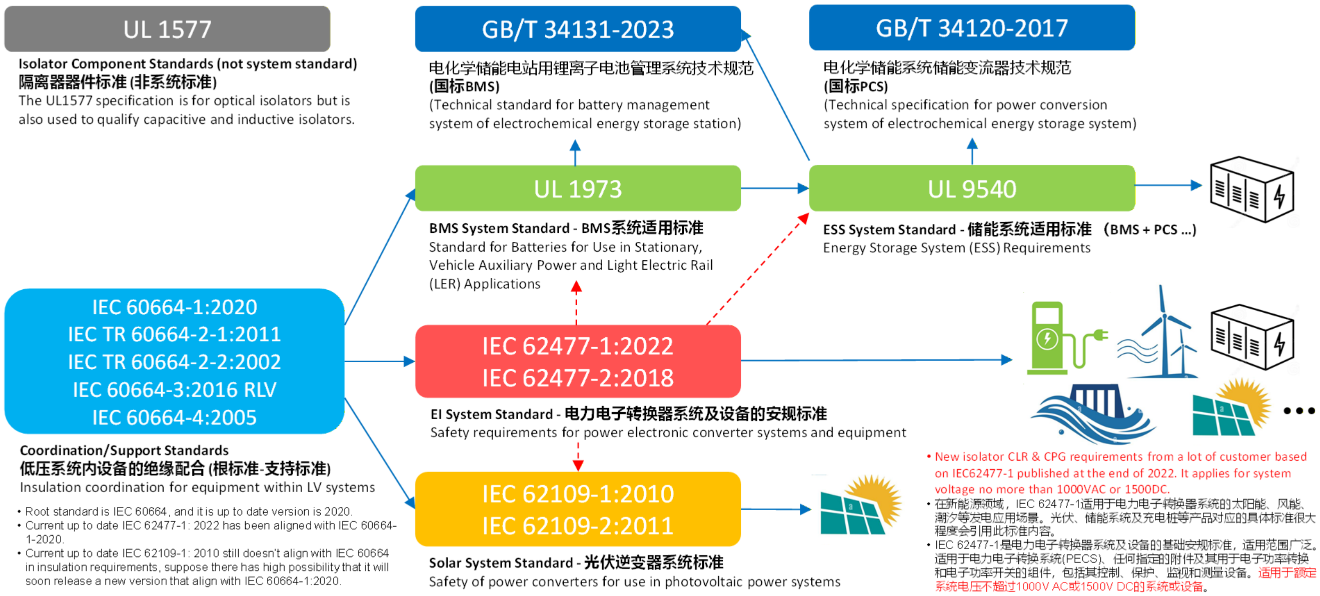

Figure 2-5. Example – Safety Standards in Solar and ESS

3 Understanding the Role of the Safety Standards in System Applications

An important step, after understanding how to distinguish the different safety standards and how to match the different standards to a system, is understanding the roles these standards play in the actual system applications and how to select the appropriate isolated components based on the safety requirements.

3.1 Purposes of Safety Requirements

Unlike other electrical specifications in product datasheets, the parameters defined by safety standards do not cover performance or functional characteristics of equipment. Designers must understand the underlying principles of the safety requirements to develop safe equipment. The application of safety standards is intended to reduce the risk of human injury or damage, such as the common risk of electric shock.

According to the UL 60950-1 standard (equivalent to IEC 60950-1 and GB 4943.1), steady-state voltages over 42.4V AC peak, or 60V DC, are regarded as hazardous under dry conditions for an area of contact equivalent to a human hand. Voltages below this level, such as the common 3.3V DC, 5V DC, and 12V DC are typically non-hazardous and touchable by a user. These non-hazardous voltage circuits must be isolated from hazardous voltages to protect users from dangerous voltages.

Figure 3-1 shows an example of a solar inverter application. The high-voltage side of the inverter is connected to photovoltaic (PV) strings, then boosted by maximum power point tracking (MPPT), and inverted to AC power for grid or loads. For residential applications, the bus voltage can be up to 1100V, and even up to 1500V or 2000V for commercial-industrial or grid-scale applications, much higher than the hazardous voltage threshold. The low-voltage side of the inverter has an human machine interface (HMI) for communication or other operational purposes, that users can touch to check and adjust the inverter operating status. Therefore, the product must be designed to have enough insulation between the HV side and LV side to protect humans against electrical shock.

Figure 3-1. Solar Inverter Application Example

3.2 Levels of Safety Insulation

There are several levels of safety insulation:

- Functional insulation
- Basic insulation
- Supplementary insulation
- Double insulation
- Reinforced insulation

Figure 3-2 draws an analogy between safety insulation levels and wearing clothes to better demonstrate the relationship between different levels of safety insulation.

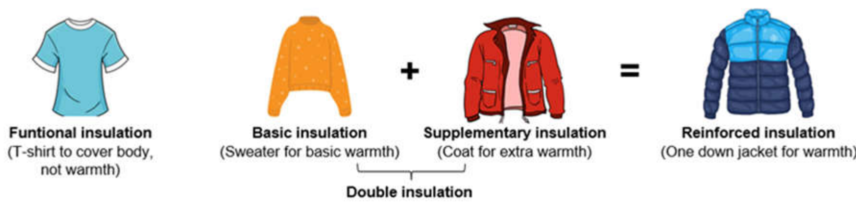

Figure 3-2. Easy Understanding of Safety Insulation Levels

For HV systems with dangerous voltage levels, there are two types of individuals whose safety must be considered, service persons and users (or operators). Service people are those who assemble, install, and maintain HV products or equipment. Service people are professionally trained and capable of working on the high-voltage parts of the equipment. High-voltage parts which are only accessible to service people generally require basic insulation. The term users is applied to all people other than service people. The protection requirements for users must assume that these individuals are not trained to identify hazards, but the individuals do not intentionally create a hazardous situation. Reinforced insulation is required between hazardous voltage and parts that a user can touch, like the HMI mentioned in the Figure 3-1 example.

3.2.1 Functional Insulation

Functional insulation is the lowest level. The only purpose of functional insulation is to maintain proper function of the circuit, such as adding insulation between conductive parts within a circuit for a high voltage and low voltage connection, or common-mode transient immunity (CMTI). Functional insulation does not provide protection against electrical shock.

3.2.2 Basic Insulation

Basic insulation is applied to hazardous live parts to provide basic protection against electrical shock. Basic insulation targets protection against electrical shock under fault-free conditions.

3.2.3 Supplementary Insulation

Supplementary insulation is independent insulation applied *in addition to* basic insulation for fault protection. Therefore, supplementary insulation cannot exist alone.

Note

Basic insulation and supplementary insulation are separate; each is designed for basic protection against electrical shock. Supplementary insulation can help provide extra protection when a circuit issue occurs and the basic insulation fails.

3.2.4 Double Insulation

Basic insulation and supplementary insulation work together to form double insulation.

3.2.5 Reinforced Insulation

Reinforced insulation is the highest insulation for hazardous live parts. Reinforced insulation provides a degree of protection against electrical shock equivalent to double insulation, and certification institutes admit that reinforced insulation and double insulation can achieve the same insulation performance at the system level. However, reinforced insulation must be an integral whole. Meaning, though reinforced insulation can comprise several isolation layers, the isolation must be achieved by a single isolator and cannot be tested separately as basic insulation and supplementary insulation.

3.3 Example – Safety Requirements of 1500V String Inverter

As a standard mapping example, take the string inverter with a 1500V bus voltage in Figure 3-3. The string inverter is typically divided into several parts:

- The main control board
- The Arc-Fault Circuit Interrupter (AFCI) ARC board
- The proportional-integral-derivative (PID) board
- The communication board

The first three parts are all on the HV side and basic insulation is sufficient if these parts must communicate with each other. The communication board is located on the low-voltage side and connected to an external human-machine interface (HMI) where users have access to touch or operate the interface, therefore, reinforced insulation is required.

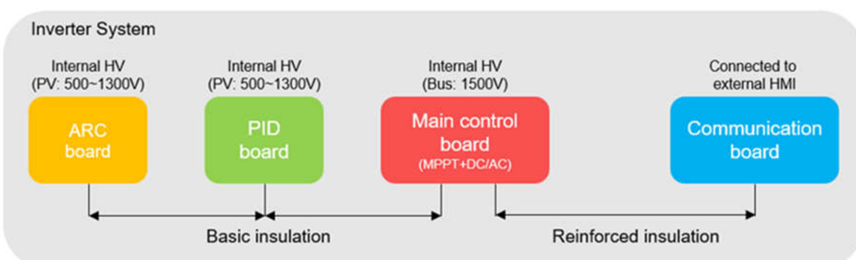

Figure 3-3. String Inverter Function Block

After the required insulation level is determined, the first step is to confirm whether the isolators can operate at the system HV level long-term, which is V_{IOWM}. As shown in Figure 3-4, the ISO1050DW V_{IOWM} device only supports 1200VDC, which is not an appropriate isolated CAN transceiver for a 1500V string inverter system. While the ISO1042DWV device can meet the system HV level requirements with 1500VDC.

DIN V VDE V 0884-11:2017-01[2]					
V_{IORM}	Maximum repetitive peak isolation voltage	AC voltage (bipolar)	560	1200	V_{PK}
V_{IOWM}	Maximum isolation working voltage	AC voltage (sine wave); time-dependent dielectric breakdown (TDDB) test;	395	848	V_{RMS}
		DC voltage	560	1200	V_{DC}

ISO1050DW

DIN VDE V 0884-11:2017-01[2]					
V_{IORM}	Maximum repetitive peak isolation voltage	AC voltage (bipolar)	1500	1500	V_{PK}
V_{IOWM}	Maximum isolation working voltage	AC voltage (sine wave); time-dependent dielectric breakdown (TDDB) test;	1060	1060	V_{RMS}
		DC voltage	1500	1500	V_{DC}

ISO1042DWV

Figure 3-4. Comparison of the ISO1050DW and ISO1042DWV V_{IOWM} Devices

The relevant safety standards consider factors, such as overvoltage category (OVC), comparative tracking index (CTI), pollution degree, and altitude, to decide the overall clearance and creepage requirements. As shown in Table 3-1, according to the IEC 62477-1:2022 standard, for an altitude application of 4,000m, the basic insulation clearance must be over 7.095mm and creepage must be over 7.514mm, and the reinforced insulation clearance must be over 10.320mm and creepage must be over 15.029mm. For an altitude application of 5,000m, both the basic insulation clearance and creepage must be over 8.140mm, and the reinforced insulation clearance must be over 11.840mm and creepage must be over 15.029mm.

To satisfy the current limiting reactor (CLR) and creepage and clearance (CPG) requirements of a 1500V inverter or a power control system (PCS) deployed at a 5000m altitude, as shown in Figure 3-5, TI has the latest digital isolators ISO64xxDW and ISO77xxDUW that can achieve basic and reinforced isolation, respectively. Furthermore, the ISO77xxDUW device not only supports a 1500V application, but also supports a 2000V application according to the IEC 62477-2:2018 standard.

For more design details, refer to *Part II: Key Considerations to Select ISO Devices and Demystify Clearance and Creepage Distance* and *Part III: Safety Regulation Design Examples of Solar and ESS System* of the application note series.

Table 3-1. IEC 62477-1:2022 CLR and CPG Requirements for a 1500V System

1500VDC, OVC I[1], CTI-I, and Pollution Degree 2				
	Clearance (CLR)		Creepage (CPG)	
Altitude	**Basic**	**Reinforced**	**Basic**	**Reinforced**
4000m	7.095mm	10.320mm	7.514mm	15.029mm
5000m	8.140mm	11.840mm	8.140mm	15.029mm

(1) Component OVC I, co-work with SPD to achieve system OVC II

PARAMETER		TEST CONDITIONS	PACKAGE 16-DW	UNIT
IEC 60664-1			ISO64xxDW	
CLR	External clearance[1]	Side 1 to side 2 distance through air	>8.15	mm
CPG	External creepage[1]	Side 1 to side 2 distance across package surface	>8.15	mm
DTI	Distance through the insulation	Minimum internal gap (internal clearance)	>17	µm
CTI	Comparative tracking index	IEC 60112	>600	V

PARAMETER		TEST CONDITIONS	VALUE			UNIT
			DW-16	DUW-16	DBQ-16	
CLR	External clearance[1]	Shortest terminal-to-terminal distance through air	>8	>20	>3.7	mm
CPG	External creepage[1]	Shortest terminal-to-terminal distance across the package surface	>8	>20	>3.7	mm
DTI	Distance through the insulation	Minimum internal gap (internal clearance) ISO77xxDUW	>17	>17	>17	µm
CTI	Comparative tracking index	DIN EN 60112 (VDE 0303-11); IEC 60112	>600	>600	>600	V

Figure 3-5. TI's Latest Digital Isolators ISO64xxDW and ISO77xxDUW

4 Summary

Safety standards can be categorized into system and equipment standards, component standards, and coordination and support standards. When evaluating safety compliance in designs of high voltage systems, designers must distinguish whether the safety requirements apply to the whole system or a single component, as well as consider the safety standards of different regions. Depending on the insulation location and the individuals requiring protection, different insulation levels and the appropriate isolators must be selected based on the corresponding safety standards.

5 References

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25. VDE, *VDE 0884-5:2015-11: Part 5-5: Optoelectronic Components – Optocouplers*, standard.