Technical White Paper

Circuit Board Insulation Design According to IEC60664 for Motor Drive Application

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ABSTRACT

The International Electrotechnical Commission (IEC) standard IEC 60664: Insulation coordination for equipment within low-voltage systems specifies the requirement for clearances, creepage distances, and solid insulation for equipment based upon their performance criteria.

Motor drive systems typically consist of high-voltage and low-voltage subsystems. Such systems demand reliable galvanic isolation to isolate high-voltage circuits from low-voltage circuits.

To better assimilate the method to calculate the insulation distances when designing the circuit board in motor drive system, this document aims to present the insulation design guide and example to meet the requirement coming from IEC60664-1.

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1 Introduction of Key Terms in IEC60664

1.1 Clearance and Creepage

Clearance: Defined as the shortest distance between two conductive materials measured through air. Sufficient clearance distance prevents an ionization of the air gap and a subsequent flashover. Similar to creepage distance the pollution degree, temperature and relative humidity influence the tendency for a breakdown. Breakdown along a clearance path is a fast phenomenon where damage can be caused by a very short duration impulse. Therefore, it is the maximum peak voltage, including transients (overvoltage category [OVC] level), that is to be used to determine the required clearance spacing. Figure 1-1 shows the definition of clearance.

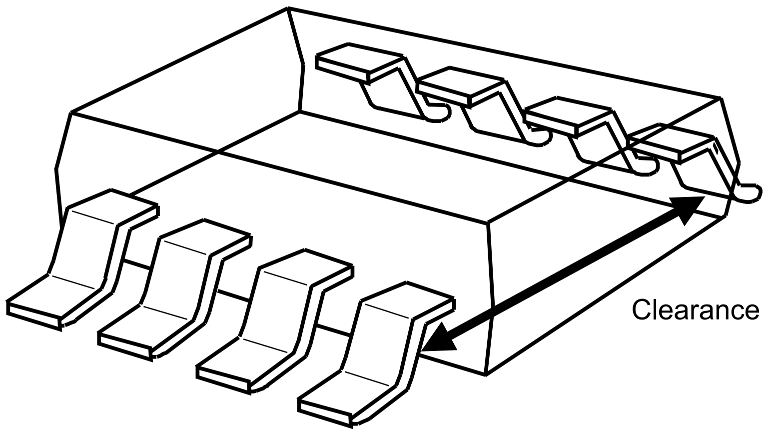

Figure 1-1. Definition of Clearance

Creepage: Defined as the shortest path between two conductive materials measured along the surface of an isolator which is in between. Maintaining a certain creepage distance addresses the risk of tracking failures over lifetime. The generation of a conductive path along the isolator surface due to the high voltage applied over time is related to the root mean square (RMS) value and depends on environmental conditions, which are described by a pollution degree and the material characteristics of the isolator comparative tracking index (CTI). Breakdown of the creepage distance is a slow phenomenon determined by DC or RMS voltage rather than peak events or transients. Inadequate creepage spacings can last for days, weeks or even months before failure. Figure 1-2 shows the definition of creepage.

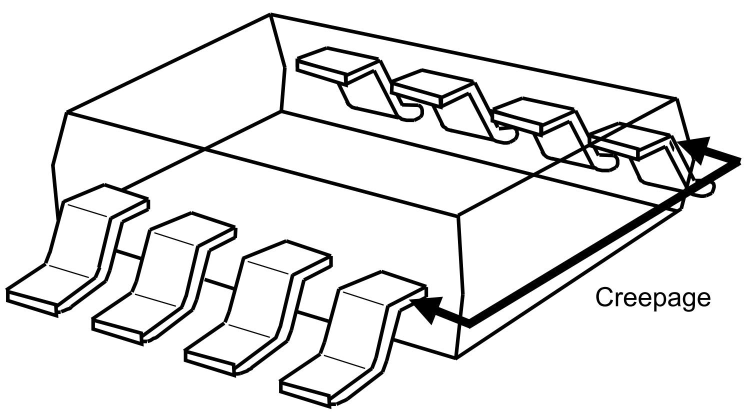

Figure 1-2. Definition of Creepage

1.2 Insulation Type

Functional insulation: Insulation between conductive parts which is necessary only for the proper functioning of the equipment. Functional insulation passes a signal or power from a system at one voltage potential to another system and a different voltage. Functional insulation does not protect against electrical shock..

Basic insulation: Insulation applied to live parts to provide basic protection of persons against electric shock.

Double insulation: Double isolation takes a system with basic insulation and adds a supplementary insulation layer between the electrical parts and the end user to reduce the likelihood of electrical shock in the event that basic isolation fails.

Reinforced insulation: A single insulation system applied to live-parts, which provides a degree of protection against electric shock equivalent to double insulation. A device with reinforced isolation provides basic isolation; plus, the insulation is designed to provide the physical separation between printed circuit board traces, cores, windings, pins, and so forth.

1.3 Decisive Voltage Class and Extra-Low Voltage

DVC: Decisive voltage class is the classification of voltage range used to determine the protective measures against electric shock. The limit of DVC can be referred to table 3 of the international standard IEC61800-5-1 (adjustable speed electrical power drive systems, part 5-1: safety requirements for electrical, thermal and energy)

ELV: Extra low voltage defines any voltage not exceed 50V ac-rms and 120V dc. Protection against electric shock is dependent of the DVC. DVC A and B are contained in the voltage range of ELV.

1.4 Protection Class

Class 1: Equipment in which the protection against electric shock does not rely on basic insulation only, but which includes an additional safety precaution in such a way that means are provided for the connection of accessible conductive parts to the protective conductor (Earth).

Class 2: Equipment in which the protection against electric shock does not rely on basic insulation only, but in which additional safety precautions such as double insulation or reinforced insulation are provided, there being no provision for protective earthing or reliance upon installation conditions.

Section 1.4 shows the typical class 1 and class 2 device.

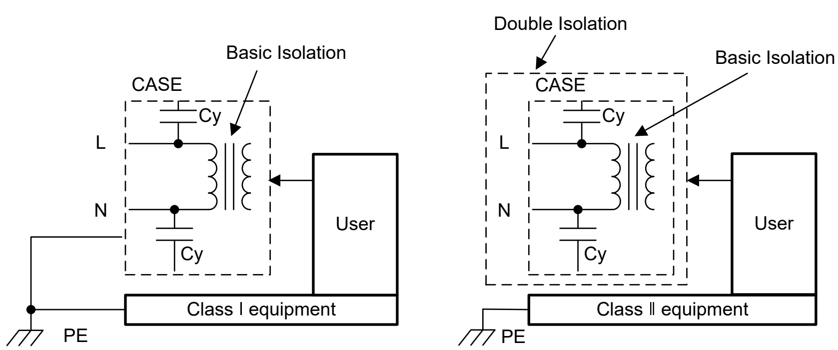

Figure 1-3. Class I and Class II Device

1.5 Pollution Degree

Pollution: Any addition of foreign matter, solid, liquid, or gaseous that can result in a reduction of electric strength or surface resistivity of the insulation.

Micro-environment: Immediate environment of the insulation which particularly influences the dimensioning of the creepage distances.

Pollution degree: Numeral characterizing the expected pollution of the micro-environment. This classification is important since it affects creepage and clearance distances required to ensure the safety of a product. Table 1-1 distinguishes the four pollution degrees with examples.

Table 1-1. Degree of Pollution

Pollution Degree	Micro-Environment	Example
1	No pollution or only dry, non-conductive pollution occurs. The pollution has no influence.	In an air-conditioned lab or by extension for the insulation distance under a protection coating or in internal layer
2	Normally, only non-conductive pollution occurs. Occasionally, however, a temporary conductivity caused by condensation is to be expected, when the EE is out of operation.	In an enclosure or an electrical cabinet or household appliances
3	Conductive pollution or dry non-conductive pollution occurs which becomes conductive due to condensation which is to be expected	Electrical equipment of machine tools
4	The pollution generates persistent conductivity caused, for example, by conductive dust or rain or snow	Electrical equipment for outdoor use

1.6 Overvoltage Category

Roman numeral is used to define a transient overvoltage condition. That is, a short time overvoltage lasting not more than few milliseconds, oscillatory or not, usually strongly damped.

- Category I (OVC I) applies to equipment connected to a circuit where measures have been taken to reduce transient overvoltage to a low level. Example, inside the electrical circuit.
- Category II (OVC II) applies between the circuits not directly supplied by mains or the environment. Examples, appliances, portable tools and other plug-connected equipment.
- Category III (OVC III) applies to the circuits directly supplied by mains or the environment. Examples, downstream of and including the main distribution board like switchgear and other equipment in an industrial installation.
- Category IV (OVC IV) applies to equipment permanently connected at the origin of an installation. Examples, upstream of the main distribution board like electricity meters, primary overcurrent protection equipment and other equipment connected directly to outdoor open lines.

Figure 1-4 shows an example of overvoltage category reduction in industrial drive system with electrical circuit connected directly to the supply mains.

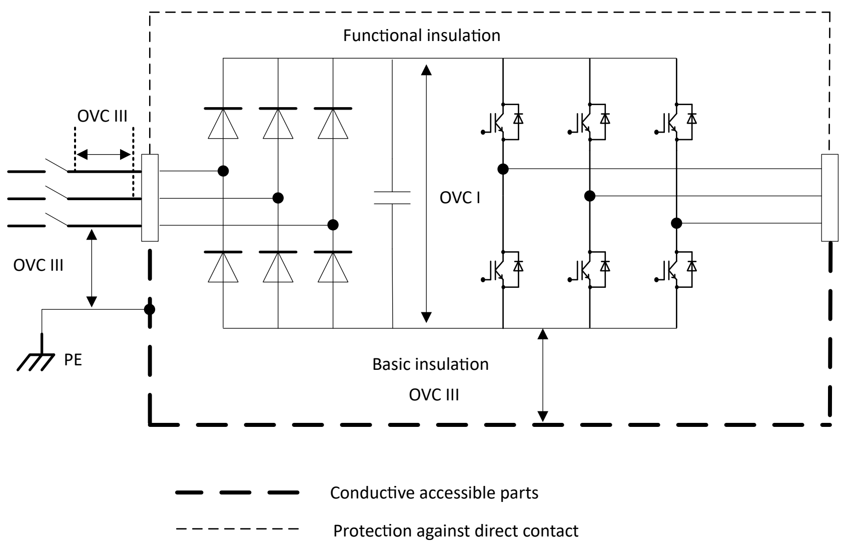

Figure 1-4. OVC Level With Electrical Circuit Connected Directly to the Supply Mains

1.7 System Voltage

System voltage is the voltage used to determine insulation requirements and the product is intended to be used with. For example, 120 Vac, 240 Vac, 480 Vac, 690 Vac, can be single-phase or a multiphase source. The product must be labeled with this voltage. For single-phase systems, the rated voltage is the value between the two phases. For 3-phase systems, the rated voltage is dependent on the type of source transformer, “delta” or “wye”.

“delta” has the same phase-to-phase voltage as the phase to ground voltage. “wye” has a different phase to phase voltage then the phase to ground voltage. For products that are only designed for “center ground wye” source, the product must be labeled such as a rating 480_277Vac. For products designed for “delta” source, the product also works on a “wye” source and is label with just the voltage such as 480 Vac. The “delta” source can also be called “corner grounded” system.

Figure 1-5 shows these two types of power source.

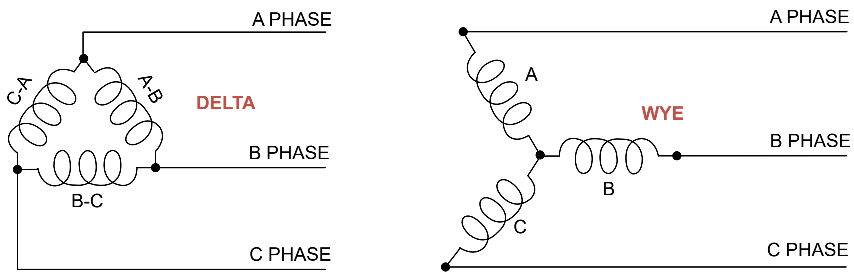

Figure 1-5. Delta and WYE Type of Power Source

1.8 Working Voltage and Voltage Block

Working voltage is the voltage that at rated supply conditions and worst-case operating conditions which occurs by design in a circuit or across insulation. The working voltage can be either DC or AC voltage. Both the RMS and recurring peak values of voltage are used. The value can be done either by simulation, calculation or measurement. Figure 1-6 shows three types of working voltage described in IEC61800-5-1.

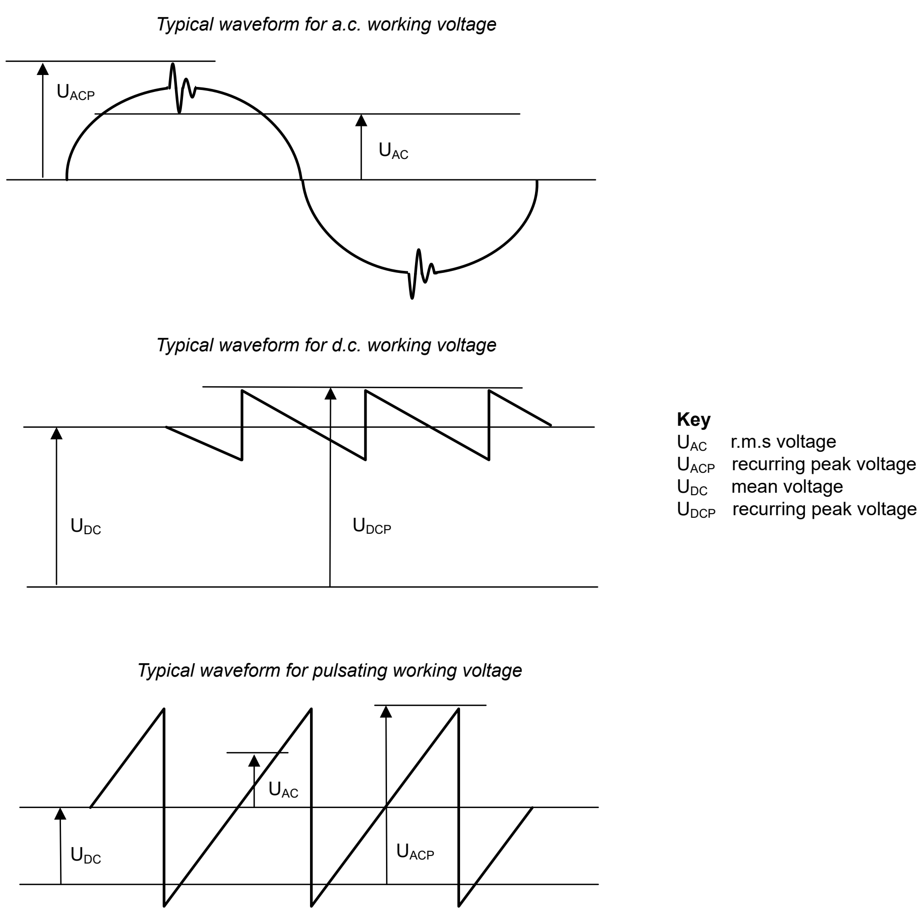

Figure 1-6. Circuit Evaluation for Working Voltage

2 Insulation Distance Definition

2.1 Clearance and Creepage Determining Process

Normally, the product specifications contain sufficient information allowing insulation coordination definitions such as:

- Functional blocks on circuit board
- System Voltage
- Environment conditions (pollution degree) for circuit board
- Mechanical constrains around circuit board. For example, limited height, closed to the conductive parts connected to earth

The process of the insulation distances determining is shown in Figure 2-1.

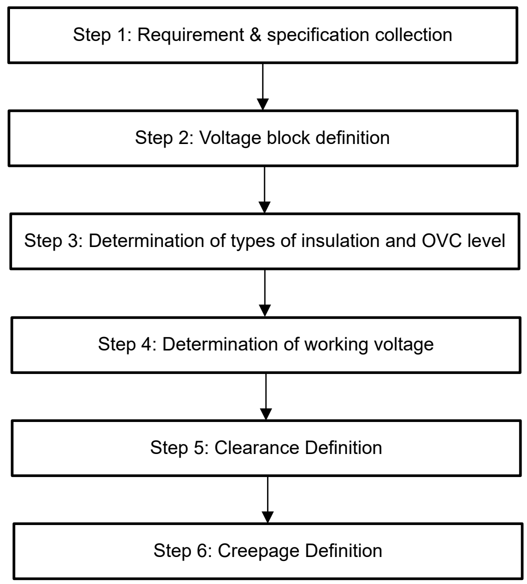

Figure 2-1. Insulation Distance Determining Process

2.2 Clearance and Creepage Determining Method Example

To better assimilate the process described previously, this chapter introduces a detailed example of how to define the insulation distances according to Figure 2-1 step by step.

Step 1: Requirement collection. An industrial motor drive system is listed with the following specifications:

- Class I device (In a metallic cabinet with chassis connect to earth)
- 3-phase power source with nominal 220 Vac and 380 Vac (wye power source), OVC III
- Industrial pollution degree 2 micro-environment
- Isolation required by end-user (Human Machine Interface - HMI)
- Hot side MCU control
- Operating altitude < 2000 m

Figure 2-2 shows the block diagram of the system.

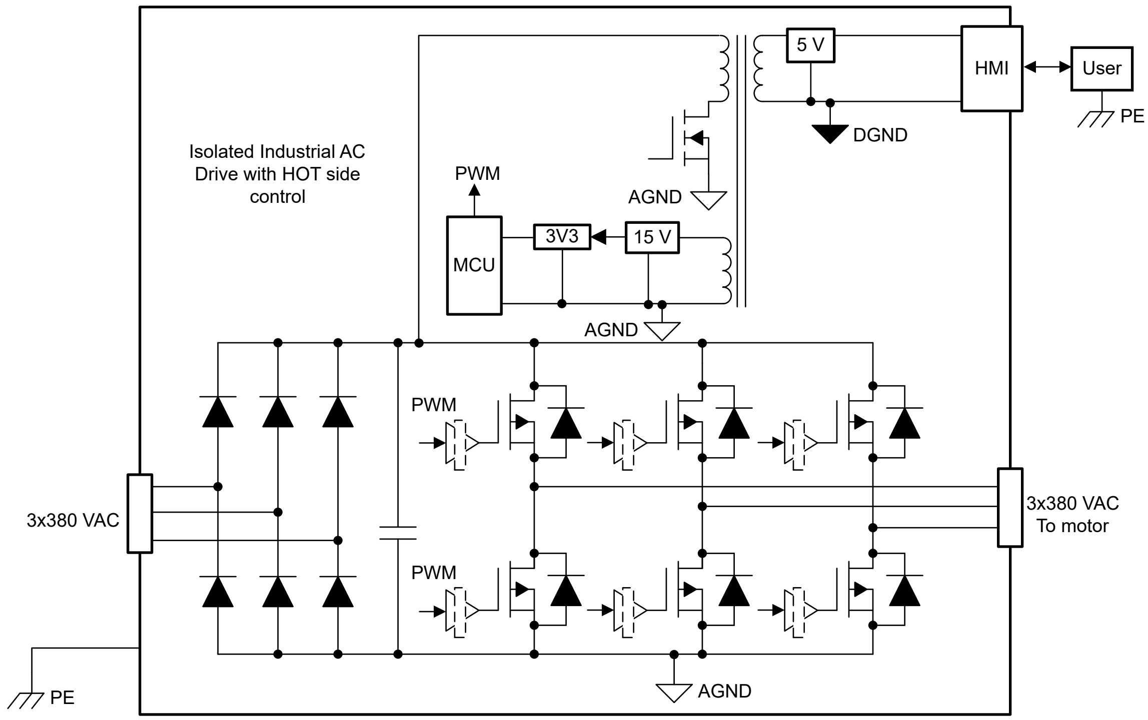

Figure 2-2. Isolated Industrial Motor Drive System Typical Block Diagram

Step 2: Voltage Block definition. This step specifies the voltage blocks in the electrical schematic. The electrical circuit without internal galvanic isolation in which the voltage between two conductors cannot be above 50 Vac and 120 Vdc for clearance.

Figure 2-3 shows all the voltage blocks defined based on the block diagram of step 1.

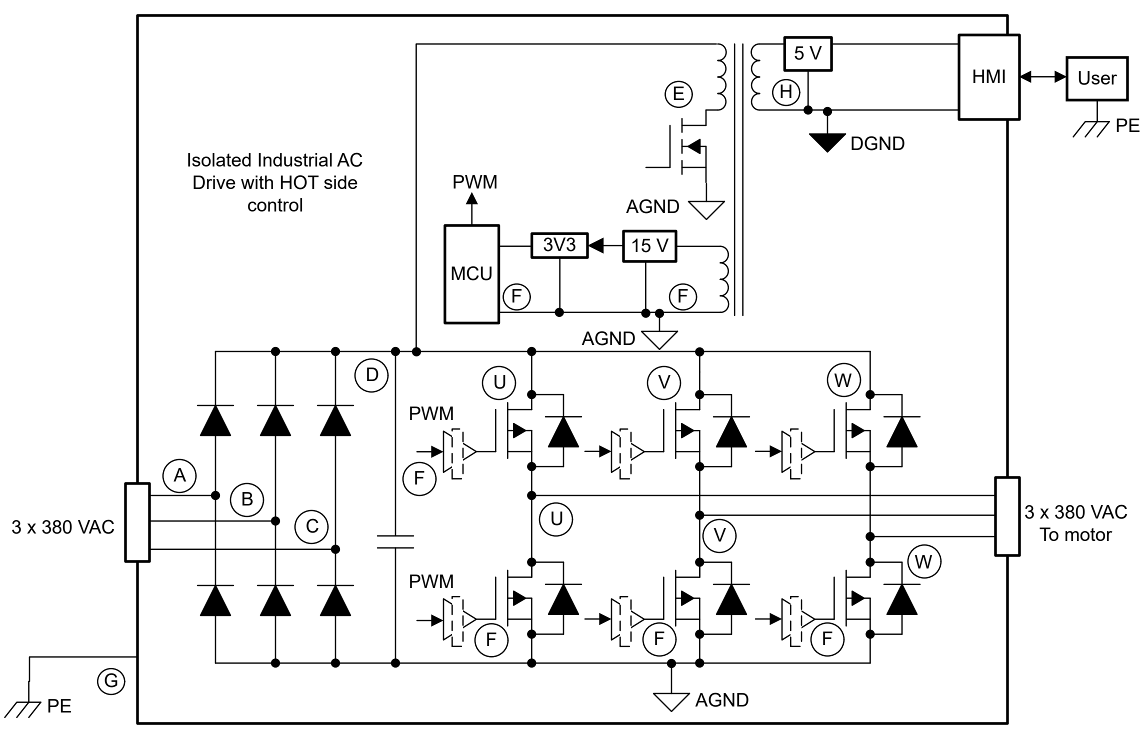

Figure 2-3. Isolated Industrial Motor Drive System Typical Voltage Blocks

Step 3: determine the insulation type and OVC level. The insulation type includes basic, functional and reinforced insulation. The OVC level includes I, II, III and IV. Table 2-1 shows the insulation type and OVC level between each voltage blocks.

Table 2-1. Insulation Type and OVC Level Between Each Voltage Block

Insulation Type OVC	Voltage Blocks										
	A	B	C	D	E	F	G	H	U	V	W
A		BASIC	BASIC	BASIC	BASIC	BASIC	BASIC	REINFORCED	BASIC	BASIC	BASIC
B	III		BASIC	BASIC	BASIC	BASIC	BASIC	REINFORCED	BASIC	BASIC	BASIC
C	III	III		BASIC	BASIC	BASIC	BASIC	REINFORCED	BASIC	BASIC	BASIC
D	III	III	III		FUNCTIONAL	FUNCTIONAL	BASIC	REINFORCED	FUNCTIONAL	FUNCTIONAL	FUNCTIONAL
E	III	III	III	I		FUNCTIONAL	BASIC	REINFORCED	FUNCTIONAL	FUNCTIONAL	FUNCTIONAL
F	III	III	III	I	I		BASIC	REINFORCED	FUNCTIONAL	FUNCTIONAL	FUNCTIONAL
G	III	III	III	III	III	III		BASIC	BASIC	BASIC	BASIC
H	III	III	III	III	III	III	I		REINFORCED	REINFORCED	REINFORCED
U	III	III	III	I	I	I	III	III		FUNCTIONAL	FUNCTIONAL
V	III	III	III	I	I	I	III	III	I		FUNCTIONAL
W	III	III	III	I	I	I	III	III	I	I	

Step 4: determine the working voltage (WV). The rated working voltage for clearance (CL) is the peak value and is referred to table B of IEC60664-1 while the working voltage for creepage (CR) is the RMS value. The table B of IEC60664-1 consists of 50 V, 100 V, 150 V, 300 V, 600 V, and 1000 V these 6 levels working voltages. Table 2-2 shows the working voltage for both clearance and creepage between each voltage blocks. The working voltage value is done by simulation and calculation.

Table 2-2. Working Voltages Between Each Voltage Block

WV for CL_WV for CR (V)	Voltage Blocks										
	A	B	C	D	E	F	G	H	U	V	W
A		300_400ac	300_400ac	300_400ac	300_400ac	300_400ac	300_400ac	300_400ac	300_440ac[(2)]	300_440ac	300_440ac
B			300_400ac	300_400ac	300_400ac	300_400ac	300_400ac	300_400ac	300_440ac	300_440ac	300_440ac
C				300_400ac	300_400ac	300_400ac	300_400ac	300_400ac	300_440ac	300_440ac	300_440ac
D					300_565dc[(1)]	300_565dc	300_400ac	300_400ac	300_565dc	300_565dc	300_565dc
E						300_565dc	300_400ac	300_400ac	300_565dc	300_565dc	300_565dc
F							300_400ac	300_400ac	300_565dc	300_565dc	300_565dc
G								50_10ac	300_400ac	300_400ac	300_400ac
H									300_400ac	300_400ac	300_400ac
U										300_400ac	300_400ac
V											300_400ac
W											

(1) 565 V is the Vbus voltage = $\sqrt{2} \times 400$ V
(2) 440 V is the simulation results = 1.1 × mains phase to phase voltage

Clearance distance: Table F.1 of IEC60664-1 defines the rated impulse voltage according to each working voltage and OVC level while table F.2 defines the clearances to withstand transient over-voltages. Clearances shall be dimensioned to withstand the required impulse withstand voltage according table F.1 and F.2. With respect to impulse voltages, clearances of reinforced insulation shall be dimensioned as specified in Table F.2 corresponding to the rated impulse voltage but one step higher in the preferred series of values than that specified for basic insulation.

For 220-V or 380-V systems, the impulse voltage is 1500 V for OVC1 with functional isolation, 4000 V for OVCIII with basic isolation and 6000 V for reinforced insulation. Then the corresponding clearance of pollution degree 2 is 0.5 mm for 1500 V with functional isolation, 3 mm for 4000 V with basic isolation and 5.5 mm for 6000 V with reinforced isolation.

Creepage distance: Table F.4 of IEC60664-1 defines the creepage distances for functional, basic insulation to avoid failure according to different pollution degrees and material group of printed circuit board. Creepage distance for reinforced insulation shall be twice the creepage distance for basic insulation from table F.4. IEC61800-5-1 also defines that when the creepage distance is less than clearance determined by impulse voltage, then it shall be increased to that clearance.

Creepage for 400-V working voltage = 2 mm (functional, basic), 4 mm (reinforced) (1)

Creepage for 440-V working voltage = 40 V × (2.5 mm – 2 mm) / (500 V – 400 V) + 2 mm = 2.2 mm (2)

Creepage for 565-V working voltage = 65 V × (3.2 mm – 2.5 mm) / (630 V – 500 V) + 2.5 mm = 2.8 mm (3)

Table 2-3 shows clearance and creepage distance between each voltage blocks.

Table 2-3. Clearance and Creepage Distance Definition

CL_CR PD2 (mm)	Voltage Blocks										
	A	B	C	D	E	F	G	H	U	V	W
A		3_2	3_2	3_2	3_2	3_2	3_2	5.5_4	3_2.2	3_2.2	3_2.2
B			3_2	3_2	3_2	3_2	3_2	5.5_4	3_2.2	3_2.2	3_2.2
C				3_2	3_2	3_2	3_2	5.5_4	3_2.2	3_2.2	3_2.2
D					0.5_2.85	0.5_2.85	3_2	5.5_4	0.5_2.85	0.5_2.85	0.5_2.85
E						0.5_2.85	3_2	5.5_4	0.5_2.85	0.5_2.85	0.5_2.85
F							3_2	5.5_4	0.5_2.85	0.5_2.85	0.5_2.85
G								0.2_0.04	3_2	3_2	3_2
H									5.5_4	5.5_4	5.5_4
U										0.5_2	0.5_2
V											0.5_2
W											

Finally, select the maximum value between clearance and creepage as the insulation distance, then put the values into PCB design tool as the constrain rules as Table 2-4 shows.

Table 2-4. Insulation Distance on PCB

Spacing Net Name	CR_Inner Layer (mm)	CR_Outer Layer (mm)	CL (mm)
A, B, C - A, B, C	3	3	3
A, B, C - D, E, F	3	3	3
A, B, C - G	3	3	3
A, B, C - H	5.5	5.5	5.5
A, B, C - U, V, W	3	3	3
D, E, F - D, E, F	2.85	2.85	0.5
D, E, F - G	3	3	3
D, E, F - H	5.5	5.5	5.5
D, E, F - U, V, W	2.85	2.85	0.5
G - H	0.2	0.2	0.2
G - U, V, W	3	3	3
H - U, V, W	5.5	5.5	5.5
U, V, W - U, V, W	2	2	0.5

Since the requirement is defined, the operating altitude is below 2000 meters. When the product or circuit board requires higher altitude than 2000 m, be sure to consider altitude correction factors. Table A.2 of IEC60664-1 defines the multiplication factor for air clearance. For example, 4000-m altitude correction factor is 1.29. Clearance distance for 2000 m is 3 mm, then clearance for 4000 m is 3 mm × 1.29 = 3.87 mm.

3 Summary

This document introduces the insulation design guide and example to meet the requirement coming from IEC60664-1 when designing a circuit board for motor drive application.

4 Reference

1. International Electrotechnical Commission, *IEC-60664-1, Insulation coordination for equipment within low-voltage systems, part 1: principles, requirements and tests*, standard
2. International Electrotechnical Commission, *IEC-61800-5-1, Adjustable speed electrical power drive systems, part 5-1: Safety requirements - Electrical, thermal and energy*, standard
3. Texas Instruments, *Isolation in AC Motor Drives: Understanding the IEC61800-5-1 safety standard* functional safety manual
4. Texas Instruments, *High-voltage reinforced isolation: definitions and test methodologies* marketing white paper

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