TE INDUSTRIAL AND COMMERCIAL TRANSPORTATION (ICT)

48 VOLT EVALUATION STRATEGY

1. Purpose

To verify that there is enough protection between conducting parts, to prevent electrical breakdown over the life of a product and is important for safety and performance related reasons. This can include different ways in which electrical breakdown can occur: through insulation, on an insulation surface, and through air between conductive components, collection of conductive contaminants that can end up conductive with moisture (i.e. dust.). Additionally, it takes an account for occasional overvoltage on the mains voltage.

As the transportation industry moves toward higher voltage systems, it is important for TE Connectivity (TE) to take a lead role in providing up-to date data regarding product electrical performance characteristics.

2. Applicability

This assessment report is applicable for all ICT products, which are internally recognized by TE as 48 volt eligible products.

3. Reference Document

- UL 840, Insulation Coordination Including Clearances and Creepage Distances for Electrical Equipment, Underwriters Laboratory, USA
- IEC 60664-1:2007, Insulation coordination for equipment within low-voltage systems - Part 1: Principles, requirements and tests

4. Definitions of Creepage and Clearance

There are two factors that determine the maximum safe operating voltage of electrical connectors: **Creepage** and **Clearance**.

Creepage is when unwanted electrical current flows between conductors over the surface of the insulating material that separates them. In electrical connectors, the conductors are the terminals with wires crimped on, and the insulating material is typically the plastic housing that retains the terminals. Under ideal conditions, no current will flow on the surface of the housing between the terminals. However, if contamination such as dirt and/or moisture is introduced into the housing, a conductive path can form over time if the voltage is high enough. The likelihood of this happening is reduced as the path over the surface between the terminals is made larger, or the sealing rating of the connector is increased to reduce the amount of contamination.

Clearance is the distance measurement, through air, between conductors. Per the industry specifications, for a given nominal voltage rating, a corresponding higher over-voltage rating is given. Over-voltage may occur due to instabilities in the electrical supply. If the over-voltage is sufficiently high, or the distance between the conductors sufficiently short, an electrical arc may form via dielectric breakdown of air. The dielectric breakdown level is further influenced by humidity, altitude, and contamination. The likelihood of this happening is reduced similarly to creepage: increased distance between conductors, insulating barriers and reduced contamination via sealing.

5. General Information on ICT 48 Volt Evaluation Strategy

TE's connector evaluation process takes into consideration ways in which electrical breakdown can occur and determines the required minimum distances between components for given applications.

TE Transportation Solutions has conducted studies for a wide range of products and determined suitability of these products to both UL 840 (Insulation Coordination Including Clearances and Creepage Distances for Electrical Equipment) and IEC 60664-1 (Insulation coordination for equipment within low-voltage systems – Principles, requirements and tests) standards. These standards differ slightly, but each contain similar information for evaluating electrical components. Covered in the following pages is TE's strategy for evaluating connectors for 48 Volt applications along with a general example. The studies conducted determine if the insulating material used and terminal spacing is enough to operate at 60 volts, to support 48 Volt systems, by considering the nominal terminal spacing along with potential shift within the connector cavities due to available freedom of movement. The studies determine if products are capable of meeting requirements under the assumption of a pollution degree 2 environment (for sealed connectors) and at a 2,000 meter elevation. For more stringent requirements, application parameters should be discussed with the responsible TE Product Engineer.

6. 48V Connector Evaluation Methodology

To initiate a study, the Creepage and Clearance values from the specifications (UL or IEC), given the nominal Operating Voltage, Pollution Degree, Altitude, Overvoltage Category and Housing Material Properties are determined. Once the creepage and clearance requirements are found, a CAD model of the subject parts with the electrical terminals is assembled. A cross section of the CAD model is taken and evaluated for the shortest distance between terminals pairs. This can be done manually or via specialized software. Once the area to be evaluated is chosen, the distance analysis is performed. A safety factor is used to account for positional variations in actual location of the terminals and dimensional tolerance stack-ups. If the distance measurements are greater than the required values + safety factor, the parts can be said to meet requirements. If it is less, then a more in-depth analysis must be performed that includes worst case positional variation and tolerance stack-up.

6.1 Determining Creepage and Clearance

The first step of TE's 48-volt connector evaluation strategy is to determine the minimum creepage and clearance values of the connector. The following general example explains the basic process of finding creepage and clearance distances for a given product. This is simply an illustrative example. A copy of the UL840 or IEC 60664-1 should be purchased to conduct actual product evaluations.

6.1.1: Determine Material Group

The material group of the insulating material is defined by the CTI Comparative Tracking Index) and PLC (Performance Level Category) by pulling this information from the part specification or from the appropriate material data sheet provided by the material manufacturer.
Material CTI values between 100 and 600 volts are used to determine whether the material group is group I, group II, group IIIa, or group IIIb. In this example, PEI material is used and a PLC of 4 determines the material group is IIIb.

6.1.2: Determine Pollution Degree

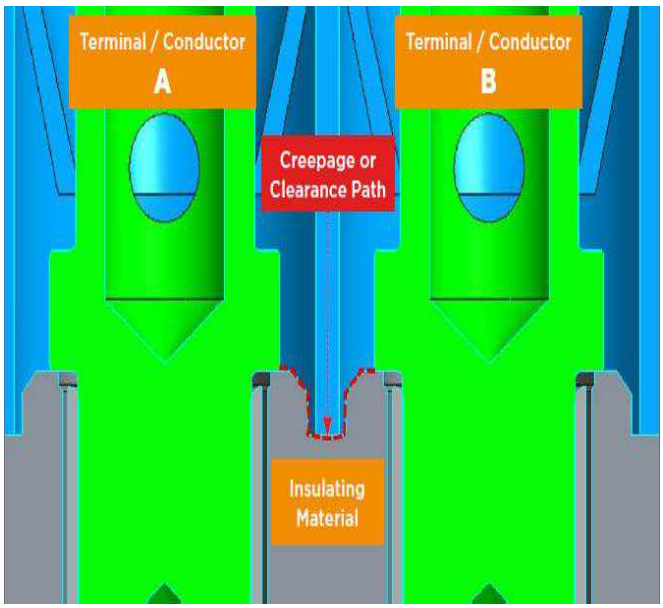
The presence of contaminants in the connector housing increases the likelihood of a conductive path forming between terminals and of dielectric breakdown of air. Therefore, to find minimum creepage and clearance distances, it is necessary to determine the degree of pollution to which the connector is exposed.

POLLUTION DEGREE	CRITERIA
1	No contamination or only dry nonconductive contamination.
2	Nonconductive contamination with potential temporary conductivity due to condensation.
3	Conductive contamination or conductivity due to expected condensation.
4	Contamination creating steady conductivity through conductive contamination or consistent moisture.

Most sealed connectors fall between pollution degrees 2 and 3. Since this example is a sealed connector system and only nonconductive pollution is expected if present, the pollution level is 2.

6.1.3: Determine Minimum Creepage Distance

Minimum creepage distance can now be determined using tabled values. This is accomplished by viewing the appropriate material group and pollution degree along with the desired operating voltage. For 48V systems, typical charging voltages can be expected up to 60V, so for this example 63V is used as the operating voltage. From the table within UL 840 IEC 60664-1 the minimum creepage distance is found to be 1.25 mm.



Overvoltage Category*	II
Material Group*	IIIb (PLC4)
Pollution Degree*	2
Altitude, (m)*	2000
Safety Factor	1.5
Clearance Min Requirement, mm	0.2
Clearance Path Length, from CAD, (mm)	2.4
Clearance Requirements Met	Yes
Creepage Path Min Requirement, (mm)	1.25
Creepage Path Length, from CAD, (mm)	2.4
Creepage Requirements Met	Yes
**These assumptions may change depending on connector design, application and materials used.*	

Connector Evaluation Example

6.1.4: Altitude Correction Factor

The next step is to determine whether connectors are expected to operate at high altitude levels. Altitude level influences dielectric breakdown of air and thus affects minimum clearance distance. Another table is used to find the altitude multiplication factor by viewing the appropriate altitude between 2,000 and 10,000 meters in altitude. In this example the product is expected to operate at 2000 meters, so the correction factor is 1.

6.1.5: Overvoltage Category

To determine overvoltage category, the type of equipment must be identified.
Electrical connectors are generally considered to be at the power consumption level, so for this example the overvoltage category is II.

CATEGORY	*DEFINATION*
Overvoltage Category IV	Equipment operating as part of the main power supply
Overvoltage Category III	Equipment operating to distribute power
Overvoltage Category II	Equipment that consumes the power supplied
Overvoltage Category I	Equipment operating at signal power levels

6.1.6: Determine Clearance Distance

Now the clearance distance can be determined. This is accomplished by viewing the clearance distance required based on the overvoltage category and the appropriate pollution degree. If the withstand voltage is 100V (as this is the next level above 60 volts at pollution degree 2), the resulting clearance distance is 0.2 mm

7. Testing Alternative

If the evaluation of a connector returns results that do not meet the desired requirements, both the UL and the IEC specifications allow testing as a viable alternative to physical measurement. Note that this testing can only be performed to validate Clearance (overvoltage) requirements; there is no defined test method for Creepage. The specifications handle testing slightly differently, so please determine your organization's preference prior to beginning any tests.

8. Terminal Damage and Safety Consideration

As with any power system, operating at 48-60 volts can create potentially harmful conditions. Terminal damage and safety concerns can occur due to an electrical arc during connector un-mating operations which can be very destructive for the terminal surfaces in the range of voltages of 48 Volt systems. Consequently, electrical current should always be discontinued before separating a mated connector pair.

It is recommended that all electrical power remain discontinued for any unmated connectors. If an energized connector is left in an unmated state, direct contact with exposed terminals whether with a human finger or any conductive device or hand tool must be strictly avoided. Shorting between terminals may well result in physical harm or heavy arcing resulting in terminal or connector surroundings damage.

There is also risk of a destructive arc during a connector mating operation due to potential breaking of current due to terminal misalignment, contact sliding, bounce, etc.; therefore, it is also recommended electrical power be discontinued before engaging a connector pair in a 48 Volt system.

In 48V systems electrical energy should be discontinued before connectors are separated, while connectors remain separated, and while the connectors are being re-engaged until the connector is fully seated and locked in place.

9. Summary

The process of using industry specifications for determining Creepage and Clearance distances is relatively straightforward given knowledge of the connector application and materials used. However, evaluating the parts to find the correct path lengths can be more challenging, particularly when complicated geometries and dimensioning & tolerancing schemes are used. Therefore, engineering judgement must be used on a case-by-case basis, with an appropriate safety factor applied, or tolerance stack-up analysis performed before a definite conclusion can be made regarding the connector voltage rating. Anyone conducting product ratings should acquire an official copy of the appropriate UL 840 or IEC 60664-1 specifications to review the published material and work through the steps involved.

Contact the TE Product Engineer regarding the voltage rating studies for any ICT product of interest.

10. List of Qualified Products under 48 Volt Evaluation

10.1 DT Series

Reference Product Base Part Numbers DT04-2P, DT04-3P, DT04-4P, DT04-6P, DT04-08PX, DT04-12PX (receptacles), and DT06-2S, DT06-3S, DT06-4S, DT06-6S, DT06-08SX, DT06-12SX (plugs), X refers to A, B, C, D keys; XXXX refers to product modification. Refer to modifications list for qualified modifications.

Receptacle Part Numbers	Plug Part Numbers
DT04-2P-XXXX	DT06-2S-XXXX
DT04-3P-XXXX	DT06-3S-XXXX
DT04-4P-XXXX	DT06-4S-XXXX
DT04-6P-XXXX	DT06-6S-XXXX
DT04-08PX-XXXX	DT06-08SX-XXXX
DT04-12PX-XXXX	DT06-12SX-XXXX

A. Modification

Note:
Modifications include, but are not limited to, the following list.
Modifications listed are for reference only and may not be available for every arrangement.

Mod	Description
B016	Receptacle has extended shell and enhanced keys, plug has seal retention (P012), 12-Pin
B033	Receptacle Shell design for switch interface, 4 Pin
BE01	Plug with Seal Retention (P012) extended shell and enhanced keys (B016), Short Cap
BE02	Receptacle with extended shell and enhanced keys (B016), Short Cap
BE03	Receptacle with extended shell and enhanced keys (B016), Short Cap, black
BE04	Receptacle with extended shell and enhanced keys (B016), Short Cap, E- seal, black
BE05	Receptacle with extended shell and enhanced keys (B016), Short Cap, sealed flange, E-seal, Threaded Inserts
BE07	with extended shell and enhanced keys (B016), Long Cap
BK01	Plug with Ink Stamping
BL04	Receptacle with extended shell and enhanced keys (B016), Flange
BL05	Receptacle has extended shell and enhanced keys (B016) welded Flange w/o Seal, Short Cap
BL06	Receptacle has extended shell and enhanced keys (B016), Flange E-Seal, Short Cap, black
BL08	Receptacle with extended shell and enhanced keys (B016), Flange, black
BL09	Receptacle with extended shell and enhanced keys (B016), sealed flange, E-seal, Threaded Inserts
BL10	Receptacle with extended shell and enhanced keys (B016), sealed flange, E-seal, Long Cap, Threaded Inserts
BL11	Receptacle with extended shell and enhanced keys (B016), sealed flange, E-seal, Short Cap, Threaded Inserts
BL12	Receptacle has extended shell and enhanced keys welded Flange (B016), E-Seal, Short Cap
BL13	Receptacle has extended shell and enhanced keys welded Flange (B016),E Seal
C015	E-seal
C017	Solid rear grommet, Short Cap
CE01	E-seal, Short Cap
CE02	E-seal, black
CE03	E-seal, Short Cap, black
CE04	E-seal, Long Cap

CE05	Plug with E-seal, Seal Retention (P012), Short Cap
CE06	Plug with E-seal, Seal Retention (P012)
CE07	Receptacle with extended shell and enhanced keys (B016), Short Cap, E-seal
CE08	Receptacle with extended shell and enhanced keys (B016), E-seal
CE09	E seal, Long Cap, black
CE10	Plug with E-seal, Seal Retention (P012), black
CE11	Plug with E-seal, Seal Retention (P012), Short Cap, black
CE12	Plug with E-seal, Seal Retention (P012), Long Cap, black
CE13	Plug with E-seal, Seal Retention (P012), Long Cap
CE14	Plug with E-seal, Seal Retention (P012), latch guard cap, black
CE15	Plug with E-seal, Seal Retention, Dovetail Cap
CE18	Plug with E-seal, seal Retention enhanced keys (B016)
CE26	Solid rear grommet, Short Cap, black
CL03	E-seal, Flange
CL07	E-seal, sealed flange, Long Cap
CL08	E-seal, Flange, Short Cap, disabled latch
CL09	E-seal, sealed flange, Short Cap, black
CL10	Receptacle, E-seal, flange, Tie wrap cap, black
CL11	Receptacle, E-seal, Sealed flange, inside mount, gasket, short cap
CL13	Receptacle, E-seal, short cap, flange, black
CL15	E-seal, Flange, black, A key
CL17	E-seal, Flange, black, B key
CP01	Solid rear grommet, Seal Retention (P012), Short Cap
E003	Short Cap
E004	Black housing
E005	Black, Short Cap
E008	Long Cap
E012	Receptacle, green weld cap, green
E013	Receptacle, brown weld cap, brown
E014	Green
E015	Brown
EE01	Long Cap, black
EF02	Fluorosilicone front seals, Latch Guard Cap
EP04	Short Cap (same as E003)
EP05	Latch Guard Cap
EP06	Plug with Seal Retention (P012), Short Cap
EP07	Plug with Seal Retention (P012), black
EP08	Plug with Seal Retention (P012), Short Cap, black
EP09	Plug with Seal Retention (P012), Latch Guard Cap, black
EP11	Plug with Seal Retention (P012), Long Cap, black
EP20	Plug with seal retention (P012), Long Cap
FL02	Receptacle with extended shell and enhanced keys (B016), Viton seal, sealed flange, Short Cap, E-seal, Threaded Inserts.
FL03	Receptacle with extended shell and enhanced keys (B016), Fluorosilicone grommet, sealed flange, Short Cap, E-seal, Threaded Inserts.
FP02	Plug with Seal Retention (P012), Fluorosilicone Front seals, short cap

L012	Flange
L019	Backshell adapter for DIN convolute interface
L022	Receptacle Integrated with flange
LC01	DIN Backshell adapter weld cap with E-seals and seal retention
LE01	Sealed flange, inside mount, gasket, short cap
LE03	Sealed flange, outside mount, Short Cap (12-Pin), Long Cap (8-Pin)
LE05	Sealed flange, inside mount, gasket, Short Cap
LE06	Sealed flange, inside mount, gasket, Short Cap, E-seal
LE07	Flange, Short Cap
LE08	Flange, Long Cap, gray
LE09	Sealed flange, Short Cap, black
LE10	Sealed flange, inside mount, gasket, Short Cap, black
LE11	Flange, Short Cap, black
LE12	Flange, Long Cap, black
LE13	Special adapter, round housing, Short Cap, black
LE14	Flange, black
LE17	Receptacle with extended shell and enhanced keys (B016), sealed flange, Short Cap, black
LE20	Receptacle, E-Seal, Snap Flange, short cap
LE21	Receptacle with extended shell and enhanced keys (B016), sealed flange, Short Cap, E-seal, Threaded Inserts.
LE24	Receptacle with extended shell and enhanced keys (B016), sealed flange, Short Cap, E-seal black
P004	Same as standard part without modification
P012	Plug and Wedge Lock Seal Retention. 2,3,4,6 pin plugs are black

10.2 DTP Series

Reference Product Base Part Numbers DTP04-2P, DTP04-4P and DTP06-2S, DTP06-4S. XXXX refers to product modification. Refer to modifications list for qualified modifications.

Receptacle Part Numbers	Plug Part Numbers
DTP04-2P-XXXX	DTP06-2S-XXXX
DTP04-4P-XXXX	DTP06-4S-XXXX

B. Modifications

Note:
Modifications include, but are not limited to, the following list.
Modifications listed are for reference only and may not be available for every arrangement.

Mod	Description
C015	E-seal, gray
C017	Solid rear grommet, gray
CE01	E-seal, Short Cap, gray
CE02	E-seal, black
CE03	E-seal, Short Cap, black
CE09	E seal, Long Cap, black
E003	N-seal, Short Cap, gray
E004	N-seal, black
E005	N-seal, Short Cap, black

EE01	N-seal, Long Cap, black
L012	N-seal, Weld on Flange, gray
L025	N-seal, Molded Flange, gray
LE07	N-seal, Short Cap, Weld on Flange, gray

10.3 HD10 Series

Product Base Part Numbers HD10-9-1939P (receptacle), and HD16-9-1939S (plug), X refers to N, E seal type. XXXX refers to special modification. Refer to modifications list for qualified modifications.

Receptacle Part Numbers	Plug Part Numbers
HD10-9-1939PX-XXXX	HD16-9-1939SX-XXXX

C. Modification

Note:
Modifications include, but are not limited to, the following list.
Modifications listed are for reference only and may not be available for every arrangement.

Mod	Description
B009	Raised Key Removed from Front of Flange
B022	With D-hole panel mount
B025	D-hole panel mount and no rear accessory thread, black
BE09	With D hole panel mount, grey
BP03	with D-hole panel mount per SAE 1939-13 Type 2
C016	HD10 - 9 Pin w/ 2 Holes Blocked (H & J)
P080	SAE 1939-13 Type 2

10.4 HDP SERIES

Product Base Part Numbers, HDP24-18-XXP/SX-XXXX, HDP24-24-XXP/SX-XXXX, HDP26-18-XXP/SX-XXXX, HDP26-24-XXP/SX-XXXX. Where XX is pin arrangement, X is seal type (N, T, E), XXXX is modification code. Refer to modifications list for qualified modifications.

Receptacle Part Numbers	Plug Part Numbers
HDP24-18-6X-XXXX	HDP26-18-6X-XXXX
HDP24-18-8X-XXXX	HDP26-18-8X-XXXX
HDP24-18-14X-XXXX	HDP26-18-14X-XXXX
HDP24-24-7X-XXXX	HDP26-24-7X-XXXX
HDP24-24-9X-XXXX	HDP26-24-9X-XXXX
HDP24-24-14X-XXXX	HDP26-24-14X-XXXX
HDP24-24-16X-XXXX	HDP26-24-16X-XXXX
HDP24-24-18X-XXXX	HDP26-24-18X-XXXX
HDP24-24-19X-XXXX	HDP26-24-19X-XXXX
HDP24-24-21X-XXXX	HDP26-24-21X-XXXX
HDP24-24-23X-XXXX	HDP26-24-23X-XXXX
HDP24-24-29X-XXXX	HDP26-24-29X-XXXX
HDP24-24-31X-XXXX	HDP26-24-31X-XXXX
HDP24-24-47X-XXXX	HDP26-24-47X-XXXX

D. Modification

Note:
Modifications include, but are not limited to, the following list.
Modifications listed are for reference only and may not be available for every arrangement.

Mod	Description
C030	4 size 16 cavities blocked (1, 2, 5, 6)
C038	3 size 4, 4 size 16, special size 4 AWG contacts
C041	Receptacle with diagnostic keying
CL16	Four size 16 cavities blocked (1, 2, 5, 6) and ring adapter for back
CL18	3 size 4, 4 size 16, special size 4 AWG contacts and ring adapter for backshell
CL19	3 size 4, 4 size 16, special size 4 AWG contacts and threaded adapter for backshell
CL20	Plug with diagnostic keying
CL21	4 size 16 cavities blocked (1, 2, 5, 6) and threaded adapter for backshell
CL22	3 size 4, 4 size 16, special size 4 AWG contacts and wide threaded adapter for backshell
L015	Threaded adapter for backshell
L017	Ring adapter for backshell
L024	Wide threaded adapter for backshell

10.5 AS16 SERIES

Product Base Part Numbers are listed as below. Example 776427-X is a plug assembly, 776428-X is a cap assembly, X is key type (1, 2, 3, 4) which refers to key A, B, C, and D key respectively. Keying option may not be available for every arrangement.

Cap Assembly Part Numbers	Plug Assembly Part Numbers
776428-X	776427-X
776534-X	776522-X
776430-X	776429-X
776535-X	776523-X
776488-X	776487-X
776536-X	776524-X
776434-X	776433-X
776537-X	776531-X
776495-X	776494-X
776538-X	776532-X
776438-X	776437-X
776539-X	776533-X
1456821-X	1456820-X
2035368-X	2035367-X
1456823-X	1456822-X
2035370-X	2035369-X
2035379-X	2035378-X
2035381-X	2035380-X
2098241-X	2098237-X
2098242-X	2098238-X
2098554-X	2095553-X
2098556-X	2098555-X

2035560-X	2035559-X
2035562-X	2035561-X

10.6 HDSCS SERIES

Product Base Part Numbers are listed as below. Example X-1564407-1 is a tab housing assembly, X-1418390-1 is a receptacle assembly, X is key type (1, 2, 3, 4) which refers to key A, B, C, and D key respectively. Keying option may not be available for every arrangement.

Tab Housing	Receptacle Housing
X-1564407-1	2278730-1
X-1564412-1	2278730-2
X-1564414-1	2306960-1
X-1564416-1	X-1418390-1
X-1564512-1	X-1418437-1
X-1564516-1	X-1418448-1
X-1564518-1	X-1418448-2
X-1564520-1	X-1418469-1
X-1564522-1	X-1418479-1
X-1564526-1	X-1418480-1
X-1564528-1	X-1418483-1
X-1564530-1	X-1563759-1
X-1564532-1	X-1563878-1
X-1564534-1	X-1564330-1
X-1564536-1	X-1564337-1
X-1564544-1	X-1564514-1
X-1564546-1	X-1564542-1
X-1670214-1	X-1670894-1
X-1670730-1	X-1670901-1
X-1703648-1	X-1703639-1
X-1703773-1	X-2208157-1
X-1703808-1	X-2299782-1
X-1703818-1	X-2299782-2
X-1703820-1	
X-1703839-1	
X-1703841-1	
X-1703843-1	

10.7 LEAVYSEAL SERIES

Product Base Part Numbers are listed as below.

Tab Housing	Receptacle Housing	Receptacle Housing
1355328-1	1-1452722-1	1-2112231-1
5-1703998-1	2-1452722-1	3-2112231-1
	0-2282162-1	3-2112231-2
	1-1452228-9	3-2112231-2

1. REVISION HISTORY

Rev Ltr	Brief Description of Change	Date	Dwn	Apvd
A	Initial Release	12/5/2019	D.B.	D.K.
B	Added List of Qualified Products	9/29/2020	D.B.	C.B