APPLICATION NOTE

Low voltage control and protection products in high altitudes

Information and technical guidance for applications above 2000 m sea level

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Foreword

This application note is written as a general guide for people working with low-voltage switchgear and controlgear applications. All these are relevant for IEC-based applications and is suitable for international applications depending on the local standard. For example, the minimum clearance and minimum creepage distance values of the IEC standard are essentially identical to those of UL 840, so these applications could also be found extensively in the UL market.

All the information provided in this guide is only general and each application must be handled as a specific case. Be sure to always follow all national and local installation regulations/codes for your specific application.

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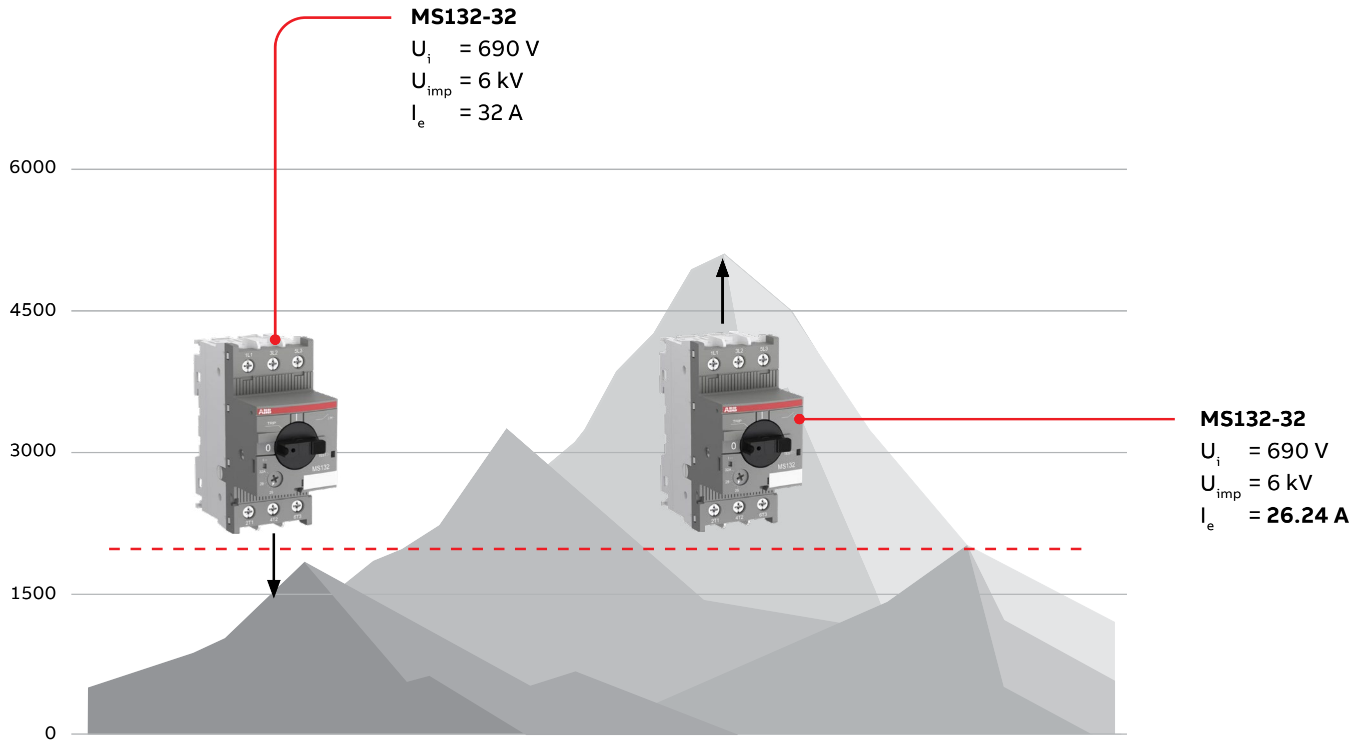
1 Introduction



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01 Example of possible values changes in high altitudes. Up to 2000 m the values are covered by the product standard of the IEC 60947 series.

The performance of switchgear depends on environmental variables. The standards cover the most relevant and important environmental parameters:

- air pressure
- temperature
- pollution
- relative humidity
- condensation

Nevertheless, essential for high altitude applications are effects linked to dimensional parameters like clearances and creepage distances due to reduced air pressure with increasing altitude. The electrical field stress through solid insulation under dedicated environmental parameters depends on the device construction and is validated by test procedures according to the applicable product standards for application altitudes of 2000 m only. There are also products which can be installed above 2000 m altitude due to their construction and parameters. Some limitations may be necessary to be applied.

Above 2000 m the following parameters need to be considered and re-evaluated:

- Rated insulation voltage U_i,
- Rated impulse withstand voltage U_{imp} and
- Rated current I_e

For device construction the dimensioning of clearances, creepage distances and solid insulation between separate circuits, the highest voltage ratings shall be used.

- Evaluation of the rated impulse withstand voltage U_{imp} gives the parameter for clearances and associated solid insulation.
- Evaluation of the rated insulation voltage being larger or equal the the working voltage gives the basis for the creepage distances.
- Evaluation of the rated current correction.

Based on U_e and U_{imp} also the correlation between the nominal voltage of the supply system and the rated impulse withstand voltage of the equipment needs to be evaluated to identify in which overvoltage category the device can be used at which working voltage and which measures need to be applied to enable the use.

Provided that certain correction factors are applied and additional measures are taken, the devices can be used at higher altitudes. These methods are described in this document.

(!) These methods are described at the beginning of this document. The last chapter “Correction factor tables for ABB control products for use at altitudes greater than 2000 m” concerns the derating factors that customers can use to ensure the safety of the equipment at higher altitudes.

2 Evaluation of the rated impulse withstand voltage U_{imp}

First consider the rated impulse withstand voltage U_{imp}, which is a requirement based on the rated voltage U_e and the overvoltage category. In most cases, the user would like to maintain impulse withstand voltage U_{imp} also in high altitude, but this is only possible if the degree of contamination and the minimum permissible distances can be maintained. A rated operational voltage U_e of an equipment is a voltage which, combined with a rated operational current, determines the application of the equipment and to which the relevant tests and the utilization categories are referred. It should be noted that at high altitudes the air pressure changes, which affects the behavior of the breakdown voltage and thus also the allowed minimum clearance distances. The switching of contactors, for example, can also generate voltage peaks.

According to Paschen's law (1), the behavior of air to withstand a maximum stress value (breakdown voltage) is related to the air pressure. From all these correlations and Paschen's law, certain conclusions have to be drawn, i.e. the device must be validated to meet the higher requirements for the rated impulse withstand voltage U_{imp} at higher altitudes.

2.1. Pollution degree of environmental conditions

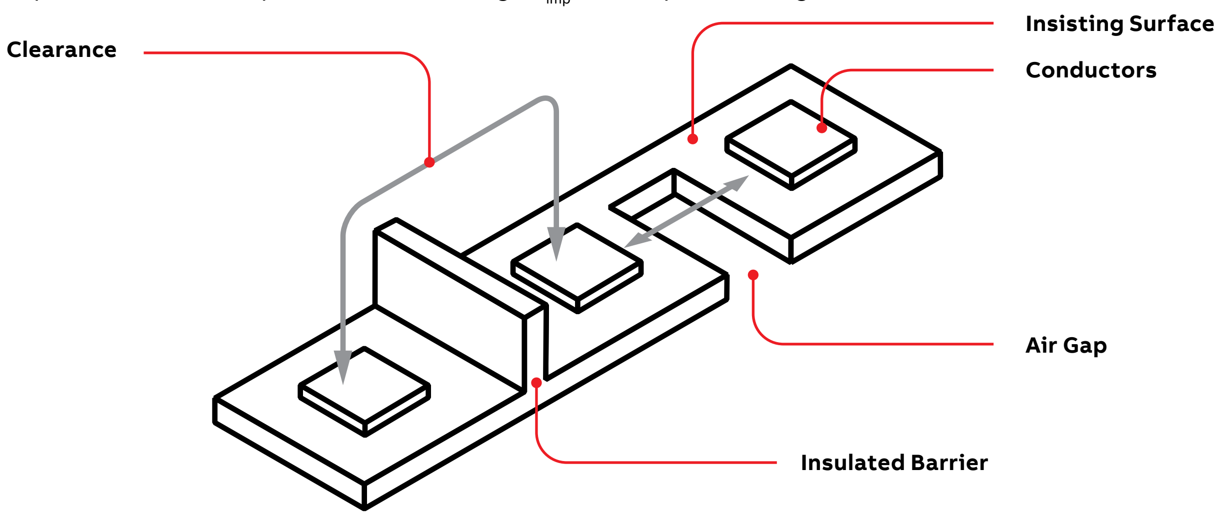
The pollution degree of contamination is the condition number based on the amount of conductive or hygroscopic dust, ionized gas, or salt, as well as the relative humidity and frequency of their occurrence. These environmental characteristics could lead to hygroscopic absorption or condensation of moisture, resulting in a reduction in dielectric strength or surface resistance. Standard IEC 60947-1 distinguishes four pollution degrees:

Pollution Degree	
1	No pollution or only dry, non-conductive pollution occurs.
2	Normally, only non-conductive pollution occurs. Occasionally, however, temporary conductivity caused by condensation may be expected.
3	Conductive pollution occurs, or dry, non-conductive pollution occurs which becomes conductive due to condensation.
4	The pollution generates persistent conductivity caused, for instance, by conductive dust or by rain or snow.

Table 01 Pollution degree according to 7.1.3.2 of IEC 60947-1. These categories are identical with the North American stadard, UL 840 Insulation Coordintion Including Clearances and Creepage Distances for Electrical Equipment.

2.2. Minimum clearance distances

The clearance defines the distance between two conductive parts in the air (see Figure below). The respective requirements depend on the rated impulse withstand voltage U_{imp} and the pollution degree.



02 Exemplary representation of the clearance distance

(1) F. Paschen, "Ueber die zum Funkenübergang in Luft, Wasserstoff und Kohlensäure bei verschiedenen Drucken erforderliche Potentialdifferenz," Annals of Physics, vol. 273, no. 5, pp. 69 – 96, 1889. doi:10.1002/andp.18892730505

2.3. Rated impulse withstand voltage U_{imp}

The rated impulse withstand voltage U_{imp} is defined according to IEC60947-1 as the peak impulse withstand voltage of prescribed form and polarity: which the equipment can withstand without failure under specified test conditions which the equipment can withstand without failure under specified test conditions and to which the values of the distances refer. The rated impulse withstand voltage of an equipment shall be equal to or higher than the values stated for the transient overvoltages occurring in the circuit in which the equipment is fitted.

For devices tested in conformance to the standard IEC 60947-1, are the minimum values given in Table 2 of this standard:

Rated impulse withstand voltage U_{imp}	**Minimum clearances** in mm							
	Case A - Inhomogeneous field conditions				**Case B - Homogeneous field ideal conditions**			
	Pollution degree				**Pollution degree**			
kV	**1**	**2**	**3**	**4**	**1**	**2**	**3**	**4**
0.33	0.01				0.01			
0.5	0.04	0.2			0.04	0.2		
0.8	0.1		0.8		0.1		0.8	1.6
1.5	0.5	0.5		1.6	0.3	0.3		
2.5	1.5	1.5	1.5		0.6	0.6		
4.0	3	3	3	3	1.2	1.2	1.2	
6.0	5.5	5.5	5.5	5.5	2	2	2	2
8.0	8	8	8	8	3	3	3	3
12.0	14	14	14	14	4.5	4.5	4.5	4.5

NOTE: The typical values in the industrial Low Voltage Directive are those for Case A, Pollution degree 3 and for a Rated Impulse withstand voltage U_{imp} of 4, 6, 8, and 12 kV (see values marked in gray and bold). The values of minimum clearances in the air are based on 1.2/50 µs impulse voltage, for barometric pressure of 80 kPa, equivalent to normal atmospheric pressure at 2000 m above sea level.

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Table 02 Extract of Table 13 of the IEC 60947-1, Minimum clearance in air. These values are essentially identical to those in UL 840, Table 8.1.

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2.4. Clearance evaluation based on Paschen's law

Paschen's law is an approximate formula that describes the experimentally determined relationship between dielectric strength, gas pressure, and impacts distance, that is, the spatial distance between the electrodes. So that means according to Paschen's law, the behavior of air to withstand a maximum voltage value is in relationship with air pressure. The resulting correction factors for altitudes above 2000 m are given in Table A.2 of IEC 60664-1.

Altitude correction factors

Altitude m	**Normal barometric pressure** kPa	**Multiplication factor k_d for clearances**
2000	80.0	1.0
3000	70.0	1.14
4000	62.0	1.29
5000	54.0	1.48
6000	47.0	1.7

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Table 03 Extract of Table A.2 from the IEC 60664-1, Altitude correction factors for clearance correction

When these correction factors for altitudes above 2000 m are applied for determining the clearances, the test voltage for the impulse voltage test must also be corrected accordingly.

Multiplying the minimum clearance distance (from table 13 of IEC 60947-1) by the altitude correction factor k_d (from table A.2 of IEC 60664-1) leads to an adjusted table for minimum clearances in air at higher altitudes (table on the right):

Altitude correction factors

Altitude m	**Normal baro-metric pressure** kPa	**Altitude correc-tion factor k_d for clearances**
2000	80.0	1.0
3000	70.0	1.14
4000	62.0	1.29
5000	54.0	1.48
6000	47.0	1.7

→

Resulting minimum clearances in air (in mm)

Altitude m	**for U_{imp}= 4 kV**	**for U_{imp}= 6 kV**	**for U_{imp}= 8 kV**	**for U_{imp}= 12 kV**
2000	3.0	5.5	8.0	14.0
3000	3.4	6.3	9.1	16.0
4000	3.9	7.1	10.3	18.1
5000	4.4	8.1	11.8	20.7
6000	5.1	9.4	13.6	23.8

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Table 04 The conclusion from two tables: the extract from Table 13 of IEC 60947-1 (Minimum clearance in air) multiplied by Table A.2 from IEC 60664-1 (altitude correction factors for clearance correction).

There are now two possibilities to address the use, for example, at 4000 m altitude, declare a reduced U_{imp} or validate with a U_{imp} test or measurement:

- With an installation altitude of 4000 m and the use of the correction factor, a clearance of 10.3 mm is required to maintain the 8 kV U_{imp}. As the device in the example is validated for 8 kV, the clearance of min. 8 mm according to table 13 is proven. This means that this device can be used at 4000 m only with a specified 6 kV U_{imp} according to the table above (7.1 mm).

- To validate the suitable spacings for the final application altitude (see table above) it is possible to either re-test the impulse withstand voltage with the requested level or validate the requested spacings by measurement. In the example given, a rating of 8 kV at 4000 m needs to be validated with a rated impulse withstand voltage U_{imp} of rated 12 kV and a test voltage of 14.8 kV (sea level) or 10.3 mm clearance measurement.

In case the rated impulse withstand voltage U_{imp} is too low for the given application, an additional option is to improve the U_{imp} value by using Surge Protective Devices (SPDs). When using SPDs, ensure that suitable type 1/type 2 SPDs are used in combination with other measures. Other measures could be: a greater distance to conductive parts or other electrical equipment with opposite polarity or grounding.

2.5. Correlation between the nominal voltage of the supply system and the rated impulse withstand voltage of equipment

The correlation between the nominal voltage of the supply system and the rated impulse withstand voltage is provided in Annex H.1 of IEC 60947-1. The annex is intended to give the necessary information concerning the choice of equipment for use in a circuit within an electrical system or part thereof.

Table H.1 provides examples of the correlation between nominal supply system voltages and the corresponding rated impulse withstand voltage of equipment. The values of rated impulse withstand voltage given in Table H.1 are based on the performance characteristics of surge arresters.

The overvoltage category of a circuit or within an electrical system is a conventional number based on limiting (or controlling) the values of prospective transient overvoltages occurring in a circuit (or within an electrical system having different nominal voltages) and depending upon the means employed to influence the overvoltages.

Additional Information: In an electrical system, the transition from one overvoltage category to another of lower category is obtained through appropriate means complying with interface requirements, such as an overvoltage protective device or a series-shunt impedance arrangement capable of dissipating, absorbing, or diverting the energy in the associated surge current, to lower the transient overvoltage value to that of the desired lower overvoltage category.

The electrical equipment is assigned to one of the 4 overvoltage categories: Specially protected level, Load level, Distribution circuit level and Origin of installation level. Electrical devices in the overvoltage category I can withstand low overvoltages (surge voltage). Electrical devices in overvoltage category IV can withstand higher surge voltages.

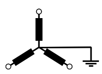
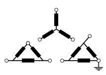
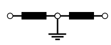
Max. value of rated operate. voltage to earth	**Nominal voltage U_e of the supply system (£ rated insulation voltage of the equipment)**				**Preferred values of rated impulse withstand voltage U_{imp} (1.2/50 ms) at 2000 m**			
					**Overvoltage category**			
					IV	**III**	**II**	**I**
AC RMS or DC V	**AC RMS** V	**AC RMS** V	**AC RMS or DC** V	**AC RMS or DC** V	**Origin of installation level (service entrance)**	**Distribution circuit level**	**Load level (appliance, equipment)**	**Specially protected level**
50	–	–	12.5, 24, 25 30, 42, 48	60-30	1.5	0.8	0.5	0.33
100	66/115	66	60	–	2.5	1.5	0.8	0.5
150	120/208 127/220	115, 120 127	110, 120	220-110, 240-120	4	2.5	1.5	0.8
300	220/380, 230/400 240/415, 260/440 277/480	220, 230 240, 260 277	220	440-220	6	4	2.5	1.5
600	347/600, 380/660 400/690, 415/720 480/830	347, 380, 400 415, 440, 480 500, 577, 600	480	960-480	8	6	4	2.5
1000	–	660 690, 720 830, 1000	1000	–	12	8	6	4

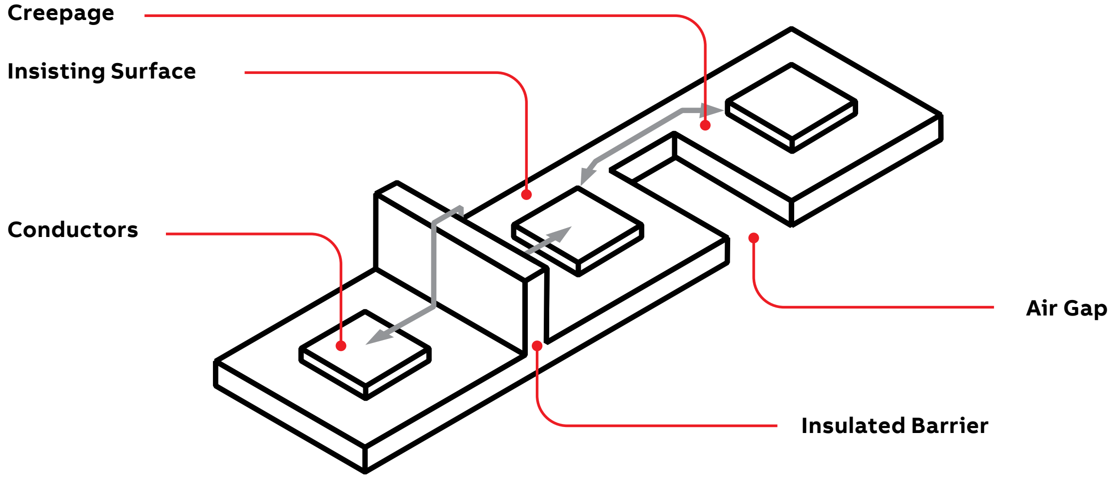
Table 05 Extract of Table H.1 of IEC 60947-1 or in IEC 61349-1 Table G.1, Correspondence between the nominal voltage of the supply system and the equipment rated impulse withstand voltage

3 Evaluation of the rated insulation voltage U_i

The rated insulation voltage U_i of a device is the voltage that dielectric tests and **creepage distances** are referred to. The maximum value of the rated operating voltage must not exceed the value of the rated insulation voltage U_i in any case. For installation at an altitude higher than 2000 m above sea level, the insulation level of external insulation under the standardized reference atmospheric conditions should also be redetermined.

3.1. Minimum creepage distances

The creepage distance defines the shortest distance between two conductive parts along the surface of the insulation (Figure below). The respective requirements depend on the working voltage and the type of insulation.



03 Exemplary representation of the creepage distance

For devices tested in conformance to IEC 60947-1, minimum values are shown in Table 6 of this standard:

Rated insulation voltage of equipment or working voltage AC RMS or DC [b,c,d]	Minimum creepage distances for equipment subject to long term stress													
	Printed wiring material													
	Pollution degree													
	1	**2**	**1**	**2**			**3**				**4**			
	Material groups													
	All	**All except IIIb**	**All**	**I**	**II**	**III**	**I**	**II**	**IIIa**	**IIIb**	**I**	**II**	**IIIa**	**IIIb**
V	mm	mm	mm	mm	mm	mm	mm	mm	mm	mm	mm	mm	mm	mm
10	0.025	0.04	0.08	0.4	0.4	0.4	1	1	1		1.6	1.6	1.6	
12.5	0.025	0.04	0.09	0.42	0.42	0.42	1.05	1.05	1.05		1.6	1.6	1.6	
16	0.025	0.04	0.1	0.45	0.45	0.45	1.1	1.1	1.1		1.6	1.6	1.6	
20	0.025	0.04	0.11	0.48	0.48	0.48	1.2	1.2	1.2		1.6	1.6	1.6	
25	0.025	0.04	0.125	0.5	0.5	0.5	1.25	1.25	1.25		1.7	1.7	1.7	
32	0.025	0.04	0.14	0.53	0.53	0.53	1.3	1.3	1.3		1.8	1.8	1.8	
40	0.025	0.04	0.16	0.56	0.8	1.1	1.4	1.6	1.8		1.9	2.4	3	
50	0.025	0.04	0.18	0.6	0.85	1.2	1.5	1.7	1.9		2	2.5	3.2	
63	0.04	0.063	0.2	0.63	0.9	1.25	1.6	1.8	2		2.1	2.6	3.4	
80	0.063	0.1	0.22	0.67	0.95	1.3	1.7	1.9	2.1		2.2	2.8	3.6	
100	0.1	0.16	0.25	0.71	1	1.4	1.8	2	2.2		2.4	3	3.8	
125	0.16	0.25	0.28	0.75	1.05	1.5	1.9	2.1	2.4		2.5	3.2	4	
160	0.25	0.4	0.32	0.8	1.1	1.6	2	2.2	2.5		3.2	4	5	
200	0.4	0.63	0.42	1	1.4	2	2.5	2.8	3.2		4	5	6.3	
250	0.56	1	0.56	1.25	1.8	2.5	3.2	3.6	4		5	6.3	8	
320	0.75	1.6	0.75	1.6	2.2	3.2	4	4.5	5		6.3	8	10	
400	1	2	1	2	2.8	4	5	5.6	6.3		8	10	12.5	
500	1.3	2.5	1.3	2.5	3.6	5	6.3	7.1	8		10	12.5	16	
630	1.8	3.2	1.8	3.2	4.5	6.3	8	9	10		12.5	16	20	a
800	2.4	4	2.4	4	5.6	8	10	11	12.5		16	20	25	
1000	3.2	5	3.2	5	7.1	10	12.5	14	16		20	25	32	
1250			4.2	6.3	9	12.5	16	18	20		25	32	40	
1600			5.6	8	11	16	20	22	25		32	40	50	
2000			7.5	10	14	20	25	28	32		40	50	63	
2500			10	12.5	18	25	32	36	40		50	63	80	
3200			12.5	16	22	32	40	45	50		63	80	100	
4000			16	20	28	40	50	56	63	a	80	100	125	
5000			20	25	36	50	63	71	80		100	125	160	
6300			25	32	45	63	80	90	100		125	160	200	
8000			32	40	56	80	100	110	125		160	200	250	
10000			40	50	71	100	125	140	160		200	250	320	

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Table 06 Extract of Table 15 from the IEC 60947-1, Minimum creepage distances. These values are essentially identical to those in UL 840, Table 9.1.

NOTE: The typical values for industrial electrical products are those for Pollution degree 3 and Material groups II (see values marked in gray).

a Values of creepage distances in this area have not been established. Material group IIIb is in general not recommended for application in pollution degrees 3 above 630 V and in pollution degrees 4

b As an exception, for rated insulation voltages 127 V, 208 V, 415/440 V, 660/690 V and 830 V, creepage distances corresponding to the lower values 125 V, 200 V, 400 V, 630 V and 800 V respectively may be used

c The values of creepage distances stated for 250 V can be used for 230 V (±10 %) nominal voltage

d It is appreciated that tracking or erosion will not occur on insulation subjected to working voltages of 32 V and below. However, the possibility of electrolytic corrosion must be considered and for this reason minimum creepage distances have been specified

3.2. Evaluation of rated insulation voltage U_i under consideration of the altitude

The insulation level of external insulation under the standardized reference atmospheric conditions should be determined by multiplying the insulation withstand voltages required at the service location by a factor K_a in accordance with IEC 60071-2 chapter 4.2.2. Correction factor K_a is related to the atmospheric pressure dependence on altitude. The correction factor can be calculated from:

$$K_a = e^{m\left(\frac{H}{8150}\right)}$$

The value H is the altitude above sea level in meters and for normal insulators, m = 0.5 may be applied.

With this multiplication correction factor K_a, the required insulation voltage $U_{i\ required}$ at the application altitude is determined.

Example: U_i of the device under consideration is 690 V, which is applicable up to 2000 m. If the device needs to be used at 4000 m application altitude, what is the required $U_{i\ rerquired}$?

To be suitable for use at e.g. 4000 m (and m = 0.5) K_a can be calculated:

$$K_a = e^{m\left(\frac{H}{8150}\right)}$$

$$K_a = 1.277$$

The required $U_{i\ rerquired}$ at 4000 m is: 690 V x 1.277 = 881 V

According to table 15 of IEC60947-1 an U_i of 881V requires a creepage distance of 14 mm.

Dielectric testing is a commonly used practical test method. This is a test to prove that the required insulation voltage meets the specification, which means that successfully performing this test proves that the device design meets the minimum creepage distance requirements. Usually these tests are performed by the manufacturer and the resulting maximum values are published in the product specifications. The power frequency validation for this value U_i = 888 V/AC is to be performed with an AC test voltage of 2200 V/AC according to the table below.

The dielectric test voltage corresponding to the rated insulation voltage

Rated insulation voltage U_i	AC test voltage (RMS)	DC test voltage [b,c]
V	V	V
$U_i \leq 60$	1000	1415
$60 < U_i \leq 300$	1500	2120
$300 < U_i \leq 690$	1890	2670
$690 < U_i \leq 800$	2000	2830
$800 < U_i \leq 1000$	2200	3110
$1000 < U_i \leq 1500$a	–	3820

a For d.c. only
b Test voltages based on 6.1.3.4.1, fifth paragraph of IEC 60664-1:2007
c A direct current test voltage may be used only if an alternating test voltage cannot be applied. See also 3) b) ii) of 9.3.3.4.1.

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Table 07 Extract of Table 19 of the IEC 60947-1, Dielectric test voltage corresponding to the rated insulation voltage

4 Evaluation of the rated current I_e correction

At installation altitudes above 2000 m, the reduced heat dissipation of all electrical components must be evaluated and if needed to be corrected. Affected are insulated wires and individual components with conductive parts in a plastic housing (e.g. TOL). Concerning the reduced heat dissipation of conductors in high altitudes, correction factors must be applied depending on the Ie of the devices and the ambient temperature at the installation altitude.

Regarding the thermal effects, particular attention should be paid to the following points:

- thermal exchanges depending on type of wire (e.g. in single core, multi core or double insulated cables)
- thermal exchanges by convection, conduction, or radiation
- efficiency of heating or air-conditioning at installation site
- Thermal exchanges of panel construction type, size and material

4.1. Rated operational current I_e

A rated operational current of an equipment is stated by the manufacturer and takes into account the rated operational voltage, the rated frequency, the rated duty and the utilization category.

As mentioned in the previous chapters, Paschen's law states that the behavior of air to withstand a maximum stress value is related to atmospheric pressure. The corresponding correction factors for altitudes above 2000 m are given in Table A.2 of IEC 60664-1. Reduced air pressure with increasing altitude lowers the air density causing the reduction of heat dissipation. Assuming linear dependencies, constant breakdown voltage at a certain level and constant clearance distance, following relationships are obtained for the current correction factors:

$$I_h = I_e \sqrt{\frac{p_h}{p_n}}$$

p_h Air pressure at altitude h
p_n Air pressure at altitude n (≤ 2000 m)
I_h current at altitude h
I_e current at altitude n (≤ 2000 m)

Below are general correction factors of the rated operational current I_e.
The correction factors of the rated operational current Ie in chapter 5 are ABB evaluated and may deviate from the general correction factors.

Altitude correction factors

Altitude m	**Normal barometric pressure** kPa	**Multiplication factor k_d for clearances**	**I_e correction factor**
2000	80.0	1.0	1.0
3000	70.0	1.14	0.93
4000	62.0	1.29	0.88
5000	54.0	1.48	0.82

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Table 08 Extract of Table A.2 from IEC 60664-1, Altitude correction factors for clearance correction and the current correction factor

4.2 Copper conductor correction factors

At higher altitudes, the switchgear and the connecting cables between the switchgear and the electrical panel to the load are affected by the influences of heat dissipation at high altitudes. Table 9 of IEC 60947-1 references the required copper conductors and the current. In this context, it is important to identify and verify the Ie correction factors (see Chapter 4.1). These factors consider heat dissipation at higher altitudes and adjust the corresponding cable diameters' current values.

The table shows the dependencies between the cable size, current, and application altitudes:

Range of test current up to 2000 m [a]		**Conductor size** [b, c, d]		**I_e up to 2000 m**	**I_e up to 3000 m**	**I_e up to 4000 m**	**I_e up to 5000 m**
A		mm²	AWG	A	A	A	A
0	1	0,2	24				
1	2	0,34	22				
2	3	0,5	20				
3	6	0,75	18				
6	8	1,0	-				
8	12	1,5	16	12	11	11	10
12	15	2,5	14	15	14	13	12
15	20	2,5	12	20	19	18	16
20	25	4,0	10	25	23	22	21
25	32	6,0	10	32	30	28	26
32	50	10	8	50	47	44	41
50	65	16	6	65	60	57	53
65	85	25	4	85	79	75	70
85	100	35	3	100	93	88	82
100	115	35	2	115	107	101	94
115	130	50	1	130	121	114	107
130	150	50	00	150	140	132	123
150	175	70	00	175	163	154	144
175	200	95	00	200	186	176	164
200	225	95	00	225	209	198	185
225	250	120	250 kcmil	250	233	220	205
250	275	150	300 kcmil	275	256	242	226
275	300	185	350 kcmil	300	279	264	246
300	350	185	400 kcmil	350	326	308	287
350	400	240	500 kcmil	400	372	352	328

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Table 09 Extract of Table 9 from IEC60947-1, Test copper conductors for test currents up to 400 A inclusive updated with applied correction factors up to 5000 m

a The value of test current shall be greater than the first value in the first column and less than or equal to the the second value in that column.
b For the convenience of testing and with the manufacturer's consent, smaller conductors than those given for a stated test current may be used.
c The tables give alternative sizes for conductors in the metric and AWG/kcmil system and bars in millimetres and inches. Comparison between AWG/kcmil and metric sizes is given in Table 1.
d Either of the two conductors specified for a given test current range may be used.

Alternatively, appropriate larger wire sizes in combination with device separation may be used to correct or compensate the heat dissipation in high altitudes.

It is important to remember that the devices are normally not used at the limits of their continuous current capability, and the ambient temperature at higher altitudes is often lower than the 40 °C ambient temperature according to the product standard unless otherwise stated.

5 Correction factor tables for ABB control products for use at altitudes greater than 2000 m

ABB offers a wide range of low voltage control and protection products for high altitudes. An overview and the corresponding correction factors can be found here in the following chapter. The requested U_i at the application altitude has either been validated by test or construction with the requested min. creepage distances according to table 15 of IEC 60947-1.

Manual motor starters

				up to 2000 m			**up to 3000 m**		
AC-1, AC-3/AC-3e, pollution degree 3, 3-phase system grounded, at < 60 °C	Max U_e V	U_i V	U_{imp} kV	Disconnect function	Distance to conductive parts mm (1)	I_e derating factor	Disconnect function	Distance to conductive parts mm (1)	I_e derating factor
MS116	690	690	6	Yes	0	1	No	10	0.93
MS132 (K)	690	690	6	Yes	0	1	No	10	0.93
MS132 / MO132	690	690	6	Yes	0	1	No	10	0.93
MS165 / MO165	690	1000	8	Yes	0	1	No	10	0.93

Manual motor starters

				up to 4000 m			**up to 5000 m**		
AC-1, AC-3/AC-3e, pollution degree 3, 3-phase system grounded, at < 60 °C	Max U_e V	U_i V	U_{imp} kV	Disconnect function	Distance to conductive parts mm (1)	I_e derating factor	Disconnect function	Distance to conductive parts mm (1)	I_e derating factor
MS116	690	690	6	No	10	0.88	No	10	0.82
MS132 (K)	690	690	6	No	10	0.88	No	10	0.82
MS132 / MO132	690	690	6	No	10	0.88	No	10	0.82
MS165 / MO165	690	1000	8	No	10	0.88	No	10	0.82

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Table 10 Effect of high altitudes on the Manual motor starters. Only the changes in the high altitudes are shown.

(1) or other devices with the same U_e. Note definition in chapter 7.

AF Contactors

		up to 2000 m			up to 3000 m			up to 3500 m		
Pollution degree 3, 3-phase system grounded	Max U_e V	U_{imp} kV	Distance to conductive parts mm (1)	I_e derating factor	U_{imp} kV	Distance to conductive parts mm (1)	I_e derating factor	U_{imp} kV	Distance to conductive parts mm (1)	I_e derating factor
3 or 4-pole Contactors AF09 … AF36 AC-1 at 40 °C	690	6	0	1	6	0 (3)	1	6	10	0.9
3 or 4-pole Contactors AF40 … AF65 AC-1 at 40 °C	690	6	0	1	6	0 (3)	1	6	10	0.9
3 or 4-pole Contactors AF80 … AF96 AC-1 at 40 °C	1000	8	0	1	8	0 (3)	1	8	10	0.9
3-pole Contactors AF116 … AF2850 4-pole Contactor AF116 … AF370 AC-1 at 40 °C	690	8	0	1	8	10	1	8	10	0.9
3-pole Contactors AF146 … AF2850 AC-1 at 40 °C	1000	8	0	1	**	**	1	**	**	0.9
3-pole Contactors AF09 … A38 AC-2 / AC-3 / AC-3e / AC-4 at 60 °C	≤ 230	6	0	1	6	0 (3)	1	6	10	0.9
	230 … 440	6	0	1	6	0 (3)	1	6	10	0.9
	440 … 500	6	0	1	6	0 (3)	1	6	10	0.9
	500 … 690	6	0	1						
3-pole Contactors AF40 … AF65 AC-2 / AC-3 / AC-3e / AC-4 at 60 °C	≤ 230	8	0	1	6	0 (3)	1	6	10	0.9
	230 … 440	8	0	1	6	0 (3)	1	6	10	0.9
	440 … 500	8	0	1	6	0 (3)	1	6	10	0.9
	500 … 690	8	0	1	6	0 (3)	1	6	10	0.9
3-pole Contactors AF80 … AF96 AC-2 / AC-3 / AC-3e / AC-4 at 60 °C	≤ 230	8	0	1	8	0 (3)	1	8	10	0.9
	230 … 440	8	0	1	8	0 (3)	1	8	10	0.9
	440 … 500	8	0	1	8	0 (3)	1	8	10	0.9
	500 … 690	8	0	1	8	0 (3)	1	8	10	0.9
3-pole Contactors AF116 … AF2050 AC-3 / AC-3e / AC-4 at 60 °C (AC-3e up to AF190 only/ AC-4 refer to catalogue)	≤ 230	8	0	1	8	10	1	8	10	0.9
	230 … 415	8	0	1	8	10	1	8	10	0.9
	415 … 500	8	0	1	8	10	1	8	10	0.9
	500 … 690	8	0	1	8	20	0.85	8	20	0.88
	1000	8	0	1						
GF875, GF1050, GF1325 DC-PV3	1500 V DC	8	25	1	8	25	1	6	25	0.9
GAF460 up to GAF2050 (DC-1)	1000 V DC	8 (2)	0	1	8 (2)	40	1	8 (2)	40	0.9

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Table 11 Effect of high altitudes on the AF Contactor. Only the changes in the high altitudes are shown.

(1) or other devices with the same U_e. Note definition in chapter 7.
(2) U_{imp} coil = 6 kV
(3) Note that for switchgear combinations, e.g. with a manual motor starter, the nessesary distance of the other devices must also be taken into account.
** on request

AF Contactors

			up to 4000 m			up to 5000 m		
Pollution degree 3, 3-phase system grounded	Max U_e V	U_{imp} at 2000 m kV	U_{imp} kV	Distance to conductive parts mm (1)	I_e derating factor	U_{imp} kV	Distance to conductive parts mm (1)	I_e derating factor
3 or 4-pole Contactors AF09 … AF38 AC-1 at 40 °C	690	6	6	10	0.88	4	10	0.82
3 or 4-pole Contactors AF40 … AF65 AC-1 at 40 °C	690	6	6	10	0.88	6	10	0.82
3 or 4-pole Contactors AF80 … AF96 AC-1 at 40 °C	690	6	6	10	0.88	6	10	0.82
3-pole Contactors AF116 … AF2850 4-pole Contactor AF116 … AF370 AC-1 at 40 °C	690	8	6	10	0.88	6	10	0.82
3-pole Contactors AF146 … AF2850 AC-1 at 40 °C	1000	8	**	**	0.88	**	**	0.82
3-pole Contactors AF09 … AF38 AC-2 / AC-3 / AC-3e / AC-4 at 60 °C	≤ 230	6	6	10	0.88	4	10	0.82
	230 … 440	6	6	10	0.88	4	10	0.82
	440 … 500	6	6	10	0.88			
	500 … 690	6						
3-pole Contactors AF40 … AF65 AC-2 / AC-3 / AC-3e / AC-4 at 60 °C	≤ 230	6	6	10	0.88	6	10	0.82
	230 … 440	6	6	10	0.88	6	10	0.82
	440 … 500	6	6	10	0.88	6	10	0.82
	500 … 690	6	6	10	0.88			
3-pole Contactors AF80 … AF96 AC-2 / AC-3 / AC-3e / AC-4 at 60 °C	≤ 230	8	8	10	0.88	6	10	0.82
	230 … 440	8	8	10	0.88	6	10	0.82
	440 … 500	8	8	10	0.88	6	10	0.82
	500 … 690	8	8	10	0.88	6	10	0.82
3-pole Contactors AF116 … AF2050 AC-3 / AC-3e / AC-4 at 60 °C (AC-3e up to AF190 only/AC-4 refer to catalogue)	≤ 230	8	6	10	0.88	6	10	0.82
	230 … 415	8	6	10	0.88	6	10	0.82
	415 … 500	8	6	10	0.88	6	10	0.82
	500 … 690	8	6	20	0.88	6	20	0.82
	1000	8						
GF875, GF1050, GF1325 DC-PV3	1500 V DC	8	6	25	0.88	6	25	0.82
GAF460 up to GAF2050 (DC-1)	1000 V DC	8 (2)	8 (2)	40	0.88	8 (2)	40	0.82

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Table 12 Effect of high altitudes on the AF Contactor. Only the changes in the high altitudes are shown.

(1) or other devices with the same U_e
(2) U_{imp} coil = 6 kV
** on request

Overload relays

				up to 2000 m		up to 3000 m		up to 4000 m		up to 5000 m	
AC-1, AC-3/AC-3e, pollution degree 3, 3-phase system grounded, at < 60 °C	Max U_e V	U_i V	U_{imp} kV	Distance to conductive parts mm (1)	I_e derating factor	Distance to conductive parts mm (1)	I_e derating factor	Distance to conductive parts mm (1)	I_e derating factor	Distance to conductive parts mm (1)	I_e derating factor
T16	690	690	6	0	1	10	0.93	10	0.88	10	0.82
TF42	690	690	6	0	1	10	0.93	10	0.88	10	0.82
TF65	690	690	8	0	1	10	0.93	10	0.88	10	0.82
TF96	690	690	8	0	1	10	0.93	10	0.88	10	0.82
TF140DU (2)	690	690	8	0	1	10	0.93	10	0.88	10	0.82
TA200DU (2)	690	690	6	0	1	10	0.93	10	0.88	10	0.82
E16	690	690	6	0	1	10	0.93	10	0.88	10	0.82
EF19	690	690	6	0	1	10	0.93	10	0.88	10	0.82
EF45	690	690	6	0	1	10	0.93	10	0.88	10	0.82
EF65	1000	1000	8	0	1	10	0.93	10	0.88	10	0.82
EF96	1000	1000	8	0	1	10	0.93	10	0.88	10	0.82
EF146	1000	1000	8	0	1	10	0.93	10	0.88	10	0.82
EF205	1000	1000	8	0	1	10	0.93	10	0.88	10	0.82
EF370	1000	1000	8	0	1	10	0.93	10	0.88	10	0.82
EF460	1000	1000	8	0	1	10	0.93	10	0.88	10	0.82
EF750	1000	1000	8	0	1	10	0.93	10	0.88	10	0.82

—
Table 13 Effect of high altitudes on the Overload relays. Only the changes in the high altitudes are shown.

(1) or other devices with the same U_e. Note definition in chapter 7
(2) at T_a < 55 °C

ESB installation contactors

			up to 2000 m			up to 3000 m			up to 4000 m			up to 5000 m		
AC-1, AC-3/ AC-3e, pollution degree 3, 3-phase system grounded, at < 60 °C	Max U_e V	U_i V	U_{imp} kV	Distance to conductive parts mm (1)	I_e derating factor	U_{imp} kV	Distance to conductive parts mm (1)	I_e derating factor	U_{imp} kV	Distance to conductive parts mm (1)	I_e derating factor	U_{imp} kV	Distance to conductive parts mm (1)	I_e derating factor
ESB16	230	400	6	0	1	4	10	0.93	4	10	0.88	4	10	0.82
ESB20	230	400	6	0	1	4	10	0.93	4	10	0.88	4	10	0.82
ESB25	400	500	6	0	1	6	10	0.93	4	10	0.88	4	10	0.82
ESB40	400	500	6	0	1	6	10	0.93	6	10	0.88	6	10	0.82
ESB63	400	500	6	0	1	6	10	0.93	6	10	0.88	6	10	0.82
ESB100	400	500	6	0	1	6	10	0.93	6	10	0.88	6	10	0.82

—
Table 14 Effect of high altitudes on the ESB installation contactor. Only the changes in the high altitudes are shown.

(1) or other devices with the same U_e. Note definition in chapter 7

M-Range mini-contactors

			up to 2000 m			up to 3000 m			up to 4000 m			up to 5000 m		
AC-1, AC-3/ AC-3e, pollution degree 3, 3-phase system grounded, at < 60 °C	Max U_e V	U_i V	U_{imp} kV	Distance to conductive parts mm (1)	I_e derating factor	U_{imp} kV	Distance to conductive parts mm (1)	I_e derating factor	U_{imp} kV	Distance to conductive parts mm (1)	I_e derating factor	U_{imp} kV	Distance to conductive parts mm (1)	I_e derating factor
MC1/MC2	690	750	6	0	1	6	10	0.93	4	10	0.88	4	10	0.82

—
Table 15 Effect of high altitudes on the M-Range mini-contactors. Only the changes in the high altitudes are shown.

(1) or other devices with the same U_e. Note definition in chapter 7.

B6/B7 mini-contactors

			up to 2000 m			up to 3000 m			up to 4000 m			up to 5000 m		
AC-1, AC-3/ AC-3e, pollution degree 3, 3-phase system grounded, at < 60 °C	Max U_e V	U_i V	U_{imp} kV	Distance to conductive parts mm (1)	I_e derating factor	U_{imp} kV	Distance to conductive parts mm (1)	I_e derating factor	U_{imp} kV	Distance to conductive parts mm (1)	I_e derating factor	U_{imp} kV	Distance to conductive parts mm (1)	I_e derating factor
B6/B7	690	690	6	0	1	6	10	0.93	6	10	0.88	6	10	0.82

—
Table 16 Effect of high altitudes on the B6/B7 mini-contactors. Only the changes in the high altitudes are shown.

(1) or other devices with the same U_e. Note definition in chapter 7.

Interface relays

		up to 2000 m			up to 3000 m			up to 4000 m			up to 5000 m		
AC-12 and AC-15	Max U_e V	U_i V	U_{imp} kV (between coil and contacts)	I_e derating factor	U_i V	U_{imp} kV (between coil and contacts)	I_e derating factor	U_i V	U_{imp} kV (between coil and contacts)	I_e derating factor	U_i V	U_{imp} kV (between coil and contacts)	I_e derating factor
CR-P…1	230	400	5	1	400	4	0.93	250	4	0.88	250	2.5	0.82
CR-P…2	230	400	5	1	400	4	0.93	250	4	0.88	250	2.5	0.82
CR-M…2	230	250	4	1	250	4	0.93	250	4	0.88	250	2.5	0.82
CR-M…4	230	250	2.5	1	250	2	0.93	250	2	0.88	250	2	0.82

—
Table 17 Effect of high altitudes on the Interface relays. Only the changes in the high altitudes are shown.

Pilot devices

AC-15, pollution degree 3	U_i	I_e	up to 2000 m			up to 3000 m			up to 4000 m		
	V	A	U_{imp} kV	I_e derating factor	Distance to conductive parts mm	U_{imp} kV	I_e derating factor	Distance to conductive parts mm	U_{imp} kV	I_e derating factor	Distance to conductive parts mm
Modular plastic range contact block MCB											
≤ 120 V	≤ 120 V	8	6	1	5	6	0.94	5	6	0.88	5
≤ 230 V	≤ 230 V	6	6	1	5	6	0.94	5	6	0.88	5
≤ 400 V	≤ 400 V	4	6	1	5	6	0.94	5	6	0.88	5
≤ 690 V	≤ 690 V	2	6	1	5						
Compact range											
≤ 240 V	≤ 240 V	1	4	1	3	4	0.94	3	4	0.88	3
Modular metal range contact block P9B											
≤ 24 V	≤ 24 V	10	4	1	2	2.5	0.94	2	2.5	0.88	2
≤ 48 V	≤ 48 V	10	4	1	2	2.5	0.94	2	2.5	0.88	2
≤ 60 V	≤ 60 V	10	4	1	2	2.5	0.94	2	2.5	0.88	2
≤ 110 V	≤ 110 V	6	4	1	2	2.5	0.94	2	2.5	0.88	2
≤ 220 V	≤ 220 V	3	4	1	2	2.5	0.94	2	2.5	0.88	2
≤ 380 V	≤ 380 V	2	4	1	2	2.5	0.94	2	2.5	0.88	2
≤ 500 V	≤ 500 V	1.5	4	1	2	2.5	0.94	2	2.5	0.88	2
≤ 600 V	≤ 600 V	1.2	4	1	2						

—
Table 18 Effect of high altitudes on the Pilot devices. Only the changes in the high altitudes are shown (up to 4000 m).

Pilot devices

AC-15, pollution degree 3	U_i V	I_e A	up to 5000 m			up to 6000 m		
			U_{imp} kV	I_e derating factor	Distance to conductive parts mm	U_{imp} kV	I_e derating factor	Distance to conductive parts mm
Modular plastic range contact block MCB								
≤ 120 V	≤ 120 V	8	4	0.82	5	4	0.77	5
≤ 230 V	≤ 230 V	6	4	0.82	5	4	0.77	5
≤ 400 V	≤ 400 V	4	4	0.82	5	4	0.77	5
≤ 690 V	≤ 690 V	2						
Compact range								
≤ 240 V	≤ 240 V	1	4	0.82	3	4	0.77	3
Modular metal range contact block P9B								
≤ 24 V	≤ 24 V	10	2.5	0.82	2	2.5	0.77	2
≤ 48 V	≤ 48 V	10	2.5	0.82	2	2.5	0.77	2
≤ 60 V	≤ 60 V	10	2.5	0.82	2	2.5	0.77	2
≤ 110 V	≤ 110 V	6	2.5	0.82	2	2.5	0.77	2
≤ 220 V	≤ 220 V	3	2.5	0.82	2	2.5	0.77	2
≤ 380 V	≤ 380 V	2	2.5	0.82	2	2.5	0.77	2
≤ 500 V	≤ 500 V	1.5	2.5	0.82	2	2.5	0.77	2
≤ 600 V	≤ 600 V	1.2						

—
Table 19 Effect of high altitudes on the Pilot devices. Only the changes in the high altitudes are shown (up to 6000 m).

Softstarters

					up to 2000 m		up to 3000 m		up to 4000 m		up to 5000 m	
	Max U_e V	U_i V	U_{imp} V	Max U_s V	U_{s-imp} kV by Over-load	I_e derating factor	U_{s-imp} kV by Over-load	I_e derating factor	U_{s-imp} kV by Over-load	I_e derating factor	U_{s-imp} kV by Over-load	I_e derating factor
PSR U_s = 100 … 240 V AC	600	600	6	240	4	0.93	4	0.87	2.5	0.8	2.5	0.73
PSR U_s = 24 V AC/DC	600	600	6	24	-	0.93	-	0.87	-	0.8	-	0.73
PSRC	600	600	6	240	4	0.93	4	0.87	2.5	0.8	2.5	0.73
PSE	600	600	6	250	4	0.93	2.5	0.87	2.5	0.8	2.5	0.73
PSTX	600	600	6	250	4	0.93	2.5	0.87	2.5	0.8	2.5	0.73
	690	600	6	250	4	0.93	2.5	0.87	2.5	0.8	2.5	0.73

—
Table 20 Effect of high altitudes on the Softstarters. Only the changes in the high altitudes are shown.

Power Supplies

	Output current derating factor			
	up to 2000 m	up to 3000 m	up to 4000 m	up to 5000 m
CP-S.1	1	0.9	0.8	0.7
CP-C.1	1	0.96	0.91	0.87

—
Table 21 Effect of high altitudes on the Power Supplies. Only the changes in the high altitudes are shown.

Universal Motor Controller 100.3

	Output current derating factor			
Motor voltage U_e = 480-690 V with isolated wired, at < 40 °C	up to 2000 m	up to 3000 m	up to 4000 m	up to 5000 m
UMC100.3	1	0.9	0.8	0.7

—
Table 22 Effect of high altitudes on the Universal Motor Controller. Only the changes in the high altitudes are shown.

* devices capability including measures

6 References

The following international standards are referenced in this Application Note:

IEC / EN / UL 60947-1	Low-voltage switchgear and controlgear - Part 1: General rules
IEC / EN 60664-1	Insulation coordination for equipment within low-voltage systems - Part 1: Principles, requirements and tests
IEC / EN 60071-2	Insulation co-ordination - Part 2: Application guidelines (see complementary information below)
UL 840	Standard for insulation coordination including clearances and creepage distances for electrical equipment

To meet the need for greater harmonization in the North American market, the UL 508 standard for industrial control equipment has been harmonized with selected chapters of the IEC 60947 series of standards for low-voltage switching and control devices. Therefore, the values and information shown here can also be used in the North American market.

Additional information about IEC/EN 60071-2: For systems above 1 kV, the standard IEC/EN 60071-2 applies, but the physical principle is the same as for low voltage and is based on the same physical considerations (Paschen's law). The correction factor K_a is related to the dependence of air pressure on altitude

7 Glossary and Definition

Clearance	Shortest distance in the air between two conductive parts
Creepage distance	Shortest distance along the surface of solid insulating material between two conductive parts
Distance to conductive parts	Distance to conductive parts refers only to the horizontal distance, for the vertical distance could be bigger, please look here at the product data, e.g. MS132 has to be at least 75 mm. The term “Distance to conductive parts” refers to two different phenomena. A: the minimum distance that must be maintained between conductive components within these devices and the devices next to them. This is a crucial safety measure to prevent electrical arcing, which could lead to equipment failure. B: Additional this distance supports the heat dissipation in high altitude application. If devices are too close together, the heat may not be removed effectively, this is to be seen together with the rated current Ie correction, to prevent overheating. Affected are insulated wires and individual components with conductive parts in a plastic housing (e.g. TOL).
Electrical breakdown	Failure of insulation under electric stress when the discharge completely bridges the insulation, thus reducing the voltage between the electrodes almost to zero
RMS withstand voltage	Highest RMS value of a voltage that does not cause a breakdown of insulation under specified conditions
Rated impulse voltage (U_{imp})	Impulse withstand voltage value assigned by the manufacturer to the equipment or a part of it, characterizing the specified withstand capability of its insulation against transient overvoltage
Rated operational voltage (U_e)	A rated operational voltage of equipment is a value of voltage which, combined with a rated operational current, determines the application of the equipment
Rated insulation voltage (U_i)	The rated insulation voltage of equipment is the value of voltage to which dielectric tests and creepage distances are referred
Rated impulse withstand voltage (U_{imp})	The peak value of an impulse voltage of prescribed form and polarity the equipment is capable of withstanding without failure under specified conditions of test and to which the values of the clearances are referred
Rated operational current (I_e)	A rated operational current of equipment is stated by the manufacturer and considers the rated operational voltage, the rated frequency, and the utilization category
Overvoltage category	Conventional number based on limiting (or controlling) the values of prospective transient overvoltage occurring in a circuit

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