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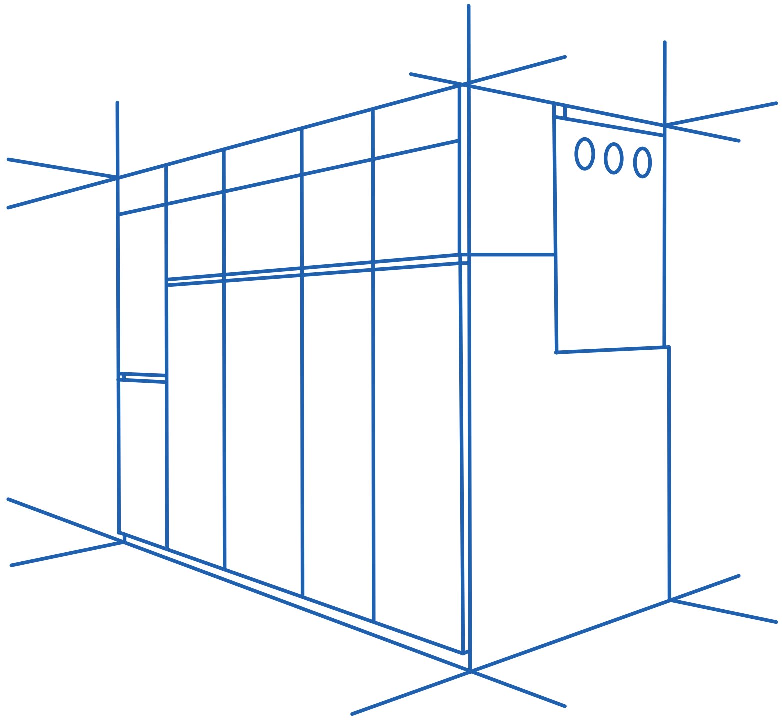

MV Air-insulated Equipment De-rating for High Altitude Installations

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Overview

This paper demonstrates and compares the correction factors required for electrical ratings of IEC and ANSI air-insulated, medium voltage switchgear when installed and operated at altitudes above their standard designs.

Application cases addressed in this paper indicate that discharge voltage (BIL) is the rating most impacted by altitude.

This white paper is intended as a reference for the proper selection of the type of medium voltage switchgear to be used according to its altitude of service. An incorrect selection can lead to problems such as dielectric failures, oversizing of the electrical equipment (higher cost), or the application of other solutions such as gas insulated switchgear (also higher cost).

1. Introduction

South America can be characterized by geographical conditions requiring the need for electrical equipment installations at high altitude. The Andes between Argentina, Chile, Bolivia, Peru, Ecuador, Colombia and part of Venezuela, are a mountain range that in which you can find cities, industries and mining operations at altitudes higher than 1,000 meters above sea level. At these heights, the dielectric properties of the electrical operating ranges of the equipment are affected due to the reduction in air density.

In this paper we will present two application examples. Both of which show the main electrical factors of switchgear operation affected by high altitude installations. They include: voltage and basic impulse level (BIL) ratings, with the latter being of greater importance when the altitude is greater than 1000 m.a.s.l. since the correction factor is directly related to the value of an exponential function.

2. Standardization of electrical switchgear ratings

2.1 Conditions of normal operation

Normal operating conditions as defined by the construction standards of IEC and ANSI to function normally under the following variables and ranges: environmental temperature, operating altitude, humidity and solar radiation. For unusual operating conditions the standards recommend the use of correction factors.

Table No. 1: Normal Operation

Standard	**IEC** **IEC 62271-200**	**ANSI** **IEEE C37.20.2**
Temperature		
Instant environment 0 ° C		
Minimum	-5 °C	-30 °C
Maximum	-40 °C	+40 °C
Maximum daily average	35 °C	Not specified
Altitude		
Maximum altitude (meters)	≤ 1000	≤ 1000
Solar radiation		
Solar radiation	Not specified	Not significant ANSI Std C37.24-1986
Moisture		
Average relative humidity over a period		(*)
24 hours	95%	Not specified
01 month	90%	Not specified

Table referenced IEC standards 62271-200 and ANSI C37.20.2

Note:
(*) The ANSI C37 1999-2000 recommended in clause 8.1.4.3 resistors using appropriate quantities and of sufficient strength to minimize condensation in all compartments.
- General Electric draws on maximum non-condensing humidity of 90% for its medium voltage equipment (CCM). Manual implementation GET-6840C.

2.2 Electrical Ratings

Electric ratings are defined by IEC and ANSI standards as ratings of voltage, current and insulation levels.

2.2.1 Voltage Range

The IEC standard defines nominal voltage as: Un (kV) and the ANSI standard defines the maximum voltage as: Umax (kV).

Table No. 2: Voltage Ranges

IEC Serie I Un (kV)	3.6		7.2		12		17.5	24		36		40.5
IEEE Umax (kV)		4.76		8.25		15			27		38	

Table referenced standards IEC 62271-100: 2006 and ANSI C37.06.1-2000
I referred to IEC Series indoor equipment

2.2.2 Current Range

Defined values of current (Ir) according to each standard.

Table No.3: Current Range

IEC (A)	630		1250	1600		2500		3150
ANSI (A)		1200			2000		3000	

Table referenced standards IEC 62271-100: 2006 and ANSI C37.06.1-2000
(*) There is no forced ventilation

2.2.3. Insulation Levels
The standards classify insulation levels for switchgear as:
- Power Frequency Voltage (RMS)
- Discharge Voltage

Table No.4: Insulation Levels

Voltaje (kV)		Voltaje Frecuencia Industrial (kV rms)		Voltaje decarga Atmosférica BIL (kVp)	
Grado Umax	Rango Un				
ANSI	IEC	ANSI	IEC	ANSI	IEC
4.16		19		60	
7.2	7.2	36	20	95	60
	12		28		75
13.8		36		95	
	17.5		38		95
	24		50		125
27		60		125	
	36		80		170
38		80		150	
	40.5		95		185

Table referenced standards IEC 62271-100: 2006 and ANSI C37.06.1-2000

3. Altitude correction factor

3.1 According to IEC standard

The standard clauses of IEC 62271-200, recommend the use of correction factors for installations in unusual conditions such as altitude.

Critical variables affected:

3.1.1 Voltage Correction Factor

The voltage correction is directly related to the effect of atmospheric pressure at high altitudes, which is referenced in the standard IEC 721-2-3. The following formula is used for the calculation of the correction factor:

Table No.5: Voltage correction factors for altitude

Item	Factor	ACF
Voltage	m = 1	$Ka = e^{m (H-1000)/8150}$

Table referenced standards IEC 60071-2: 1996

Note:

The exponent m is dependent on several parameters including the minimum discharge path which is generally unknown at the design stage. Determining the exponent m is based on the IEC standard 60-1.

- H= Altitude above sea level in meters give
- m= 1.0 for coordination atmospheric pulse voltage it can handle.
- m = 1.0 for industrial frequency voltages can be supported by air spaces and clean insulators.

3.1.2. Current Correction Factor

The current correction is directly related to the effect of atmospheric pressure at high altitudes and is referenced to IEC 721-2-3. The correction factor can be calculated from the following formula.

Table No.6: Correction factors for current

Item	ACF
Corrientes	ACF = 1 –0.02 * (H-1000)/1000

Table referring to IEC 60071-2
Note: H = Altitude above sea level given in meters

3.2 According to ANSI standard

As stated by ANSI C37.20.2-1986, clause 8.1.3, for unusual conditions such as altitude, it recommends the use of correction factors for the voltage and current, given in the following table:

Table No.7: Correction for altitude

Altitud (m)	Altitud (ft)	ACF for dielectric withstand voltage	ACF for continuous current
1000	3300	1.00	1.00
1200	4000	0.98	1.00
1500	5000	0.95	0.99
1800	6000	0.92	0.99
2000	6600	0.91	0.99
2100	7000	0.89	0.98
2400	8000	0.86	0.97
2700	9000	0.83	0.97
3000	10000	0.80	0.96
3600	12000	0.75	0.95
4000	13000	0.72	0.94
4300	14000	0.70	0.94
4900	16000	0.65	0.925
5500	18000	0.61	0.91
6000	20000	0.56	0.9

From standard ANSI C37.20-1999.

For calculation of correction factors for voltage and current for altitudes above 1,000 meters General Electric uses the following equations:

3.2.1 Correction factor for voltage

The correction factor can be calculated with the following formulas:

Table No. 8: Altitude correction factors

Ítem	Altura (feet)	ACF
Voltaje	A<3300	ACF= 1.0
	3300≤A<5000	ACF = 1.0 – [0.0294 x (A – 3.3 Mft)]
	5000≤A<10000	ACF = 0.95 – [0.03 x (A – 5.0 Mft)]
	A≥10000	ACF= 1.0 – [0.02 x A]

The table refers to catalog GET-6840C, General Electric, reflecting the adoption of ANSI C37.14

3.2.2 Current Correction Factor

The correction factor can be calculated with the following formulas:

Table 9: altitude correction factors

Ítem	Altura (feet)	ACF
Corriente	A<3300	ACF= 1.0
	3300≤A<5000	ACF = 1.0 - 0.00588 x (A – 3.3 Mft)
	5000≤A<10000	ACF = 0.99 – 0.006 x (A – 5.0 Mft)
	A≥10000	ACF = 1.0 – 0.004 x A

The table refers to catalog GET-6840C, General Electric, reflecting the adoption of ANSI C37.14

4. Examples of application

4.1 Case #1

ABC Mining Company has a project at an altitude of 3,000m and must select the medium voltage switchgear for their primary substation. The operating voltage is 13.8 kV and the current is 1500A with a main bus short circuit current of 23 kA.

<u>According to IEC standard</u>:
The switchgear required at an altitude of 3,000m should be de-rated in electric ratings.

1. Calculating the voltage correction factor:

$$Ka = e^{(3{,}000-1{,}000)/8{,}150} = 1.278$$

2. Calculation of current correction factor:

$$ACF = 1 - (3{,}000-1{,}000)/1{,}000 * 0.02 = 0.96$$

3. Selection of switchgear:

Table No. 10: altitude correction factors IEC

Rango	Voltaje de operación a 3,000 m.s.n.m	Factor Ka	Nuevo rango a 3,000 m.s.n.m	Rango Switchgear (ver Tabla 2,3,4)
Voltaje Operación	13,8 kV	1.278	17.63 kV	**24 kV**
Voltaje de descarga atmosférica	95 kV	1.278	121.41 kV	**125 kV**
Corriente Continua	1,500 A	0.96	1440 A	**1600 A**

Prepared by author

According to the above table, the equipment to be used will be GE SecoGear switchgear 24 kV, 1600A current and a BIL of 125 kV, 25 kA.

<u>According to ANSI standard:</u>
The switchgear required at an altitude of 3,000m should be de-rated in electric ratings.

1. Calculating the voltage correction factor:

Si A ≥ 10 Mft; USAR: ACF= 1.0 – [0.02 x A]

ACF = 1.0-[0.02 x (10)] = 0.8

2. Calculation of current correction: factor

Si A ≥ 10 Mft; USAR: ACF = 1.0 – 0.004 x A

ACF = 1.0 – 0.004 x (10) = 0.96

3. Selection of switchgear:

Table 11: Correction factors for altitude ANSI / NEMA

Rango	Voltaje de operación a 3,000 m.s.n.m	Factor	Nuevo rango a 3,000 m.s.n.m	Rango Switchgear (ver Tabla 2,3,4)
Voltaje Operación	13,8 kV	0.8	17.25 kV	**27 kV**
Voltaje de descarga atmosférica	95 kV	0.8	118.75 kV	**125 kV**
Corriente Continua	1,500 A	0.96	1440 A	**2000 A**

Prepared by author

According to the above table, the equipment to be used will be GE PowellVac switchgear 27 kV, 2000A current and a BIL of 125 kV, 25 kA.

4.2 Case 2:

DEF Mining Company has a project at an altitude of 4,500m and must select the medium voltage switchgear for its primary substation. The operating voltage is 22.9 kV and the current is 1500A with a main busbar short circuit current of 25 kA.

According to IEC standard:

1. Calculating voltage correction factor:

$Ka = e^{(4,800-1,000)/8,150} = 1.594$

2. Calculation of current correction factor:

ACF = 1 – (4500-1000)/1000 * 0.02 = 0.93

3. Selection of switchgear:

Table No.12: Correction factors for altitude IEC

Rango	Voltaje de operación a 4,500 m.s.n.m	Factor Ka	Nuevo rango a 4,800 m.s.n.m	Rango Switchgear (ver Tabla 2,3,4)
Voltaje Operación	22,9 kV	1.56	35.724 kV	**40.5 kV**
Voltaje de frecuencia industrial	50 kV	1.56	78kV	**95 Kv**
Voltaje de descarga atmosférica	125 kV	1.56	195 kV	**185 kV**
Corriente Continua	2,500 A	0.93	2,325 A	**2,500 A**

Prepared by author

According to the above table, the equipment to be used will be GE SecoGear switchgear rated 40.5 kV, 2500A of current and with a BIL of 185 kV, 25 kA.
(You would need to have a conversation with your customer to assure that the 185 kV would be sufficient.)

According to ANSI standard:

1. Calculating voltage correction factor:

Si A ≥ 10 Mft; USAR: ACF= 1.0 – [0.02 x A]

ACF = 1.0-[0.02 x (14,753/1,000)] = 0.70

2. Calculation of current correction: factor

Si A ≥ 10 Mft; USAR: ACF = 1.0 – 0.004 x A

ACF = 1.0 – 0.004 x (14,753/1,000) = 0.94

3. Selection of switchgear:

Table No. 13: Correction for altitude ANSI / NEMA

Rango	Voltaje de operación a 4,500 m.s.n.m	Factor	Nuevo rango a 4,500 m.s.n.m	Rango Switchgear (ver Tabla 2,3,4)
Voltaje Operación	22,9 kV	0.7	31,42 kV	**38 kV**
Voltaje de frecuencia industrial	50 kV	0.7	71.42 kV	**80 Kv**
Voltaje de descarga atmosférica	125 kV	0.7	178.6 kV	**150 kV**
Corriente Continua	1,500 A	0.94	1410 A	**2000 A**

Prepared by author

According to the above table, the equipment recommended will be a model PowellVac GE switchgear 38 kV, 2000A current and BIL of 150 kV, 25 kA.
(You would need to have a conversation with your customer to assure that the 150 kV would be sufficient.)

5. Conclusion

From the above cases we can conclude that altitude is an important factor in the de-rating of electrical characteristics (voltage and current) for switchgear (Table No. 2, 3 and 4). It is shown that nominal voltage, power frequency voltage and discharge voltage (BIL) are most affected because their de-rating factors are related exponentially with the altitude (Table 6).

For Case No. 2, it can be observed that to an altitude of 4500 masl and a service voltage of 22.9 kV, the derating of electric characteristics would require a switchgear rating of 38 kV NEMA or 40.5 kV IEC. In both cases the standard electrical ratings of the equipment did not meet the necessary requirements. It can be noted that the altitude correction factors cause the discharge voltage (BIL) levels to exceed any standard equipment ratings as listed by NEMA and IEC.

An alternative solution is to follow the recommendations of IEEE C37.20.2 where in clause 8.1.3 an arrester is recommended for altitudes above 1,000m to maintain transient voltages below the permissible limit of the equipment or you should examine the possibility of using SF6 gas insulated switchgear. This type of equipment is not affected by altitude as its active parts are enclosed in SF6. A thorough technical and economic analysis should be used to determine which is the best type of equipment to be applied in each specific installation.

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