The Effect of Altitude on the Operation Performance Of Low Voltage Switchgear and Controlgear Components

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***Abstract*- Decreased air density due to increased altitude can have an effect on the operation performance of low voltage switchgear and controlgear components. For applications at high altitude little is known about this effect on the operation performance of these components. Characteristics such as dielectric voltage-withstand, thermal ampacity, overload calibration, contact life and interruption capability can be affected by the decreased air density. Tests were conducted in an electrical laboratory capable of producing needed electrical circuit parameters. The testing was conducted using a vacuum chamber to artificially lower the air density to simulate altitudes up to 6000 m. A fact finding study was developed defining the operation performance capabilities for low voltage components at higher altitudes.**

I. INTRODUCTION

There is little technical guidance for high altitude applications, e.g. altitudes from 1000 m to 6000 m, of low voltage switchgear and controlgear components (LVCs) used in low voltage switchgear assemblies, motor control centers and panels. These LVCs include: molded case circuit breakers, disconnect switches, fuses, starters, contactors, soft start solid state starters, variable frequency drives, overload relays, control relays, and transformers. Since the air pressure and density decrease as the altitude increases the operation performance for LVCs is affected, in theory, the dielectric voltage withstand is reduced, thermal ratings are reduced, calibration is affected, contact life is affected, contactor interruption performance is reduced, and short-circuit interrupting capability is reduced. There is some guidance based on IEEE Std. 27 which provides empirical correction factors for the voltage rating (dielectric withstand) and current rating (thermal ampacity) [1]. See Table I. An example of how these altitude correction factors can be applied is shown in Table II, However, information is not provided on operation performance criteria such as current interruption, which may also be affected by the reduction of the dielectric and thermal characteristics at higher altitudes. Thus, engineers applying equipment at high altitudes have little guidance for properly selecting LVCs, and in reality, no guidance at all is provided for applications at altitudes above 3000 m.

TABLE I
ALTITUDE CORRECTION FACTORS FROM IEEE STD. 27

METAL-ENCLOSED LOW VOLTAGE POWER CIRCUIT BREAKER SWITCHGEAR		
	CORRECTION FACTORS	
ALTITUDE (m)	VOLTAGE	CURRENT
2000	1.00	1.00
2600	0.95	0.99
3900	0.80	0.96

ALL OTHER TYPES OF SWITCHGEAR ASSEMBLIES		
	CORRECTION FACTORS	
ALTITUDE (m)	VOLTAGE	CURRENT
1000	1.00	1.00
1500	0.95	0.99
3000	0.80	0.96

NOTE: INTERMEDIATE VALUES MAY BE OBTAINED BY INTERPOLATION.

TABLE II
BUS AMPACITY AT DIFFERENT ALTITUDES
@ 40°C AMBIENT WITH A 50°K RISE

ALTITUDE (m)	BUS AMPACITY (A)				
0 - 1000	800	1200	1600	2000	2500
1500	792	1188	1584	1980	2475
3000	768	1152	1536	1920	2400

An example of LVC industry standards where altitude requirements are found is the NEMA Standard ICS 1-1993 [2]. This NEMA standard defines two altitude classes. Class 1 Km is for equipment installations that do not exceed an altitude of 1000 m. Systems using power semiconductor equipment are usually Class 1 Km.

Class 2 Km is for equipment installations that do not exceed an altitude of 2000 m. Electromagnetic and manual devices are Class 2 Km. However, guidance is not given in this standard for qualifying LVCs above these altitudes. Also, the International Electrotechnical Commission (IEC) Standard, IEC 60947-1, includes a restriction that LVCs should not be applied above 2000 m [3]. However, included in IEC 60947-1 is a note that permits LVCs to be used at higher altitudes, but the reduction of dielectric strength and cooling effects of the air must be addressed. As in the NEMA standard, guidance is not provided in IEC 60947-1 for qualifying LVCs for use above 2000 m nor is there guidance on how, at higher altitudes, the reduction of dielectric strength and cooling effects can be addressed.

Thus, in order to address these LVC performance and application issues at different altitudes, a research program was initiated. This program was designed to investigate, not only, the effects caused by reduction of dielectric strength (dielectric withstand performance) and cooling effects (thermal capacity) of air at higher altitudes, but also investigate other operation performance criteria to determine if there were any significant performance changes, e.g., calibration, overload interruption, contact life, and short-circuit interruption. To investigate the affect on the operation performance for LVCs at increasing altitude, tests were conducted using a vacuum chamber to simulate the air densities normally found at the corresponding altitudes. See Fig. 1. The LVCs tested consisted of components qualified or addressed by IEC Standards, NEMA Standards, and Underwriters Laboratory Standards (Standards, et al) [3][4][5][6][7][8][9][10][11].

II. TEST PROGRAM COMMENTS

It must be noted that this investigation was not meant to be a qualifying type test program but a program to establish if there is significant change in the performance data due to changes in air density. Therefore, the test parameters, at times, were more severe than the norm in order to make this determination. Also, the test devices were selected as representative samples of LVCs and with the hope that the testing of these particular samples might demonstrate significant findings. This program is a first step process to determine which operational performances would indicate significant trends. Further testing may be required to more accurately determine the exact impact that altitude has on the operational performances.

The altitude stated as 0 m in this investigation, air pressure norm 101.3 kPa, was not actually at sea level, but at the altitude of the test laboratory which is approximately 200 m [12]. The air pressure of the laboratory was recorded before each test series and ranged from 99.9 kPa to 103.3 kPa. The air pressure in the test chamber was set at 47.1 kPa for the maximum test altitude of 6000 m. Fig. 2 shows the correlation of air pressure to altitude and was used for establishing the pressure for the testing with the base of 101.3 kPa for the air pressure at sea level [12].

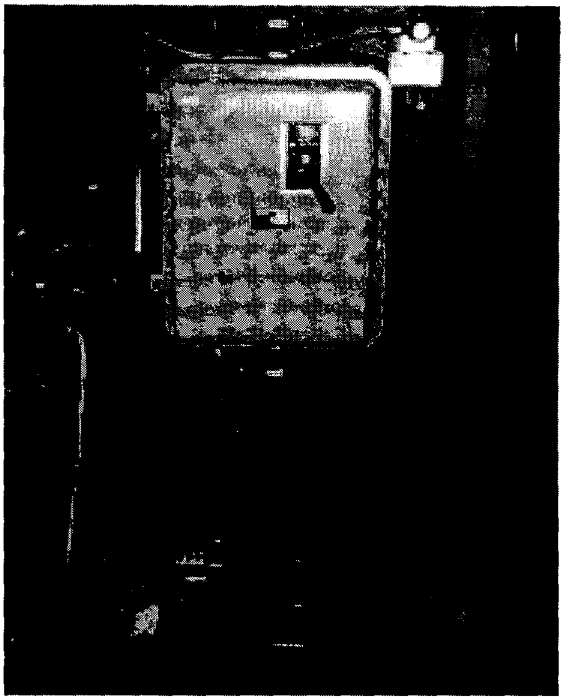

Fig. 1. Test Setup

Although humidity was not considered in the study, it may have had some effect on certain tests. The humidity was monitored throughout the testing and the humidity did change at the different altitudes, e.g., 0 m to 6000 m altitudes, the humidity decreased from 17% RH to 12% RH respectively.

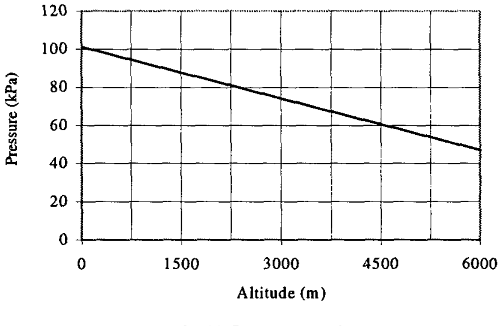

Fig. 2. Air Pressure at Altitude

III. DIELECTRIC WITHSTAND PERFORMANCE

The Standards, et al, require through air and over surface requirements as well as a dielectric withstand test. These dielectric performance requirements are conservative and the LVCs have a very high dielectric withstand capability. Therefore, performing dielectric withstand tests on a product may not indicate any significant correlation to field usage at high altitude. Factors of material selection, the porosity of the materials used, and the design configuration may be more significant on LVC dielectric withstand performance than the reduction in dielectric strength due to the effects of lower air density at higher altitudes. However, to address the effects in dielectric withstand performance at higher altitudes, LVC samples were tested in a devised circuit based on Standards, et al. The dielectric withstand test was as follows:

1) The three line terminals were connected together by jumpers. The three load terminals were also connected together by jumpers. A dielectric withstand test voltage of 2200 V was applied between the line and load terminals, with the device contacts open. See Fig. 3a.
2) The air pressure was gradually decreased until the air pressure corresponding to an altitude of 6000 m was attained, i.e. altitude from 0 m to 6000 m.
3) The circuit was changed. The jumpers were removed. The B phase line terminal was connected to earth by a jumper. The A and C phase load terminals were connected together by a jumper. The device contacts are closed and a dielectric withstand test voltage of 2200 V was applied between the B and the C phase line terminals. See Fig 3b.
4) The air pressure was gradually increased until the air pressure corresponding to an altitude of 0 m was attained, i.e., altitude from 6000 m to 0 m.

The duration of the test for each LVC was approximately 4 minutes. The current of the high voltage source was monitored throughout the duration of the test and set to trip at 50 mA leakage current.

The following LVCs were subjected to dielectric withstand tests: IEC contactor, NEMA contactor, IEC circuit breaker, NEMA circuit breaker. All the devices successfully withstood 2200 V without breakdown at all altitudes. The findings indicated that there is sufficient margin in the design of the devices so that de-rating is not required for dielectric withstand performance at higher altitudes.

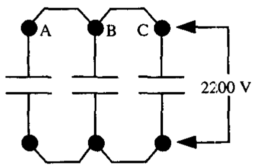

Fig. 3a. Dielectric performance (Contacts Open)

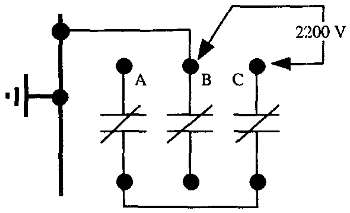

Fig. 3b. Dielectric performance (Contacts Closed)

IV. THERMAL AMPACITY

It is known that for bus bar systems in open air the cooling and resultant thermal ampacity is adversely affected due to the lower air density at higher altitudes. Thus, IEEE Std. 27, as indicated in Table I, provides guidance regarding current de-rating based on altitude [1]. However, lower air density at higher altitudes, should have less effect on LVCs since the internal component's current carrying parts are in contact with component moldings. Substantial cooling occurs by the conduction of heat through the molding material, which in turn, distributes the heat to the mounting plate. The effect on thermal ampacity for the LVCs was evaluated by placing the devices in the altitude test chamber and conducting a temperature rise test at the simulated altitude air pressures. However, because the vacuum test chamber's thick aluminum walls might act as a heat sink and effect the test results, the test's samples were not mounted directly to the chamber but were suspended by wires. Thus, the change to the air density should be the only variable which would affect the temperature test results.

The following LVCs were subjected to a temperature test: IEC contactor, NEMA circuit breaker, HRC fuse. All the temperature tests were run at the maximum rated current for the LVC. The findings of the temperature rise test are shown in Fig. 4. The tests indicate that thermal capacity is significantly affected by altitude. The tests also indicate that devices with thermal elements, such as circuit breakers and fuses, are affected more significantly than devices without

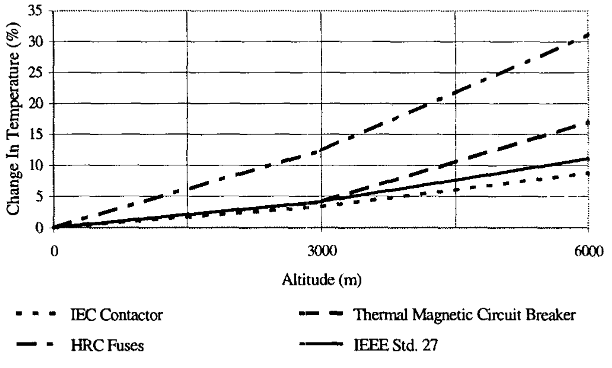

Fig. 4. Temperature Test

thermal elements, such as contactors. Interestingly, fuses were affected to such a great degree that this performance would need to be addressed when applying fuses at high altitudes. Also, plotted in Fig. 4 for comparison, is the thermal correction factor for 0 m to 3000 m based on IEEE Std. 27 with 3000 m to 6000 m extrapolated.

V. COMPONENT CALIBRATION PERFORMANCE

LVCs that provide overload current protection contain bimetallic, eutectic, or electronic elements for monitoring the current. This being the case, the decreased air densities at higher altitudes can have an effect on the calibration because the load current or I^2R is actually monitored through heat transfer, e.g., convection and radiation of the heat to a bimetal. Also, the electronic devices often contain heat sensing elements, e.g., thermistors. These elements are used for monitoring the ambient, the circuit board, reset time, etc., and may affect the operation performance at lower air densities. A comparison of the calibration at different altitudes was evaluated by conducting an overload calibration test at 300% of the overload's trip setting and monitoring the trip time.

The following LVCs were subjected to the overload calibration test: NEMA eutectic overload relay, IEC bimetal overload relay, IEC electronic overload relay with current transformers, IEC electronic overload relay with hall effect current monitors. The findings of the calibration performance tests are shown in Fig. 5. The tests show that the eutectic and bimetal overload relays are affected by the air density at higher altitudes and that the electronic overload relays are not adversely affected. Therefore, it would be necessary to use altitude correction factors with the eutectic and bimetal overload relays in order to avoid nuisance tripping. The findings support the use of electronic overload relays for applications above 2000 m.

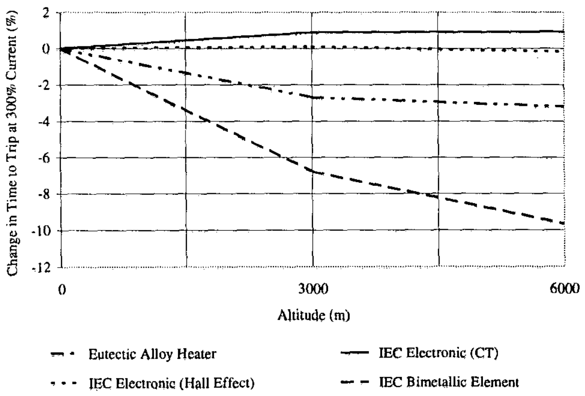

Fig. 5. Overload Calibration

VI. CONTACT LIFE PERFORMANCE

Contact life is a part of the application requirements for motor contactors. The type of operation affects the selection and sizing of the contactor for a given application, e.g., number of normal start and stop operations (AC3), percent of inching and plugging duty (AC4), etc. [3]. Manufacturers supply contactor life curves and formulas to assist the application engineer in selecting the appropriate size contactor for the application. However, should there be a significant change to contact life at higher altitudes, the application engineer would have to address this change. A contactor with well known contact life was chosen for this testing. The contactor samples were disassembled and each of the contacts were carefully weighed. The contactors were then reassembled and a contact life performance test at the various altitudes was run. The contacts were re-weighed upon conclusion of the testing. Using this data, the altitude effect on contact life performance was evaluated.

NEMA contactors were subjected to the contact life test. An example of the findings of the contact life test are shown in Fig. 6. The findings indicate there is no significant effect on the contact life caused by lower air densities at higher altitudes. To the contrary, the findings indicate that the contact life is slightly improved at higher altitudes. Therefore, it would not be necessary to change the contact life criteria used for selecting and sizing contactors at altitudes up to 6000 m.

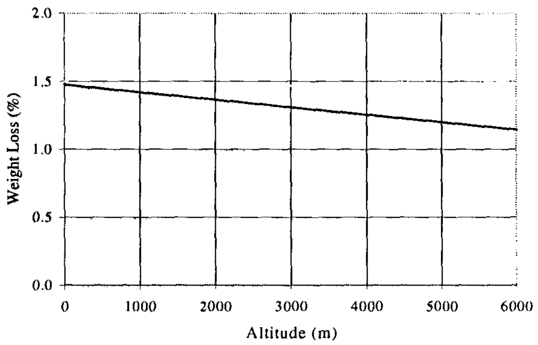

Fig 6. Loss of Contact Material

VII. CONTACTOR OVERLOAD INTERRUPTION PERFORMANCE

Switching devices with limited interrupting capacity, such as contactors and disconnects, may be required to interrupt currents of ten to twenty times their ratings, e.g., lock rotor currents, inrush currents, etc. This interruption capacity is not a normal duty requirement, but a requirement under an overload condition. Thus, it is essential that the interrupting capacity should not be reduced with the increase in altitude. A contactor with well documented interruption capacity was chosen for this testing. The starting test current for each test altitude was 50 A less than the known maximum interruption current of the contactor at sea level. Understandably, there is some variation in the interruption performance level, therefore, five test trials were conducted at each current level. The current level was increased 50 A if the device passed, and the test series repeated until the maximum interruption level was determined. To keep the test conditions as constant as possible, the tests were conducted as opening (O shots) only. Thus, on these tests an external close-in contactor was used to eliminate any influence on the test sample interruption performance.

IEC contactors were subjected to the contactor overload interruption test. The findings of the interruption performance tests are shown in Fig. 7. The findings indicate that the contactor interruption is improved at higher altitudes. The amount of current the contactor could successfully interrupt, increased as the altitude increased. Therefore, the interrupting rating of the contactors would not require de-rating at altitudes up to 6000 m.

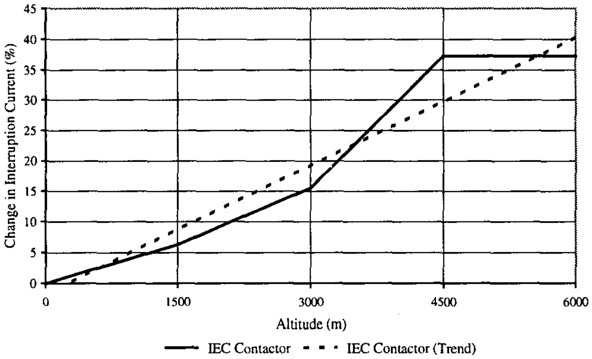

Fig. 7. Contactor Overload Interruption

VIII. SHORT-CIRCUIT INTERRUPTION PERFORMANCE

As part of the test program, both HRC fuses and inverse time current limiting circuit breakers were tested under short-circuit conditions. Since there is margin in the short-circuit interruption capabilities for these devices, the decision was made to keep the short-circuit test conditions constant. Then monitoring the peak let-through current (I_p) the let-through energy (I^2t) and the interruption time, determine if there was any significant change due to the change in air density. The tests were conducted as opening (O shots) only, in order to keep the test conditions more constant. The test station's making switch was used to initiate the short-circuit current. Since the test samples are current limiting devices, a test closing angle of 70° for phase A was chosen because this angle is consistent to current limiting fuse testing standards [13]. Experience has shown that this closing angle is a difficult case for interruption by current limiting breakers as well.

The following LVCs were subjected to a short-circuit interruption test: IEC circuit breaker, NEMA circuit breaker, HRC fuse. The short-circuit interruption tests were run at the rated short-circuit current and voltage for the LVC. Examples of the findings for the interruption performance tests are shown in Fig. 8 through Fig. 10. The findings indicate that all the LVCs appear to have sufficient margin in the design of the devices enabling them to interrupt their rated interrupting current at higher altitudes. However, the findings also indicate that while the peak currents remain fairly constant, the clearing times are longer and, in some cases, let-thru values increase at higher altitudes. The fuses appear to be more affected, especially at higher fault currents, than the circuit breakers by this trend. In a combination starter this may result in more damage to the components and affect the Type 1 or 2 Coordination Classification [3]. Further short-circuit testing of combination starters to study this effect should be considered.

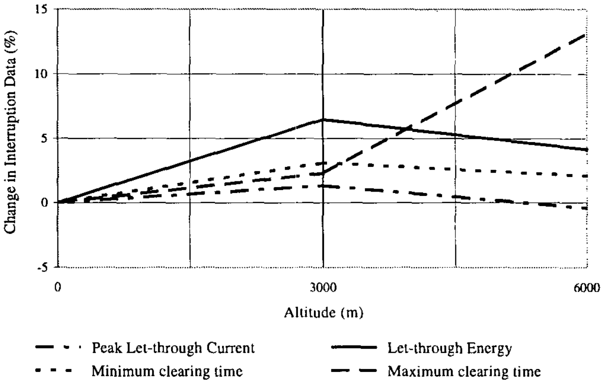

Fig. 8. Short-Circuit Interruption Tests- 244 V, 100 kA
(NEMA Circuit Breaker)

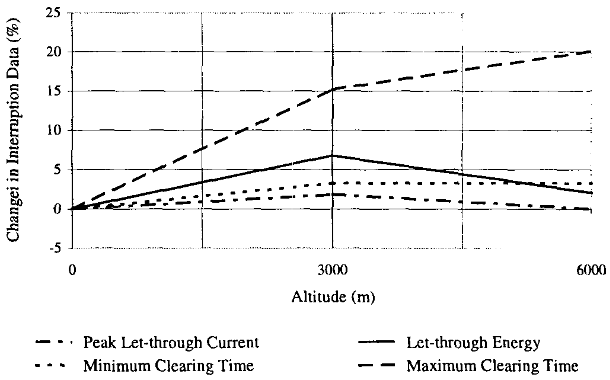

Fig. 9. Short-Circuit Interruption Tests- 401 V, 71 kA
(IEC Circuit Breakers)

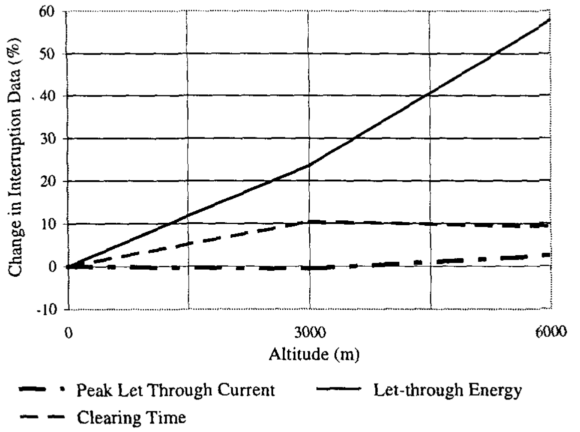

Fig. 10. Short-Circuit Interruption Tests- 616 V, 200 kA (HRC Fuses)

IX CONCLUSIONS

As previously indicated, this program was a fact finding process for the purpose of determining if there are any significant changes in performance at higher altitudes (3000 m to 6000 m) for LVCs. If a significant change was determined, a recommendation was made concerning future action, e.g., further testing, types of tests, increased sampling, etc.

What was determined from this program is the following:

1) Dielectric withstand performance was not significantly affected at higher altitudes and further investigation is not warranted.
2) Thermal ampacity performance was affected at higher altitudes for LVCs with thermal elements and there was a significant effect to fuses. Further testing and sampling should be carried out on such thermal element LVCs, i.e., thermal magnetic circuit breakers, fuses, thermal type overloads relays. On components without thermal elements, further investigation is not warranted, i.e., contactors, disconnects, switches.
3) Calibration performance was affected at higher altitudes on devices with thermal elements but not on LVCs with electronic over-current sensing. Further testing and sampling should be carried out on thermal element LVCs, i.e., thermal magnetic circuit breakers, fuses, thermal type overload relays. On LVCs without thermal elements, further investigation is not warranted, and these types of devices should be considered for the high altitude applications, i.e., electronic type overload relays, electronic trip unit circuit breakers.
4) Contact life performance was not reduced at higher altitudes and further investigation is not warranted.
5) Contactor overload interruption performance was improved at higher altitudes and further investigation is not warranted.
6) Short-circuit interruption performance was affected at higher altitudes and there was a more significant effect to fuses. Further testing and sampling should be carried out and combination starter units should be included to determine the effect to the Type 1 and Type 2 coordination classifications.

Finally, other additional components should also be considered for future test programs, e.g., control circuit transformers, soft start solid state starters, variable frequency drives.

ACKNOWLEDGEMENT

A substantial amount of work went into this project. Over 1000 tests were conducted as well as numerous consultation and assistance from others. The authors would like to thank those that helped and provided valuable assistance in the total program but with a special thanks to Henry Czajkowski, Gary Bruski and Emmad Jamaleddin.

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