Medium Voltage Switchgear in Corrosive Environments: Challenges and Solutions

Technical Collection

Technical paper N° MATPOST2015_0069

Abstract

Medium voltage switchgear installed at industrial or commercial facilities is exposed to both indoor and outdoor environments. Composed of different kinds of metals and surface treatments, switchgear components are subjected to deteriorating corrosion processes, the rate of which strongly depends on the presence of various gases, vapors, particles, and combinations thereof in the surrounding air. This paper provides a brief overview of challenging environmental conditions and explores how best to control them by examining their impact on the most commonly used metals and surface treatments in MV switchgear. It also discusses aspects of surface treatments and their effect on various corrosive environments. Paper focuses on Fretting corrosion and Corrosion of Switchgear components in highly polluted environment mainly hydrogen sulfide which is less known corrosion phenomena but very critical to the reliability and performance of the products. The author has investigated the challenges faced by switchgear designers in selecting appropriate surface treatments based on application and environmental conditions to improve performance in highly corrosive environments.

Keywords:

MV Switchgear, Harsh environment, Corrosion, Surface Treatment, Fretting corrosion, Hydrogen Sulfide

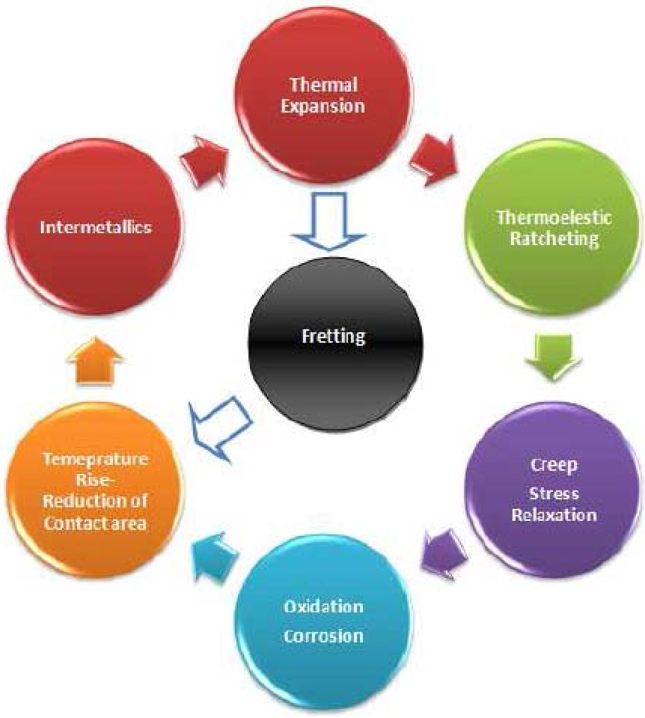
Introduction

The installation of electrical equipments, mainly medium voltage (MV) switchgear, in adverse environments containing corrosive gases, liquids, or dust can cause severe and rapid deterioration of the equipment. Historically, it has been recommended that customers keep electrical equipment free of these contaminants through the use of special enclosures or separate rooms. Now MV switchgear could be exposed to both indoor and outdoor environments according to customer needs. Corrosion is defined as the deterioration of a base metal resulting from a reaction with its environment. The electrical components most affected are those fabricated from copper, aluminum, and silver compounds, and steel, both carbon and stainless. This paper explores possibilities for controlling this corrosion so that switchgear can fulfill the intended 30- to 40-year lifespan without breakdown. It is found that of the various corrosion types, fretting corrosion is key to deteriorating the life of switchgear and destroying its functionality.

Medium voltage switchgear

The electricity industry is conservative. Among the reasons for this is the fact that the lifetime of medium voltage switchgear is around forty years. Transmission system and distribution network operators need stability and assurance. Maintenance and repair of such long-lived devices needs to be ensured. It is critical to consider the atmospheric condition in which the switchgear is installed; the aspects that must be examined during the design of switchgear and its components include contacts, enclosures, busbars and other critical components made by metals and alloys. In the last 20 years considerable switchgear design changes have been observed, but still there are aspects of the corrosion of metals and alloys that are not sufficiently addressed by designers of switchgear and its components. The closed electrical contact has to perform its function of passing electric current reliably and continuously and with no change in its contact resistance for the entire duration of its life. The contacts have to perform this function even though the ambient atmosphere in which they reside contains pollutants that can cause the contacts to tarnish or corrode. Fig. 1 shows the schematic diagram of various degradation mechanisms in switchgear contacts. Each degradation mechanism, including fretting and corrosion, leads to a rise in temperature and eventually failure of the contacts.

Figure 1
Schematic of degradation mechanisms



Factors affecting reliability of contacts

Reliability is most commonly defined as the probability of equipment or a process to function without failure, when operated correctly, for a given period of time, under stated conditions. Anything outside of that is a failure. One of the most significant problems in providing reliability to electrical contacts is the discrete nature of the interface of contacts.

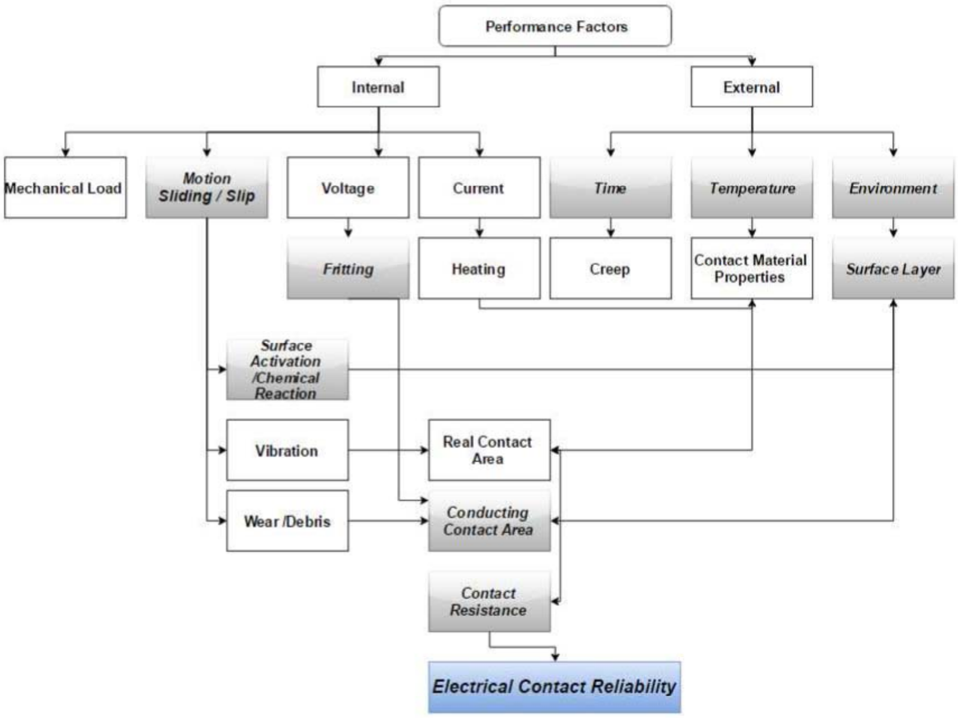


Figure 2

Effect of performance factors on the reliability of electrical contacts

Fig. 2 shows the variety of factors can be conventionally divided into performance factors governed by operating conditions and design-technological factors determined by the fabrication characteristics of a contact unit. The performance factors (parameters) are basically divided into two groups: internal and external, schematically showing the influence of design-technological factors on the reliability and quality of electrical contacts. The intermediate layers that separate the contacting surfaces, the quality of the deposited coatings, and the contact surface micro relief determine the apparent contact area, size, number, and distribution of contact spots. This, in turn, influences the real and electrical contact areas, the constriction and surface film resistances, and, lastly, electrical contact reliability. The internal factors are mechanical (the contact load, the type and characteristics of motion such as case, the sliding velocity, and reciprocation) and electric (type and strength of current, operating voltages). The external factors may be temperature-time variation, humidity, atmospheric pressure, effect of aerosols, etc. These are often uncontrollable. The performance factors affect the properties of contact materials and surface films, the occurrence of physical and chemical processes in the contact zone, and wear particle formation thus influencing the state of the interface and, finally, the contact resistance and reliability of electrical contacts.

Internal factors are controllable factors and can be managed by good design. In contrast, external factors are normally out of reach for designers to control, so it's of key importance to design products that can control them. This paper focuses on the environment and surface layer or surface treatment on contacts that affect product performance.

Switchgear in corrosive environments

Composed of different kinds of materials, both pure metals and alloys, electrical equipment is subjected to deteriorating corrosion processes, the rate of which strongly depends on the presence of various gases, vapors, particles, and combinations thereof in the surrounding air. There are different types of corrosive atmospheres, such as indoor, rural, marine and industrial, which have different severity levels in terms of corrosion on switchgear components. See Table 1 below for a brief classification and environmental details.

Table 1

Classification of corrosive atmosphere

Corrosive Atmosphere and Category	Description in Brief
Indoor Atmosphere **C1 – Very Low** **C2 -Low**	Mild, Ambient Humidity Not evacuated or filled with Liquid. Fumes from Switchgear in certain conditions can be highly corrosive
Rural **C2-Low** **C3-Medium** **C4-High**	Do not contain Strong Chemical. Dry or Tropical sometime with very High Relative Humidity. High Average temperatures, intense sunlight, little or no rainfall. Condensation during night such conditions may produce highly corrosive environment
Marine **C5-M**	Fine particles with Salt settle on exposed surface, Salt concentration may decrease with respect to distance from ocean. Splashing of sea water on equipments produces worst environment and intermittent immersion with wet and dry cycling produces highly corrosive environment
Industrial Atmosphere **C4-High** **C5-Very High**	Mainly Sulfur compounds (SO_2); from burning coal or other fossil fuels acid settles in microscopic droplets and falls on exposed surfaces ("acid rain"). Hydrocarbons and ozone cause smoky fog. The contaminants in an industrial atmosphere, together with dew or fog, produce a highly corrosive, wet, acid film on exposed surfaces Electrical systems are often installed in confined areas close to ground level or, worse, below ground where high humidity may prevail

Note that this list is not exhaustive. Apart from these chemically active substances due to vehicle pollution and dust particles, there are possibilities of corrosion. The major dilemma for designers is which surface treatment to choose to control or eliminate the harmful effects of corrosion that arise due to chemically active substances. As per IEC 60271-3 and IEC 60271-4, the values remain almost the same. However the nomenclature of the class is different.

Electrical equipment and components in corrosive environments

MV switchgear industries aim for a 25-40 year switchgear lifespan and also strive for zero defects in manufacturing, but due to the incorrect selection of corrosion protection, switchgear can fail in the first 5-10 yrs. The reason for these types of failures is the insufficient corrosion protection provided to components. The primary cause of insufficient protection is inadequate knowledge about the environment in which the switchgear is to be installed and its harmful effect. Knowledge of the rate of corrosion in various different environments is very important to avoid failures due to corrosion. The table below shows the rate of corrosion in various environments.

Table 2

Corrosion rates

Chemically Active Substance	Unit of Measurement	Rural	Urban	Industrial-C4	Industrial -C5	Industrial-CX - De Icing	Industrial - CX-Marine
Sulfur dioxide S02	mg/m²d	4	24	80	240	4000	4000
Chlorine	mg/m²d	3	60	80	80	240	240
Sulfur dioxide S02	μg/m³	5	30	100	300	5000	5000
Chlorine	μg/m³	3.75	75	100	100	300	300
Sulfur dioxide S02	mg/m³	0.00375	0.075	0.1	0.3	5	5
Chlorine	mg/m³	3.8E-06	7.5E-05	0.1	0.1	0.3	0.3
Humidity	% RH	90	90	98	98	98	98

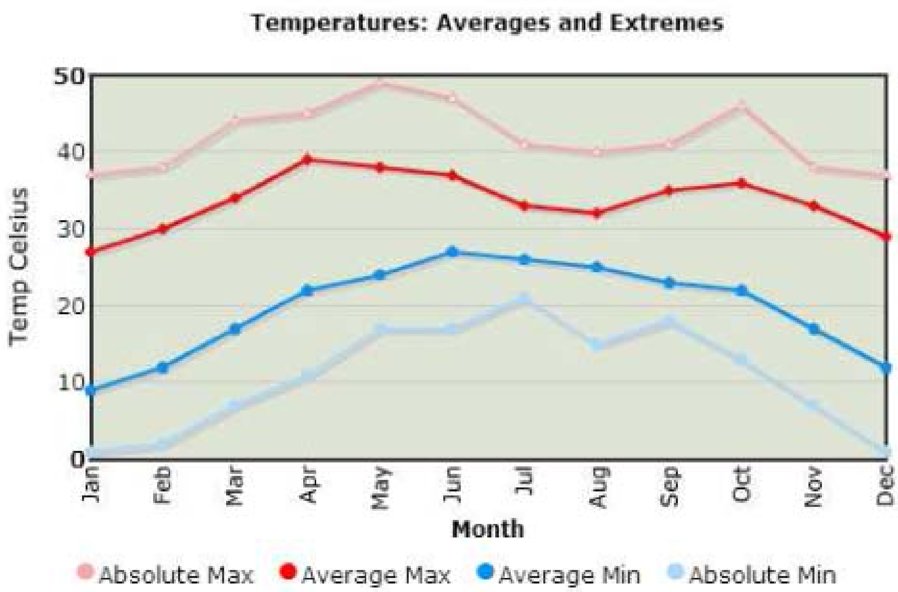
Table 2 is an important reference when considering the corrosion resistance of the components for various applications of MV switchgear.
Schneider Electric had conducted a study to examine the effects of chlorine and other chemically active substances on stainless steel grade AISI 304 (1.4301).

Corrosion of steel in secondary switchgear – ring main unit (RMU)

A study was conducted to examine various aspects of corrosion on an RMU tank kept at Mundra Port, Kutch, India. The objective was to design and improve the reliability of the product, which is indoor equipment, in the harshest environment. This RMU tank was kept at the port for approximately two years to simulate the conditions of a harsh corrosive atmosphere, study the corrosion behavior, and analyze the corrosion of stainless steel .This RMU tank was kept at various temperatures from 3-50°C. Fig. 3 shows the temperature variation at the site.

Figure 3

Temperature variation at Mundra Port, India



There was continuous salt mist exposure and a high humidity level at the port that generated pitting corrosion on the stainless steel sheet metal. The pitting was then analyzed to find its root cause, and it was observed that the deterioration was much deeper because pitting corrosion eventually generated stress corrosion and micro cracks in the stainless steel. Fig. 4 and Fig. 5 show the macro view of the pitting corrosion whereas Fig. 6 and Fig. 7 show the scanning electron microstructure analysis of the sheet metal pitting.

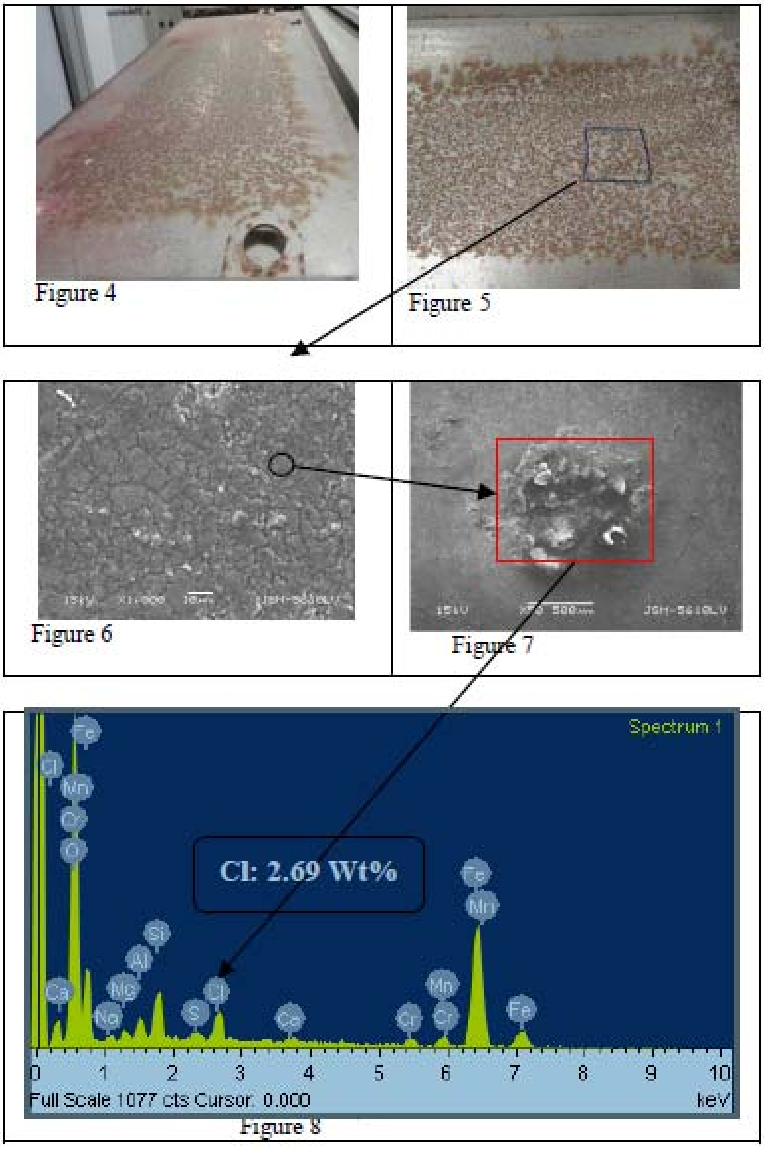


Figure 4
RMU tank- after two years

Figure 5
Location of samples for analysis

Figure 6
Pitting corrosion on top surface

Figure 7
Analysis of Pits

Figure 8
EDS analysis of Pit

A high level of chloride content was observed in an EDS analysis of the pits on the outer surface. Generally the pitting was a superficial phenomenon, but when the inner surface of the sheet metal was analyzed, a few micro cracks were observed. The combination of high humidity and temperature with high levels of chlorine provided a perfect combination of pitting and stress on the sheet metal and generated stress corrosion cracking.

Fig. 9 shows the microstructure of the inner surface of the tank, which shows that the corrosion was so severe that it penetrated a thick sheet of 2 mm. Further analysis was done by SEM and EDS, which can be observed in Fig. 10, Fig. 11 and Fig. 12.

Figure 9

Inner surface of sheet – intergranular cracks

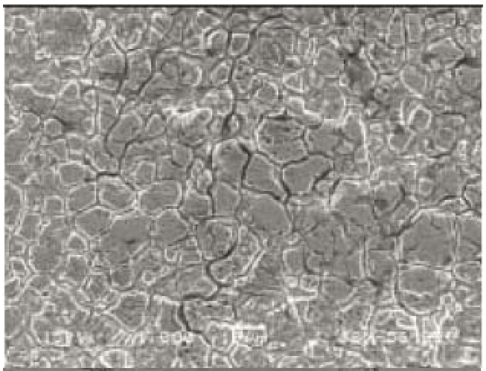


Figure 10

Micro crack - intergranular

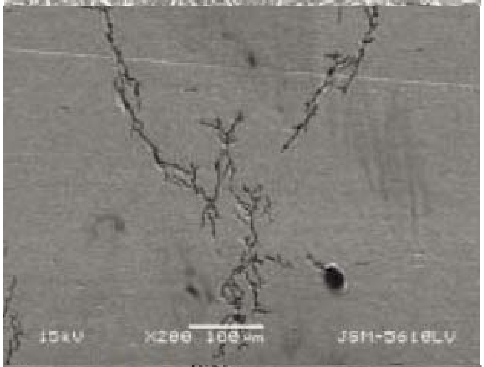


Figure 11

Branch type crack-500X

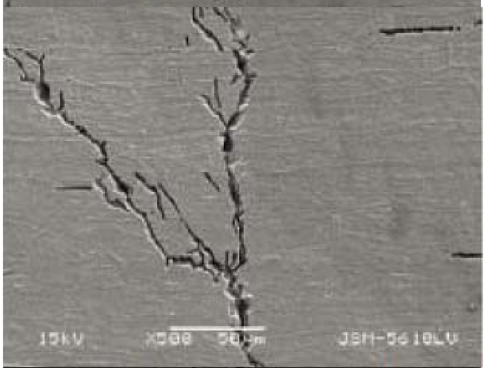
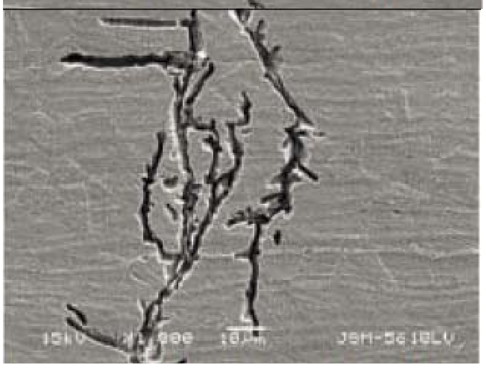


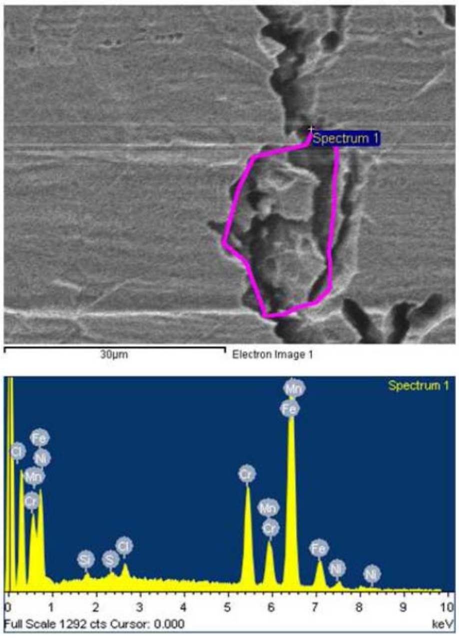
Figure 12

Magnification-1000X



It was observed that the crack had an intergranular branch-type structure, and propagated throughout the thickness. The salty environment created pitting on stainless steel over a period of time, and chlorine from pitting combined with stresses in the metal and created micro cracks. The constant deposition of chloride (salt mist) on the tank over a period of time increased the chloride concentration and resulted in severe corrosion of the steel.

Figure 13
EDS analysis of crack



Element	Weight%	Atomic%
Si K	0.44	0.85
S K	0.33	0.56
Cl K	1.02	1.57
Cr K	18.69	19.56
Mn K	8.53	8.45
Fe K	67.61	65.88
Ni K	3.38	3.13
Totals	100.00	

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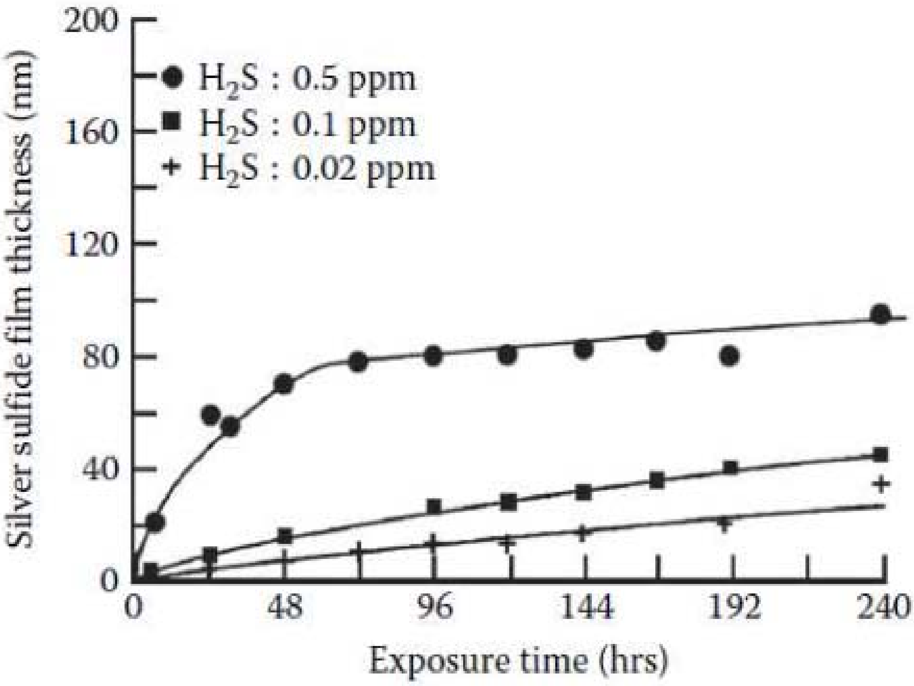
EDS analysis shows a high level of chlorides in developed cracks in the sheet metal. The permissible level of chlorides for SS304 is 200 ppm and for AISI 316 is 1000 ppm. It was observed that the chloride content is more than 2000 ppm in these materials so it has observed stress corrosion cracking. The only way to solve this problem is to keep equipment in the enclosed area or apply a surface coating to the steel. The epoxy base surface coating was to solve this problem. However, a detailed description of this coating is outside the scope of this paper.

Effect of H2S and fretting corrosion

Silver is a widely used surface treatment metal in electrical connections and sliding contacts. The susceptibility of silver to form electrically insulating tarnish films, such as silver sulfide and/or silver chloride, impedes use of the metal as a finish on electrical contacts. Gold is an option, but due to its high cost, the exploration of silver finish as a replacement for gold in electrical contacts is being pursued. The formation of silver sulfide tarnish films stems from a chemical reaction of silver with free sulfur or sulfur-containing atmospheric pollutants such as hydrogen sulfide (H2S) present even in trace amounts of air. Fig. 14 shows the growth rate of silver sulfide in air containing traces of H2S, at a temperature of 25°C and a relative humidity of 75%, as indicated in the graph. The growth rate is clearly affected by the concentration of H2S. Silver tarnish films can grow rapidly to a much larger thickness than indicated in Fig. 14 if both the H2S concentration and the relative humidity are increased, and if traces of nitrogen dioxide (NO2) are also present.

Figure 14

Growth rate of silver sulfide in air containing various trace amounts



Silver oxidizes at room temperature only in the presence of ozone to form Ag2O. This oxide is relatively soft and easily removable mechanically, and decomposes at about 200°C. Because it does not adhere strongly to the metallic substrate, it is generally not considered deleterious to the generation of stable electrical contacts.

Figure 15

Tarnishing of silver on switchgear contact of H2S

Figure 16

Tarnishing of silver plating on busbar of H2S

Figure 17
Porosity on the plated surface of H2S

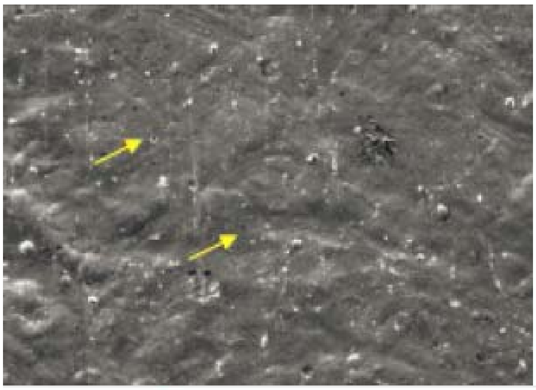


Figure 18
Sulfir content in plated surface of H2S

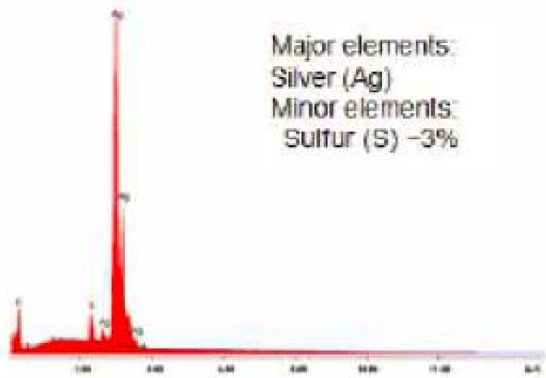


Fig. 15 and Fig. 16 show the tarnishing of silver contacts. An analysis of the tarnished surface found high levels of sulfur content and many porosities.

The electrical conductivity of the conductor depends on its conductivity parameters, surface, shape, type of joint and even quality of the joint. Electrical conductivity of the material is reduced by surface resistance, which is mainly reduced by corrosion. So it is necessary to protect conductors from resistance, which can be achieved with preferable protective coating and corrosion control. Another important problem that exists in the electrical circuit is fretting corrosion. Fretting corrosion occurs when there is a relative movement between electrical contacts with surfaces of ignoble metal. Fretting corrosion is relatively responsible for increasing the contact resistance of a circuit, and eventually it is heated so that failure occurs under the worst condition.

Propagation of fretting corrosion

Copper plated with silver,if exposed to atmosphere rich with H2S, can experience fretting corrosion. It is known that hydrogen sulfide (H2S) is present in many industrial chemical processes, such as marine/saline environments as well petrochemical/food processing industries. It is also found in steel, sugar/chemical water processing units, oil, boiler plants, etc. Silver sulfide is formed by contact with SO2 in moist air. Fig. 19 and Fig. 20 show typical sliding contacts for circuit breakers. Generally it has a surface treated with silver and has a potential risk of fretting.

Figure 19

Design of CB contacts as per rating and geometry

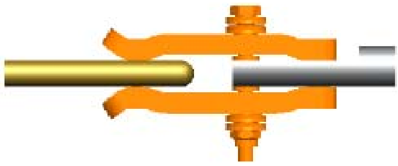


Figure 20

Sliding contacts

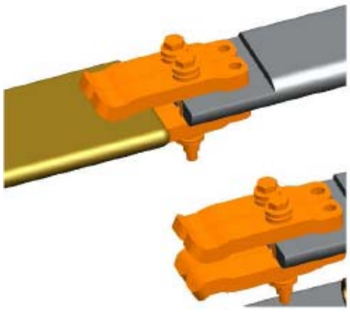


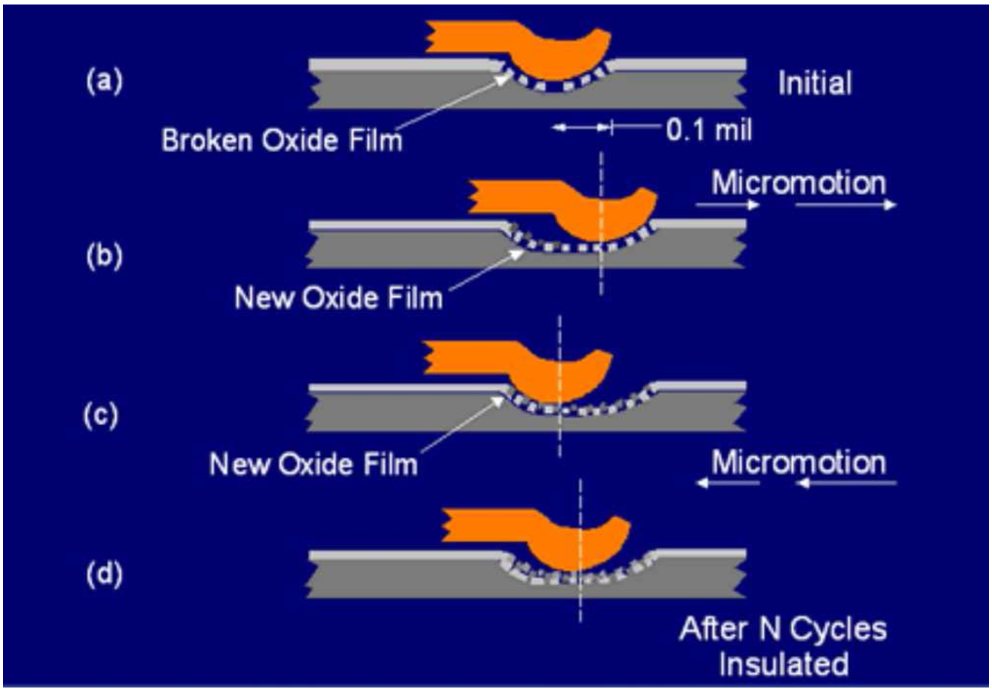
Figure 21

Sliding contacts with gold plating

When a thick layer of Ag_2S is formed on silver plating and the parts are exposed to a high temperature and hydrogen sulfide, the new process of growing thin filaments (whiskers) begins.

Silver whiskers usually grow in certain areas of the switchgear where they are exposed to H_2S. They grow more intensely in the areas with higher temperatures, mainly bus joints and sliding contacts, outside edges and corners of the contacts. Silver corrosion results in a high resistance, which produces more heat, which in turn stimulates further tarnishing and the growth of whiskers. Fig. 22 shows the mechanism of fretting in sliding contacts. Due to the sliding motion the preventive oxide film is broken and a new oxide film generates over a period of time. Eventually it results in an insulating film. This insulating film contributes to contact heating to produce catastrophic switchgear failure.

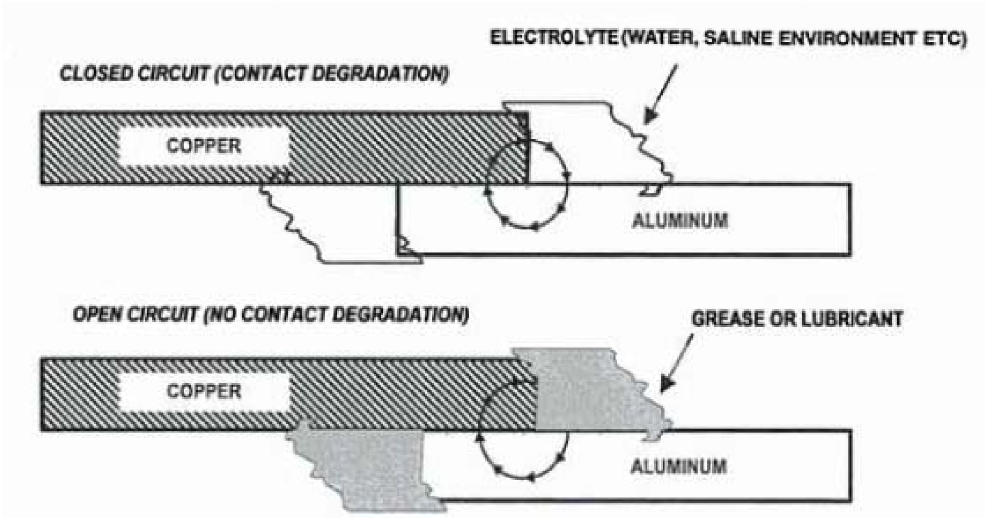
Figure 22
Mechanism of fretting in sliding contacts



Control of fretting corrosion

It is difficult to form rules in switchgear design, but some guidelines are mentioned in this paper. The designer's experience is an important factor, and the design depends on their expertise in application, material, type of the conductor used, etc. Fig. 21 shows the gold plating on the sliding contacts. Tin (Sn) coating is prohibited in spring contact because it causes tin embrittlement and fretting corrosion. To control the Fretting corrosion lubrication plays a very important roles. Lubrication plays a very important role in controlling fretting corrosion. Lubrication does not allow moisture to enter the pits of the contact erosion due to sliding/misalignment or caused by excessive temperature/vibration or mechanical alignment, etc. Most switchgears are installed in relatively clean air with normal humidity. In such cases, lubrication of the silver-plated joints seals the joints adequately and protects them against the entrance of an electrolyte and the possibility of galvanic corrosion. Due to application of the lubrication, temp bearing capacity of the electrical joint increases. Fig. 23 shows how lubrication can be applied to avoid galvanic corrosion in aluminum to copper sliding contacts.

Figure 23
Schematic of galvanic corrosion in aluminum-to-copper joints



Guidelines to prevent corrosion for MV switchgear

The following tables list the corrosion behaviors of different contact material combinations and the mitigating measures required to suppress the effect of corrosion. They also provide guidelines for designers and application engineers.

Table 3
Guidelines to control corrosion for various material combinations

Material Combination	Corrosion Behavior	Mitigating Measures
Al-Cu	Corrosion of Al in Saline atmosphere	Lubrication + Al Transition Washers
Al-Cu(Sn Plated)	Thickness <10 µm – Severe > 10 µm – Not Severe Corrosion	Lubrication Use lubricated Al transition washers
Al-Cu(Ag Plated)	Thickness >5 µm no Severe Corrosion of Contacts	Lubrication not required Current-carrying contact-pairing should be avoided due to formation of intermetallics
Tin-Plated Aluminum/Copper (alloy)	In industrial environment corrosion of tin and its peeling intensifies corrosion of aluminum	Remove tin and lubricate Use lubricated Al transition washers
Tin-Plated Aluminum/ Tin-Plated Copper (alloy)	Plating thickness < 10 µm no severe corrosion of aluminum surface	Remove tin and lubricate Use lubricated Al transition washers.
Nickel Plated Aluminum/ Copper (alloy)	If not protected corrosion at nickel-aluminum interface in saline environment can occur	Lubrication
Nickel-Plated Aluminum/ Nickel-Plated Copper	If not protected corrosion at nickel-aluminum interface in saline environment can occur	Lubrication

Schneider Electric helps customers avoid corrosion in their MV switchgear equipment and satisfies their stringent requirements by implementing best practices developed from years of experience. However, these must be used as guidelines.

Table 4
Guidelines for H2S atmosphere

Material	Corrosion Severity	Corrosion Protection
Bare Uncoated copper	High	Fixed Contact – Tin Plated Sliding Contacts – Ag+Rh Plating
Silver Plated Copper	Medium	Both and Fixed and Moving Rh, Pd, Au
Bare uncoated Aluminum	No Effect	Not required
Aluminum Tin Coated	Low	Not required
Aluminum Silver Coated	High	Ag+Rh Plating
Steel + Painting Steel +Zinc and Chromium Steel – Phospated Galvanized Steel	No effect on current passage	No special treatment required

Table 5
Guidelines for SO2 atmosphere

Material	Corrosion Severity	Corrosion Protection
Bare Uncoated copper	High	Fixed Contact – Tin Plated Sliding Contacts – Ag+Rh Plating
Silver Plated Copper	Low	Not required
Bare uncoated Aluminum	Medium	Fixed Contact – Tin Plated
Aluminum Tin Coated	Low	Not required
Aluminum Silver Coated	Low	Ag Plating is okay
Steel + Painting Steel +Zinc and Chromium Steel – Phosphated Galvanized Steels	No effect on current passage	No special treatment required

The above guidelines were developed for MV switchgear components for specific installations in harsh environments.

Conclusion

Satisfactory performance during a switchgear's lifespan depends on the metals and alloys used for its components. Applying the right surface treatment to power connections enhances the life of switchgear. The electrical contacts, connection and its usage in a harsh environment can decrease the desired lifetime because the environment in which it is installed plays a major role. It is important to analyze site pollution before design activity in order to create a reliable design. This is because the effect of a small amount of chlorides in the atmosphere can generate severe failure, even in stainless steel, if not properly used. Concerning the effect of environments, special attention must be paid to polluting substances and elements. They are usually contained in very small concentrations, but can create catastrophic failures. Silver and some of its alloys are particularly susceptible to tarnishing and fretting corrosion due to minute quantities of H2S that occur in many environments. Switchgear designers faces many challenges when coping with environmental problems and their negative effects on switchgear; however, basic guidelines are available for designing and installing switchgear for the harshest environments.

Schneider Electric has many years of experience in dealing with these types of challenges and always provides reliable products to their customers.

References

[1] Bravnovic Factors Affecting Reliability of Power Connections, Electrical Contacts- Principles and ApplicationsCRC Press2013247-48, pp 247-249
[2] Corrosion of Silver-Plated Copper Conductors,ESA1984 [3] Corrosion Protection of Electrically Conductive Surfaces, Advanced Corrosion Resistant Alloys for Energy Production, Storage, and Transportation Systems,Metals, pp 4-5
[4] Chudnovsky, Bell H, Electrical Power Transmission and Distribution,CRC Press pp 99-101
[5] ISO Standard, Corrosivity of atmospheres, NF EN ISO 9224AFNOR 2012, pp 9.
[6] Schneider Electric, Electrical Equipment and Components in Adverse /Corrosive EnvironmentSchneider Electric USA,2004, pp 2-4
[7] Technical specification - Electrodeposited Silver coatings –Schneider electric FTR00047, pp 4-6
[8] AFNOR. "Corrosion protection of steel structures by protective paint systems." AFNOR, September 1998.

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