Factors Affecting the Life Time of the Electric Joints

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ABSTRACT:
When an electrical contact is put into service, it is importance to predict its probable length of life with respect to its operating temperature. High current busbar systems are used in power stations and high-power buildings. In this paper, the effect of harmonics, dust, coating materials, humidity, the oxidation film resistance and operating temperature on the life time of electric contact is studied. Also, a mathematical model for aging mechanisms in electric contacts is presented. The results show that the coated connections give excellent stability and low initial contact resistance. Series dust contamination formed on contact surface is one of the main reasons of the electric contact failure. Films on the surface of contacts create an excess of the electric resistance which also can cause failures in contact applications. Humidity in the atmospheric environment also influences the surface of contacts.

Key Words: life time, coating, dust, harmonics, joints, contact resistance

1 INTRODUCTION

Electrical connections represent the weakest parts along the busbar systems. One of the main problems of electrical distribution systems is connection failure. The main reason for these failures is contact resistance between the elements of connection. Films on the surfaces of contact create an excess of electrical resistance which can cause failure in contact applications [1, 2]. Humidity in the atmospheric environment also influences the surfaces of contact. Contact resistance is the main criterion in the electrical contact reliability. Therefore, its measurement is necessary for the test and development of new contact materials suitable for various working conditions and applications. Oxides, sulphides and other surface contaminants have of course higher resistance than the base metal. Copper like all other common metals, readily develops a very thin surface oxide film even at ordinary temperatures when freely exposed to air [3 – 7]. The most widely used coating materials are Nickel and silver. Compared with uncoated copper connections the nickel and silver coating of copper connections showed excellent stability and low initial contact resistance. Contact resistance between the busbar joint elements causes unequal distribution of currents in the upper and lower joint parts. Therefore, there will be higher power losses at the joint ends, hence higher temperature. The temperature distribution is calculated. It is found that the highest power loss along the joint, hence the joint temperature occurs at the joint ends. This higher temperature leads to increase of the contact resistance at the joint ends. Hence , there will be an additional increase to the temperature at these points [8, 9]. In the present study the oxidation processes is analysed. A mathematical model of contact which takes the oxidation processes into consideration is presented. The general laws of ageing of electric contact are presented together with the influence of the variations in load or ambient temperature on their life [10]. Harmonics means distorted waveform for either voltage or current or both. This distortion in waveforms has effects on different equipments. By using a mathematical model, a simulation program is developed to calculate the life of the busbar joints. Effect of harmonics on the life time of joints is taken into consideration [10,11]. Serious dust contamination formed on contact surface is one of the main cause of electric contact failure. These contaminations may be due to surface oxidation, dust deposition and corrosion of contact material [12-14].
The main objective of this paper is to study the effects of harmonics, coating materials, dust contamination, operating temperature, humidity, length of joint, a clamping force and loading currents on the life time of busbar joints. The obtained results show that harmonics current and dust contamination increase contact resistance, contact temperature and losses of busbar joints. The increase in contact resistance is generally attributed to corrosion film growth. So, the contact reliability is greatly degraded and contact life time is greatly reduced. Analytical results are in agreement with the corresponding experimental results.

2 FACTORS AFFECTING ON THE LIFE TIME OF JOINTS

Many factors affect on the performance and life time of the electric joints such as follows:
1- **Dust pollution:** Many buildings, laboratories and factories install windows with only one layer of glass, no special device is considered for dust filtering. Therefore, a layer of visible dust is covered on the surface which is usually found inside or outside the electric equipment. Dust seriously influences the reliability of electric contacts. Dust indentation would seriously damage the

contact surface. Dust particles on the surface of electric contact leads to increase the contact resistance of the joints.

2- **Humidity**: Films on the surfaces of contact create an excess of electrical resistance which can cause failure in contact applications. Humidity in the atmospheric environment also influences the surfaces of contact. So, contact resistance is increased when humidity increases.

3- **Coating materials**: The coating of the busbar with different metals is one of the most common commercial practices used to improve the stability of the connections and to prevent ambient corrosion. The most widely used coating materials are tin, silver, cadmium, and nickel.

4- **Harmonics**: Harmonics means distorted waveforms for either voltage or current or both. This distortion in waveforms has effects on different equipment. Harmonics causes increase in contact losses then increase in contact temperature and consequently increase in contact resistance.

5- **Operating and maximum temperature**: The current carrying capacity of a busbar is usually determined by the maximum temperature at which the busbar is permitted to operate. These upper temperature limits have been chosen because at higher maximum operating temperatures, the rate of surface oxidation in air of conductor materials increase rapidly and may give rise in the long term to excessive local heating at joints and contacts.

6- **Contact clamping force:** Increasing the clamping force leads to decrease the contact resistance. The continuous increasing of the clamping force improves the performance of the contact joint, but if it exceeds a certain limit, the a-spot would be damaged and so the contact resistance will be higher, i.e. a bad contact performance. This limit depends on the kind of joint material and its hardness.

7- **Joint length**: The increase of the joint length improves the performance of the joint, because it leads to increase the contact area and causes the transformers of more heat to the environment, which means a good performance of the joint. However, it was noticed that the increase of the joint's length above a certain limit has no significance on the joint's performance.

3 MODELLING OF JOINT RESISTANCE

Contact resistance may be divided into three major components[1,2]:

1. Resistance of the basic metal.
2. Resistance due to converging of the lines of current flow as they pass through the small area "true conducting area" of the joint called "the constriction resistance".
3. Resistance resulting from surface tarnish films (oxidation films), trapped between the members of the joint, frequently called as film resistance which is affected directly by the environment "temperature, humidity, vapors, dust,….".

A contact is characterized by the meeting of two metal members pressed against each other by the contact load. The contact takes place at a certain number of points termed a-spots, characterized by their number n and their average radius a [1, 10]. The number of spots and their radius can be estimated in accordance with the following equations [1] :

$$n = 2.5 \cdot 10^{-5} \cdot H^{0.625} \cdot F^{0.2} \quad (1)$$

$$a = (F / (\pi \cdot n \cdot \eta \cdot H))^{0.5} \quad (2)$$

Where,

- n : number of a-spot.
- a : the radius of a-spots (cm).
- F : contact clamping force (or contact load) in N.
- H : the metal collapsing breaking point (N / m^2).
- η : is a non dimensional constant between 0.3 and 0.6 according to the contact load and evenness of the contacts. Here an average value of 0.45 is considered.

Associating with each contact spot a radius circle "ℓ" such that:

$$\ell = (S_C / (\pi \cdot n))^{0.5} \quad (3)$$

Where:

- ℓ : radius of action, (m).
- S_C : apparent contact surface, (m^2).

The contact resistance can be expressed as:

$$R_C = (\rho / (n \cdot \pi \cdot a)) \cdot \arctan ((\ell^2 - a^2)^{0.5} / a) - 1.25 \cdot ((\ell^2 - a^2)^{0.5} / S_C) + (\sigma / (n \cdot \pi \cdot a^2)) \quad (4)$$

In the general case in which ℓ >> a,

$$R_C = (\rho / (2 \cdot \pi \cdot a)) + (\sigma / (n \cdot \pi \cdot a^2)) \quad (5)$$

Where :

- R_C : the contact resistance, (Ω).
- ρ : metal resistivity, (μΩ – cm).
- σ : resistivity of oxidation film, (Ω ·m).

An approximate relation between the surface resistivity σ and the total oxide thickness S of the copper oxide at the interface [1] :

$$\sigma = 315 \cdot 10^{10} \cdot S^{2.68} \quad (6)$$

4 MODELLING OF LIFE TIME OF ELECTRIC JOINTS

The length of life is defined as the time at the end of which either the insulation of the contact by oxidation is complete (breaking of contact) or when the softening temperature of the metal is reached. The effect of ageing mechanism on electrical contacts studied by Johannet [10]. The ageing mechanism takes place according to two factors; the surface of the a-spots are progressively corroded and the surface resistivity oxide layer grows progressively.

4.1 REDUCTION OF THE A-SPOT AREA

The reduction of the spot radius is one of the factors which control the life time, the following equation is used to estimate the spot radius a(t) at any time [10].

$$a(t+\Delta t)=a(t)-0.66\cdot 10^{10}\cdot\tau\cdot m\cdot\Delta t \qquad (7)$$

$$m = \frac{\partial S}{\partial t} = (e^{B}) / ((S_o)^2 + t\cdot e^{B}) \qquad (8)$$

Where,

$$B = (34.31 - (11740 / T_c))$$

Where,

t : time in hours.

Δt : time step.

τ : the ageing factor (≥ 1)

T_C : is the temperature of contact joint, (in degree K).

S_O : is the thickness of oxidation film which forms almost immediately on the metal when it is exposed to air (S_O = 20 Angstrom for copper).

The thickness of the copper oxide forms obeys the relation obtained by Holm [1]:

$$S(t) = (S_O^2 + t\cdot e^{[34.31 - (11740 / TC)]})^{0.5} \qquad (9)$$

4.2 THE INCREASE OF SURFACE RESISTIVITY

The increase of surface resistivity is estimated during the time in accordance with the increase of the oxidation film. Assuming that the temperature T_C is constant during an interval of time Δt and considering that the oxide increase simultaneously on the two surfaces, the increase in the oxide thickness will be such that [10]:

$$S(t+\Delta t) = S(t) + 2\cdot 10^{-10}\cdot\tau'\cdot m\cdot\Delta t \qquad (10)$$

Where, τ' : is the pollution factor (≤ 1)

And

$$\sigma(t+\Delta t) = 315\cdot 10^{10}\cdot [S(t+\Delta t)]^{2.68} \qquad (11)$$

5 EXPERIMENTAL SETUP

5.1 EFFECT OF HARMONICS:

In order to validate the analytical results obtained from the developed model. A experimental work was carried out. The experimental setup contains two busbars. They are made of a copper (99.9 %). The dimensions of each busbar are 38 mm by 12 mm by 110 mm. A diode (TET B5 200T3) is used as a source of harmonics. Harmonic analyzer model (power Harmonic Analyzer Series 901) is used for detecting the harmonic level.

5.2 EFFECT OF COATING MATERIAL AND HUMIDITY:

The tests are conducted on the two copper busbars mentioned above. The two joints used in the test are copper busbar joint and copper busbar joint coated by silver. The aim of the measurements was to evaluate the constriction resistance and to compare the initial contact resistance of uncoated and coated copper joints. And then the two joints were placed in a sealed humidity chamber with the contacts in the open position. Circulating air with 95 – 99 % relative humidity, maintained at 55 ^{O}C for 50 days was used to accelerate contact oxidation. The joints were then removed from the chamber and allowed to dray for 10 days. Then the contact resistance of the two joints was measured.

5.3 EFFECT OF DUST:

Two identical copper busbar joints are used, the same dimension on (5.1). The first joint is new and very clean from the dust. The second joint is exposed to a source of dust for three months. And the initial contact resistance is measured. The two joints were then placed in a sealed humidity chamber for 50 days at 55 ^{O}C. The contact resistance was measured again after the oxidation.

6 RESULTS

Table (1) shows the initial contact resistance of the different joints at the same contact force. It can be seen that the initial contact resistance of the cleaned copper joint without harmonics is higher than the initial contact resistance of the joint with harmonics. But, initial contact resistance of the dusty copper joint and the copper joint with harmonic are greater than the initial contact resistance of the cleaned copper joint without harmonics. The percentage increase of the contact resistance of uncoated joint is higher than the corresponding value of coated copper joint. The life time of electric joints is affected by some factors as presented in references [4,5] such as the contact clamping force, the joint length, the loading current, and the initial operating temperature of the contact. On the basis of the analysis and results mentioned in reference [4, 5], it is evident that the life time of electric joint is depends mainly on the contact resistance of the joints. The contact resistance of the joints is affected by the coating materials as indicated by the experimental results in Table (1). The dust particles cause electric contact failures which seriously influence the reliability of the electric systems. Therefore, a layer of dust which can cover the surface should be prevented. In contaminated atmospheres, metal samples are subjected to dust and humidity. So, corrosion of the surfaces will occur. Sulphide and oxide film grow on their surfaces. When such corroded surfaces are in contact with each other, the contact resistance increases due to current lines constriction. Hence, the increase in contact resistance is generally attributed to corrosion film growth. So, the contact reliability is greatly degraded and the contact performance and life time are impaired. A mathematical model for ageing mechanisms in electric contact is introduced. Using this mathematical model, a simulation program is developed to calculate the life time of the busbar joints with and without harmonics. It can be noticed that the life time is decreased by 25% due to effect of harmonics. Also, it can be noticed that the life time is decreased by 32 % due to effect of dust and humidity. But, the life time is increased by 21 % due to coating material by silver as shown in Figs. (1 - 7).

Table 1 : The initial Contact Resistance of different joints

Materials	**R_C (μΩ) Before Oxidation**	**R_C (μΩ) After Oxidation**	**% Increase of R_C**
Clean Copper Joint without Dust	56.00	69.00	23.21
Copper Joint Coated by Silver	41.50	43.00	3.61
Copper Joint with Dust	63.00	80.50	27.77
Clean Copper Joint without Harmonics	56.00	73.93	23.22

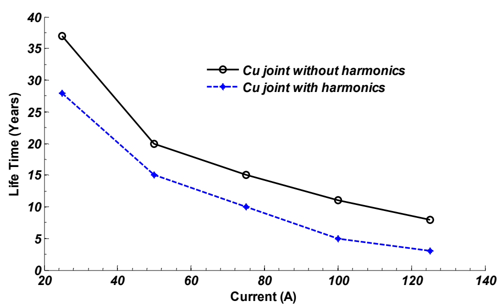

Fig. (1) Life time of copper joints against current with and without harmonics

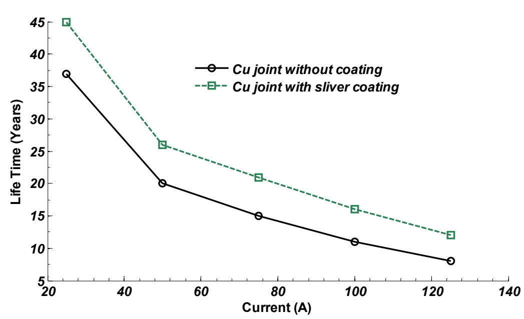

Fig. (2) Life time of copper joints against current with and without coating by silver

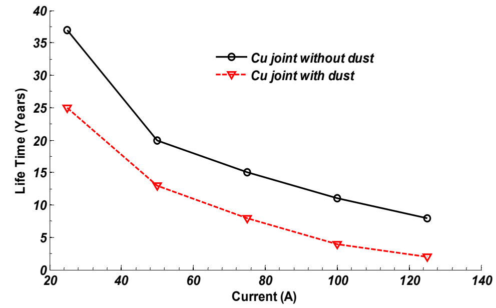

Fig. (3) Life time of copper joints against current with and without dust

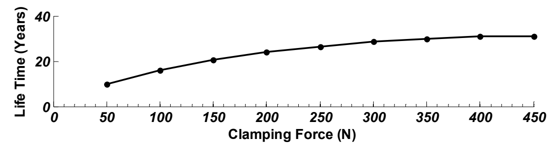

Fig. (4) Life time of copper joints against clamping force at loading current = 200 A and maximum temperature = 150 ^{O}C

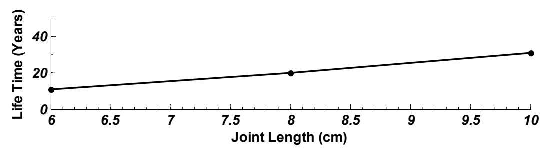

Fig. (5) Life time of copper joints against joint length at loading current = 200 A , maximum temperature = 150 ^{O}C and clamping force = 250 N

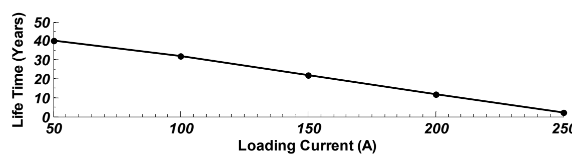

Fig. (6) Life time of copper joints against loading current at clamping forc = 250 N and maximum temperature = 150 ^{O}C

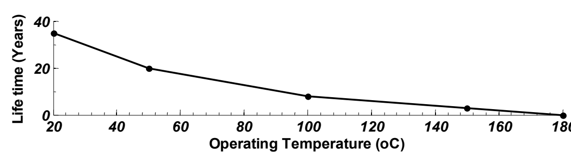

Fig. (7) Life time of copper joints against operating temperature at loading current = 200A and clamping force = 250 N.

7 CONCLUSIONS

The temperature in the contact zone is directly related to the voltage drop across the interface. Also, the fundamental mechanism behind the observed behavior of contact spot is very sensitive to its temperature. The flow of harmonic current leads to excess heating in all equipments. This heat can be expected to raise equipment temperature and leads to reduce the insulation life. The following conclusions are obtained in this paper:

1- Harmonic current increases contact resistance, contact temperature and losses of busbar joints. So, the contact reliability is greatly degraded and contact performance and life time are greatly reduced.
2- The coated connections showed better stability and low initial contact resistance. The life time of the silver coated joints is increased.
3- Dust particles collected on contact surfaces will cause metal corrosion. So, the contact resistance is increased due to dust contamination. The contact temperature is increased due to the dust and therefore the life time will be decreased. Possible ways of eliminating dust effect such as: reducing the size of particles by using filtering or shielding devices, cleaning the surfaces with special tools, turning contact surfaces to an optimum direction.
4- Increasing the clamping force decreases the contact resistance. The continuous increasing of clamping force improves the performance of the contact joint. But, if the clamping force exceeds a certain limit, the a-spot may be damaged and so the contact resistance increases again, i.e. resulting a bad contact performance. This limit depends on the kind of joint material and its hardness. Generally, the life time of the contact increases by increasing the clamping force.
5- The increase of the joints length improves the performance of the joint, because it increases the contact area and causes the transfer of more heat to the environment. This means a better performance of the joint. However, it was noticed that the increase of the joint's length above a certain limit has no significance effect on the joint's performance. The life time of the contact joints is increased by increasing the joint length.
6- Increasing the load current increases the power loss which appears as heat. Thus, the increase of the load current decreases the life time of the joints.
7- The life time of the joints decreases with the increase of the operating temperature.

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