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SPARKS AND EXTERNAL PARTIAL DISCHARGES ON LOW AND MEDIUM VOLTAGE POWER LINES

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ABSTRACT

Partial discharges are a common phenomenon on the power lines of the electrical network. This paper presents the occurrence of sparks and external partial discharges on insulators and the conditions under which they take place. Furthermore, it is investigated the probability of the appearance of sparks on bare conductors of low and medium voltage and the external factors, as humidity and pollution, which affect this phenomenon. Finally, it is estimated that the thermal stress of a wooden crossarm on a pylon of medium voltage could not lead to the ignition of the crossarm. For its ignition, overextended humidity and a very contaminated environment is required.

KEY WORDS

Partial discharges, sparks, external partial discharges, crossarm ignition energy.

1. Introduction

Sparks on insulators are defined as transitory luminous and audible glow partial discharges. Luminous and audible glow around the conductors are also called sparks (phenomenon corona). Sparks are very common on high voltage (e.g. of 150 kV) and on medium voltage (e.g. of 20 kV) power lines. Although it is spectacular, it is not dangerous as it is just noise and radiation and not glowing metal parts.

Sparks occur at first on insulators due to the layer of foreign deposits on them. Sometimes (due to extended humidity and large number of deposits) these partial discharges lead to leakage currents, which can cause surface breakdown or flashover, resulting in power interruption from the line protection systems (such as circuit breakers) or even in a Black-Out (voltage interruption on many power lines).

The conditions that are necessary for the appearance of sparks on insulators or partial discharges or surface breakdown or flashover, are: the existence of extended humidity (steam overlays the insulators) and contaminated environment (sea water salt, dust and smut are deposited on the insulators). For this reason, this phenomenon appears on the medium and high voltage lines, mostly early at the morning during the autumn (October, November) when the rain is absent (otherwise the insulators would be clean) and the humidity is high and in areas where the contamination is extended. As a consequence, the appearance of sparks occur on power lines near the sea (great probability of sea salt deposits on insulators), or near contaminated industrial areas.

In a simplified model for sparks and external partial discharges, sparks are light radiation and sound (mainly because of the electron flow on the anode), and external partial discharges are the leakage on the insulator due to the ohmic resistance of the combination “pollution - humidity”. The first case refers to dry bands and the second to wet bands on the insulator [1-3].

2. The occurrence of sparks on bare conductors of medium voltage

Sparks around the conductors also depend on the existence of extended humidity and contaminated environment during the autumn as it is mentioned above. For the appearance of sparks and even more the breakdown between the conductors, a drastic decrease in the insulating ability (or in the dielectric strength) of air is needed. This is possible when the percentage of conductive dirt in the air is high as it occurs in the case of smut. The electric field strength which is required for the occurrence of partial discharges on the conductors of a power line - e.g. on medium voltage line of 20 kV is given [5] by the equation:

$$E = m_1 \cdot m_2 \cdot \delta \cdot 30 \cdot \left(1 + \frac{0.3}{(\delta \cdot r)^{1/2}}\right) \text{ kV/cm}$$

where r is the radius of the conductor (e.g. r = 8.62 mm for a ACSR conductor's type of an equivalent copper cross-section of 95 mm^2 [5]), m_1.=0.98-0.83 (depending on the state of the conductors), m_2=1 for drought and the coefficient δ is approximately equal to 0.91.

For the conductor above, the electric field strength is:

$$E = 0.83 \cdot 1 \cdot 0.91 \cdot 30 \cdot \left(1 + \frac{0.3}{2.8}\right) = 25.15 \ \ \text{kV/cm}$$

In order for the partial discharges to take place, at least the above value of the electric field strength is required. The geometrical (p) constant of the field between two conductors is given [6] by the following equation:

$$p = \frac{(r + d)}{r}$$

where d is the distance between the conductors. If the distance d is equal to 1000 mm, the value of p is greater than 19.6 (p>19.6) and consequently the degree of consistency of the field (η) is [6]:

$$\eta = \frac{2 \cdot r \cdot \ln\left(2 + \frac{d}{r}\right)}{d}$$

by using the numerical values of the parameters:

$$\eta = \frac{2 \cdot 8.62 \cdot \ln\left(2 + \frac{1000}{8.62}\right)}{1000} = 0.02$$

Therefore the field's electric strength E_1 for the value of the voltage (U=20 kV) is:

$$E_1 = \frac{U}{\eta \cdot d}$$

by substituting the numerical values:

$$E_1 = \frac{20}{0.02 \cdot 100} = 10 \ \ \text{kV/cm}$$

The value of E_1 is almost 2.5 times less than the above value of E. Therefore, the appearance of sparks or corona phenomena or other form of partial discharges or even more the breakdown, between the conductors is not possible. For the appearance of sparks between the conductors, the coexistence of humidity and contamination (e.g. smut in the air) is required, in order a drastic decrease in the insulating ability (or in the dielectric strength) of air to occur. The carbon's resistivity ρ_c is among 0.083 to 33.3 MΩ·m and the air's resistivity ρ is greater than 1000 TΩ·m. This is the reason why the smut creates conduct paths in the air causing the appearance of sparks or even more the breakdown.

The insulating resistance is reliable where its value is equal to or greater than 1000 Ω/V (R≥1000 Ω/V). The resistance of a cylindrical column of air with a cross-section of 1 mm^2 between the conductors is:

$$R = \frac{\rho \cdot l}{A} = \frac{1 \cdot 10^{15}}{10^{-6}} = 10 \cdot 10^{20} \ \ \Omega$$

This value is much greater than the required one for an appropriate insulation. The value of the current (I) during the appearance of sparks is in the region of mA (e.g. I=10 mA). If the column above was a mixture of air and smut then the value of the resistance (R_2) would be:

$$R_2 = \frac{U}{I} = \frac{20000}{10.10^{-3}} = 20 \cdot 10^5 \ \ \Omega$$

This value does not provide the required insulation as it is 10 times less than the reliable one (according to the R≥1000 Ω/V, for 20 kV voltage the resistance should be 20 MΩ). The mixture's resistivity is:

$$\rho_2 = \frac{R_2 \cdot A}{l} = 20 \ \ \Omega \cdot m = 0{,}00002 \ M\Omega \cdot m$$

This value of R_2 (or ρ_2), shows that there is not an appropriate insulation because a conductive path has been created between the two conductors resulting in the appearance of sparks.

3. The impossibility of the occurrence of sparks on bare conductors of low voltage

The distance d between the bare conductors of low voltage (380 V/220 V) power lines is 30 cm. For comparison reasons we presume that these bare conductors have the same characteristics with these of medium voltage. Therefore p>19.6 and η=0.02. Consequently, the electric field strength E_1 for a voltage of 0.38 kV is:

$$E_1 = \frac{U}{\eta \cdot d} = \frac{0{,}28}{0{,}02 \cdot 30} = 0.0002 \ \ \text{kV/cm}$$

thus:

$E = 1.25 \cdot 10^5 \cdot E_1$

It is obvious that for the occurrence of sparks on low voltage bare conductors, a much more contaminated environment than this of medium voltage lines is required. Practically these conditions are not met in nature. This is the reason why the sparks occur on high and medium voltage and not on low voltage power lines.

4. Thermal stress of wooden crossarm on pylon of medium voltage due to sparks and external partial discharges on its insulators

On the following calculations the values of the parameters are always these that favor the occurrence of sparks.

The ignition temperature of wood θ depends according to the literature [5] on its type (usually among 300 ^oC to 400 ^oC). The heat (Q) of 1 kg of wood under the ignition temperature of 300 ^oC is:

$$Q = M \cdot c \cdot \theta = 1000\,\text{gr} \cdot 0.33 \frac{\text{cal}}{\text{gr} \cdot \text{grad}} \cdot 300\ ^oC = 99000\ \text{cal}$$

(where c=0.33 cal/gr·grad is the specific heat of wood [1]).

Sparks are a form of partial discharges which are referred as external partial discharges when they take place on the surface of insulators. The external partial discharges take place when the voltage has its peak value. Thus, the time of their periodically occurrence (τ) is between T/4 and T/2 (where T is the period of alternative current) [7-9]. Therefore the max value of τ is

$\tau = 0.01$ sec

The max duration of a partial discharge (a spark) is according to the literature 100 nsec [6]. Therefore the max number of sparks (N_σ) during a period is:

$N_\sigma = \tau/100 = 10^5$

The energy of free electrons under the occurrence of partial discharges which are followed by luminous glow (that is sparks) is according to the literature, 2 eV to 8 eV [11]. Henceforth, the energy is supposed to be:

$W_e = 8\ \text{eV} = 8 \cdot 1.6 \cdot 10^{-19}\ \text{Ws} = 12.8 \cdot 10^{-19}\ \text{Ws}$

or substituting 1 Ws with $2.38 \cdot 10^{-1}$ cal:

$W_e = 12.8 \cdot 10^{-19} \cdot 2.38 \cdot 10^{-1}\ \text{cal} = 3.04 \cdot 10^{-19}\ \text{cal}$

The value of current due to the partial discharges is of the order of 10 mA. These are current impulses, each of which has a duration of Δt=100 nsec as it is already mentioned.

The value of the current is:

$i = dq/dt \approx \Delta q/\Delta t$

where q is the electric load and t is the time. Consequently:

$$\Delta q = i \cdot \Delta t = 10\ \text{mA} \cdot 100\ \text{nsec} = 10 \cdot 10^{-3} \cdot 100 \cdot 10^{-9} = 10^{-9}\ \text{cb}$$

Therefore, the number of free electrons (N_e) of a partial discharge is:

$N_e = \Delta q/e = 10^{-9} / 1.6 \cdot 10^{-19} = 0.63 \cdot 10^{10}$

Accordingly, the energy of the total number of free electrons ($N = N_\sigma \cdot N_e$) for a period is:

$$W_T = N_\sigma \cdot N_e \cdot W_e = 10^5 \cdot 0.63 \cdot 10^{10} \cdot 3.04 \cdot 10^{-19} = 1.91 \cdot 10^{-4}\ \text{cal}$$

Supposing that sparks took place for a day (24 hours) and their energy was added to the heat of wooden crossarm without any energy loss to the environment (this is not possible in any way to happen), then the daily number N of periodically occurrence of sparks would be:

$$N = (3600\ \text{sec} \cdot 24\ \text{hours})/T = (3600 \cdot 24)/0.02 = 4.32 \cdot 10^6$$

And the sparks' energy for a duration of 24 hours would be:

$W_m = W_T \cdot N = 1.91 \cdot 10^{-4} \cdot 4.32 \cdot 10^6\ \text{cal} \approx 825\ \text{cal}$

This proves that this value W_m is approximately 120 time less than the ignition energy (Q=99000 cal) of 1kg of wood which is a very small part by comparison with the whole mass of the crossarm. Therefore, the very little energy of these sparks is impossible to cause the ignition of a wooden crossarm.

For the ignition of the wooden crossarm, overextended humidity and a very contaminated environment is required so as external partial discharges (current leakage on insulator's surface) to occur, mainly due to the ohmic behavior of the combination "pollution - humidity".

5. Conclusion

Sparks on insulators are not glowing metal parts as it is already mentioned. They appear on medium voltage power lines in cases of extended humidity and contaminated environment, factors which lead to the creation of conductive paths between the conductors. On the other hand, it is almost impossible for the sparks to take place on low voltage conductors as the presumed conditions are not practically met.

Finally, it is proved that it is impossible for a wooden crossarm on a pylon of the medium voltage power line to be ignited due to sparks. The energy which is necessary for the crossarm to reach its ignition temperature, is 120 times greater than the total energy which could be acquired from the energy of the free electrons radiated light under the most adverse conditions (it is assumed that there was no energy loss to the environment as well as the value of free electron energy was 8eV instead of a value between 2eV and 8eV).

References

[1] P. Bourkas & C.G. Karagiannopoulos, *Measurements on Industrial Apparatus and Materials* (NTUA Editions, Athens, 2004).

[2] H.B. Knight, *The Arc Discharge – Its Application to Power Control* (Chapman & Hall Ltd, London, 1960).

[3] Reference Book, *Electrical Transmission and Distribution* (Westinghouse Electric Corporation, USA, 1950)

[4] *Hutte Taschenbuch fur Betriebsingenieure*, *Band II*, *4 Auflage* (Verlag von Wilhelm Ernst & Sohn, Berlin 1953).

[5] I. Mpousoulas *Forest blazes* (NTUA Editions, Athens, 2002).

[6] H. Philippow *Taschenbuch Elektrotechnik, Band 2* (Starkstromtechnik, Berlin 1983).

[7] H. Tsitsoglou, *Partial Discharges under alternative voltage and electrostatic unload in polymer solid insulators* (PhD thesis, NTUA Editions, Athens, 1995).

[8] P. Bourkas, *Partial Discharges in non-homegeneous insulating material under impulse voltage of different forms* (PhD thesis, NTUA Editions, Athens, 1985).

[9] D. Kind, *Einfuhrung in der Hochspannungtechnik* (Braunschweig, 1978).

[10] P. Bourkas, *High Voltage Applications* (NTUA Editions, Athens, 1996).

[11] I.A. Stathopulos & P.Bourkas, F.V. Topalis, High Voltage Test Measurements, (NTUA Editions, Athens, 1991).