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Modeling The Behavior of The Electric Insulators in Polluted Desertic Medium

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Abstract: Our research directed towards the analysis and the prevention of the desert and marine effects pollution on ectric insulation in the electric transmission lines power. The fundamental objective of this research is to mprove the service quality by decreasing the interventions frequency and by minimizing the maintenance cost of the equipment line. While basing on theoretical models and the in-situ tests, we present research results on the pollution of the Medium voltage insulators in the areas desert at the Tunisian Sahara.

Key words: Insulation, leakage current, pollution, arc, discharge surface, conductivity, flashover

INTRODUCTION

The air lines as well as DC or AC electric stations of the power grid system , installed in areas where a notably polluted environment exist, suffer from the phenomenon of the flashover. Indeed this one causes the short circuit of the insulator strings or the polluted insulating columns by an electric arc resulting from the elongation of one or more small discharges which are on the surface of the insulator[1]. Accordingly a research program based on mathematical modelling and in situ test in the Tunisian desert are undertaken to predict the flashover under the preset atmospheric conditions.

PARTICULARITES OF THE STUDIED AREAS

The Kebili area is located at 28E northern latitude. It is camped in the Tunisian Sahara whose ground is composed of clayey sand. On the other hand the Zarzis area is located at 31E northern latitude, its ground is composed of blocks of limestone and sand. We should also announce that this area is located beside the Mediterranean, where the marine spray which is the origin of the electric insulators pollution.

Climatic factors: The principal climatic factors of the two sites (Table 1) were taken over eight year's period[2].

Sources of pollution: The physicochemical analysis of the pollutants deposits recovered on standard insulators installed in these areas, made it possible to detect the presence of elements such as silicon, sodium, calcium..., (Tables 2 and 3). Moreover the granulometry analysis of the samples taken on polluted insulators showed that the sand grains have in majority a diameter 0.03mm. The conductivity of these sand samples lies between 0.5μs and 16 μs[3].

Table.1: Principal climatic factors

Climatic factors	Zarzis area	Kebili area
Average rainfall	2 to 40 mm	3 to 30 mm
Sand storm	25days/year	frequent
Average temperature Variation	18^0	15^0
wind maximum speed	North - north west 25 m/s	North - west and west 30 m/s
Average relative Humidity	70%	62%
Fog	October - December	November - December

MODELING THE FLASHOVER OF POLLUTED INSULATORS

In the literature devoted to the flashover of the insulator strings, several experimental models and several theoretical analysis methods were used in which the goal is to predict flashover voltage and to improve knowledge of the physical phenomena implied in the flashover mechanism and to avoid possible power supply. cut-offs[4-5-6]. Indeed, the majority of these models are empirical or semi empirical, without final answers being able to be brought. This work concerns the use of a recent dynamic model[7] of discharge propagation on a polluted surface. This model uses an electric circuit and physical laws and its application on real samples for determining the various parameters of the discharge and the critical conditions of the flashover. We consider that the phenomenon of the discharge development can be represented by the following physical model:

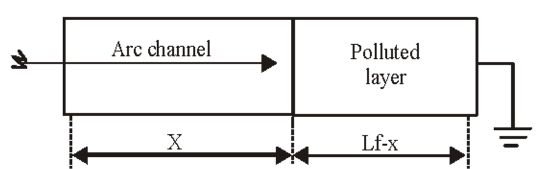

Fig.1: Representation of the arc development

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Table 2: Analysis of filtered water (lower surface)

Ca mg l⁻¹	Mg mg l⁻¹	Na mg l⁻¹	K mg l⁻¹	Si mg l⁻¹	Al mg l⁻¹	Fe mg l⁻¹	Cu mg l⁻¹	Mn mg l⁻¹	Zn mg l⁻¹	PH mg l⁻¹	CL^- mg l⁻¹	SO_4^- mg l⁻¹
533	12	800	12	7	< 0.1	< 0.1	< 0.1	< 0.1	0.14	6.48	1200	1330
Conductivity (µS/cm) 3600												

Table 3: Analysis of filtered water (upper surface)

Ca mg l⁻¹	Mg mg l⁻¹	Na mg l⁻¹	K mg l⁻¹	Si mg l⁻¹	Al mg l⁻¹	Fe mg l⁻¹	Cu mg l⁻¹	Mn mg l⁻¹	Zn mg l⁻¹	PH mg l⁻¹	CL^- mg l⁻¹	SO_4^- mg l⁻¹
23.9	1.5	36	1.0	3	< 0.1	< 0.1	< 0.1	< 0.1	0.14	6.9	40	65
Conductivity (µS/cm) 264												

Where: x: length of the discharge.
Lf: length of the leakage distance.
V: applied voltage.
k: constant.

The electric diagram are equivalent to this model, is given by the following figure:

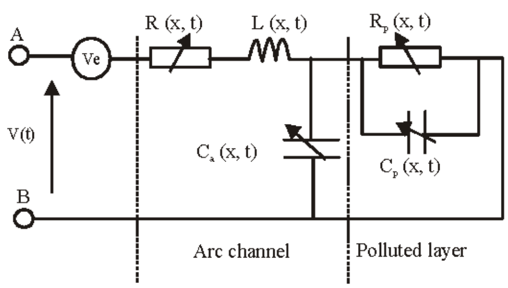


Fig.2: Equivalent model of the discharge in series with the polluted layer

Where: Ve: voltage fall cumulated on the electrodes.
R(x, t): resistance of the arc channel.
L(x, t): inductance per length unit of the arc channel.
C_a (x, t): capacity at the arc head.
R_p (x, t): resistance of the polluted layer.
C_p (x, t): capacity of the polluted layer.

Parameters of the discharge

Resistance of the arc channel: The resistance of the outfall channel is defined by[7]:

$$R(x,t) = \frac{V(t)}{\mu_e.\pi.n_e.e.r_{arc}^2} \quad (1)$$

$$\text{With}: r_{arc} = \sqrt{\frac{I}{k.\pi}}$$

μ_e, e: are, respectively mobility and the electric charge.

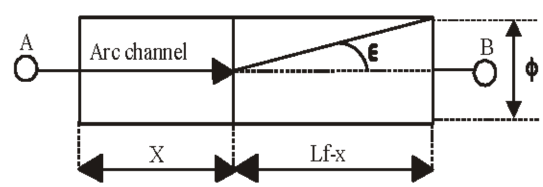
n_e : electronic density.
r_{arc} :ray of arc.

Inductance per length unit of the arc channel: Arc channel Polluted layer Inductance per length unit of the arc channel is defined by[7]:

$$L(x,t) = \frac{\mu_0}{2\pi}.[0.25 + \ln(\frac{Df}{r_{arc}})] \quad (2)$$

Df: being the distance to the channel axis where the electric field is null.

Capacity at the head of the arc: The capacity is obtained by a spherical approximation[7].



$$C_{arc} = 2.\pi.\alpha.\varepsilon[1 + \frac{r_{arc}}{Lf - x}] \quad (3)$$

$$\alpha = 1 - \frac{1}{\sqrt{1 + [\frac{\phi}{2.Lf}.\frac{1}{1 - \frac{x}{Lf}}]^2}}$$

ε: represent the medium permittivity in which the discharge is propagated.

Resistance of the polluted layer: The shape of a real insulator is very complex. However it is very difficult to express the polluted resistance by a simple equation. For making a choice of the polluted layer resistance expression between several models, Polluted layer we had recourse to software allowing the calculation of fields; it is called flux3d. Thus, we calculated the equivalent resistance between the arc head and the opposite electrode for different positions[3]. In addition, we showed the importance of the constriction phenomenon of the lines current from the discharge foot. The model of Wilkins[8] seems to give good results compared with the results of the numeric simulation.

$$Rp = \frac{1}{\delta.2.\pi}.[\frac{\pi(Lf - x)}{a} + \ln\frac{a}{2\pi.r_{arc}}] \quad (4)$$

With: σ , Lf, x, r_{arc} and a are respectively thesurface conductivity pollution, the totalleakage length, the arc length, the arc ray and the bandwidth.

Capacity of the polluted layer: Generally the capacity relating to the polluted layer is calculated by making the linear approximation[9]:

$$C_p = \varepsilon\rho.\frac{S_p}{(Lf - X)} \quad (5)$$

With:
ε_p : Polluted permittivity
S_p : Polluted layer section

CRITERION OF DISCHARGE PROPAGATION

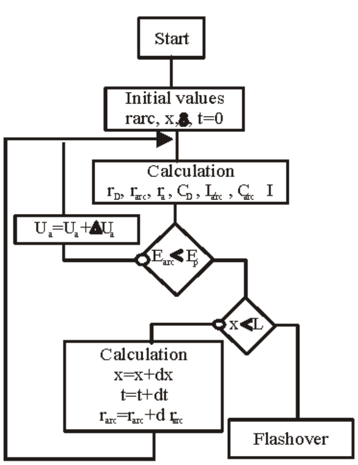
The criterion used is Hampton[10]:

$$E_a < E_p \quad (6)$$

E_a: field inside the arc.
E_p : field in the polluted layer .

The necessary condition so that flashover occurs, is that the field Ep in the polluted layer exceeds the field inside the arc E_a.

ORGANIGRAMME



EXPERIMENTAL VALIDATION

Method of applied voltage: The voltage must be applied to the insulator under test starting from a sufficiently low value to avoid any effect of overpressure due to the transitory phenomena of interlocking. It should grow slowly to allow a precise reading of the instruments, but without causing a useless prolongation from the object constraint under test in the vicinity of the test voltage (Fig. 3). These specifications are generally filled when the voltage rise speed is above 75% of the end value.

Test results: The tests were carried out on standard insulators type (Table 3).

Insulator profile	Reference	Leakage line length (mm)
	U 70 BL N 16 ϕ 250	242

Table 3: Insulator types.

Comparison between experiments maximum given voltage to the calculated by the model: Figure 4 presents an experiments maximum given voltage for a salinity of 56 g L^{-1}.
Measured voltage: 42 kV
Calculated voltage: 47 kV
Results analysis: The simulation results giving the critical flashover voltage are in concord with those found in experiments.

We notice that the arc current grows slowly during the phase of propagation, then, quickly during the last stage

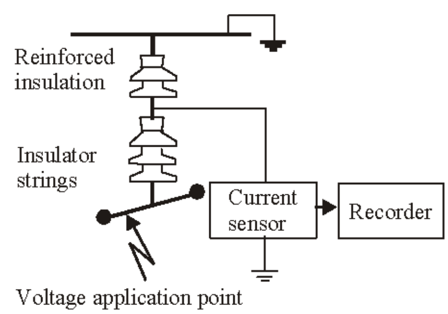


Fig. 3: Device used under test

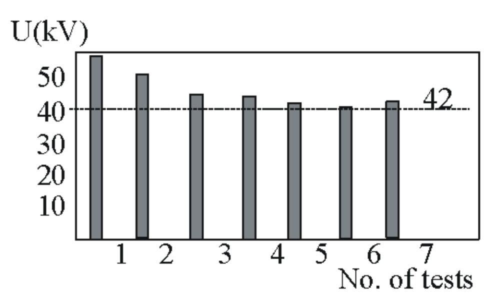


Fig.4: Maximum critical voltage

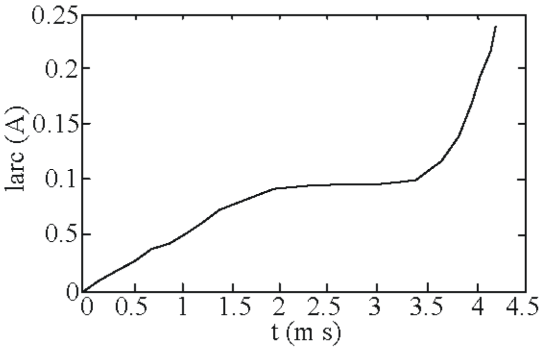


Fig. 5: Arc current according to time

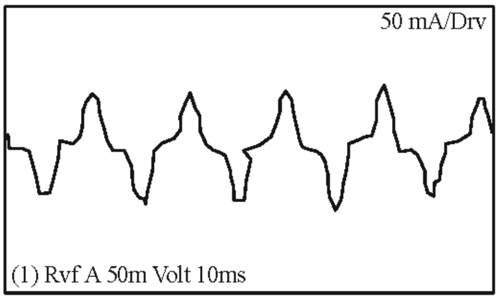


Fig. 6: Wave form of the experimental leakage current: case of a standard insulator.

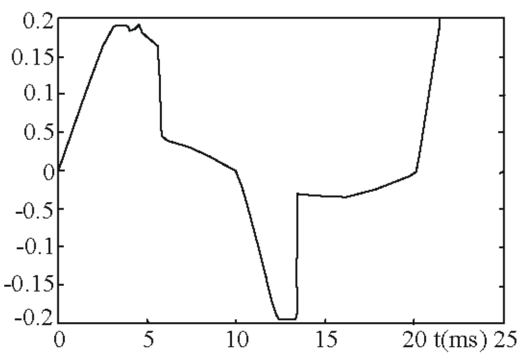


Fig. 7: Wave form of the simulated leakage current: case of a standard insulator

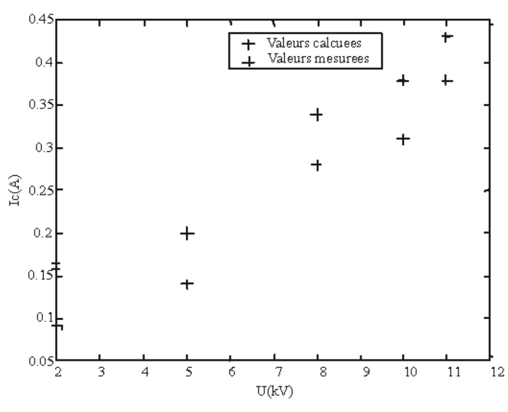


Fig. 8: Current according to voltage for 10 ó=7.6 10^4 μS/cm

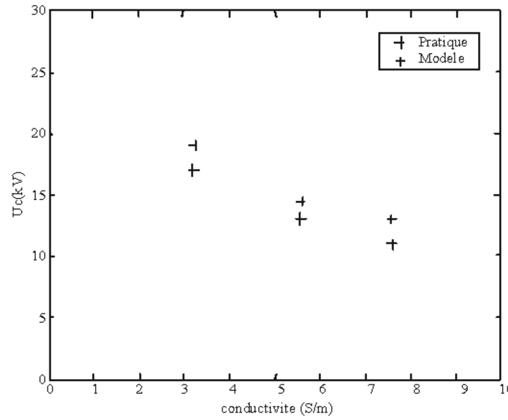


Fig. 9: Flashover according to conductivity

of the flashover (Fig. 5) this result corroborates measurements which we took[3].

The wave shapes of the leakage current recorded and simulated (Fig. 6 and 7), show well that the current leakage is not sinusoidal; this proves well that the resistance of the polluted layer is not linear.

Figure 8, represents the variation of the current leakage simulated and measured according to the applied voltage for a conductivity ó = 7.6 10^4 μS/cm. The computed and measured values show that the current grows proportionally with the voltage.

Figure 9 illustrates well the influence of conductivity on the insulators behaviour. We notice that the dynamic model gives flashover voltage higher than those obtained in experiments.

CONCLUSION

By the physicochemical analysis of the recovered deposits on standard insulators type in the Zarzis and Kebili areas , we notes well that the most significant agents of pollution in these desert zones is the sodium chloride (NaCl), whose conductivity is very high.

The results of simulation giving the current leakage testifies to validity of the model and this by comparison with the experimental test results carried out on standard insulators in situ.

However the dynamic model is an appreciable tool for predicting the flashover voltage and to describe the evolution of the various electric parameters system submitted to an alternative voltage.

Moreover it makes it possible to rationalize the experiments conceived to explore the flashover mechanism.

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