STUDY OF THE ELECTRICAL FLASHOVER OF AN INSULATING SURFACE POLLUTED BY AN ALTERNATING CURRENT DISCHARGE

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KEY WORDS : HVAC Insulator, pollution, flashover, modelling, multi-arc model

Abstract- In order to determine the flashover behaviour of polluted high voltage insulators and to identify the physical mechanisms that govern this phenomenon, the researchers have been brought to establish a modelling. The observation of the discharge, during its elongation, on an electrolyte filled channel modelling a polluted HV line insulators shows that the latter emite, from its tip, some branches, which have a weaker luminous intensity. Departing from the modelling of Cheng and Nour, we have developed a survey that permit to determine a critical length of the discharge from which the system elongates using a model derived from Obenaus's electric circuit This new approach gives better account of the physical phenomena that governs the extension of the body of the discharge. The results indicate that it exists a zone of transition from multi-arc model to single-arc model. This phenomenon could be explained by changing of propagating mechanism.

I. INTRODUCTION

In general flashover is defined as the dielectric breakdown of a gaseous atmosphere or *of* vacuum in the neighborhood of an insulating surface. The discharge initiates and always develops in the gas because its dielectric strength is invariably inferior to that of a solid. Depending on gas pressure and electrical conductivity of the surface, the primary phenomena can be totally different, also the flashover *progress* mostly depends on the experimental conditions[1], [2].

Generally, the dielectric strength of a gas decreases in the vicinity of an insulating solid surface; this decrease, which depends on the experimental conditions (nature of gas and solid, system geometry....), is only about 50 % for a clean surface while in the vicinity of the polluted surfaces, the electrical fields permitting the development of flashover can be less than 5 % of the dielectric strength of the ambient gas. This phenomenon can be a very inconvenient for exploiting an electrical network because the electrical component breakdown strength (*overhead* transmission line insulators, bushings, tie-bars...) is generally determined, with a safety factor, for clean components. In a natural environment, their surfaces can be covered with pollution (dirt, snow, dew,...). These deposits can be natural conductors (soot,...) or can become one in the presence of rain or fog (cement,...). They are thus traversed by leakage currents, which modify the potential distribution along the leakage paths. When the field becomes sufficiently high in certain zones, a discharge can initiate, short-circuiting a part of the insulation leading to an energy loss, electromagnetic disturbances, etc… and if certain conditions are fulfilled, this discharge can even extend itself until grounding the high voltage through an arc. The protection system must therefore disconnect at least provisionally, a part of the circuit.

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The present article will be oriented towards the study of 50 Hz sinusoidal voltage flashover because of its widespread use in the electrical energy distribution network.

II. THEORICAL SURVEY

The objective of these studies was to understand why and how a discharge, ignited over a weakly conducting surface, could spread until a live joining conductor with the ground by an are. The procedure followed was that of modeling the surface by an equivalent electrical circuit in order to *link up* the different observable electrical and geometrical magnitudes. This circuit having the shape of a dipole, Ohm's law enables us to write the following expression:

$$f(U,I,X,L) = O \qquad (1)$$

in which :

U is the voltage applied to the insulator,
I is the current delivered by the source
X is the length of the discharge.

MODEL OF OBENAUS

After a study of the earlier publications, the first model utilized was inspired by two simplifying hypotheses:

a) The behavior of a polluted insulator subjected to discharges can be described by a discharge in series with a resistance R equal to that of the pollution [3]

b) This can be described by a constant resistance r per unit length all along the leakage path of length L, such as

$$R = (L-X)\, r \qquad (2)$$

The model utilized is represented in figure 1 and its schematical equivalent in figure 2

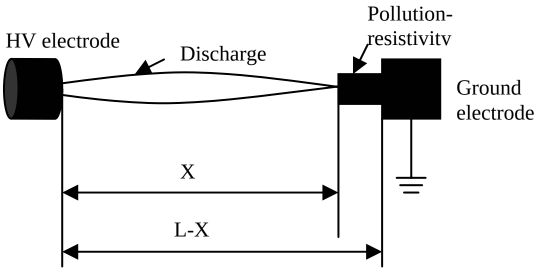

Figure 1. Experimental set-up derived from Obenaus model

The experimental value of the measured current intensity during flashover (some hundreds of milliamperes) makes us think that the discharge is of an intermediate type between luminescence and arc. The voltage gradient in which case then has the form:

$$E_a = A.I\text{-}n \qquad (3)$$

By neglecting the accumulated voltage drop across the discharge, a legitimate approximation whenever its length is not extremely small, ohm's law leads to the relationship:

$$U = X.A.I^{-n} + (L-X).r.I \qquad (4)$$

A and n are the constants depending on the nature of the atmosphere in which the model is housed.

The pertinence and the applicability of this model which we will call<<Obenaus model>> has lead to numerous publications within our team.

The U (I) graphs, Figure 2, represent the relation (4) at x = constant

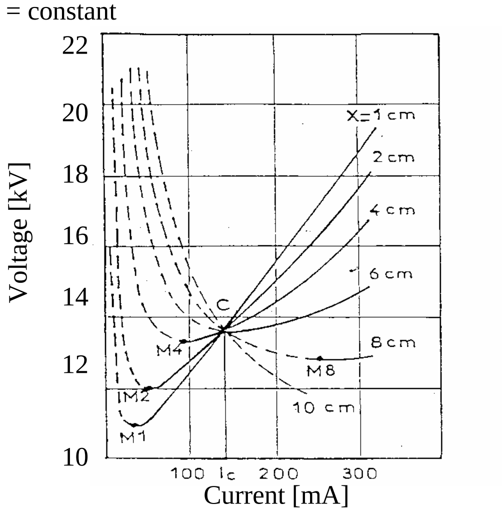

Figure 2. V(i) characteristics for several values of X with A = 63, n = 0.76,r = 10kOhms/cm, l = 10cm

---- electrically unstable points

— electrically stable points

THE TWIN-LAYER MODEL

One of the reserves that one can have with reference to the Obenaus model is that it presumes that the whole source current traverses the discharge. This is only true if the space under the discharge is perfectly dry and the insulator is completely surrounded by this dry zone. If these conditions are not fulfilled, a leakage current will shunt the discharge. To take this into account, Flazi [4] thought of a model with two layers superposed on each other. Its schematic equivalent is given in figure 3.

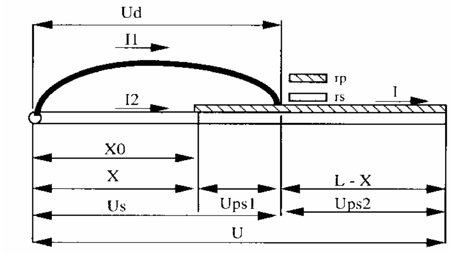

Figure 3. Layout of bidirectional flashover model

The following designations will apply :

r_s : the resistance per unit length along the leakage path of the unpolluted insulator.

r_p : the resistance per unit length of the pollution deposited on the insulator.

ρ : the ratio r_s/r_p

Not neglecting anymore the voltage V_e accumulated across the discharge electrodes, the voltage across the model terminals is given by :

$$U = X.A.\, I^{1-n} + V_e + (L-x).\, Ir_s/1+\rho) \qquad (5)$$

The U(I) graphs, figure 4, represents the above relation (5) at X = constant.

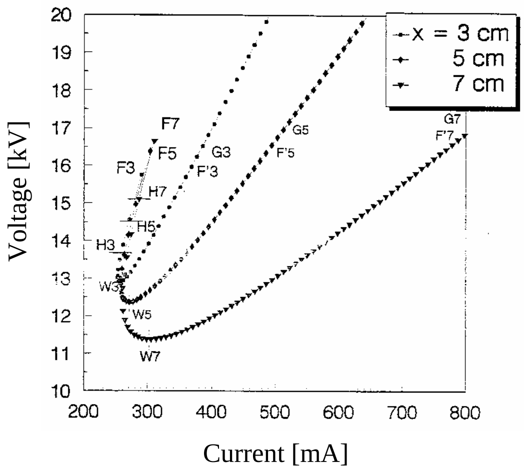

Figure 4. V(i) characteristics according to twin layer model for : rp = 10 kOhms/cm, rs = 10kOhms/cm, Ve = 800V, i1 > 10mA

Comparing with figure 2 of Obenaus model, great differences are remarked :

- The V - shaped' curves are more inclined towards the right and have two stable branches.

- They no longer have any common intersection and the research for the critical values of flashover (that we could continue to designate by U_c and I_c) is going to be more delicate.

- These curves would be described from F_x to G_x when the current Ii traversing the discharge increases. The F_x points correspond to a current I_1 = 10mA in the discharge (limit chosen for the validity of the model, taking into account the discharge nature), while the G_x points indicate only a direction on the curve and can be rejected very far towards the right. As the two branches of V are electrically stable, for the lowest values of the applied voltage, the operating point is on the left branch, while for higher values, it is on the right branch, the transition from a branch to the other occurring from F_x to F'_x, no operating point can be found over the interval :] W_x ; F'_x [.

- Another consideration is to be taken into account : if $r_s < r_p$ (an insulator little polluted or an insulator covered with a lightly conducting protection layer), the potential distribution along the leakage path is more regular and the discharge does not ignite : the model is reduced to a simple association of resistances whose characteristic U(I) is a straight line passing through the origin and situated on the right of V-curves of figure 6. So long as the discharge remains unignited , the operating point remains on this straight line and the flashover, evidently, is impossible. When the discharge is ignited, the operating point jumps on F'_x G_x branch and the flashover occurs if the necessary conditions are fulfilled. However, if the applied voltage is inferior to the level defined by Fx, Fx', the discharge current is less than 10 mA, the discharge is of the luminescent type and its resistance high, the characteristic without discharge is little modified and the operating point can not attain the first branch of V. Besides, a luminescent type of discharge can not lead to flashover.

The flashover voltage calculation with the help of this model is detailed in the publication [5]. The utilization of conducting layers had been recommended by other authors. .

THE BIDIRECTIONAL FLASHOVER MODEL

In order to decide if the necessary conditions for flashover are fulfilled, Flazi has calculated the application domain in figure 6 graphs of the criteria laid down in the study of *Obenaus'* model. The domain where Hampton condition is fulfilled is limited by the points H_x and G_x while the Wilkins condition is fulfilled between the points W_x and G_x. One can remark, in case of figure 6, that the two criteria are simultaneously fulfilled only when the operating point is on a branch W_xG_x.

In order to decide the validity of application for one criterion or the other, he imagined [6] an experimental device, represented in figure 5, which offered the discharge two paths for its extension towards the ground and on which by manipulating the geometry of the two channel sections, each criterion is fulfilled on a single trajectory. After a very detailed study, he shows experimentally that none of the criteria prevails, and that the deciding parameter is the electrical field ahead of the discharge root, the field being of the order of 3KV/cm. We will comment on this value later on.

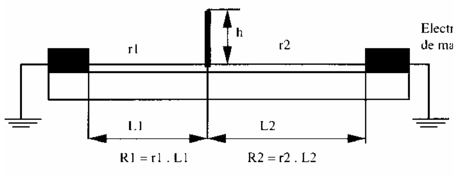

Figure 5. Layout of bidirectional flashover model

CONCLUSIONS ON THE MODELS

The models constitute the first indispensable step for the study, but their complexity increases as and when one approaches a real insulator. Moreover, the models described are static. In order to apply them, it is necessary to admit that the system passes through a series of stationary states of identical nature and [6]<< that at every point of the trajectory, the flashover criterion is fulfilled >>. Wilkins and Al-Baghdadi [7] have signaled the existence of a current parallel to the arc column in the electrolyte on an Obenaus type of model. Mercure and Drouet [8] have measured that current directly and shown that during the flashover of a channel of electrolyte, the zone where the discharge current transfer towards the liquid takes place can spread over several tens of millimeters. Cheng and Nour [9] have proposed a model comprising of several discharges in parallel compatible with this observation. Nevertheless, none of these models describes without additional hypothesis the physical phenomena which are responsible for the extension of the discharge and thus can not *give an account of* the dynamics of the flashover. Therefore, comes the idea of observing the discharge propagation while measuring the variation of electrical quantities which accompany it.

III. PROPOSED PROPAGATING MODEL

The survey of the luminous intensity during the elongation of the discharge during the phenomenon of flashover showed us that the discharge can change likely to the course of its elongation. Modeling by an unique equation is in contradiction with the observations returned in the optic analysis using high speed camera [] ,then the principle of the propagation discharge by ignition of the successive ramifications of the main column of the discharge seems to be adapted better to describe our observations.

The equation describing the process is :

$$V_c^{2n+2}+r_p\left(L+\frac{a}{2\pi}Log\left(\frac{a^2}{4\pi.r_d^{\ 2}}\right)\right)\frac{800^{2n+2}}{A}x_c^{2n+1}-\left(\frac{800^{2n}}{A}x_c^{2n-1}.V_c^3+r_p.\frac{800^{2n+2}}{A}x_c^{2n+2}\right)=0$$

(6)

Critical length was given by :

$$x_c=\frac{L}{(n+1)}\left(1+\frac{a}{2\pi}Log\left(\frac{a^2}{4\pi^2.r_d^{\ 2}}\right)\right)$$

(7)

Taking into account the effect of constriction of the current lines

However modeling didn't measuring dynamic propagation of the discharge while it doesn't identify physical mechanism responsible in it 's extension . This means that the multi - discharge model supposes a concentration of the current in the last ramification of the extension discharge

$$V=A.i_m^{-n}.x_m+r_p.(L-x_m).\sum_{k=1}^{m}i_k+V_e \quad (8)$$

In order to determine unsteady discharges with weak current :

$$V=\alpha+(\beta+x_m)\gamma\left(\ln\frac{i_m}{\delta}\right)^{-3}+r_p(L-x_m)\sum_{k=1}^{m}i_k+V_e \qquad (9)$$

We are going to make a parametric analysis of Cheng and Nour model while supposing that it exists m simultaneous discharges and as there adding the arc re-ignition condition (modified multi - arc model) established by Claverie and Porcheron because the HV supply is AC. The equations of critical flashover current for our formalism are given by the following relations:

$$\begin{cases} i_m=\left(\dfrac{n.A.x_m}{r_p.(L-x_m)}\right)^{\frac{1}{n+1}} & (10)\\ \displaystyle\sum_{k=1}^{m}i_k=\frac{A.i_m^{-n}}{r_p} & (11)\end{cases}$$

and

$$\begin{cases} \dfrac{-3}{i_m}.\gamma.\left(Ln\dfrac{i_m}{\delta}\right)^{-4}(\beta+x_m)+r_p.(L-x_m)=0 & (12)\\ \displaystyle\sum_{k=1}^{m}i_k=\frac{\gamma}{r_p}\left(Ln\frac{i_m}{\delta}\right)^{-3} & (13)\end{cases}$$

The graphic representation of these relations is shown on the figure 3 . We notice that the total current decreases with the growth of the length of the last branch of the discharge whereas the current in this ramification increases. It means that the multi - discharge model supposes a concentration of the current in the last ramification of the extension discharge.

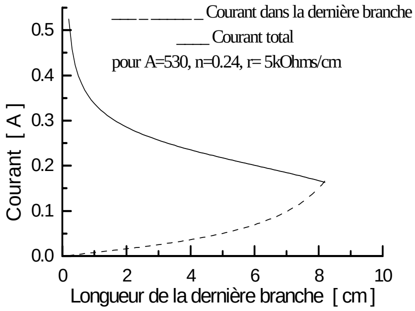

Figure 6 *Analysis of multi-discharge of Cheng and Nour model A =530, n =0.24*

Besides the intersection of curves adjoins them - 8.16cm, when the discharge burns atmosphere of which the parameters (fig. 6) , it means that there is only one branch of discharge in the outdoor electrodes because the current is equal informed in the last branch. Therefore in Reider's equation this intersection is average four centimeters (fig.7)with current of 60mA , then the use of modeling for lower currents.

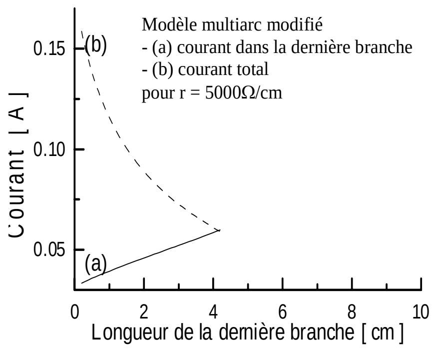

Figure 7**.** *Analysis of multi-discharge of Cheng and Nour modified model for r = 10000Ω/cm*

This point of intersection representing the passage of a multi-arc model to a model with only one branch of the discharge is the value critical of the length of the discharge of this model . In this model the critical voltage is greater than the ones founded by Wilkins.

Figures 8 and 9 illustrate the variations of the flashover voltage and the current , calculated, according to the resistance per length of the pollution as well as the experimental values .

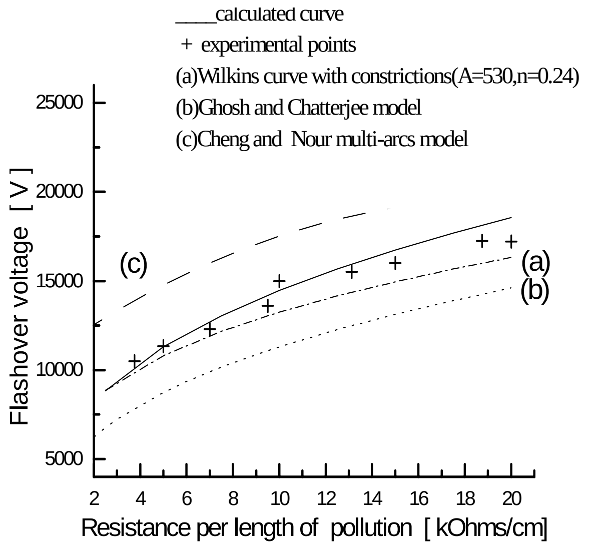

Figure 8. Variation of flashover voltage against the resistance per length of the pollution.

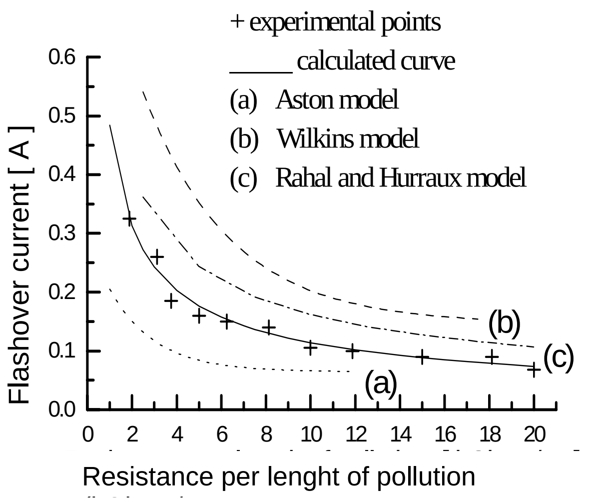

Figure 9. Variation of flashover current against the resistance per length of the pollution.

IV.CONCLUSION

The parametric analysis of the modified multi -arcs model showed us that the Cheng and Nour model is the good adapted to describe the discharge by several branches by different equations. The critical voltage of this model comes closer of the critical voltage measured on the experimental device. The fragility of this model resides in the fact that the value of the total current decreases when the length of the last ramification of the discharge comes closer of its critical value.

We can get round this weak point when we replace the equation of Ayrton by the one of Reider to describe the last branch of discharge whereas the other branches are described by the equation of Ayrton.

The critical value of the extension discharge of the last ramification is independent of the resistance of the pollution in the modified model of Cheng and Nour (equation of Ayrton) but depends the atmosphere in which it burns rather. On the other hand whereas it varies when the discharge is described by the equation of Reider.

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