Flashover Modeling of Arcing Horns Using the MODELS Simulation Language

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Abstract —— In this paper, a new flashover model for arcing horns is proposed. This model is based on the leader-development method. It is realized using the MODELS simulation language in the ATP version of EMTP. A state machine approach is used for representing the three states of the arcing horn. The flashover voltage and predischarge current calculated by this model are compared with measurements and with results calculated using the conventional integration method.

Keywords: Flashover, Arcing horn, MODELS, EMTP, ATP

I. INTRODUCTION

An arcing horn flashover model using what is called the integration method has been widely used. [1]-[3],[8] Recently, a new approach has been proposed for use in lightning surge analysis, named the leader development method. This approach simulates how the horn-to-horn impedance varies in time considering the presence of a predischarge current. [4]-[9],[11]

The flashover models developed in [3]-[9],[11] are based on the leader development method, and are implemented as equivalent circuits built using EMTP elements such as nonlinear inductances, nonlinear resistances, and controlled switches. In this paper, no equivalent circuit is needed. This point is new compared to the model in reference [11]. The experimental equations derived from measurements are used directly in the MODELS language description.[12], [13] A state machine approach is used for representing the three states of operation of the arcing horn: no-arc-no-leader, no-arc-with-leader, and arc. The model is applied in this paper to arcing horns with relatively short gap lengths as used in 33 to 77 kV transmission lines.

II. FLASHOVER MODEL FOR ARCING HORNS

A. Integration method

In the integration method, arcing takes place at moment T_b, when the integral reaches the value L. Integration starts at T_0, when $u(t)$ exceeds the reference voltage U_0. The dielectric withstand level is determined by

$$\int_{T_0}^{T_b} (u(t) - U_0)^n \, dt = L \qquad (1)$$

characterized by the parameters L, n, and U_0. For a 350-mm gap length, the values are L=0.056 (volt-sec), n=0.93, and U_0=188 (kV).[10] The model starts calculating the integral when the gap voltage exceeds U_0, and closes a switch when the integral reaches the value L.[10]

B. Leader development method

A flashover model was developed for a short-gap arcing horn, based on the leader development method. This method represents the development of the leader in time. This is accomplished by describing the changing velocity of the leader development in function of the voltage and of the length of the leader. An outline description of this method is given below. This representation has been tested before in [7]. It is based on the original leader development method [4] and is modified to get better adjustment in the wave tail flashover region of the voltage-time characteristic of the air gap.

The leader development velocity *vel*(*t*) is defined by expression (1), and the predischarge current *i*(*t*) is defined by expression (2).

$$vel(t) = K_1 \frac{u(t)^2}{D-2x(t)} + K_2 \frac{u(t)\cdot i(t)}{D-2x(t)} \cdot \frac{x(t)}{D} \quad (2)$$

where,

vel(*t*) : leader development velocity (m/s)

x(*t*) : leader length evolving from each electrode (m)

u(*t*) : gap voltage (V)

i(*t*) : predischarge current (A)

D : gap length (m)

K_1,K_2 : constants independent of gap length and voltage waveform

$$i(t) = C \cdot u(t) \cdot vel(t) \quad (3)$$

where,

C : capacitance per unit length of leader

$$C = \begin{cases} C_0 + (C_{max} - C_0)\cdot 4x(t)/D & (2x(t) < D/2) \\ C_{max} & (2x(t) \geq D/2) \end{cases} \quad (4)$$

where,

$C_0 = C_{max}$

$C_{max} = 5\times 10^{-10}\, F/m$

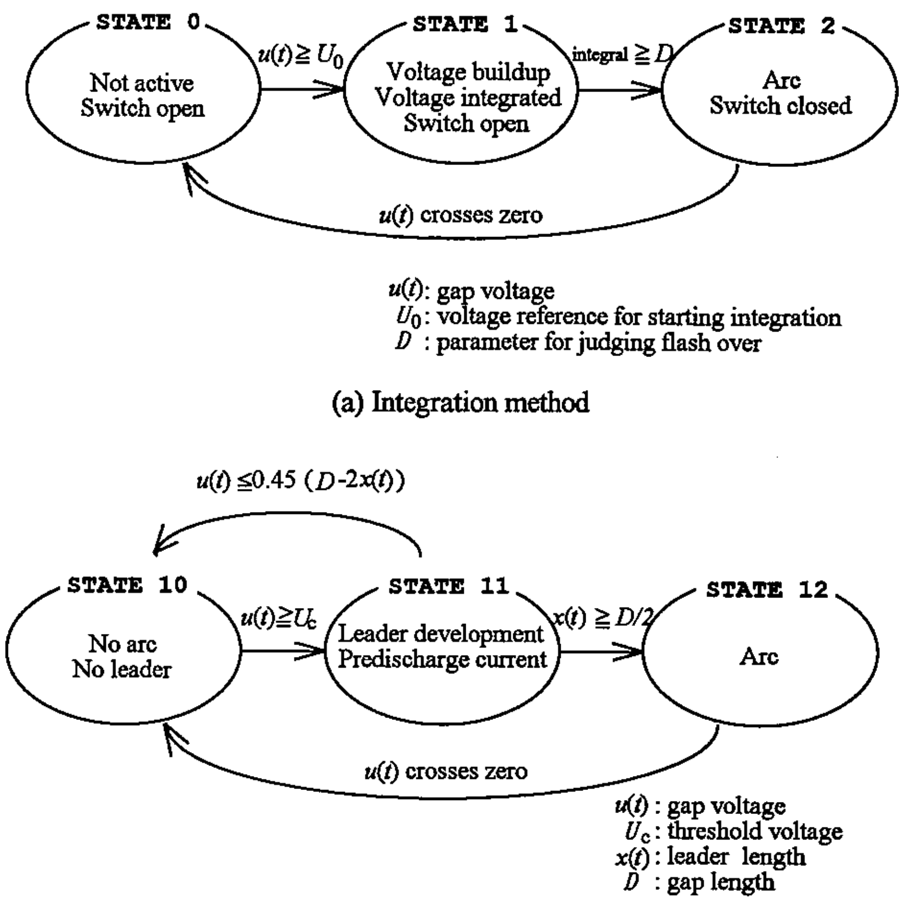
Variable x is the length of the leader evolving from each electrode. This model does not take into account any polarity effect. The values of K_1 and K_2 can be changed according to the gap configuration and the polarity of each electrode. By combining a circuit equation with expressions (2) and (3), it is possible to calculate the conditions of leader development with time, the variation in predischarge current, and the equivalent impedance.

The start and stop conditions of leader development can be defined as follows:

It is approximately assumed that leader development begins to occur when the critical flashover voltage of an arcing horn is attained. It is also assumed that the critical flashover voltage for a short gap length is given by the following expression:

$$Uc = 550\cdot D + 80 \quad \text{(kV)} \quad (5)$$

The flashover voltage obtained from this expression roughly coincides with the critical flashover voltage of the voltage-time characteristic in a rod-to-rod gap. The time at which the leader length evolving from both ends of the gap covers the full length of the gap, defines the starting time of the flashover. When the applied voltage decreases during leader development and the average electrical field at the unbridged part of the leader [*u*(*t*)/(*D*-2*x*(*t*))] is below 0.45 MV/m, the leader is considered extinguished and the model is reset. The model parameters for the leader development method in the case of positive polarity are: $K_1 = 1 \times 10^{-7}$, $K_2 = 3.5 \times 2.5 \times 10^{-3}$.[7]



(a) Integration method

(b) Leader development method

Fig. 1. Concept of Arching Horn Model

III. MODEL DESCRIPTION USING MODELS

In both cases of the integration method and the leader development method, the gap discharge is described in a model, using a small state machine shown in Fig. 1. This approach has the advantage of not only identifying clearly the different states or stages of the represented phenomenon, but also of describing explicitly the conditions associated with each transition from state to state, and the behavior at each state.

The integration method model has three states: not active (0), voltage buildup (1), and arc (2). The transition from 0 to 1 occurs when the gap voltage exceeds a threshold voltage. The transition from 1 to 2 is when the calculated integral reaches the gap distance. The transition from 2 to 0 is when the voltage returns to zero. This transition is normally assumed to be related to the zero crossing of the current but in the present study is detected simply by using the voltage according to the conventional way. When in state 2, the output signal closes a switch in the circuit, to represent flashover.

The leader development method also has three states: no arc and no leader (10), leader (11), and arc (12). The transition from 10 to 11 occurs when the gap voltage exceeds a threshold voltage, and from 11 to 12 when the length of the leader bridges the length of the gap. The state can also return from 11 to 10 when the field decreases below a certain value. The model is reset from 12 to 10 when the voltage returns to zero. The model is shown in Fig. 2. The state of leader development of the arcing horn is represented as a nonlinear resistance R_{ARC} (TYPE91). In state 10, the resistance value is high because there is no leader. As the leader develops, a predischarge current flows and the resistance is calculated by expression (1) to (3). At flashover, the resistance becomes nearly zero. At that point, the arc behaves mostly as an inductance, with a generally-used value of 1μH/m.

IV. COMPARISON BETWEEN INTEGRATION MODEL AND LEADER DEVELOPMENT MODEL

This chapter compares results obtained from the two methods of representing the air gap. Test circuit is shown in Fig. 3. Both cases use a lightning impulse voltage waveform obtained at no load. Both cases also represent the back impedance by a 390-ohm resistance in series with the gap.

Fig. 4. shows the calculated results for both methods. In the integration method, no leader development is observed in the gap current waveform, and the flashover current rises abruptly. In the leader development method, the predischarge current is represented. This coincides with the actual measurements. [7]

For the gap voltage, similar results are observed. In the integration method, the voltage waveform is too sharp when the flashover occurs. This is because no voltage drop is generated by the predischarge current and the back impedance.

The flashover voltage and current values obtained using each method are different from each other.

V. CONCLUSIONS

The arcing horn model proposed here is an improved version of the conventional leader development model. It has the feature of enabling accurate simulation of a wide range of characteristics, inclusive of predischarge current and wave-tail flashover. Therefore, if this model is used, it is considered possible to analyze accurately multiple flashovers by lightning surges in circuits that contain arcing horns, irrespective of voltage waveforms and circuit conditions. Measurements and simulations have been conducted for various voltage waveforms and circuit conditions, although the examples cannot all be shown here. From these results, the accuracy of this new model has been confirmed.

The proposed model is realized using the MODELS simulation language. The structure of the model clearly shows the state machine which represents the three states of the arcing horn, i.e. no arc/no leader, no arc/with leader, and arc.

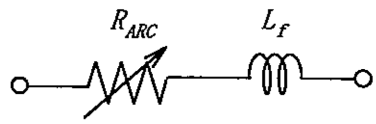


Fig.2. Leader Development Method Model

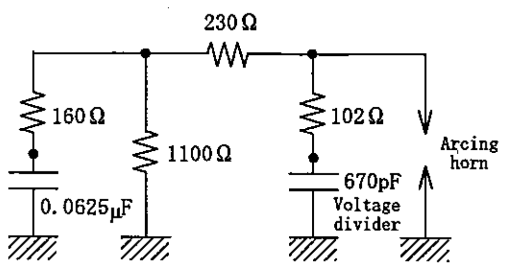


Fig. 3. Test Circuit for lightning impulse

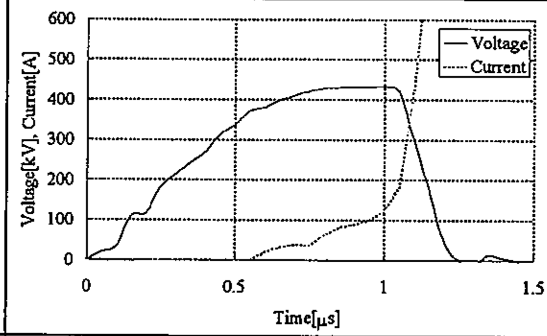
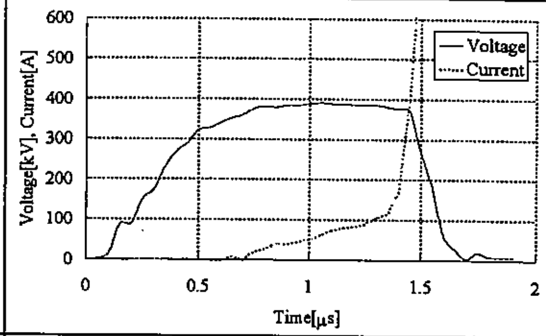
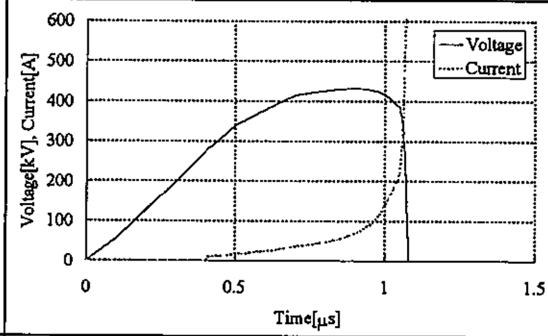
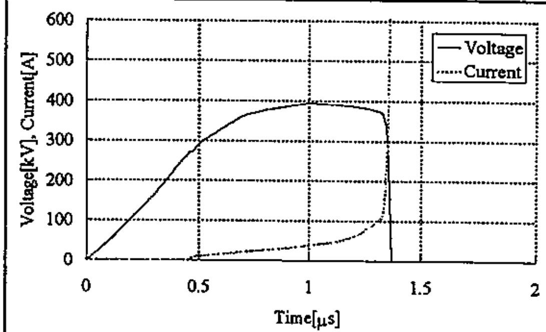
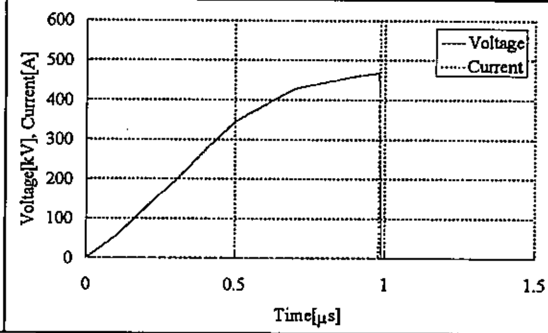
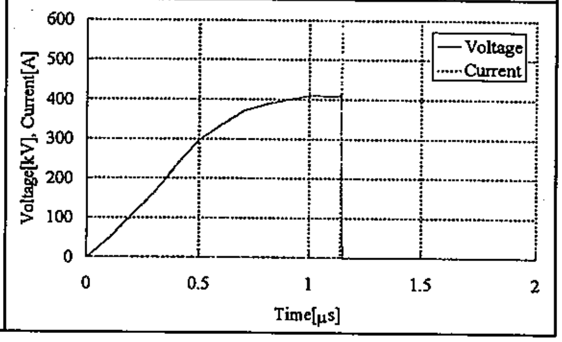
Case	Wave Front Flashover	Wave Tail Flashover
Measurement		
Leader Development Method Model		
Integration Method Model		

Fig. 4. Comparison between Integration Method Model and Leader Development Method Model

The voltage and current values produced by the two methods are different, because the integration method does not take into account any predischarge current. The values of air gap voltage and current obtained when using the leader development method closely match measurements.

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