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Three Phase Line Model with Transient Corona Effect

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Abstract: The electrical networks has always exposed at the lightning strokes an electric line, striking either a phase conductor, a pylon or an earth wire, provoking an important surges on the lines classified as the most dangerous constraints for the electrical systems. During the over-voltages propagation towards the electric stations, the surge wave will be deformed and attuned by corona and skin effect in ground and in conductors. Another side of the corona effect is a paradoxal phenomenon that should be taken into consideration. The corona effect is created by the electric field increase around the conductor, which it self caused by the lightning impact and takes part directly in the electric insulation coordination by its lightning surge reduction. In this context that we participate by this study where we present a three-phase line modal with a transient corona effect.

Key words: Corona effect, lightning, overvoltage, line, model

INTRODUCTION

The lightning impact on one of a three-phase line conductors, recognized by the bi-directional propagation of an over-voltage wave of hundreds of Kv, classified among the most dangerous constraints not only in the domain of the isolation coordination but the electromagnetic compatibility as well as.

This atmospheric overvoltage normalized by the CEI (International committee of electricity) 1, 2/50 ms Fig. 1 produces the electric field increase around the conductor and when this field reaches a critical threshold Ec Peek voltage, the apparition of the corona phenomenon is immediate.

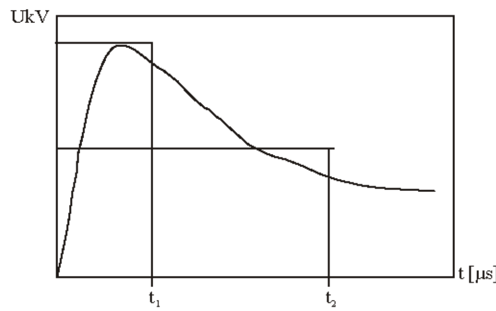

Fig. 1: Wave of lightning overvoltage normalized CEI, lasted of the forehead: t_1 = 1.2±0.36 µs, lasted of the tail (mi-value): t_2 = 50±10 µs

The transient corona effect: In high voltage, the corona effect indicates the entire phenomena related to conductivity gas' apparition in the environment around the conductor of high voltage. This conductivity is due to the ionization phenomenon provoked by the existence in the air of a certain number of ions+pair and free electrons created by cosmic radiance.

When these electrons are put under an electric field, they are accelerated and if this field is intense, the energy that they acquire becomes sufficient to provoke the neuter molecule ionization that they will also ionize other molecules and so forth the process takes the pace of an avalanche. In order to maintain this process, the form must reach a critical size and that the apparition field of corona effect must have a sufficient value in the conductors environment.

$$E_c = 31\frac{3{,}92P}{273+t}m\left(1+\frac{0{,}308}{\sqrt{\frac{3{,}92P}{273+t}r}}\right) \qquad (1)$$

Ec: Critical threshold of the corona effect apparition
P: Air pressure in Hg cm
m: The surface state coefficient of the conductor.
r: The conductor radius.

Analysis of the transient cycle of charge: From the famous experimental tests of Mr. Claude Gary[1] in EDF

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laboratories translated by several charge cycles q = f (v), we describe the influence of the corona effect on the conductor's state through its contour and its lineic parameters, especially its capacity that will take other transient values (Fig. 2).

A shared linearization of one of these graphics (Fig. 3) and by the numeric regression simple methods, we can interpret the charge quantity variation around the conductor according to the applied voltage by the following expressions:

$$\text{for } U < U_1 : q = C_g.U$$
$$\text{for } U \geq U_1 : q = q_g + q_{esp} = C_g.U + q_{esp} \quad (2)$$

Before the corona effect apparition, the charge quantity around the conductor is only capacitive and linear according to the transient voltage: q (t) = C.U (t)

U1: is the corresponding voltage threshold to Ec.
Cg: is the geometric capacity of the line

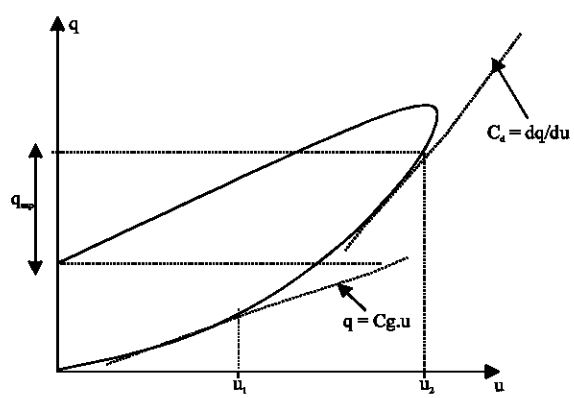

Fig. 2: Charge cycle q = f (u) by C.Gary in EDF laboratory

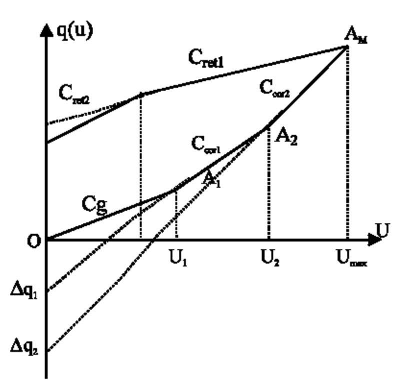

Fig. 3: Charge cycle linearization q = f (U)

q_{esp} is the supplementary charge quantity in the space caused by the corona effect and it is a non-linear function of the applied voltage and its derivation ($dq\ du^{-1}$).

From the linearized curve (Fig. 3) we determine 03 steps of the cycle evolution:

Step OA_1: corresponds to the voltage zone lower than the critical voltage U_1 with a slope.

$$q = CgU \Leftrightarrow Cg = \frac{q}{U}$$

Step A_1A_2: corresponds to the first ionization phase and of corona activity which will provide a dynamic capacity superior to Cg:

$$q = C_{cor\,1}\,U + \Delta q_1$$
$$C_{cor\,1} = C_g + \Delta C_1 \quad (3)$$

Step A_2A_M: corresponds to the second and the extreme ionization phase and its slope reinforces the dynamic capacity superior to Cg:

$$q = C_{cor\,2}\,U + \Delta q_2$$
$$C_{cor\,2} = C_g + \Delta C_2 \quad (4)$$

$$\Delta q = \Delta q_1 + \Delta q_2 = q_{esp}$$
$$\Delta C = \Delta C_1 + \Delta C_2 = C_{cor}$$

The analytic development of these equations leads us to express the charge amount evolution according to the applied voltage surrounding the conductor of the lightning impact by:

$$q = Uc_g + (U-U_1)(C_1-C_g) + (U-U_2)(C_2-C_1) \quad (5)$$

in the same way for the static capacity between the conductor and soil according to the applied voltage by:

$$C = C_g + (1-\frac{U_1}{U})(C_1 - C_g) + (U - U_2)(C_2 - C_1) \quad (6)$$

with $C_1 = C_{cor1}$ and $C_2 = C_{cor2}$ which represent the additional capacities corresponding to voltages U_1, U_2.

Coupling electrostatic coupling: When the lightning impact takes place on a three phase line conductor, the corona effect influence is not only limited directly on this conductor but influences also by induction on the other line conductors. To explain better this influence between phases, we must define the electrostatic coupling with corona. The conductor's potentials of a three phase

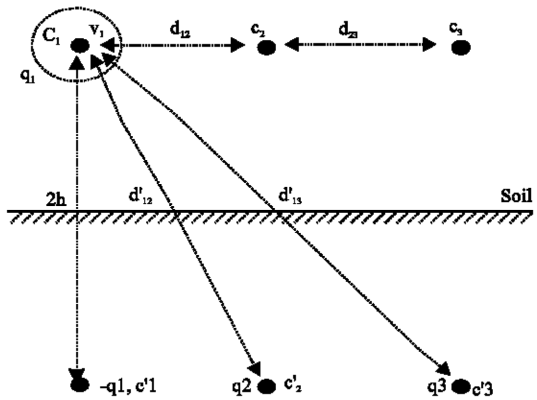

Fig. 4: Three phase line geometry according to the image theory

line are related to the carried and the surrounded charge $V_j = \alpha_{ij} q_i$ for the influence coefficients computation, we will use the theoretical images method of conductors with regard to the soil[2] Fig. 4 to find first the potentials Vj and then to deduct the influence coefficients.

If the conductor 1 is the seat of corona effect, the entire charge that surrounds it, is then:

$$q_1 = q'_1 + q''_1 \quad (7)$$

q'_i is the geometric charge on the conductor.
q''_i is the supplementary charge around the conductor induced by corona effect.

Computation of the conductors potentials: The potential of every conductor is the sum of two terms, the first induced by the same phase v', the other by its image v''. By electrostatics laws[3], Gauss and Ostrogradsky theorems, the potential conductors will be:

$$\begin{cases} V_1 = \dfrac{1}{2\pi\varepsilon_o}\ln\dfrac{2h}{r}q_1 + \dfrac{1}{2\pi\varepsilon_o}\ln\dfrac{d'_{12}}{d_{12}}q_2 + \dfrac{1}{2\pi\varepsilon_o}\ln\dfrac{d'_{13}}{d_{13}}q_3 \\ V_2 = \dfrac{1}{2\pi\varepsilon_o}\ln\dfrac{d'_{21}}{d_{21}}q_1 + \dfrac{1}{2\pi\varepsilon_o}\ln\dfrac{2h}{r}q_2 + \dfrac{1}{2\pi\varepsilon_o}\ln\dfrac{d'_{23}}{d_{23}}q_3 \\ V_1 = \dfrac{1}{2\pi\varepsilon_o}\ln\dfrac{d'_{31}}{d_{31}}q_1 + \dfrac{1}{2\pi\varepsilon_o}\ln\dfrac{d'_{32}}{d_{32}}q_2 + \dfrac{1}{2\pi\varepsilon_o}\ln\dfrac{2h}{r}q_3 \end{cases} \quad (8)$$

The potential coefficients α_{ii} are then expressed by:

for i = j

$$\alpha_{ii} = \frac{1}{2\pi\varepsilon_o}\ln\frac{2h_{ij}}{r_{ij}} \quad (9)$$

for i = j

$$\alpha_{ij} = \frac{1}{2\pi\varepsilon_o}\ln\frac{d'_{ij}}{d_{ij}} \quad (10)$$

Electrostatic coupling with corona effect: Generally in practice, the phase potentials are the known parameters but the charges are unknown, therefore the resolution of the previous system is useless whereas its transformed matrix shape to another shape that gives the column vector of charges is an optimal solution for our case.

If the lightning strikes the conductor 1(phase A) and is therefore, the seat of corona effect, with its neighboring conductor 2 (phase B) it gives the following potential system:

$$\begin{cases} V_1 = \alpha_{11} q_1 + \alpha_{12} q_2 \\ V_2 = \alpha_{21} q_1 + \alpha_{22} q_2 \end{cases} \quad (11)$$

the total charge of the conductor 1 is:

$$q_1 = q_g + q_{esp} = q' + q''$$

q_{esp} is the supplementary charge injected around the conductor by corona effect, the conductor 2 is supposed to floating potential ($q_2 = 0$):

$$\alpha_{11} = \frac{V_1}{q_1} = \frac{1}{C_1} \quad (12)$$

C_1 is a static capacity that depends on the entire charge quantity and the applied voltage to the conductor 1:

$$C_1 = f(q_1, V_1)$$

$$\alpha_{11} = \frac{V_1}{q_g + q_{esp}} = \frac{V_1}{q_g + \Delta q} = \frac{1}{C_1} \quad (13)$$

$$C_1 = C_{stat} = \frac{q_1(V_1)}{V_1} \quad (14)$$

This analysis directly implies the influence of corona effect on its own potential coefficient what permits us to affect a more meaningful sign:

$$\alpha_{11} = \alpha_{cor} \text{ and } C_1 = C_{stat} = C_{cor} \quad (15)$$

The element $\alpha_{11} = \alpha_{cor}$ belongs to the matrix $[\alpha]$ therefore in its inverse $[\alpha]^{-1}$that depend on determining of $[\alpha]$ and $\alpha_{11} = \alpha_{cor}$.

The most important conclusion of the previous analysis, is that the electrostatic coupling matrix [C]

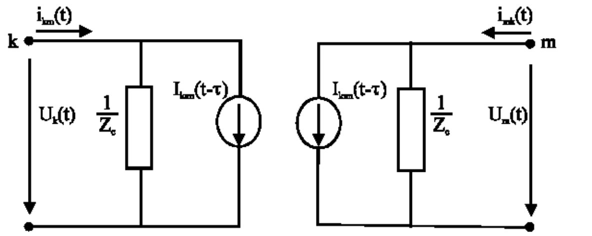

Fig. 5: Bergeron mode 1 for a line with distributed constants and without losse

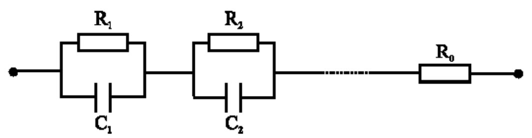

Fig. 6: Equivalent circuit of characteristic impedance

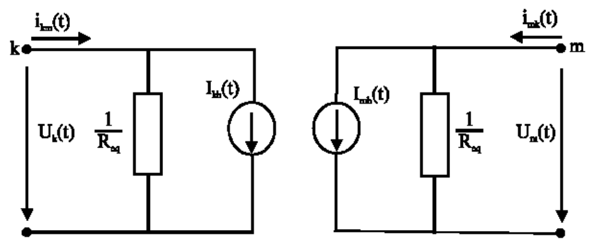

Fig. 7: Model of J R. Marti of a line with parameters depending on the frequency

depends also on this coefficient, that implies the corona influence on all capacities, belonging to every conductor and mutual between the three phases line $C_{ij} = f(\alpha_{cor})$

Models line with corona effect: In the literature, one finds models of power line with and without transient corona effect that which does not take account of the corona discharge is based primarily on the telegraphic equations

$$\frac{\partial u(x,t)}{\partial x} = -Ri(x,t) - L\frac{\partial i(x,t)}{\partial t}$$
$$\frac{\partial i(x,t)}{\partial x} = -Gu(x,t) - C\frac{\partial u(x,t)}{\partial t} \quad (16)$$

This model without corona effect meaning with linear parameters which do not change values in particular its capacity, among the existing models one can extract:

Bergeron model (line without losses): For line, without losses, of propagation constant τ, real characteristic impedance Zc and ends K, m.

The general solution of the telegraphic equations for a line without losses[4] with a theory of mobile waves applied to the single observer of Bergeron[5]:

$$U_k(t-\tau) + Z_c i_{km}(t-\tau) = U_m(t) - Z_c i_{mk}(t) \quad (17)$$

$$i_{mk}(t) = \frac{U_m(t)}{Z_c} + I_{mk}(t-\tau) \quad (18)$$

That makes it possible Bergeron to resort to the following Fig. 5.

Model of J R. marti: In the J R. Marti model, the impedance characteristic *Zc* of the line is represented by a chain of circuits R-C, Zeq,[6] Fig. 6.

Replacing *Zc* by impedance Zeq, J R. Marti [5] lead to the following model:

The power source of the equivalent shape will be the sum of the two following source.

$$I_k(t) = -\int_{\tau}^{\infty} i_h(t-v)a_{1a}(v)dv \quad (22)$$

i_h: is the sum of $i_{mk}(t)$ and the current which crosses the characteristic impedance to the node m

a_{1a}: Is the opposite Fourier transform of the ponderation function.

For the models which with corona effect are based on the variation of the charge cycle around the conductor according to the voltage applied as the Gary Cycle, on no linearity of the telegraphic equations and the instability of the linear capacity value, among these models one finds:

Boehme model: In the presence of corona effect, the telegraphic equations are not linear, Boehme[6] proposes an original approach of the atmospheric over voltages deformation. However, its model treats only the single-phase line; the surge wave applied to the one on the line ends is divided into a number n of samples.

When the conductor potential is higher than the threshold of effect corona, it develops around the conductor a charges space having for consequence an increase in the capacity of the line. For each sample of the surge wave corresponds a new capacity and thus a propagation velocity.

Boehme formulates the telegraphic equations adapted to the corona effect as follows:

$$\frac{\partial[V(x,t)]}{\partial x} = -[R][I(x,t)] - [L]\frac{\partial[I(x,t)]}{\partial t} \quad (23)$$

$$[Q(x,t)] = [C][V(x,t)]$$

EMTP Model of J.F.Guilliet: The model which we go presented in this paragraph and realized with E.M.T.P

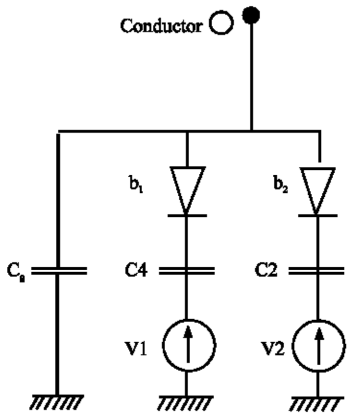

Fig. 8: EMTP model by JF Guillet

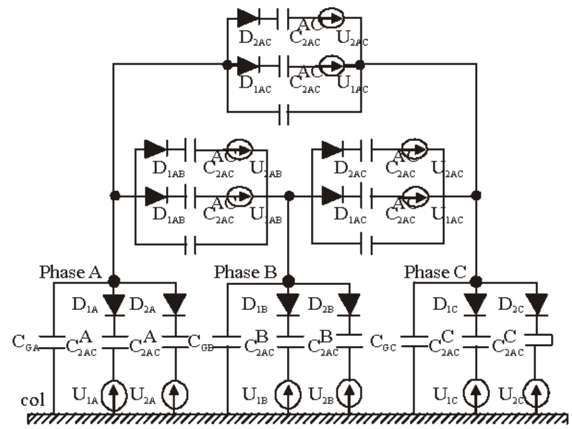

Fig. 9: Model of a three phase line with corona effect

software. The charge cycle q = f (V) for conductor i, with lightning over voltages are obtained from tests in laboratory[6] or from physical models of discharge.

The charge cycle q = f (V) in its ascending part is linearized in various segments with the required precision: two capacities C1 and C2, starting from the basic elements of library E.M.T.P. (diodes D1, D2, C1 capacities, C2, sources of v1 tension, v2) the Analog model for a line single-phase current will be designed by EMTP Model of J.F. Guilliet (Fig. 8).

A three phase line model with transient corona effect: The models of line with effect corona that we quoted above, represent for us like a screen to evaluate our case of modeling (Fig. 9).

The common points between these models, imply the variation of the quantity of load q around driver, the variation of the lineïc capacity and the treatment of the case single-phase current, on the other hand, they are differed in the approach with which, were conceived and their validity on the case real of a line three-phase current and the aspect of the coupling between conductors and ground.

This analysis of comparison on the models existing us A makes it possible to propose it our with the idea that it carries the difference and the improvement.

These Eq. 26 and 27 will be an important advantage to construct a corresponding model, (Fig. 6).

$$q = UC_g + (U-U_1)(C_{cor1}-C_g) + (U-U_2)(C_{cor2}-C_{cor1}) \quad (26)$$

$$C_{stat} = C_g + (1-\frac{U_1}{U})(C_{cor1}-C_g) + (1-\frac{U_2}{U})(C_{cor2}-C_{cor1}) \quad (27)$$

Functioning process model : When the applied voltage on the phase conductor A is lower to the critical level apparition of corona effect, the diodes 1 and 2 are blocked and is only the geometric capacity C_{gA} that presents the line, if the applied voltage exceeds the generator one U_{1A}, the diode D_{1A} is transitory and the capacity C_{Acor1} is added to the geometric to form the conductor's new capacity according to soil and it becomes again more important if the applied voltage exeeds the one of the generator U_{2A} and with a value of C_{stat}:

$$C = C_{gA} + (1-\frac{U_{1A}}{U})(C^A_{cor1}-C_g) + (1-\frac{U_{2A}}{U})(C^A_{cor2}-C^A_{cor1})$$

It is the own behaviour of the conductor seat of the corona effect whereas the mutual behaviour or by induction between this conductor A and others of the line, present a situation that depends on the applied voltage on the second phase B by induction and when this last does not exceed the critical level, the conductors capacity value according to the ground is only the geometric C_{gB}. This capacity changes the value if diodes D_{1B} and D_{2B} are transitory , such a case will occur only when this new applied voltage is successively superior to those of the generators U_{1B} and U_{2B}, the new capacity of this phase will be:

$$C = C_{gB} + (1-\frac{U_{1B}}{U})(C^B_{cor1}-C_g) + (1-\frac{U_{2B}}{U})(C^B_{cor2}-C^B_{cor1})$$

The same process is repeated for the other cases of induction of the phase with regard to soil and of the phase A the corona effect seat according to the other line conductors.

This progress of the proposed model gives a convenient satisfaction that suits the mathematical model represented by the experimental curves of the load cycles described in the previous paragraphs.

CONCLUSION

The corona effect generated by the atmospheric overvoltages, influences directly on the line parameters , notably its capacity, that is changed of original value to an another, so-called : an appeared one more superior, what provokes another transient behaviour of the three phase line by the phenomenon of electrostatic coupling and induction.

The mathematical and analogical models, permits to know the instantaneous and transient behavior of the line and then to place another asset in the scientifical and technical researches in the electric networks in general and principally in the electric insulation.

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