FAST CALCULATING FORMULAS OF CURRENT PASSING THROUGH GROUNDING SYSTEM OF HIGH VOLTAGE SUBSTATION WHEN LIGHTNING STRIKES AT THE GROUNDING WIRE OF TRANSMISSION LINE

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***ABSTRACT**: Current injecting a grounding system of high voltage substation decides the amplitude and the voltage distribution along the grounding grid [1]-[2]. Therefore, the determination of short circuit current at substation is always cared by the designers. This paper presents a method to fast calculate the current passing through grounding system of high voltage substation when lightning strikes at the grounding wire of transmission line.*

1. INTRODUCTION

To calculate the current of lightning exactly, we must not only apply numerical analysis but also use computer. This problem requires that users need to have professional knowledge and the ability of programming or using specialized software that are very expensive.

Thus, this paper presents some new formulas to calculate the current passing through grounding system of high voltage substation when lightning strikes at the grounding wire of transmission line.

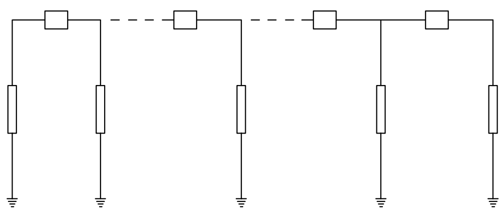

Fig 1. Equivalent circuit of grounding wire line

Based on transmission line models [3]-[5], the grounding wire system can be modeled as equivalent circuit (Fig.1). Where, n is the number of span, each span is represented by a pi-circuit. The shunt impedance Zp is the grounding impedance of pole and the series impedance Zs is the impedance of grounding wire (if the transmission line has two grounding wires then this series impedance will be $Z_s / 2$). Z1 is the impedance of grounding system of the first substation and Z2 is the impedance of grounding system of the second substation. In case of open-ended grounding wire line, Z2= ∞. The system of grounding wire and impedance of pole can be modeled as a series of connected n pi-elements equivalent circuit with lumped Zs-Zp. So, the calculation of lightning current will be a process to solve this n pi-elements equivalent circuit.

Z_s 1 Z_s k

2. CALCULATING THEORY

2.1 Impedance

From [6]-[7], in case of open-ended grounding wire line, we get the Thevenin impedance (seeing from the position that lightning strikes to the end of the grounding wire line) as follows:

$$Z_{th0} = \frac{\alpha_1\left(b-\sqrt{4Z_sZ_p+Z_s^2}\right)^n - \alpha_2\left(b+\sqrt{4Z_sZ_p+Z_s^2}\right)^n}{\left(b+\sqrt{4Z_sZ_p+Z_s^2}\right)^n - \left(b-\sqrt{4Z_sZ_p+Z_s^2}\right)^n} \qquad (1)$$

where:

$$b = 2Z_p + Z_s$$

$$\alpha_1 = \frac{-Z_s + \sqrt{4Z_sZ_p + Z_s^2}}{2}$$

$$\alpha_2 = \frac{-Z_s - \sqrt{4Z_sZ_p + Z_s^2}}{2}$$ or $\alpha_2 = -(Z_s + \alpha_1)$

In case of the end of the grounding wire line connecting with the grounding system impedance (Z1), we get the Thevenin impedance as follows (see Appendix):

$$Z_{th1} = Z_{th0} - \frac{Z_{pTD}^2}{Z_{th0} + Z_1}. \qquad (2)$$

where:

$$Z_{pTD} = \frac{2^n Z_p^n \sqrt{4Z_sZ_p + Z_s^2}}{\left(b+\sqrt{4Z_sZ_p+Z_s^2}\right)^n - \left(b-\sqrt{4Z_sZ_p+Z_s^2}\right)^n} \qquad (3)$$

2.2 Calculation of current

We consider two cases (Fig. 1):

Case one: When lightning strikes at the gate pole of the first substation, we have the following equivalent circuit:

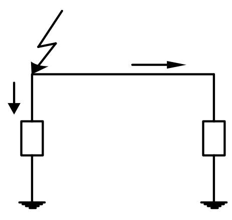

Fig 2. Equivalent circuit

Current passing through grounding system of substation 1 (Fig. 2) is calculated as follows:

$$I_{z1} = \frac{Z_{th2}}{Z_1 + Z_{th2}} I \qquad (4)$$

where Z_{th2} is the Thevenin impedance of the grounding wire of transmission line (seeing from the position that lightning strikes to the second substation) (Ω). Z_1 is the grounding system impedance of first substation (Ω). I is the lightning current value (kA).

Case two: When lightning strikes at the k^{th} pole on the grounding wire of transmission line.

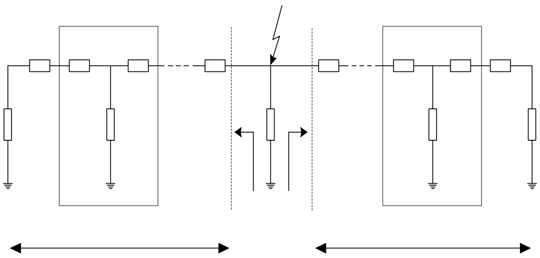

Fig 3. Equivalent circuit model

We alter the circuit in (Fig.3) for (Fig.4).

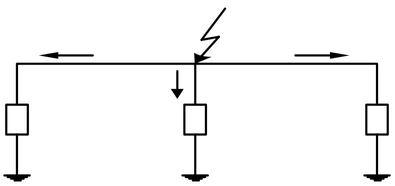

Fig 4. Equivalent Thevenin circuit

Then, current passing through grounding system of substation (Fig.4) is calculated as follows:

$$\begin{cases} I_1 = \dfrac{Z_{th2} Z_p}{Z_p Z_{th1} + Z_{th2} Z_p + Z_{th1} Z_{th2}} I & (5) \\ I_2 = \dfrac{Z_{th1} Z_p}{Z_p Z_{th2} + Z_{th1} Z_p + Z_{th1} Z_{th2}} I & (6) \\ I_3 = \dfrac{Z_{th1} Z_{th2}}{Z_p Z_{th2} + Z_{th1} Z_p + Z_{th1} Z_{th2}} I & (7) \end{cases}$$

where Z_{th1} is the Thevenin impedance of the grounding wire of transmission line (seeing from the position that lightning strikes to the first substation) (Ω). Z_p is the shunt impedance at pole that lightning stroke (Ω).

We consider T-circuit equivalent impedance (seeing from the position that lightning strikes to the second substation) (Fig .3).

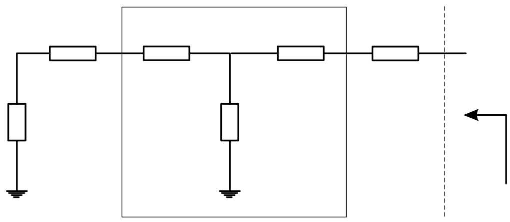

Fig 5. Equivalent circuit model to the left of the position that lightning strikes

Current passes through grounding system of first substation as follows:

$$I_{Z1} = \frac{Z_{pTD1}}{Z_1 + Z_{th01}} I_1 \qquad (8)$$

$Z_s/2$ $Z_{sTD1}/2$

where Z_{pTD1} is the elementary impedance of T - equivalent circuit to the left of the position that lightning strikes (Ω) (Fig . 5). Z_{th01} is the Thevenin impedance of the grounding wire of transmission line (seeing from the position that lightning strikes to the first substation) in case of open-ended grounding wire line at this substation (Ω). Z_1

Similar calculation:

$$I_{Z2} = \frac{Z_{pTD2}}{Z_2 + Z_{th02}} I_2 \qquad (9)$$

where Z_{pTD2} is the elementary impedance of T-circuit equivalent to the right of the position that lightning strikes (Ω). Z_{th02} is the Thevenin impedance of the grounding wire of transmission line (seeing from the position that lightning strikes to the first substation) in case of open-ended grounding wire line at this substation (Ω). Z_2 is the grounding system impedance of second substation (Ω).

Substituting the above formulas (8), (9) into equations (5), (6) we obtain:

$$\begin{cases} I_{z1} = \dfrac{Z_{pTD1} Z_{th2}}{Z_1 + Z_{th01}} \times \dfrac{Z_p}{Z_p Z_{th2} + Z_{th1} Z_p + Z_{th1} Z_{th2}} I \\ I_{z2} = \dfrac{Z_{pTD2} Z_{th1}}{Z_2 + Z_{th02}} \times \dfrac{Z_p}{Z_p Z_{th2} + Z_{th1} Z_p + Z_{th1} Z_{th2}} I \end{cases} \qquad (10)$$

2.3 Summary

From the above analysis, we have a method to calculate the current value passing through the grounding system impedance of substation when lightning strikes at any point on the grounding wire of transmission line as follows:

(i). We determine the Thevenin impedance (seeing from the position that lightning strikes to the substations) in case of open-ended grounding wire line at the substations, with the number of nodal point is $(k-1)$ and $(n-k)$ as follows:

$$\begin{cases} Z_{th01} = \dfrac{\alpha_1\left(b - \sqrt{4Z_sZ_p + Z_s^2}\right)^{k-1} - \alpha_2\left(b + \sqrt{4Z_sZ_p + Z_s^2}\right)^{k-1}}{\left(b + \sqrt{4Z_sZ_p + Z_s^2}\right)^{k-1} - \left(b - \sqrt{4Z_sZ_p + Z_s^2}\right)^{k-1}} \\ Z_{th02} = \dfrac{\alpha_1\left(b - \sqrt{4Z_sZ_p + Z_s^2}\right)^{n-k} - \alpha_2\left(b + \sqrt{4Z_sZ_p + Z_s^2}\right)^{n-k}}{\left(b + \sqrt{Z_sZ_p + Z_s^2}\right)^{n-k} - \left(b - \sqrt{4Z_sZ_p + Z_s^2}\right)^{n-k}} \end{cases} \quad (11)$$

where α_1, α_2 and b was considered in formula (1).

(ii). Determine the Thevenin impedance (seeing from the position that lightning strikes to the substations) in case of grounding wire line connecting with grounding system of these substations, with the number of nodal point is $(k-1)$ and $(n-k)$ as follows:

$$\begin{cases} Z_{th1} = Z_{th01} - \dfrac{Z_{pTD1}^2}{Z_{th01} + Z_1} \\ Z_{th2} = Z_{th02} - \dfrac{Z_{pTD2}^2}{Z_{th02} + Z_1} \end{cases} \quad (12)$$

where Z_{pTD1}, Z_{pTD2} have form as formula (3)

(iii). The current which passes through the grounding system impedance of substations when lightning strikes at any point on the grounding wire of transmission line is calculated as follows:

$$\begin{cases} I_{z1}(k) = \dfrac{Z_{pTD1}}{Z_1 + Z_{th01}} \times \dfrac{Z_p}{Z_pZ_{th2} + Z_{th1}Z_p + Z_{th1}Z_{th2}} \times Z_{th2}I \\ I_{z2}(k) = \dfrac{Z_{pTD2}}{Z_2 + Z_{th02}} \times \dfrac{Z_p}{Z_pZ_{th2} + Z_{th1}Z_p + Z_{th1}Z_{th2}} \times Z_{th1}I \end{cases} \quad (13)$$

where $Z_{th01}, Z_{th02}, Z_{th1}, Z_{th2}, Z_{pTD1}, Z_{pTD2}$ was considered in above formulas.

3. CONCLUSIONS

This paper presents a method to calculate current passing through grounding system of high voltage substation when lightning strikes at any point on the grounding wire of transmission line.

CÔNG THỨC TÍNH TOÁN NHANH DÒNG ĐIỆN ĐI QUA NỐI ĐẤT CỦA TRẠM BIẾN ÁP CAO THẾ KHI CÓ SÉT ĐÁNH TRÊN ĐƯỜNG DÂY CHỐNG SÉT

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TÓM TẮT: *Dòng điện chạy qua hệ thống nối đất của trạm biến áp cao thế quyết định độ lớn và phân bố điện áp trên lưới nối đất này [1]-[2]. Chính vì thế việc xác định được dòng điện ngắn mạch tại trạm luôn là mối quan tâm của các nhà thiết kế. Bài báo đề xuất một phương pháp tính nhanh dòng điện đi qua nối đất của trạm biến áp cao thế khi có sét đánh trên dây chống sét của đường dây tải điện.*

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APPENDIX

To determine the equivalent impedance in case of the end of the grounding wire line connecting with a grounding system impedance (Z1), we turn n pi-elements equivalent circuit into the n T-elements equivalent circuit and use characteristic matrix method.

If we consider elementary parameters of each span to be equal, then each T-circuit will be considered as a two-terminals network having the same characteristic matrix, as follows:

$$A_1 = A_2 = \ldots = A_n = A = \begin{bmatrix} \dfrac{2Z_p + Z_s}{2Z_p} & \dfrac{4Z_sZ_p + Z_s^2}{4Z_p} \\ \dfrac{1}{Z_p} & \dfrac{2Z_p + Z_s}{2Z_p} \end{bmatrix}$$

If we transform n series two-terminals networks into one then this equivalent two-terminals network will have the characteristic matrix as follows:

$$A_{TD} = A_1 \times A_2 \times \ldots \times A_n = A^n \qquad \text{(A. 1)}$$

Appling the Caylay-Hamilton theorem to solve (A .1), we have:

$$\Rightarrow A_{TD} = \begin{bmatrix} \beta_0 + \beta_1 A(11) & A(12) \\ A(21) & \beta_0 + \beta_1 A(22) \end{bmatrix} \qquad \text{(A. 2)}$$

where

$$\begin{cases} \beta_0 = \dfrac{\lambda_2\lambda_1^n - \lambda_1\lambda_2^n}{\lambda_2 - \lambda_1} \\ \beta_1 = \dfrac{\lambda_1^n - \lambda_2^n}{\lambda_1 - \lambda_2} \end{cases}$$

and

$$\begin{cases} \lambda_1 = \dfrac{2Z_p + Z_s + \sqrt{4Z_sZ_p + Z_s^2}}{2Z_p} \\ \lambda_2 = \dfrac{2Z_p + Z_s - \sqrt{4Z_sZ_p + Z_s^2}}{2Z_p} \end{cases}$$

The two-terminals network with the characteristic matrix determined at (A.2) is transformed inversely into T-elements equivalent circuit as in Fig .A.1

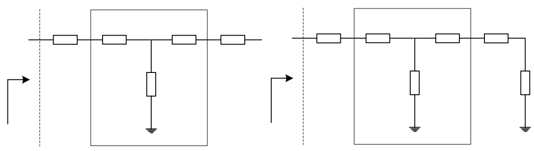

Fig A1. Equivalent Thevenin circuit

where parameters of T -elements equivalent circuit as follows:

$$\begin{cases} Z_{sTD}/2 = Z_p + \dfrac{Z_s}{2} + Z_p \dfrac{\beta_0}{\beta_1} - \dfrac{Z_p}{\beta_1} \\ Z_{pTD} = \dfrac{Z_p}{\beta_1} \end{cases}$$

Thus, the Thevenin impedance "seeing" from the position that lightning strikes to the end of the grounding wire line in case of open-ended grounding wire or the end of the grounding wire connecting with the grounding system impedance of substation (Z1):

$$\begin{cases} Z_{th0} = Z_s + Z_p \left(1 + \dfrac{\beta_0}{\beta_1}\right) \\ Z_{th1} = Z_{th0} - \dfrac{Z_{pTD}^2}{Z_{th0} + Z_1} \end{cases} \qquad \text{(A. 3)}$$

where:

$$Z_{pTD} = \frac{2^n Z_p^n \sqrt{4Z_s Z_p + Z_s^2}}{\left(b + \sqrt{4Z_s Z_p + Z_s^2}\right)^n - \left(b - \sqrt{4Z_s Z_p + Z_s^2}\right)^n}$$

and $b = 2Z_p + Z_s$