APPLICATION OF COMBINED LEADER PROGRESSION AND CSM FOR LIGHTNING STROKE CALCULATION OF ELECTRIC RAILWAY OVERHEAD FEEDING SYSTEM

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ABSTRACT: *Lightning transient over-voltage on overhead feeding system of railway can produce serious damage to railway facilities. Electro-geometric model (EGM) is a conventional method for computation the lightning stroke to electric feeding system, but in this paper combined leader progression model (LPM) analysis and charge simulation model is used for lightning stroke calculation and compared with EGM. In addition the stepwise downward leader and upward leader inception and propagation are modeled as well. The sag of conductors is considered and modeled. Towers and train are modeled too. The shielding failure outage (SFO) results are presented.*

Keywords: *Lightning stroke, charge simulation method (CSM), electric railway, overhead feeding system.*

1. INTRODUCTION

The modeling and calculation of lightning stroke to transmission line and other electric feeding system have been under consideration for a long time. Conventional and improved EGM has been used as main method for designing and calculation of lightning protection [1-5]. There are different methods that researchers have used for lightning protection analysis [6-13]. Among these methods the leader progression family absorbs more interests [6], [8-10]. By tracking the route of downward leader and a upward connecting leader the stroke point will be found by LPM. Although LPM is improved, other such as fractal approach is used by some researchers [14-15].

In field of lightning strikes to railway system also some works are done by researchers. Mazloom etal [16] modeled indirect lighting strikes to railway systems in their approach they suggested lumped components and nonlinearities such as soil ionization and insulator flashovers are suggested. Theethayi etal [17] did experimental investigation on lightning transient on Swedish railway due to indirect lightning strokes. Aodsup etal [18] used elctro-gemetric model to find the perfect shielding angle in electric railway feeding systems. In the present paper combined leader progression and CSM is used to calculate the number of lightning strokes to electric railway overhead feeding system.

2. CHARGE SIMULATION METHOD

The basic of CSM is that the charges on the surface of electrodes or dielectric interface are replaced by a set of simulation charges located outside the field domain or on the boundary. The type and location of these simulation charges are predetermined, their magnitudes are unknown. The magnitudes of the simulated charges have to be computed so that their integrated effect satisfies the boundary conditions exactly at a selected number of collocation points [19]. If different dielectric charges of any type (point, line, or ring, for instance) are used in a region, the electrostatic potential at any point C_i will be found by adding of the potentials resulting from the specific charges as long as the point C_i does not locate on any one of the charges. Let a number of n individual charges be Q_J and Φ_i be the potential at any point C_i in the space. According to super position principal:

$$\Phi_i = \sum_{J=1}^{n} P_{iJ} Q_J \qquad (1)$$

Where P_{iJ} are the coefficients potential, and can be evaluated analytically for different types of charges by solving Laplaces or poisson's equations. For example in Fig. 1, which displays three point charges Q_1, Q_2 and Q_3 in the free space, the potential Φ_i at point C_i is given by [9, 19]:

$$\Phi_i = \frac{Q_1}{4\pi\varepsilon_0 R_1} + \frac{Q_2}{4\pi\varepsilon_0 R_2} + \frac{Q_3}{4\pi\varepsilon_0 R_3} = P_{i1}Q_1 + P_{i2}Q_2 + P_{i3}Q_3 \qquad (2)$$

Therefore, once the types and positions of charges are defined, it is possible to relate Φ_i and Q_J quantitatively at any boundary position. In the CSM, the simulation charges will be placed outside the space where the field solution is aimed (or inside any equipotent surface such as metal electrodes). If C_i is a point on the boundary and is located on the surface of a conductor, then Φ_i at this contour point is equal to the Φ (conductor potential). If this procedure is applied to n contour points; it leads to the following system of n linear equations for n unknown charges.

$$\begin{bmatrix} P_{11}\cdots\cdots P_{1n} \\ P_{21}\cdots\cdots P_{2n} \\ \cdots\cdots\cdots \\ \cdots\cdots\cdots \\ \cdots\cdots\cdots \\ P_{n1}\cdots\cdots P_{nn} \end{bmatrix} \begin{bmatrix} Q_1 \\ Q_2 \\ . \\ . \\ . \\ Q_n \end{bmatrix} = \begin{bmatrix} \Phi_1 \\ \Phi_2 \\ . \\ . \\ . \\ \Phi_n \end{bmatrix} \qquad (3)$$

Equation (3) is the basic of the CSM.

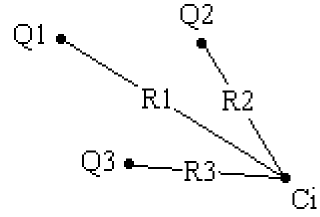

Figure. 1. Three points charges in free space.

The $(n \times n)$ matrix $[P]$ elements depend on the position and type of the charge. The vector $[\Phi]$ contains the potential of the collocation points on the boundaries. By solving the equation system for unknown magnitudes of the charges the fitness of the calculated simulation charges to boundary conditions must be checked. If this check is sufficient then the potential Φ_i and the field strength E_i in any point $C_i(x,y,z)$ in the field domain can be computed by:

$$\Phi_i(x,y,z) = \sum_{J=1}^{n} P_{ij}(x,y,z).Q_J \quad (4)$$

$$E_i(x,y,z) = \sum_{J=1}^{n} (\nabla P_{iJ}(x,y,z).Q_J) \quad (5)$$

3. ELECTRIC RAILWAY OVERHEAD FEEDING SYSTEM MODELING FOR LIGHTNING STROKE CALCULATION

In this paper the electric railway overhead feeding (EROF) is as Fig. 2.

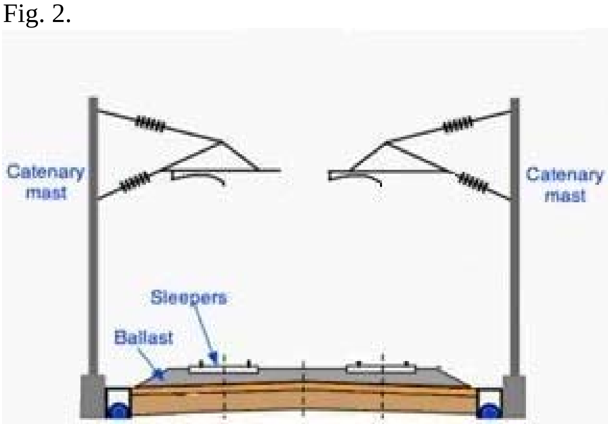

Figure. 2. Electric railway overhead feeding system.

In this modeling towers are modeled with ring charges. Train is modeled by line charges. hield and feeding wires are modeled by (horizontal and vertical) line charges as follow (Fig. 3).

The trace of wires is modeled as follow (Eq. 6) [9]:

$$Z_i = Z_{min} \times cosh(m \times (x_i - \frac{X_{span}}{2})) \quad (6)$$

Where

$$m = \frac{2}{X_{span}} \times cosh^{-1}(\frac{Z_{max}}{Z_{min}}) \quad (7)$$

4. LEADER MODELLING

In this paper total charge inside the descending lightning leader is related to lightning current as follow [8, 20, 21, 22]:

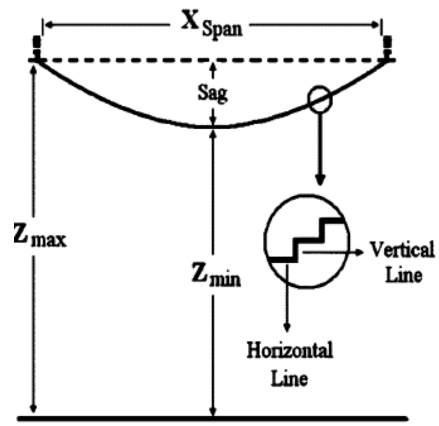

Figure. 3. Shielding and feeding wires modeling.

$$Q_T = (\frac{I}{25})^{\frac{1}{0.7}} \quad (8)$$

The leader starts at 2000 m [9] and modeled by line charges, where Q_i (each leader step charge) is as follow:

$$Q_i = \frac{1}{\sum C_i} C_i Q_T \quad (9)$$

and

$$C_i = ln\frac{H_c}{h_i} \quad (10)$$

H_c = cloud height

h_i = mean height of leader step

where:

$$h_i = \frac{h_{max} + h_{min}}{2} \quad (11)$$

"As the downward leader approaches the earth the field strength increases up to a critical value needed to start a connecting leader. In this paper model, it supposed the lightning would strike an object if there is an upward directed leader from the surface of the object" [9]. The inception criteria is the same as [9].

5. SHIELDING FAILURE CALCULATION

In order to calculate the shielding failure following sectional view is considered for overhead feeding system.

With regard to Fig. 4, four equal sub-areas are considered for the area above span. Each sub-area should divided into mesh with the length of dx (1/8 of X_{span}) in x direction and dy (10 m) in y direction ("length of each sub-area is half of span length and width of each sub-area is a distance from center of line that the leaders outside of that distance will not strike the phase conductor" [9]).

For each leader position (I, j), I = 3 kA is the lightning current which simulation start and striking point of leader will be found, for each (I, j) by continuing the simulation for different lightning current (I) the lightning current range (I_{min} , I_{max}) that lightning stroke the phase conductor will be found.

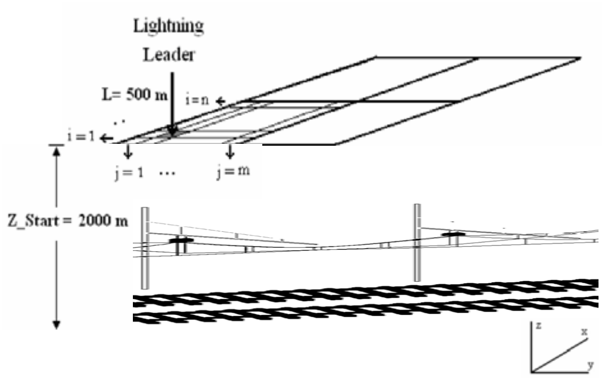

Figure. 4. Sectional view of overhead feeding system.

The shielding failure number (SFN) for the lightning current higher than a certain value I_c could be calculated. For the I_c larger than I_{min} , the SFN_{ij} per 100 km/yr for each (I, j) position is calculated as follow:

$$SFN_{ij}=0.1\gamma\frac{dx}{X_{span}}dy\int_{I_c}^{I_{max}}P(I)dI \qquad (12)$$

P(I) is the cumulative probability of lightning current exceeding *I* and computed as follow [8]:

$$log_{10}P(I)=0.05-\frac{I}{74} \qquad (13)$$

γ is the ground flash density, which is equal to 0.15 strikes per square kilometers per lightning day; T_d is the isokeraunic level, in our calculation the isokeraunic level is chosen as 40 days per year.

For $I_c<I_{min}$ the SFN_{ij} per 100-km/yr for each (I, j) position is [20, 21]:

$$SFN_{ij}=0.1\gamma\frac{dx}{X_{span}}dy\int_{Imin}^{I_{max}}P(I)dI \qquad (14)$$

For $I_c>I_{max}$, the $SFN_{ij}=0$

The SFN of transmission line per 100-km/yr for lightning current of $I>I_c$ is:

$$SFN=4\sum_{i=1}^{n}\sum_{j=1}^{m}SFN_{ij} \qquad (15)$$

In our calculation the influence of ac operating voltage during the charge simulation analysis for finding the striking point, is considered as boundary condition. Negative charge considered for leader, therefore the positive amplitude of phase voltage is used as the boundary condition in order to consider worst case.

6. SIMULATION RESULTS

An overhead feeding system same as the system of ref. [18] is used in our simulation. The dimensions of simulated system are as:

Conductors sag = 0.5 m

Phases Dis. = 8.7 m

Trains Dis. = 2 m

Shield wire height on tower (Z_{tower}) = 8 m

Phase conductor height on tower (Z_{phase}) = 6.41 m

Trains height = 5 m

Span length = 50 m

System voltage = 25 kV

Fig. 5 shows SFO for simulated system according to for shielding angle of 60.36^o (computed by EGM).

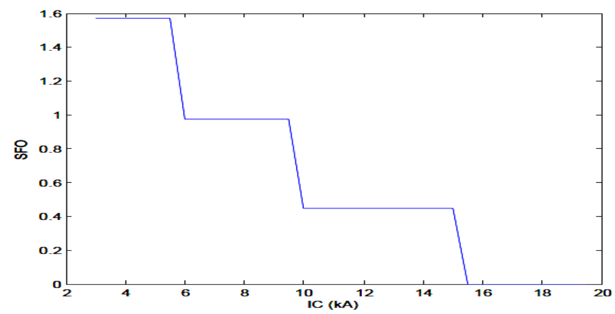

Figure. 5. SFO for simulated system (sheilding angle = 60.36^o, computed by EGM).

Fig. 6. shows SFO for simulated system according to for shielding angle of 60.36^o (computed by this paper method).

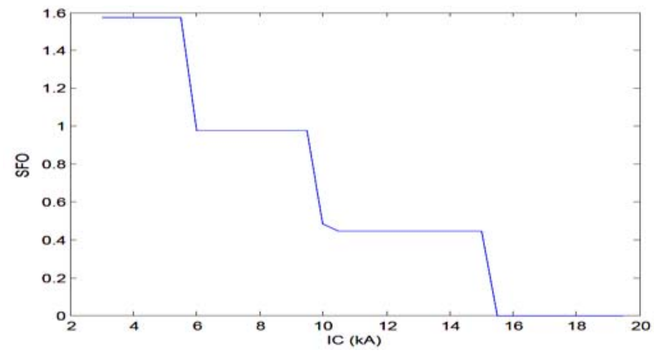

Figure. 6. SFO for simulated system (sheilding angle = 60.36^o, computed by this paper method).

SFO for electric railway overhead feeding system with one shielding wire is shown in Fig. 7 (shielding angle 57^o).

SFO for electric railway overhead feeding system without shielding wire is shown in Fig. 8.

The lightning strike to train in presence of shield wire is as fig. 9.

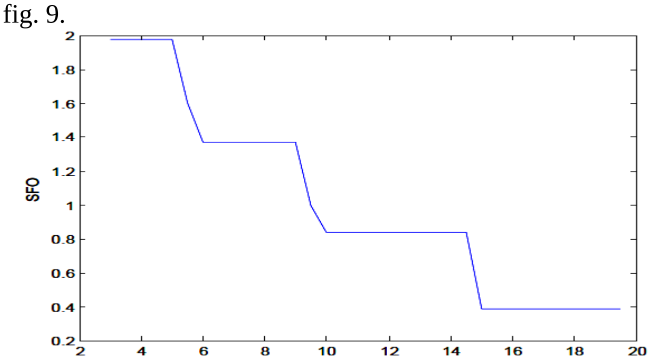

Figure. 7. SFO for simulated system (sheilding angle =57^o, one shield wire)

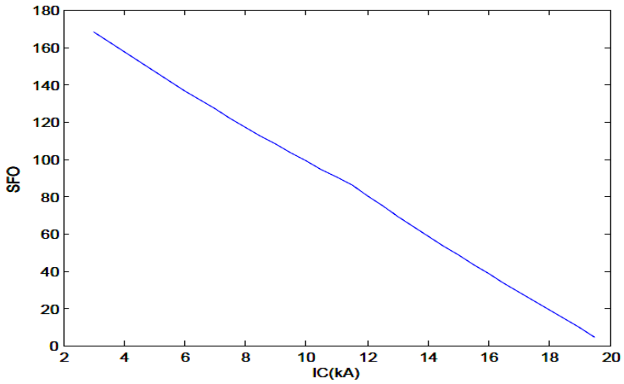

Figure. 8. SFO for simulated system without shield wire.

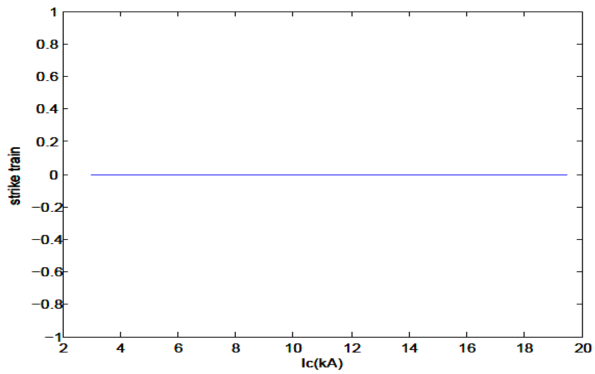

Figure. 9. Lightning strike to train.

7. CONCLUSION

In this paper combined leader progression and CSM is used to compute the lightning strike to Electric Railway Overhead Feeding System. The result is compared with EGM, it can judge that both method results are same. This paper method is a powerful tool for computing the SFO of to Electric Railway Overhead Feeding System. This paper method has this ability to compute the strike to train. This paper method can consider the physical behavior of lightning more than EGM and the results can be more reliable.

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