Surge impedance of 765 kV double circuit towers

by P H Pretorius, D Muffic, I Peter and C van der merwe, Trans-Africa Projects

The surge impedance of a power line tower is an important design parameter employed in the lightning performance and insulation co-ordination of the line. Simplified numerical models are in many cases used to determine this parameter that is costly to determine by measurement. Where equations do not exist for specific towers, such as cross rope suspension towers with guy wires, certain assumptions are made in determining surge impedance.

This paper addresses the application of an electromagnetic model to determine the surge impedance of new Eskom 765 kV double circuit towers presently under development. The tower top voltage and surge impedance obtained with the electromagnetic model are compared with the experimental findings from a Japanese UHV tower (Nishi-Gunma line, tower no. 3) study. In addition, the model is applied to the new Eskom 765 kV double circuit self support and cross-rope towers presently being developed. Application of the model and the approach covered in this paper brings about a saving in cost (by excluding experimental work) and also supports improved design in using more advanced software models.

The surge impedance of a power line tower is an important design parameter employed in the lightning performance and insulation co-ordination of the line. Simplified numerical models are in many cases used to determine this parameter that is costly to determine by measurement. Where equations do not exist for specific towers, such as cross rope suspension towers with guy wires, certain assumptions are made in determining the surge impedance.

One particular question that accompanies the application of software models relates to the accuracy of the model and its resulting output. In this particular study, the electromagnetic model developed was validated against the experimental findings of a Japanese UHV tower (Nishi-Gunma line, tower no. 3) study: the tower top voltage measured on the UHV tower and the resulting surge impedance [1].

**Tower surge impedance**

The tower surge impedance is defined in accordance with [2] and [3] as:

\[
Z_T(t) = \frac{V_{\text{TOP}}(t) - V_{\text{Base}}(t)}{I_m}
\]

Where

\[
V_{\text{TOP}}(t)
\]

is the tower top voltage (V),

\[
V_{\text{Base}}(t)
\]

is the voltage at the base of the tower and

\[
I_m
\]

is the magnitude of the current surge impressed on the tower top (typically specified as 1 A).

In this study, \( I_m \) was selected as the peak of a double exponential lightning current.

**Approach followed**

The HIFREQ module of current distribution, electromagnetic fields, grounding and soil structure and analysis software package (CDEGS) was in the computation of the tower surge impedance. The time domain double exponential current impulse (Fig. 1), injected at the top of the (3-D) tower model (Fig. 2), comprised the following parameters:

- The high rise time of 0.2 μs was selected
- Maximum magnitude: 1 A
- Fraction of max magnitude (pu): 0.5
- Fraction time: 100 μs

Following calculation of the electromagnetic contribution from each of towers members (modelled in 3-D) to other members on the tower, the time domain scalar potential (Fig. 1), was obtained by application of a reverse FFT.

The scalar potential at the top and base of the tower is presented by:

\[
V(t) = \frac{1}{2\pi} \int_{-\infty}^{+\infty} V(\omega). e^{i\omega t} d\omega
\]
Reference case

As reference case, to validate the electromagnetic model, a tower of the TEPCO, Nishi-Gunma, 1,100 kV line was used (Fig.2) [1]. This tower was selected because it was involved in a specific study that addressed tower top voltages that result from an injected surge current at the tower top [1]. In addition, sufficient data was published [1] to initiate the study reported in this paper. Additional support material was obtained from personnel involved in the Nishi-Gunma study [4]. From this material a 3-D tower (Nishi-Gunma, tower no. 3) was created as input to the electromagnetic model.

Tower members were modelled as circular conductors with an equivalent radius of 0.1 m, relative resistivity of 12 and relative permeability of 250. The base of the tower made contact with the soil through 2 m long circular conductors (rods) of 10 mm diameter. Actual soil resistivity data was unavailable and a range of soil resistivities of 100 Ω·m, 500 Ω·m and 1000 Ω·m were considered for the study.

Fig. 2: Tower of the Nishi-Gunma UHV line considered – Reference Case [1] (a) Photo image of tower [1]; (b) Tower outline [1].

Fig. 3: Voltages measured on various parts (top to base) of the Nishi-Gunma tower.

Fig. 4: Tower No 3 (centre) with two adjacent spans presented in the electromagnetic model (insulators were not modelled).

Fig. 5: Tower structures considered for the electromagnetic model. (a) 765 kV, double circuit, vertical, self support structure; (b) 765 kV, double circuit, hexagonal, cross-rope structure.

Fig. 6: The tower top voltage obtained from the electromagnetic model (100 Ω·m soil resistivity).

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As reference case, the tower top voltage measurements performed on the Nishi-Gunma Tower and the associated surge impedance calculations [1], were used for comparison of the findings from the electromagnetic (CDEGS) model. The voltages recorded on the tower (Fig. 2) are presented in Fig. 3. [1]

To calculate the tower top voltage from the electromagnetic (CDEGS) model, the 3-D model was constructed to represent two adjacent spans to tower no. 3 with the conductors terminated in the characteristic impedance of the line (Fig. 4). The geometric mean radius of the conductor bundles were used.

Application case
The two (Eskom) 765 kV double circuit towers, a self support and a cross-rope structure, are indicated in Fig. 5a and b. These tower structures are currently being developed by Eskom for application in South Africa [5]. The application case covers the exact 3-D modeling of the towers indicated in Fig. 5.

Results
Reference case
The tower top voltage obtained from the electromagnetic model is in fair agreement (magnitude wise) compared with the tower top voltage measured (Fig. 6).

Table 1 presents a summary of the surge impedances measured and calculated from the Reference case. The electromagnetic model surge impedance value of 136 Ω (max, 100 Ω.m soil) is in good agreement with that calculated from measured tower top and base voltages [130 Ω] and the numerical model proposed by Yamada, et al, [1], namely 132 Ω. Further agreement is noted from the surge impedance calculation with T-FLASH (141,3 Ω).

Application case
Vertical self support tower: Table 2 presents a summary of the surge impedances calculated for the application case - vertical self support tower. The surge impedance value of 121 Ω calculated with the numerical model from Yamada, et al, [1] is in good agreement with that calculated from electromagnetic model, 116 Ω (max 100 Ω.m soil). These are compared with the higher value calculated with T-FLASH (146 Ω) [6]. A tower value is expected considering the Nishi-Gunma tower (Fig. 2a) is 120.5 m tall, the self support tower (Fig. 5a) is 77.5 m tall and the cross rope tower (Fig. 5b) is 53 m tall.

Hexagonal cross rope tower: Table 3 presents a summary of the surge impedances calculated from the application case - hexagonal cross rope tower. A surge impedance value of 108 Ω (max 100 Ω.m soil) was calculated with the electromagnetic model which was in good agreement with that calculated with T-FLASH (100.9 Ω).

Concluding remarks
The electromagnetic model discussed in this paper presents a means of calculating the surge impedance for different tower configurations. The model can be applied in the study of different tower configurations and parts thereof. For example, cross rope suspension towers and the contribution of guy wires to lowering the overall tower surge impedance. Best agreement between
the experimental evaluation and the electromagnetic model was noted for the 100 Ω.m soil. Based on the agreement obtained between the results of the reference case and the electromagnetic model, the model is further attractive to comparative studies involving the study of tower voltages and induced voltages from switching and lightning surges. Application of the model and the approach covered in this paper brings about a saving in cost (by excluding experimental work) and also supports improved design in using more advanced software models.

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Table 3: Summary of the surge impedance calculated from the application case (hexagonal cross rope tower – Fig. 5b).

<table>
<thead>
<tr>
<th>Source</th>
<th>Surge impedance (Ω)</th>
</tr>
</thead>
<tbody>
<tr>
<td>T-FLASH model</td>
<td>101</td>
</tr>
<tr>
<td>Electromagnetic model</td>
<td></td>
</tr>
<tr>
<td>(CDEGS)</td>
<td></td>
</tr>
</tbody>
</table>

Max: 115 Ω (1,000 Ω.m); 107 Ω (500 Ω.m); 108 Ω (100 Ω.m)

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References

Contact Dzevad Muftic, Trans African Projects, Tel 011 432-2241, Trans-Africa Projects. dzevad@tapprojects.co.za