Comparison of Simulation Tools ATPDraw and TFlash for Lightning Overvoltage Studies

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Abstract—The purpose of this study is to compare two different programs, ATPDraw and TFlash by comparing the voltages across insulators, the critical current causing flashovers and arresters energy discharge. ATPDraw, a royalty free version using world-wide of Electromagnetic Transients Program (EMTP), is used for switching and lightning surge analysis, harmonic and power quality, etc. TFlash, a software package developed by Electric Power Research Institute (EPRI), is a tool to analyze the impact of lightning activity on transmission lines and can also be used for distribution lines. To compare the voltages, current and energy with these two programs, the models of insulators, lightning strokes, flashover, poles, footing impedance, grounding, etc. using in ATPDraw have been done correspond to models used in TFlash. This paper also described the models have been used for simulations in the programs. Those three comparisons reached to the conclusion that ATPDraw and TFlash give approximately the same results and both of them can be used as simulation tools for lightning overvoltage studies.

Keywords—Lightning Overvoltage, Insulators, Flashover, Arresters Energy Discharge, ATPDraw, TFlash

1. INTRODUCTION

This paper compares two different programs, ATPDraw and TFlash by comparisons the voltages across insulators, the critical current causing flashovers and arresters energy discharge when lightning strokes to overhead distribution, both stroke to pole and stroke to phase conductor. Since overhead distribution lines are usually shielded by shield wire, lightning overvoltage can be caused by strokes to either a shield wire (or strokes to pole) or a phase conductor. The first type of stroke can produce a flashover if the backflash overvoltage exceeds the insulator strength. Overvoltages caused by a shielding failure, that is, by a stroke to a phase conductor, are more dangerous, but their frequency is usually very low due to the shielding provided by shield wire [1].

For cases where acceptable backflashover rates are not attainable, surge arresters can be placed the line insulation [2]. The primary application problem is the arrester energy and the current discharged through the arrester. For shielded lines, the energy and current discharged through the arrester are in general within the arrester capability. For strokes to the shield wire, the majority of the stroke current is discharged to the footing resistance. Strokes to phase conductor are limited in magnitude to the maximum shield failure current, which for the usual line is between 5 and 15 kA. These shield failure currents plus currents from subsequence strokes produce arrester energies that normally exceed the energy caused by strokes to shield wire. However, in general, the energy discharged through the arrester is within the energy capability of the arrester [2].

ATPDraw, a royalty free version using world-wide of Electromagnetic Transients Program (EMTP), is used for switching and lightning surge analysis, harmonic and power quality, etc. TFlash, a software package developed by Electric Power Research Institute (EPRI), is a tool to analyze the impact of lightning activity on transmission lines and can also be used for distribution lines. To compare the voltages, current and energy with these two programs, the models of insulators, lightning strokes, flashover, poles, footing impedance, grounding, etc. using in ATPDraw have been done correspond to models used in TFlash.

2. MODELS OF SYSTEM STUDIED

Line Model

The overhead distribution lines both phase conductors and shield wire are represented by distributed parameter model, with lossless high frequency approximations (velocity of propagations are the speed of light). Using ATPDraw the overhead lines have been represented using the JMARTI frequency dependent model [3], [4]. The overhead line configuration has been shown in Fig. 1. Conductor sizes for phase conductors of 22 kV line is 185 mm$^2$, Partially Insulated Cable (PIC) and 25 mm$^2$, Steel, for shield wire.

![Conductor Configuration](image1)

Fig.1. A Typical of 22 kV. Overhead Distribution Lines

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Fig. 2 shows model of overhead lines in line cable dialog, Line Cable Constants (LCC), in ATPDraw.
For a single conductor above perfectly conducting earth, and assuming the frequency is high enough so there are no internal conductor flux linkages [5], the surge impedance is:

\[ Z = 60 \ln \left( \frac{2h}{r} \right) \]  

(1)

where \( r \) is the conductor radius and \( h \) is the height above ground.

Ground resistance is represented using Weck’s model [5], [6], [7]. The neutral conductor at each pole is grounded through a resistance. The impulse ground resistance is less than the measured or calculated resistance because significant ground currents cause voltage gradients sufficient to break down the soil around the ground rod. The footing impedance is determined by using the current dependence of the pole footing resistance, \( R_c \), as shown in (3)

\[ R_c = \frac{R_0}{\sqrt{1 + \frac{I}{I_g}}} \]  

(2)

where \( R_0 \) is footing resistance at low current and low frequency in \( \Omega \), \( I \) is the lightning current through the footing impedance in A and \( I_g \) is the limiting current through the footing impedance in A.

\[ I_g = \frac{1}{2\pi} \left( \frac{E_0 \rho_0}{R_0^2} \right) \]  

(3)

where \( \rho_0 \) is the soil resistivity in \( \Omega \cdot m \), \( E_0 \) is the soil breakdown gradient, typically 400 kV/m. Using the MODELS simulation language in ATP. ATPDraw supports only a simplified usage of MODELS [3]. The user writes a model-file and ATPDraw takes care of the INPUT/OUTPUT section of MODELS along with the USE of each model. Fig. 3 shows model dialog of footing impedance, in ATPDraw.

Fig. 2. Line Cable Constant Dialog in ATPDraw for Overhead Line Model

Pole and Footing Impedance Model

Fig. 3. Footing Impedance Dialog in ATPDraw for Weck’s Model

Weck’s model using MODELS language in ATPDraw has been shown as follow.

MODEL Weck  
comment-------------------------
| Pole Ground : Soil Ionization Model |
| Week's Model | 
| Input: Current through Ground | 
| Output: Ground Resistance | 

ENDMODEL
Arrester Model

Table 1 shows V-I characteristics of arresters rated 21 kV for 22 kV, overhead lines used in this simulation.

Table 1. V-I Characteristics of Arrester Rated 21 kV.

<table>
<thead>
<tr>
<th>Voltage Rating (kV-rms)</th>
<th>MCOV (kV-rms)</th>
<th>Max. Switch. Surge (kV crest)</th>
<th>Max. Discharge Voltage (kV crest) Using an 8/20 µs. Current Impulse</th>
</tr>
</thead>
<tbody>
<tr>
<td>21 kV</td>
<td>17.0</td>
<td>69.7</td>
<td>55.3</td>
</tr>
</tbody>
</table>

Fig. 5 shows arrester V-I characteristic used in ATPDraw and in TFFlash.

Surge arresters are represented with a Beizer spline fit to the discharge characteristics, with the Cigre model [6]. Fig.6 shows Cigre arrester model, where $L$ is the inductance of the current path through the arrester, $R_T$ is turn on resistance and $R_L$ represents VI characteristic which is nonlinear.

\[
\frac{dG}{dt} = \frac{G_{ref}}{T} \left( 1 + \frac{G_{ref}}{I_{ref}} \right)^2 \exp \left( \frac{U}{U_{ref}} \right) \tag{4}\]

where

- $U_{10} = 10$-kA discharge voltage, in kV
- $U = \text{voltage across the arrester, in kV}$
- $I = \text{current through the arrester, in kA}$
- $k = \text{constant ranging from about 0.03 to 0.05, depending on manufacturer}$

Fig. 7 shows model dialog of Cigre lightning arrester in ATPDraw.
**Insulator and Flashover Model**

The capacitors simulate the coupling effects of conductors to the pole structure. Pin insulators for 22 kV overhead line have been represented as a capacitor 100 pF/unit [7], [8].

The flashover mechanism of the insulators can be represented by volt-time curves. The insulator flashover voltage can be calculated using Eq (5).

\[
V_{f-t} = K_1 + \frac{K_2}{t^{0.75}}
\]

\( V_{f-t} \) = Flashover voltage, kV.
\( K_1 = 400*L \)
\( K_2 = 710*L \)
\( L = \) Insulator length, m.
\( t = \) Elapsed time after lightning stroke, \( \mu s \)

Fig. 8 shows model dialog of insulator in ATPDraw.

**Lightning Source Model**

This study used double exponential surge, stroke front time = 2 \( \mu s \), tail time = 100 \( \mu s \) as a lightning source. The lightning wave shape is shown in Fig. 10.

![Lightning Source Model](image)

**Fig. 10. Lightning Wave Shape**

3. **STUDIED CONFIGURATIONS**

A typical 22 kV overhead distribution line was modeled to analyze the lightning overvoltage. The voltages across insulators, the critical current causing flashovers and arresters energy discharge have been analyzed and compared using ATPDraw and TFlash software. The following line types have been analyzed:

Type I: No Lightning Arresters Installed and No Flashovers Allowed.
Type II: No Lightning Arresters Installed and Flashovers Allowed.
Type III: Lightning Arresters Installed and No Flashovers Allowed.
Type IV: Lightning Arresters Installed and Flashovers Allowed.

Using 5 poles, 40 meters span, the distribution line of Fig. 1. was set up using ATPDraw and TFlash.

4. **SIMULATION RESULTS**

By comparisons the voltages across insulators and arresters energy discharge of two different programs, ATPDraw and TFlash, both for stroke to phase conductor and stroke to pole. Line type I, II, III and IV have been analyzed.

**No Lightning Arresters Installed and No Flashovers Allowed**

The distribution line of Fig. 1. was set up using ATPDraw and TFlash, no lightning arresters installed on any phases of overhead line and no flashovers allowed on any insulators. The voltages across phase A insulator for lightning stroke to pole and stroke phase A conductor has been compared between those two programs. Fig. 11 and Fig. 12 show voltage across phase A insulator for stroke to phase A conductor and stroke to pole respectively.
**Lightning Arresters Installed and No Flashovers Allowed**

The distribution line of Fig. 1 was set up using ATPDraw and TFlash, lightning arresters installed at pole#3 on every phases but no flashovers allowed on any insulators. Fig. 14 and Fig. 15 show voltage across phase A insulator for stroke to phase A conductor and stroke to pole respectively.

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**No Lightning Arresters Installed and Flashovers Allowed**

The distribution line of Fig. 1 was set up using ATPDraw and TFlash, no lightning arresters installed on any phases of overhead line but flashovers allowed on any insulators. Fig. 13 shows voltage across phase A insulator for stroke to pole.

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**No Lightning Arresters Installed and Flashovers Allowed**

The distribution line of Fig. 1 was set up using ATPDraw and TFlash, no lightning arresters installed on any phases of overhead line but flashovers allowed on any insulators. Fig. 13 shows voltage across phase A insulator for stroke to pole.
Fig. 16 and Fig. 17 show energy discharge for stroke to phase A conductor and stroke to pole respectively.

**Lightning Arresters Installed and Flashovers Allowed**

The distribution line of Fig. 1 was set up using ATPDraw and TFlash, lightning arresters installed at pole#3 on every phases and flashovers allowed on any insulators. Fig. 18 and Fig. 19 show voltage across phase A insulator for stroke to phase A conductor and stroke to pole respectively. Fig. 20 shows energy discharge for stroke to pole.

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**Fig. 17. Arrester Energy Discharge for Stroke to Pole**

**Fig. 18. Voltage across Phase A Insulator for Shielding Failure (Stroke to Phase A)**

By comparisons the critical current causing flashovers of two different programs, ATPDraw and TFlash, both for stroke to phase conductor and stroke to pole. Line type II and IV have been analyzed. Table 2 shows the critical current of lightning peak causing flashovers.

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**Table 2. Critical Current Causing Flashovers.**

<table>
<thead>
<tr>
<th>Line Type</th>
<th>Critical Current Causing Flashovers</th>
<th>ATP</th>
<th>TFlash</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pole Stroke</td>
<td>Pole Stroke</td>
<td>Shielding Failure</td>
<td>Shielding Failure</td>
</tr>
<tr>
<td>II</td>
<td>-27 kA</td>
<td>-15 kA</td>
<td>-28.5 kA</td>
</tr>
<tr>
<td>IV</td>
<td>-30 kA</td>
<td>Not Flash</td>
<td>-39.8 kA</td>
</tr>
</tbody>
</table>

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**Fig. 19. Voltage across Phase A Insulator for Stroke to Pole**

**Fig. 20. Arrester Energy Discharge for Stroke to Pole**

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5. **CONCLUSIONS**

By comparisons the voltages across insulators, the critical current causing flashovers and arresters energy discharge of two different programs, ATPDraw and TFlash, both for stroke to phase conductor and stroke to pole. Those three comparisons reached to the conclusion that ATPDraw and TFlash give approximately the same results and both of them can be used as simulation tools for lightning overvoltage studies.

6. **ACKNOWLEDGMENT**

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7. **REFERENCES**

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