COMPARISON OF SIMULATION RESULTS ON LIGHTNING CURRENT DISTRIBUTIONS IN COMPLEX STRUCTURE OBTAINED IN TIME AND FREQUENCY DOMAINS

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Introduction. Various methods can be utilized for determining lightning current distributions in structures. In general, there are two groups of methods: experimental and computational. Computational methods, in turn, include circuit theory methods and electromagnetic fields theory methods. It is well known, that circuit methods are not applicable to complicated structures, because for objects having complex structure it is hard to determine correct equivalent parameters of lumped elements, which are necessary for designing of equivalent electrical circuit. Application of electromagnetic fields theory methods provides better reproducing of electromagnetic processes associated to lightning strikes to objects of complicated geometry. In this work, an application of a finite element method (by using Comsol Multiphysics software) to the determination of lightning current distribution within complicated structure is considered. Lightning impulse current components in Comsol can be modeled whether in frequency domain (FD) or in time domain (TD). Additionally, continuing current can be modeled using stationary simulation. In FD, current is simulated by a harmonic waveform of equivalent frequency, while in TD an impulse waveform can be applied.

Previous works related to investigation of lightning current distributions in frame structures have shown that frequency domain simulations can give fairly accurate results, close to that obtained by time domain simulations [1]. But it is not enough information about such accuracy when complex structures are considered, while in some works the FD approach is applied also to large complicated structures [2]. The example of complex structure discussed here is the cladding, which consists of thin metal sheets having standing round seams and halters supporting them. Other parts of cladding structure, such as sealing membranes, layers of thermal insulation etc., are not considered in this paper and substituted in model by an air. The study of this structure was previously started by utilizing frequency domain in [3], and its model geometry, as well as modeling conditions, was described there in detail.

Aim. The aim of this work is to compare the results of lightning currents distributions in cladding structure obtained by simulations in the frequency domain and time domain in order to clarify their limitations. All main types of current components are under consideration in analysis (impulse positive and negative, first and subsequent; and continuous). Additionally, simulations are performed and compared for cladding models of two dimensions, large and small.

Results and discussion.

Model geometry. Two models are considered [3]: 1) small model having top-view dimensions of 400 mm × 1000 mm (that is suitable for laboratory experiments); 2) large model having top-view dimensions of 2850 mm × 1500 mm (that one is better reproducing natural conditions for the cladding). The material of both models is stainless steel having following electrical characteristics: relative permittivity – 1, relative permeability – 1, specific conductivity – $1.429 \cdot 10^6$ S/m. The materials properties for the lightning channel and halters are assumed similar to that of the stainless steel. The contact area between supporting halters and metal sheets is 2 mm × 58 mm. The diameter of lightning channel is 6 mm. Due to the symmetry, only ¼ portions of the models have been considered.

Currents. Four main components of lightning currents according to [4] are considered in this work: 1) first positive return stroke, having amplitude of 200 kA, rise time of 10 µs and decay time of 350 µs (10/350 µs waveform); 2) first negative return stroke, 100 kA, 1/200 µs; 3) subsequent return stroke, 50 kA, 0.25/100 µs; 4) continuous current, having amplitude of 400 A and duration of 0.5 s. In frequency domain, each of lightning current components can be modeled by following frequencies, respectively [2]: 25 kHz, 250 kHz, 1 MHz, 1 Hz.

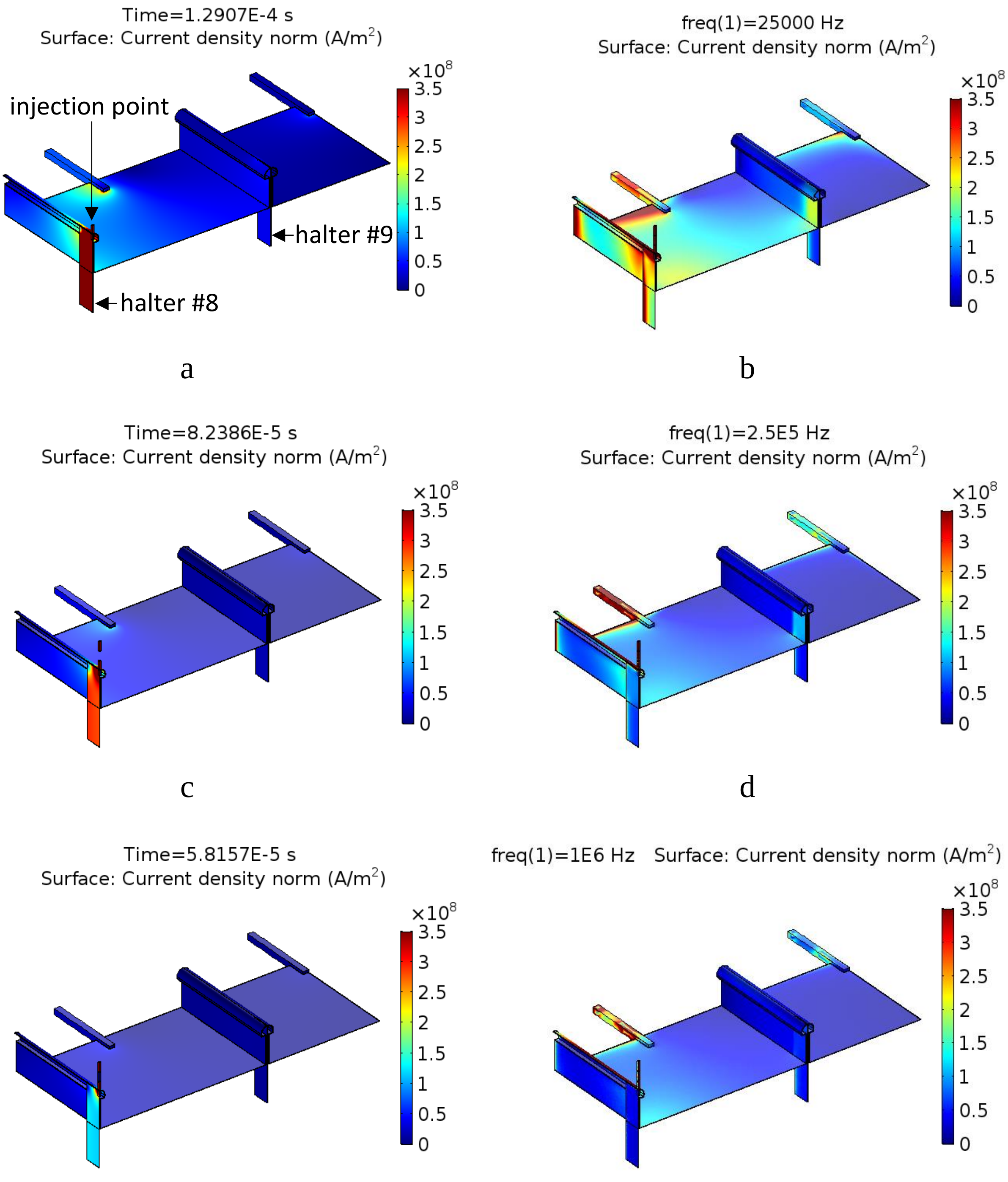
Results. In Tables 1 and 2, results of simulations are presented for all the above listed current components, for halters # 8 (main) and # 9. The positions of current injection point and halters one can see in Fig. 1. An example of simulation results on current density distributions for the small model and three impulse current components are shown in Fig. 1.

Table 1 – TD and FD current distributions in cladding structure large model

Method or parameter	Continuous current		First positive lightning stroke		First negative lightning stroke		Subsequent lightning stroke	
	I_8	I_9	I_8	I_9	I_8	I_9	I_8	I_9
FD, %	45.02	5.92	7.01	0.24	0.71	0.02	0.16	0.01
TD, %	44.95	5.91	35.00	4.22	23.80	2.77	19.60	2.16
|*TD-FD*|, %	0.07	0.01	27.99	3.98	23.09	2.75	19.44	2.15
$\frac{\|TD-FD\|}{TD}100\%$	0.16	0.17	79.97	94.31	97.02	99.28	99.18	99.54
TD/*FD*	1.00	1.00	4.99	17.58	33.52	138.50	122.50	216.00

Table 2 – TD and FD current distributions in cladding structure small model

Method or parameter	Continuous current		First positive lightning stroke		First negative lightning stroke		Subsequent lightning stroke	
	I_8	I_9	I_8	I_9	I_8	I_9	I_8	I_9
FD, %	47.67	5.68	14.40	9.42	11.44	9.37	11.36	9.29
TD, %	47.11	5.72	37.94	8.15	33.27	9.18	28.22	9.40
|*TD-FD*|, %	0.56	0.04	23.54	1.27	21.83	0.19	16.86	0.11
$\frac{\|TD-FD\|}{TD}100\%$	1.19	0.70	62.05	15.58	65.61	2.07	59.74	1.17
TD/*FD*	0.99	1.01	2.63	0.87	2.91	0.98	2.48	1.01



a b

c d

e f

Figure 1 – Surface current density distribution for the small model:
a, c, e – time dependent simulation (TD), maximum current in main halter;
b, d, f – simulation in frequency domain (FD); a, b – first positive lightning stroke;
c, d – first negative lightning stroke; e, f– subsequent return stroke

From Fig.1, one can observe that, for example, halters are loaded much more in case of simulations performed in TD approach, which are more accurate than that in FD approach and approximation of impulse current by sinusoidal one having equivalent frequency related to the impulse front.

The dissimilarity between waveform of injected current (within channel, I_L) and waveforms of currents in some elements of the cladding structure, namely, in halters #8 and #9 (I_8, I_9), is demonstrated in Fig. 2. It shows that, in addition to different peak values of these currents, the discussed waveforms indeed are very different and positions of their peaks in time are also noticeably shifted.

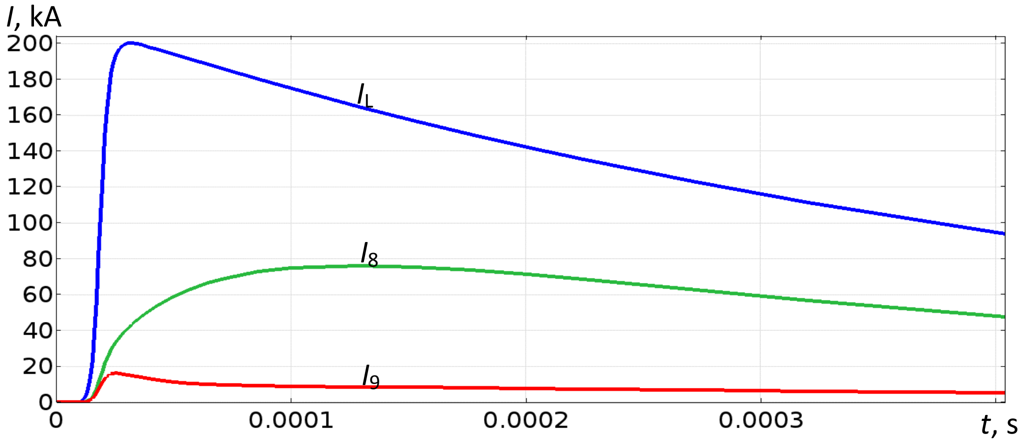


Figure 2 – Current waveforms during first positive lightning stroke in lightning channel (I_L) and halters (I_8, I_9) for the small model

Conclusions. Comparison of time domain and frequency domain simulation results has been carried out for the complicated structure of metal cladding elements. The characteristic feature of this structure is that it consists of thin metal sheets that are formed in a special way (standing round seams) and supported by numerous distributed halters. Presented results of simulations are related to stainless steel parts.

It was found, that, for the considered cladding structure, results obtained by FD and TD methods are poorly compared for the first positive, first negative and subsequent lightning strokes, while for the continuous current results obtained by two methods are similar. For the most loaded halter #8, in the small model current values can differ by 2.5 to 2.9 times, while in the large model it is increased from 5 to about 120 times. That's why the frequency domain approach and approximation of impulse current by sinusoidal one having equivalent frequency (related to the impulse front) are not suitable for studies of the structures of complicated geometry.

References

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