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Lightning Attachment Models and Maximum Shielding Failure Current: Application to Transmission Lines

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Abstract— **General relationships for the estimation of the maximum shielding failure current of overhead transmission lines have been derived by performing shielding analysis on the basis of several lightning attachment models including a recently introduced statistical one. The interdependence of maximum shielding failure current, transmission line geometry and factors employed in lightning attachment models is discussed through an application to typical 150 kV and 400 kV lines of the Hellenic transmission system. The maximum shielding failure current depends on transmission line geometry and shows a great variability among the lightning attachment models that are used in shielding analysis; electrogeometric models, thus also the IEEE Standard 1243:1997, yield higher values. These results are of great importance when considering that the maximum shielding failure current of transmission lines, besides being employed in estimating their shielding failure flashover rate, is an important parameter for insulation coordination studies.**

Index Terms— **Direct stroke shielding, lightning, maximum shielding failure current, transmission lines.**

I. INTRODUCTION

LIGNTNING is the main cause of overhead transmission line outages affecting reliability of power supply thus, consequently, resulting in economic losses. Therefore, shielding against direct lightning strokes to phase conductors of transmission lines is provided by shield wires, which are metallic elements that are able to, by physical means, launch a connecting upward discharge that intercepts the descending lightning leader from a distance called striking distance. Thus, the lightning current is conducted through the towers and dispersed by ground electrodes into earth.

The shielding design of transmission lines, that is the appropriate positioning of shield wires with respect to phase conductors, can be achieved by implementing electrogeometric models [1], representative of their application is the method suggested by IEEE Standard 1243:1997 [2], which assume the striking distance to be solely a function of the prospective stroke current [3]-[15]. Alternatively, shielding design may be realized by employing models based on more solid physical ground of lightning attractiveness [16]-[25], called hereafter, in accordance with Waters [26], generic models. Recently a statistical approach in shielding design has been introduced [27], [28] by implementing a statistical lightning attachment model derived from scale model experiments [29].

A perfect shielding of transmission lines is achieved when lightning strokes possessing peak current greater than the critical current, which causes flashover of insulation, are intercepted. Apparently, some of the less intense strokes may not be intercepted by the shield wires and strike to phase conductors, however these are not expected to cause flashover. In practice, economical shielding design of transmission lines is realized based on an acceptable shielding failure flashover rate. Hence, there is a range of currents of lightning strokes terminating at the phase conductors which may cause flashover. Although the lower limit of this range, that is, the critical current can be estimated based on the geometrical and electrical characteristics of the transmission line [2], the upper limit, called maximum shielding failure current, requires extensive geometrical analysis depending on the lightning attachment model used for shielding analysis. The maximum shielding failure current of a transmission line is used in calculations of the expected shielding failure flashover rate of the line, and it is an important parameter in insulation coordination studies; for example when studying the insulation performance of the equipment of a high voltage substation it may be considered as the upper limit of all possible lightning stroke currents impinging to the substation entrance.

For a given transmission line geometry the maximum shielding failure current has been formulated on the basis of electrogeometric models in [30] and [31]. The present work provides general expressions for the calculation of the maximum shielding failure current on the basis of generic models as there was a lack of such formulation in literature. It also introduces a simple formula for maximum shielding failure current calculations by implementing the statistical lightning attachment model [29].

The interdependence of maximum shielding failure current, transmission line geometry and factors employed in lightning attachment models is discussed. It is shown that for a given transmission line geometry there is a great variability in maximum shielding failure current among models; electrogeometric models, thus also IEEE Standard [2], yield higher values. These findings are discussed and further elucidated through an application to typical 150 kV and 400 kV overhead lines of the Hellenic transmission system.

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II. MAXIMUM SHIELDING FAILURE CURRENT FORMULATION BASED ON DIFFERENT LIGHTNING ATTACHMENT MODELS

A. Electrogeometric models

Electrogeometric models have historically been employed in transmission line shielding providing acceptable protection against direct lightning strokes to phase conductors and they are still widely used [2]. The application of these models in shielding design is based on striking distance, which is defined as the distance between the descending lightning leader and the struck object at which the upward connecting discharge is initiated. Striking distance to an object, S, is solely related to the prospective lightning peak current and can be associated to striking distance to earth surface, D, by using a factor γ as

$$S = AI^{B} = \gamma D \tag{1}$$

where I (kA) is the prospective lightning peak current and S and D are in meters. Factors A, B and γ are given in Table I.

The implementation of electrogeometric models in shielding analysis of transmission lines is described based on Fig. 1 as follows. For a design lightning peak current, I_d, the striking distances to shield wires and phase conductors, S, and to earth surface, D, are calculated according to (1) and Table I. Following, arcs of radii S are drawn from the shied wires and phase conductors; also, a line parallel to earth surface is drawn at a height D. According to the electrogeometric models, a descending lightning leader which reaches the arc between M and N will strike to the phase conductor, hence a shielding failure width, W, is defined (Fig. 1). With increasing I_d the shielding failure width decreases, thus there is a critical design current which corresponds to $W = 0$, hereafter called maximum shielding failure current, I_{MSF}.

For a given transmission line geometry, thus also shielding angle α, geometrical analysis similar to that conducted in [31] yields the following relation as a good approximation of I_{MSF}

$$I_{MSF} = \left[\frac{\gamma\left(h_m + h_p\right)/2}{A(1-\gamma \sin a)}\right]^{\frac{1}{B}} \tag{2}$$

where I_{MSF} is in kA, factors A, B, γ are given in Table I and h_m (m), h_p (m) and a are defined in Fig. 1. From (2) it can be deduced that I_{MSF} increases with increasing transmission line height, factor γ and shielding angle but decreases with increasing factors A and B, that is with increasing striking distance for a fixed lightning peak current.

Despite their simplicity and widespread applicability, the electrogeometric models, with the only exception of [4], do not consider the effects of the struck object height on striking distance S. Also, most models employ in (1) a constant value for factor γ (Table I); however, as was discussed in detail in [29], γ should depend on struck object height, lightning peak current and interception probability (i.e. the probability for a connecting upward discharge emerging from the air terminal).

TABLE I

FACTORS A, B AND γ TO BE USED IN (1)

Electrogeometric model	A	B	γ
Wagner & Hileman [3]	14.2	0.42	1
Young et al. [4]	γ27	0.32	1 for $h < 18$ m $\frac{444}{462-h}$ for $h > 18$ m h the shield wire height
Armstrong & Whitehead [6]	6.72	0.80	1.11
Brown & Whitehead [7]	7.1	0.75	1.11
Whitehead [9]	9.4	0.67	1
Love [11]	10	0.65	1
Suzuki [32] derived from Golde [33]	3.3	0.78	1
Anderson [12], IEEE WG [13]	8	0.65	$1/\beta$*
IEEE Std 1243 [2]	10	0.65	$1/\beta$**

*$\beta = 0.64$ for UHV lines, 0.8 for EHV lines, and 1 for other lines

** $\beta = 0.36+0.17\ln(43-h)$, for $h < 40$ m, $\beta = 0.55$ for $h > 40$ m where h is the phase conductor height

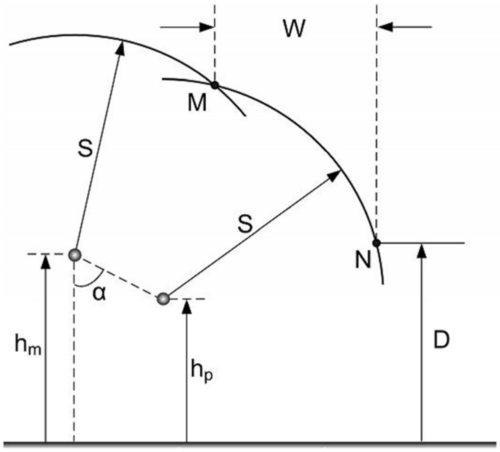

Fig. 1. Shielding analysis according to electrogeometric models. h_m shield wire height; h_p phase conductor height; α shielding angle; S striking distance to shield wire and phase conductor; D striking distance to earth surface; W shielding failure width.

B. Eriksson's model.

Eriksson [16], based on field data and by using the Carrara and Thione [34] critical radius concept for an upward leader inception criterion, modified the electrogeometric model by introducing the attractive radius in shielding design, defined as the "capture" radius at which the upward and downward leader intercept. The attractive radius, R, of a shield wire or phase conductor, is expressed as a function, besides lightning peak current, of its height, h, as

$$R = 0.67 h^{0.6} I^{0.74} \tag{3}$$

where I (kA) is the prospective lightning peak current and h and R are in meters.

Eriksson, performing a shielding analysis similar to that of the electrogeometric models, employed the attractive radius to draw arcs from the shield wire and phase conductor up to the phase conductor height, as shown in Fig. 2.

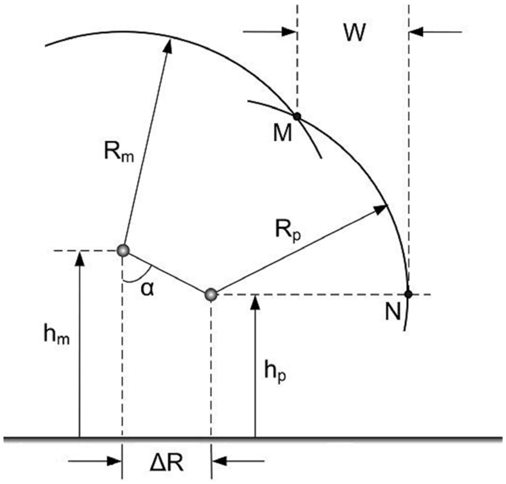

Fig. 2. Shielding analysis according to Eriksson's electrogeometric model. α shielding angle; h_m, h_p height of shield wire and phase conductor, respectively; R_m, R_p attractive radius of shield wire and phase conductor, respectively; W shielding failure width; ΔR horizontal separation distance between shield wire and phase conductor.

Based on a geometrical analysis similar to that conducted in [31], for shielding failure width $W = 0$ (Fig. 2), the maximum shielding failure current I_MSF (kA) can be expressed as

$$I_{MSF} = \left[\frac{\Delta R + \sqrt{\Delta R^2 + \Psi^2 \left(\Gamma^2 - 1 \right)}}{0.67 h_p^{\;0.6} \left(\Gamma^2 - 1 \right)} \right]^{\frac{1}{0.74}} \tag{4}$$

where $\Gamma = \left(R_m / R_p \right) = \left(h_m / h_p \right)^{0.6}$, $\Psi^2 = \left(h_m - h_p \right)^2 + \Delta R^2$ and ΔR (m), h_m (m) and h_p (m) are defined in Fig. 2. From (4) it can be deduced that I_MSF increases with increasing transmission line height and shielding angle; these effects are in accordance with those deduced for the electrogeometric models.

C. Generic models

Following Eriksson's work [16], physical models for lightning attachment that consider also the inception of the upward connecting discharge emerging from the prospective struck object were developed [17]-[25]. Thus, based on different leader inception criteria, expressions of striking distance or attractive radius which take into account, besides lightning parameters, prospective struck object height were derived. The following general expression can be used to estimate the attractive radius of an object, R, defined as the longest lateral distance from the object where lightning attachment occurs

$$R = \xi h^E I^F \tag{5}$$

where R is in meters, I (kA) is the prospective lightning peak current, h (m) the struck object height and factors ξ, E and F are listed in Table II according to different authors.

Following a shielding analysis similar to that of Rizk [18], a shielding failure will occur when the descending lightning leader enters the shielding failure width W (Fig. 3), given as

TABLE II

FACTORS ξ, E AND F TO BE USED IN (5)

Generic model	ξ	E	F
Rizk [18]	1.57	0.45	0.69
Petrov et. al. [22]*	0.47	0.67	0.67
S. Ait-Amar & Berger [25]	3	0.20	0.67

* using as h in (5) the object height plus 15 m.

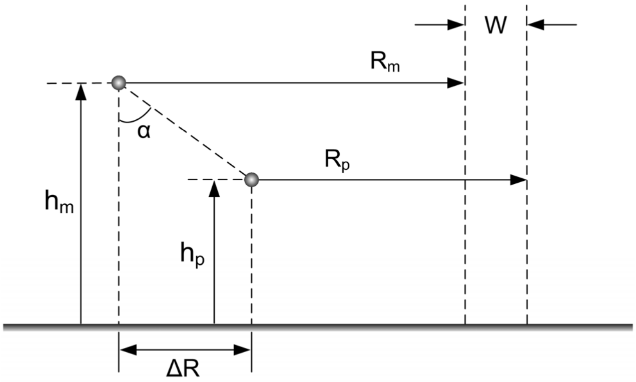

Fig. 3. Shielding analysis according to generic models. Definitions of symbols are in accordance to Fig. 2.

$$W = R_p + \Delta R - R_m \ . \tag{6}$$

Thus, for a given transmission line geometry the lightning peak current corresponding to $W = 0$ is the maximum shielding failure current. With the aid of (5) and (6) I_MSF is formulated as

$$I_{MSF} = \left[\frac{\Delta R}{\xi \left(h_m^E - h_p^E \right)} \right]^{\frac{1}{F}} = \left[\frac{\left(h_m - h_p \right) \tan a}{\xi \left(h_m^E - h_p^E \right)} \right]^{\frac{1}{F}} \tag{7}$$

where I_MSF is in kA, factors ξ, E, and F are given in Table II and ΔR (m), α, h_m (m) and h_p (m) are defined in Fig. 3. When applying Petrov et al. model [22] in (7) h_m, h_p are the heights of the shield wire and phase conductor, respectively, plus 15 m. From (7) it can be deduced that I_MSF increases with increasing transmission line height and shielding angle but it decreases with increasing factors ξ, E and F, that is with increasing attractive radius of an air terminal for a fixed lightning peak current; these effects are in accordance with those deduced by employing the electrogeometric models in shielding analysis (Subsection II.*A*).

It must be mentioned that the attractive radius equations given in [22] and [25] do not refer to the transmission line geometry; however, employing these models to calculate the maximum shielding failure current in transmission lines may provide useful information concerning their applicability. Models [17]-[25], including Eriksson's [16], have added significant value in knowledge of lightning attachment. However, as was discussed in [27], their implementation in shielding design suffers from not considering lightning interception probability.

D. Statistical model

Lightning attachment is a stochastic phenomenon, thus the most commonly employed parameters in shielding design, namely striking distance and attractive radius, should be considered as statistical quantities varying, besides struck object height and lightning stroke current, with interception probability. Their dependence upon interception probability is not considered in (1) and (5) which may attribute to the statistical behavior of striking distance and attractive radius, respectively, only through the lightning stroke current distribution.

Implementation in shielding design of a distribution for the striking distance using a mean value and a fixed standard deviation was made in [8]-[10]. Recently, investigations on the interception probability of an air terminal through scale model experiments made possible the formulation of distributions for striking distance and interception radius [29], [35] and thus a statistical approach in shielding design has been proposed [27], [36]. The interception radius is considered as statistical quantity with a mean value, referring to 50% interception probability, called critical interception radius, R_{ci}, and a standard deviation σ. It is given with reference to the striking distance to earth surface as

$$\left(\frac{R_{ci}}{D},\sigma\right)=c_1\ln\left(\frac{h}{D}\right)+c_2 \tag{8}$$

where R_{ci} is in meters, h (m) is the struck object height and D (m) is the striking distance to earth surface. The coefficients c_1 and c_2, and σ in formula form are given in Table III [29]:

TABLE III

COEFFICIENTS c_1, c_2 AND EXPRESSION OF σ TO BE USED IN (8)

Positive Lightning			Negative Lightning		
c_1	c_2	$\sigma\%$	c_1	c_2	$\sigma\%$
0.235	0.90	$1.9\left(h/D\right)^{-0.75}$	0.272	1.24	$5.0\left(h/D\right)^{-0.43}$

Equation (8) can be used for shielding analysis by using a known relation between striking distance to earth surface, D, and lightning peak current commonly expressed as $D=A'I^{B'}$. Thus, based on Fig. 3 and by using the critical interception radii of shield wire and phase conductor as calculated from (8), the shielding failure width W at critical interception is

$$W=c_1 D\ln\left(h_p/h_m\right)+\Delta R \tag{9}$$

and I_{MSF} at critical interception is formulated as

$$I_{MSF}=\left[\frac{\Delta R}{A'c_1\ln\left(h_m/h_p\right)}\right]^{\frac{1}{B'}}=\left[\frac{\left(h_m-h_p\right)\tan a}{A'c_1\ln\left(h_m/h_p\right)}\right]^{\frac{1}{B'}} \tag{10}$$

where I_{MSF} is in kA, ΔR (m), α, h_{m} (m) and h_{p} (m) are defined in Fig. 3 and c_1 is given in Table III. From (10) it can be deduced that I_{MSF} increases with increasing transmission line height and shielding angle but it decreases with increasing factors A' and B', that is with increasing striking distance to earth surface for a fixed lightning peak current; these effects are in accordance with those deduced by employing the electrogeometric and generic models in shielding analysis (Subsections II.*A-II.C*). Adopting from [11] the values of 10 and 0.65 for factors A' and B', respectively, (10) becomes for negative lightning

$$I_{MSF}=\left[\frac{\Delta R}{2.72\ln\left(h_m/h_p\right)}\right]^{\frac{1}{0.65}} \tag{11}$$

and this equation, which refers to critical interception, is used hereafter for maximum shielding failure current calculations.

It is important to note that for a given transmission line geometry the interception radii R_{m}, R_{p} are statistical quantities; they vary, besides lightning stroke current, with interception probability according to (8). Therefore also the shielding failure width, as given by (6), is accordingly statistically distributed indicating a non-deterministic value for I_{MSF}; work on this subject is in progress.

III. CALCULATION OF MAXIMUM SHIELDING FAILURE CURRENT IN TRANSMISSION LINES

Fig. 4 shows the maximum shielding failure current as a function of shielding angle, calculated by employing the lightning attachment models described in Section II. This is demonstrated for an appropriate shielding angle range of typical 400 kV double-circuit lines of the Hellenic transmission system. It is obvious that there is a great variability in I_{MSF} among lightning attachment models, however, all models predict an increase of I_{MSF} with increasing shielding angle; the latter is in accordance with results obtained through simulation [37], [38]. Also, as a general result, the electrogeometric models, thus also IEEE Std [2], yield higher values of I_{MSF} than the generic, Eriksson's and the statistical model.

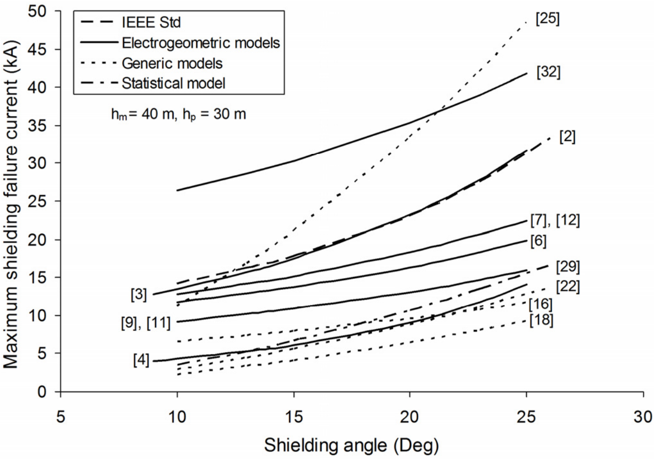

Fig. 4. Maximum shielding failure current, I_{MSF}, as a function of shielding angle.

The variability in I_{MSF} among lightning attachment models can also be deduced from the results shown in Tables IV-VI referring to typical 150 kV and 400 kV lines of the Hellenic transmission system; tower geometries are shown in Fig. 5. These calculations refer to line geometries corresponding to the tower and to the middle of the span between towers by considering sags of 5.5 m and 8.6 m for the shield wire and phase conductor, respectively. The shielding effect provided, besides shield wire, by the phase conductors in the double-circuit lines has been considered. Thus, reasonably, the lowest I_{MSF} values are found for the lower phase conductor (Tables V and VI). According to the generic models the lower phase conductor is effectively shielded ($W < 0$) against all prospective lightning stroke currents due to the negative shielding angle provided by the middle phase conductor. The same is also true for the statistical model [29] when referring to critical interception (11); however, when considering W statistically distributed the statistical model may yield values of I_{MSF} for the lower phase conductor in accordance with the electrogeometric models. Also, from Tables IV-VI it is obvious that all models yield lower I_{MSF} values at midspan than at the tower as a result of reduced both height and shielding angle in the former case; this can also be deduced from simulation results [37], [38]. Thus, I_{MSF} varies along the length of the line.

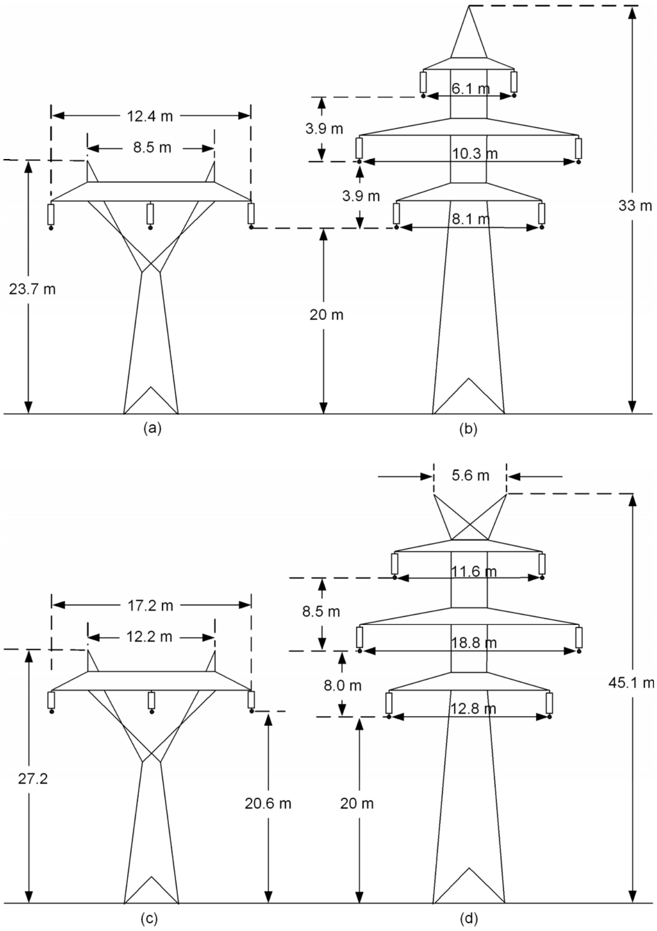

Fig. 5. Typical towers of the 150 kV (a), (b) and 400 kV (c), (d) lines of the Hellenic transmission system.

TABLE IV

MAXIMUM SHIELDING FAILURE CURRENT (kA) OF 150 kV AND 400 kV SINGLE-CIRCUIT TRANSMISSION LINES

Lightning attachment model	150 kV		400 kV	
	Tower	Midspan	Tower	Midspan
Wagner & Hileman [3]	12.0	2.4	9.8	3.0
Young et al. [4]	3.6	0.4	2.8	0.6
Armstrong & Whitehead [6]	12.1	4.8	10.4	5.4
Brown & Whitehead [7]	13.3	5.0	11.3	5.6
Whitehead [9]	8.8	3.2	7.7	3.7
Love [11]	8.5	3.0	7.5	3.5
Suzuki [32] derived from [33]	24.8	10.3	22.2	11.7
Anderson [12], IEEE WG [13]	12.0	4.2	18.7	7.9
IEEE Std 1243 [2]	12.0	3.4	10.0	3.9
Eriksson [16]	9.1	6.2	8.0	7.0
Rizk [18]	7.4	2.3	5.1	2.2
Petrov et. al. [22]	12.8	4.7	8.3	4.2
Ait-Amar & Berger [25]	32.2	8.1	22.5	8.1
Mikropoulos & Tsovilis [29]	8.9	1.9	6.3	2.0

TABLE V

MAXIMUM SHIELDING FAILURE CURRENT (kA) OF 150 kV DOUBLE-CIRCUIT TRANSMISSION LINE

Lightning attachment model	Tower			Midspan
	Upper phase	Middle phase	Lower Phase	Upper phase
Wagner & Hileman [3]	34.0	17.7	1.6	9.2
Young et al. [4]	15.5	6.2	0.2	2.6
Armstrong & Whitehead [6]	21.7	14.8	3.6	10.1
Brown & Whitehead [7]	24.7	16.5	3.6	11.0
Whitehead [9]	16.9	11.2	2.9	7.5
Love [11]	16.8	11	2.3	7.2
Suzuki [32] derived from [33]	43.4	30.5	8.3	21.5
Anderson [12], IEEE WG [13]	23.6	15.5	3.3	10.2
IEEE Std 1243 [2]	33.6	17.2	2.6	9.4
Eriksson [16]	12.7	9.7	1.3	8.5
Rizk [18]	11.9	8.4	-	5.0
Petrov et. al. [22]	17.8	13.4	-	8.2
Ait-Amar & Berger [25]	59.8	39.0	-	21.7
Mikropoulos & Tsovilis [29]	18.5	11.4	-	6.0

TABLE VI

MAXIMUM SHIELDING FAILURE CURRENT (kA) OF 400 kV DOUBLE-CIRCUIT TRANSMISSION LINE

Lightning attachment model	Tower			Midspan
	Upper phase	Middle phase	Lower Phase	Upper phase
Wagner & Hileman [3]	32.0	22.9	1.7	15.5
Young et al. [4]	14.0	8.9	0.3	5.2
Armstrong & Whitehead [6]	19.2	16.5	3.7	12.9
Brown & Whitehead [7]	21.7	18.5	3.8	14.2
Whitehead [9]	16.2	13.2	2.6	10.3
Love [11]	16.1	13.0	2.4	10.1
Suzuki [32] derived from [33]	41.9	35.0	8.7	28.5
Anderson [12], IEEE WG [13]	39.1	33.7	4.4	22.1
IEEE Std 1243 [2]	44.0	22.2	2.7	15.3
Eriksson [16]	9.3	10.2	2.3	8.2
Rizk [18]	6.9	7.2	-	3.8
Petrov et. al. [22]	8.8	9.8	-	5.2
Ait-Amar & Berger [25]	37.8	38.0	-	18.9
Mikropoulos & Tsovilis [29]	12.7	11.9	-	5.9

Fig. 6 shows the maximum shielding failure current of the 150 kV and 400 kV transmission lines calculated by using the average heights of the shield wire and phase conductor along the line, that is, the height at the tower minus two-thirds of the midspan sag. In accordance with the results in Tables IV-VI, there is a great variability in I_{MSF} among models and the electrogeometric models yield higher values of I_{MSF} than the generic, Eriksson's and the statistical model; this is more obvious for the 400 kV double-circuit transmission line (Fig. 6d). Finally, the lower I_{MSF} values found for the single-circuit (Figs. 6a and 6c) than the double-circuit lines (Figs. 6b and 6d) indicate a better shielding performance for the former lines.

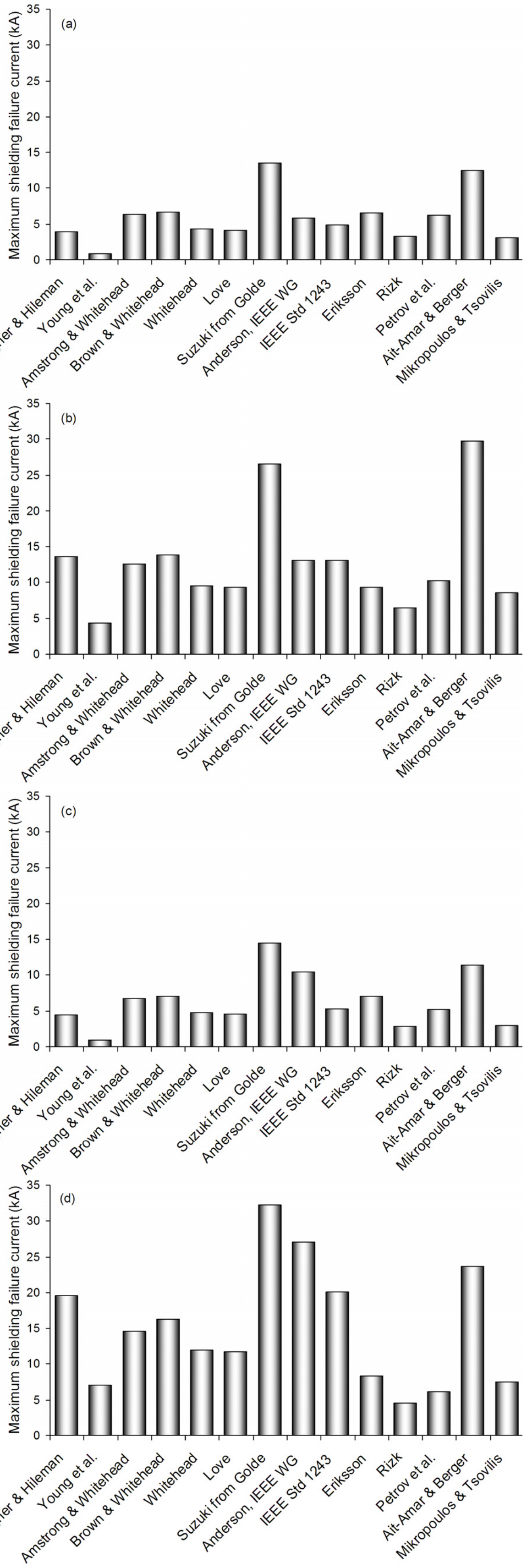

Fig. 6. Maximum shielding failure current of typical single-circuit 150 kV (a), double-circuit 150 kV (b), single-circuit 400 kV (c) and double-circuit 400 kV (d) lines of the Hellenic transmission system.

IV. DISCUSSION

The maximum shielding failure current determines the number of strokes per unit time that terminate at the phase conductors of a transmission line as a result of shielding failures. Based on [2], the shielding failure rate of a transmission line, *SFR* (shielding failures/100km/year), can be calculated as

$$SFR = 0.2 N_g \int_{0}^{\mathrm{I}_{MSF}} W(I) f(I)\, dI \tag{12}$$

where N_{g} (flashes/km^2/year) is the ground flash density, f(I) is the probability density function of the stroke current amplitude distribution and W is the shielding failure width in meters. However, a shielding failure current may not necessarily cause flashover of insulation; the minimum lightning current causing flashover, termed critical current, I_{c} (kA), is given as

$$I_c = \frac{2(CFO)}{Z_s} \text{ [2]} \tag{13}$$

where CFO (kV) is the critical lightning impulse flashover voltage of the insulation and Z_{s} (Ω) is the conductor surge impedance under corona, both as defined in [2].

Following, the shielding failure flashover rate of a transmission line, *SFFOR* (flashovers/100km/year), normally used together with backflashover rate to estimate the expected outage rate of a transmission line, is given as

$$SFFOR = 0.2 N_g \int_{\mathrm{I}_c}^{\mathrm{I}_{MSF}} W(I) f(I)\, dI \,. \tag{14}$$

Both *SFR* and *SFFOR* depend upon striking distance and interception radius since the latter shielding design parameters determine I_{MSF} and W used in (12) and (14). However, depending on transmission line geometry, the striking distance and interception radius of the shield wire may be affected by the presence of the neighboring phase conductor; this was raised by Peterson and Eriksson [39] in [18] and discussed in detail in [28] and [40]. In fact, the competing upward discharge from a neighboring phase conductor, modifying the extent of development of the connecting upward discharge from the shield wire, may result in a reduction of the striking distance and interception radius of the shield wire. Such an effect on the striking distance or interception radius of the shield wire would reasonably result in higher I_{MSF} and wider W, therefore also in bigger *SFR* and *SFFOR*.

Finally, the maximum shielding failure current, besides employed in estimations of the *SFFOR* of transmission lines, is an important parameter in insulation coordination studies. For example, when studying the insulation performance of the equipment of a high voltage substation it may be considered as the upper limit of all possible lightning stroke currents impinging to the substation entrance. Work on the implications of the variability of I_{MSF} among lightning attachment models in insulation coordination of substations is in progress.

It must be noted that the present analysis refers to overhead transmission lines on flat ground therefore any effects of topography on maximum shielding failure current calculations have not been taken into account.

V. CONCLUSIONS

General relationships for the estimation of the maximum shielding failure current of overhead transmission lines have been derived by performing shielding analysis on the basis of several lightning attachment models. The maximum shielding failure current depends on transmission line geometry therefore also it varies along the length of the line. For a fixed transmission line geometry there is a great variability in maximum shielding failure current among lightning attachment models; electrogeometric models, thus also the IEEE Standard 1243:1997, yield higher values. Maximum shielding failure current calculations have been performed for typical 150 kV and 400 kV overhead lines of the Hellenic transmission system; single-circuit lines appear to have a better shielding performance than double-circuit lines. This work provides the means to easily calculate the maximum shielding failure current which, besides being employed in estimating the shielding failure flashover rate of overhead transmission lines, is an important parameter for insulation coordination studies.

VI. ACKNOWLEDGEMENT

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