Evaluation of Lightning Current and Ground Reflection Factor using Measured Electromagnetic Field

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***Abstract*─**In this paper, an inverse procedure algorithm is proposed to evaluate lightning return stroke current wave shapes at different heights along a lightning channel, as well as the ground reflection factor using measured electromagnetic fields at an observation point while the current model can be set for different models based on the general form of the engineering current models. In order to validate the proposed method, a set of measured electromagnetic fields are used as the input parameters for the proposed algorithm. Likewise, the evaluated channel base current is compared to the corresponding measured current and also the simulated fields at another observation point (based on the evaluated current) are compared to the corresponding measured fields and the results are discussed accordingly. The results show that the evaluated current and fields based on the proposed method are in good agreement with respect to the corresponding measured values.

Index Terms - Electromagnetic fields, ground reflection factor, lightning, and return stroke current.

I. INTRODUCTION

Lightning is an important natural phenomenon that can affect power systems, buildings, and humans while the lightning current wave shape plays an important role in studies into the effects of lightning [1-3]. Several studies have been undertaken to measure the lightning return stroke base current while the lightning current can be measured directly using the triggered lightning method or by installing current coils on the top of tall towers [4-7]. The main problem with these methods is the limited number of measured currents such as measurements cannot cover the wide range of lightning occurrences. In order to set an appropriate protection level for a power system and a building, only a limited number of lightning currents are available while some of the currents are not based on local information.

On the other hand, the lightning currents can be evaluated using measured electromagnetic fields by applying the inverse procedure algorithm where by the location of the lightning is usually determined by a lightning location system (LLS) [8-9]. This method can cover a greater number of lightning occurrences based on measured electromagnetic fields while the evaluated currents are based on local information. Several studies have been undertaken to evaluate lightning currents using measured electromagnetic fields in the time and frequency domains. However, a number of inverse procedure algorithms can only evaluate the lightning currents based on measured electromagnetic fields at far distances from a lightning channel using only the radiation component of the fields in the time domain [10]. However, the error due to ignoring the other field components will enter into the calculations, which have an inverse relationship with the radial distance with respect to the lightning channel. On the other hand, some other methods can evaluate the lightning current using all the field components in

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the frequency domain but only for a restricted number of frequency samples[11, 12]. Moreover, the field sensors should be installed at fixed distances with respect to the lightning channel whilst in reality the striking point is not fully predictable. In addition, the ground reflection factor is ignored in previous methods whereby the ground reflection factor is due to the difference between the channel impedances and it is highly dependent on the ground impedance of the striking point. Therefore, additional reflected currents can enter into the channel, which can have an effect on the values of the associated electromagnetic fields. In this paper, an inverse procedure algorithm is proposed in the time domain to evaluate the full shape of the lightning currents at different heights along the channel whereby all the field components and the effect of the ground reflection factor on the calculations are considered. The proposed method can support different current models based on the general form of the engineering current models directly in the time domain without the need to apply any extra conversions. Moreover, in order to validate the proposed method, a set of measured electromagnetic fields from a triggered lightning experiment are used as input data and the evaluated current and fields at another observation point are compared to the corresponding measured current and fields, respectively. The proposed method can be used to prepare a lightning current data bank based on local information, which can be used for lightning studies. The basic assumptions in this study are listed below:

1- The lightning channel is a vertical channel to the surface of the ground.
2- The effect of lightning branches on the fields is ignored.
3- The ground conductivity is assumed to be infinite.
4- The surface of the ground is assumed to be flat.

II. RETURN STROKE CURRENT

The lightning return stroke current can be considered in two areas i.e., the channel base current at the striking point and at different heights along the lightning channel. The channel base current is usually simulated using a current function in the form of the sum of two Heidler functions [13-16], which are commonly used for the simulation due to the good agreement with the measured current. Equation (1) presents the sum of two Heidler functions. In this study, equation (1) is used as a general form of the channel base current with unknown constant parameters that will be evaluated based on the proposed inverse procedure algorithm as expressed in the next section,

$$i(0,t) = [\frac{i_{01}}{\eta_1}\frac{\left(\frac{t}{\Gamma_{11}}\right)^{n_{c1}}}{1+\left(\frac{t}{\Gamma_{11}}\right)^{n_{c1}}}\exp\left(\frac{-t}{\Gamma_{12}}\right) + \frac{i_{02}}{\eta_2}\frac{\left(\frac{t}{\Gamma_{21}}\right)^{n_{c2}}}{1+\left(\frac{t}{\Gamma_{21}}\right)^{n_{c2}}}\exp\left(\frac{-t}{\Gamma_{22}}\right)] \quad (1)$$

where i_{01}, i_{02} are the amplitudes of the channel base current, Γ_{11}, Γ_{12} are the front time constants, Γ_{21}, Γ_{22} are the decay- time constants, n_{c1}, n_{c2} are the exponents (2~10),

$$\eta_1 = \exp\left[-\left({\Gamma_{11}}/{\Gamma_{12}}\right)\left(n_{c1}\frac{\Gamma_{12}}{\Gamma_{11}}\right)^{\frac{1}{n_{c1}}}\right],$$

$$\eta_2 = \exp\left[-\left({\Gamma_{21}}/{\Gamma_{22}}\right)\left(n_{c2}\frac{\Gamma_{22}}{\Gamma_{21}}\right)^{\frac{1}{n_{c2}}}\right].$$

On the other hand, the current wave shapes at different heights along a lightning channel can be modelled using the general form of the engineering current models as expressed by equation (2) [17-19],

$$I(z',t) = [P(z')I\left(0,t-\frac{z'}{v}\right)]u\left(t-\frac{z'}{v_f}\right) \quad (2)$$

where z' is temporary charge height along lightning channel, I (z',t) is return stroke current at height of z' along lightning channel, I (0,t) is return stroke current at channel base, P (z') is attenuation height depend factor, v_f is return stoke front velocity, v is return stroke current velocity, u is Heaviside function. Equation (2) represents the current wave shapes as a function of the channel base current and an attenuation height dependent factor whereby the lightning channel is assumed to behave as a transmission line. Therefore, the different current models based on equation (2) can be a function of the attenuation height dependent factor and the return stroke current velocity along the lightning channel. The result of experimental work shows that the return stroke velocity at low heights of the lightning channel is beyond c/3 to 2c/3 where c is equal to the speed of light in free space [20]. However in reality, the velocity values along a lightning channel are variable but the velocity is usually entered into calculations as an average value between c/3 to 2c/3 [20-22].

Table 1 shows the function of the attenuation height dependent factor and the return stroke velocity for a number of widely used current models where λ is a constant factor and H is the cloud height. Moreover, the return stroke current wave shape in the presence of the ground reflection factor can be expressed by equation (3) as follows,

$$i_{gr}(z',t) = [P(z')i\left(0,t-\frac{z'}{v}\right)+\rho_g\, i\left(0,t-\frac{z'}{c}\right)]U\left(t-\frac{z'}{v_f}\right) \quad (3)$$

where,

ρ_g is ground reflection coefficient equal to $\frac{z_{ch}-z_g}{z_{ch}+z_g}$, z_{ch} is surge impedance of return stroke channel, z_g is ground impedance, $i_{gr}(z',t)$ is return stoke current at different heights along channel in presence of ground reflection factor.

Table 1: The internal parameters of widely used current models [23].

Model	Return stroke current velocity	P(z')
Bruce and Golde model(BG)	∞	1
Transmission Line model (TL)	v	1
Traveling Current Source model (TCS)	-c	1
Modified Transmission Line with Exponential decay model (MTLE)	v	exp(-z'/λ)
Modified Transmission Line with Linear decay model (MTLL)	v	(1-z'/H)

In this paper, the current wave shapes at different heights along a lightning channel are modelled using equation (3) by selecting the MTLE model and the ground reflection factor, λ and v are assumed to be unknown parameters that will be evaluated using the proposed inverse procedure algorithm.

III. LIGHTNING ELECTROMAGNETIC FIELDS

The electromagnetic fields associated with a lightning channel in the presence of a ground reflection factor at an observation point above the surface of the ground can be can be evaluated by equations (4) to (6) based on the geometry of the problem as shown in Fig. 1 whereas the dipole method is applied [24-25]. Note that all electromagnetic field components in the time period less than or equal to R (z'=0)/c are zero,

$$\overrightarrow{B_\varphi}(r,z,t_n)=\sum_{i=1}^{n}\sum_{m=1}^{k+1}\{a_m F_{i,1}(r,z,t_n,h_{m,i})-a'_m F_{i,1}(r,z,t_n,h'_{m,i})\} \quad (4)$$

$$\overrightarrow{E_r}(r,z,t_n)=\overrightarrow{E_r}(r,z,t_{n-1})+\Delta t\times\sum_{i=1}^{n}\sum_{m=1}^{k+1}\{a_m F_{i,2}(r,z,t_n,h_{m,i})-a'_m F_{i,2}(r,z,t_n,h'_{m,i})\}, \quad (5)$$

$$\overrightarrow{E_z}(r,z,t_n)=\overrightarrow{E_z}(r,z,t_{n-1})+\Delta t\times\sum_{i=1}^{n}\sum_{m=1}^{k+1}\{a_m F_{i,3}(r,z,t_n,h_{m,i})-a'_m F_{i,3}(r,z,t_n,h'_{m,i})\}, \quad (6)$$

where, $\overrightarrow{E_r}(r,z,t)$ is the horizontal electric field, $\overrightarrow{E_z}(r,z,t)$ is the vertical electric field, $\overrightarrow{B_\varphi}(r,z,t)$ is the magnetic flux density, z is height of observation point, r is radial distance from lightning channel, β=v/c, $\chi=\sqrt{\frac{1}{1-\beta^2}}$,

$$t_n=\frac{\sqrt{r^2+z^2}}{c}+(n-1)\Delta t$$

$$n=1,2,\dots,n_{max}$$

$$\Delta h_i=\begin{cases}\beta\chi^2\{(ct_i-ct_{i-1})-\sqrt{(\beta ct_i-z)^2+(\frac{r}{\chi})^2}+\sqrt{(\beta ct_{i-1}-z)^2+(\frac{r}{\chi})^2}\} & \\ \beta\chi^2\left\{-(\beta z-ct_i)-\sqrt{(\beta ct_i-z)^2+\left(\frac{r}{\chi}\right)^2}\right\} & \text{for } i=1\end{cases}$$

$$\Delta h'_i=\begin{cases}\beta\chi^2\{(ct_{i-1}-ct_i)+\sqrt{(\beta ct_i+z)^2+(\frac{r}{\chi})^2}-\sqrt{(\beta ct_{i-1}+z)^2+(\frac{r}{\chi})^2}\} & \\ \beta\chi^2\left\{-(\beta z+ct_i)+\sqrt{(\beta ct_i+z)^2+\left(\frac{r}{\chi}\right)^2}\right\} & \text{for } i=1\end{cases}$$

$$h_{m,i}=\begin{cases}\frac{(m-1)\times\Delta h_i}{k}+h_{m=k+1,i-1} & \\ \frac{(m-1)\times\Delta h_i}{k} & \text{for } i=1\end{cases},$$

$$h'_{m,i}=\begin{cases}\frac{(m-1)\times\Delta h'_i}{k}+h'_{m=k+1,i-1} & \\ \frac{(m-1)\times\Delta h'_i}{k} & \text{for } i=1\end{cases},$$

$$a_m=\begin{cases}\frac{\Delta h_i}{2\times k} & \text{for } m=1 \text{ and } m=k+1\\ \frac{\Delta h_i}{k} & \text{for others}\end{cases},$$

$$a'_m = \begin{cases} \frac{\Delta h'_i}{2\times k} & \text{for } m = 1 \text{ and } m = k+1 \\ \frac{\Delta h'_i}{k} & \text{for others} \end{cases},$$

$$R_m = \sqrt{r^2 + (z - h_{m,i})^2} \ ,$$

$$F_{i,1}(r,z,t_n,h_{m,i}) = \left(\frac{\mu_0}{4\pi}\right)\left\{\begin{matrix} \frac{r}{R_m{}^3} i_{gr}\left(h_{m,i}, t_n - \frac{R_m}{c}\right) \\ + \frac{r}{cR_m{}^2}\frac{\partial i_{gr}\left(h_{m,i},t_n-\frac{R_m}{c}\right)}{\partial t}\end{matrix}\right\},$$

$$F_{i,2}(r,z,t_n,h_{m,i}) = \left(\frac{1}{4\pi\varepsilon_0}\right)\left\{\frac{3r(z-h_{m,i})}{R_m{}^5} \times i_{gr}\left(h_{m,i}, t_n - \frac{R_m}{c}\right) + \frac{3r(z-h_{m,i})}{cR_m{}^4} \times \frac{\partial i_{gr}\left(h_{m,i},t_n-\frac{R_m}{c}\right)}{\partial t} + \frac{r(z-h_{m,i})}{c^2R_m{}^3} \times \frac{\partial^2 i_{gr}\left(h_{m,i},t_n-\frac{R_m}{c}\right)}{\partial t^2}\right\},$$

$$F_{i,3}(r,z,t_n,h_{m,i}) = \left(\frac{1}{4\pi\varepsilon_0}\right)\left\{\frac{2(z-h_{m,i})^2-r^2}{R_m{}^5} \times i_{gr}\left(h_{m,i}, t_n - \frac{R_m}{c}\right) + \frac{2(z-h_{m,i})^2-r^2}{cR_m{}^4} \times \frac{\partial i_{gr}\left(h_{m,i},t_n-\frac{R_m}{c}\right)}{\partial t} - \frac{r^2}{c^2R_m{}^3} \times \frac{\partial^2 i_{gr}\left(h_{m,i},t_n-\frac{R_m}{c}\right)}{\partial t^2}\right\}.$$

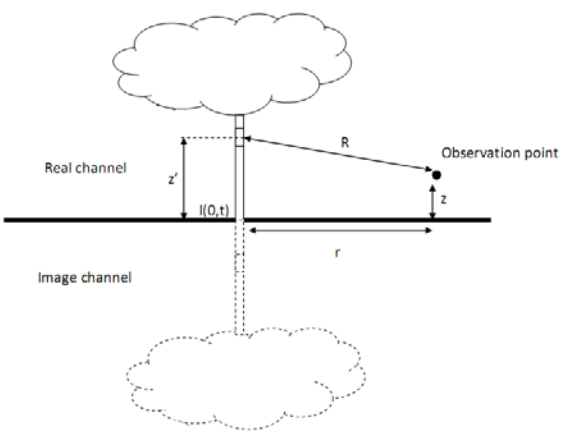

Fig. 1. The geometry of observation point with respect to lightning channel.

IV. INVERSE PROCEDURE ALGORITHM

The lightning return stroke current at different heights along a lightning channel can be evaluated using the proposed inverse procedure algorithm utilising the geometry of the required field sensors as illustrated in Fig. 2. As indicated, two field sensors (magnetic flux density and the vertical electric field) are installed at a radial distance equal to $r_1$with respect to the lightning channel to use in the proposed algorithm as input data, while the channel base current and the electromagnetic fields are measured at another radial distance (r_2) to validate the evaluated currents that are obtained from proposed algorithm. Therefore, by extending equations (4) and (6) for an observation point on the surface of the ground, the electromagnetic fields expression can be prepared as a non-linear equation system as expressed by equation (7).

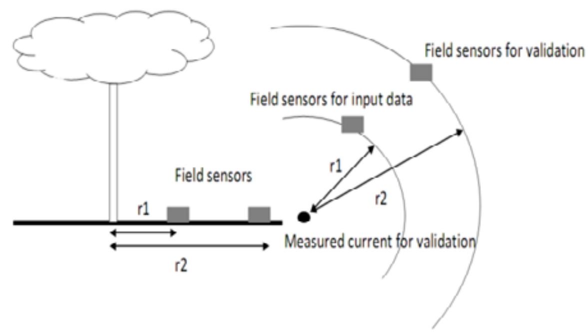

Fig. 2. The geometry of field sensors with respect to lightning channel.

$$\begin{cases} \vec{B}_\varphi(r, z=0, t_1) = \sum_{m=1}^{k+1}\{2a_m F_{i,1}(r, z=0, t_1, h_{m,i})\} \\ \vec{B}_\varphi(r, z=0, t_2) = \sum_{i=1}^{2}\sum_{m=1}^{k+1}\{2a_m F_{i,1}(r, z=0, t_2, h_{m,i})\} \\ . \\ . \\ . \\ \vec{B}_\varphi(r, z=0, t_{n_{max}}) = \sum_{i=1}^{n_{max}}\sum_{m=1}^{k+1}\{2a_m F_{i,1}(r, z=0, t_{max}, h_{m,i})\} \\ \vec{E}_z(r, z=0, t_1) = \Delta t \times \sum_{m=1}^{k+1}\{2a_m F_{i,3}(r, z=0, t_1, h_{m,i})\} \\ \vec{E}_z(r, z=0, t_2) = E_z(r, z=0, t_1) + \Delta t \times \sum_{i=1}^{2}\sum_{m=1}^{k+1}\{2a_m F_{i,3}(r, z=0, t_2, h_{m,i})\} \\ . \\ . \\ . \\ \vec{E}_z(r, z=0, t_{n_{max}}) = E_z(r, z=0, t_{max-1}) + \Delta t \times \sum_{i=1}^{n_{max}}\sum_{m=1}^{k+1}\{2a_m F_{i,3}(r, z=0, t_{max}, h_{m,i})\} \end{cases} \quad . (7)$$

Therefore, by substituting the measured fields in the left hand side of equation (7) and r_1 instead the r parameter into equation (7), the nonlinear equation system can be expressed by equation (8) as follows,

$$\begin{cases} \sum_{m=1}^{k+1}\{2a_m F_{i,1}(r_1, z=0, t_1, h_{m,i})\} - B_\varphi^{(m)}(r_1, z=0, t_1) = 0 \\ \sum_{i=1}^{2}\sum_{m=1}^{k+1}\{2a_m F_{i,1}(r_1, z=0, t_2, h_{m,i})\} - B_\varphi^{(m)}(r_1, z=0, t_2) = 0 \\ . \\ . \\ . \\ \sum_{i=1}^{n_{max}}\sum_{m=1}^{k+1}\{2a_m F_{i,1}(r_1, z=0, t_{max}, h_{m,i})\} - B_\varphi^{(m)}(r_1, z=0, t_{n_{max}}) = 0 \\ \Delta t \times \sum_{m=1}^{k+1}\{2a_m F_{i,3}(r_1, z=0, t_1, h_{m,i})\} - E_z^{(m)}(r_1, z=0, t_1) = 0 \\ E_z(r_1, z=0, t_1) + \Delta t \times \sum_{i=1}^{2}\sum_{m=1}^{k+1}\{2a_m F_{i,3}(r_1, z=0, t_2, h_{m,i})\} - E_z^{(m)}(r_1, z=0, t_2) = 0 \\ . \\ . \\ . \\ E_z(r_1, z=0, t_{max-1}) + \Delta t \times \sum_{i=1}^{n_{max}}\sum_{m=1}^{k+1}\{2a_m F_{i,3}(r_1, z=0, t_{max}, h_{m,i})\} - E_z^{(m)}(r_1, z=0, t_{n_{max}}) = 0 \end{cases} \quad , \quad (8)$$

where, $B_\varphi^{(m)}(r_1, z=0, t_n)$ is the measured magnetic flux density at time equal to t_n , $E_z^{(m)}(r_1, z=0, t_n)$ is the measured vertical electric field at time equal to t_n. On the other hand, the current function and the current model (equations (1) and (3)) with unknown constant parameters can be entered into the $F_{i,1}$, $F_{i,3}$ terms. Therefore, the number of unknown parameters will be equal to eleven i.e., eight for the current function ($i_{01}, i_{02}, \tau_{11}, \tau_{12}, \tau_{21}, \tau_{22}, n_1, n_2$), plus the return stroke current velocity (v), the constant coefficient of the current model (λ) and the ground reflection factor (ρ_g). It should be noted that the MTLE model with unknown constant coefficients is used as a current model in this paper. The unknown parameters can be evaluated by solving equation (8) via different numerical methods. In this paper, the particle swarm optimization algorithm (PSO) is used to evaluate the roots of equation (8) whereby the value of each expression in equation (8) is minimized at roots [26-27]. The proposed method can evaluate the full shape of the lightning currents at different heights by considering all the field components and the ground reflection factor, unlike previous methods. Moreover, the proposed method is very flexible for different current functions and current models and the unknown constant parameters of the current expressions can be evaluated by the proposed algorithm. Further, the proposed method is directly in the time domain and there is no need to apply any extra conversions compared to some of the previous methods. In the proposed method two field sensors are needed i.e., the vertical electric field sensor and the magnetic flux density sensor. It should be mentioned that the location of field sensors can be set at different points with respect to lightning channel whereas the values of radial distances between lightning channel and sensors are as input parameters of algorithm that can be obtained from lightning location systems and they can be entered into calculations by $F_{i,3}$ and $F_{i,3}$ terms in equation (8).

V. RESULTS AND DISCUSSION

In order to evaluate the proposed method, the measured electromagnetic fields at $r_1 = 15$ m obtained from a triggered lightning experiment are used as input data in equation (8). By applying the proposed method, the evaluated channel base current is compared to the corresponding measured current.

Moreover, the evaluated currents, ground reflection factor and return stroke current velocity are used for estimation of the magnetic flux density at another observation point with a value of r_2 of 30 m. The geometry of the field sensors with respect to the lightning channel is based on Fig. 2. Subsequently, the evaluated fields at the second observation point (field sensor at r_2) are compared to the corresponding measured fields. Figures 3 and 4 show the measured magnetic flux density and vertical electric fields at $r_1 = 15$ m, respectively, that are used as input data in the proposed inverse procedure algorithm. It is important to mention that the measured data are obtained from Florida triggered lightning campus whereas the specifications of experimental setup are presented as follow [28]:

i. The current was measured using current transformers (P 110A) and also the Meret fiber optic cable was used to transfer data to recorder. Likewise, the data were filtered using 3 dB bandwidth 20 MHz anti-aliasing filter and also they were digitized at 50 MHz.

ii. The vertical electric field was measured using a plate antenna (0.16 m^2) and also the Meret fiber optic cable was used to transfer data to recorder (with 35 MHz bandwidth) and they were filtered using 3 dB bandwidth 10 MHz low pass filter and they were digitized at 25 MHz.

iii. The rectangular loop antenna was used to measure magnetic flux density with the area about 0.56m^2 and also the Meret fiber optic cable was used to transfer data to recorder (with 35 MHz bandwidth). Moreover, they were filtered using a 10 MHz, 3 dB anti-aliasing filter before the signals were digitized in 25 MHz.

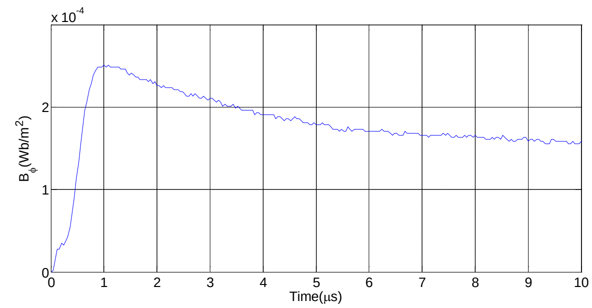

Fig. 3. Measured magnetic flux density at $r_1 = 15$ m based on geometry of problem that is illustrated in Fig. 2.

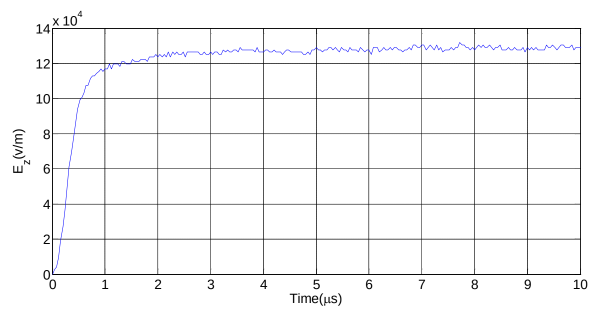

Fig. 4. Measured vertical electric field at $r_1 = 15$ m based on geometry of problem that is illustrated in Fig. 2.

The evaluated values of the current parameters are listed in Table 2 using the current function and current model set on the double Heidler function and the MTLE model, respectively.

Table 2: The evaluated values of current parameters using inverse procedure algorithm.

i_{01} (kA)	i_{02} (kA)	τ_{11} (μs)	τ_{12} (μs)	τ_{21} (μs)
17.568	9.0103	0.2722	3.8723	4.7035
τ_{22} (μs)	n_1	n_2	Λ (m)	V (m/s)
53.3559	2	2	1716	1.71x10^8

Figure 5 shows a comparison between the evaluated channel base current and the corresponding measured current. It illustrates that the evaluated current is in good agreement with respect to the corresponding measured values.

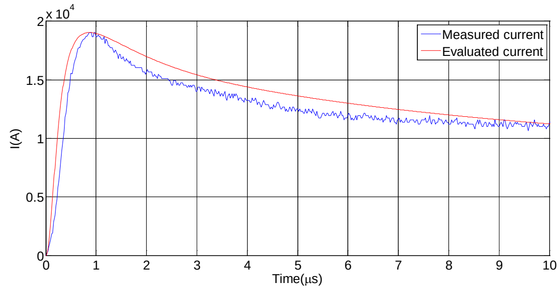

Fig. 5. Comparison between evaluated channel base current and the corresponding measured current.

Moreover, the magnetic flux density at r_2= 30 m is estimated based on the evaluated values of the current parameters from the inverse procedure algorithm as shown in Fig. 6 as compared to the corresponding measured field and the other simulated field based on $\rho_g = 0$. Figure 6 shows that by considering the ground reflector factor, the evaluated field is in good agreement with the corresponding measured field, unlike other methods of simulating the field.

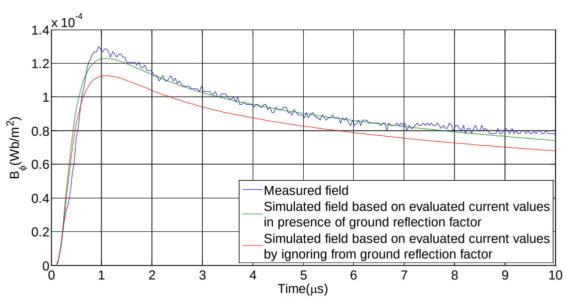

Fig. 6. Comparison between simulated magnetic flux densities and the corresponding measured field at r_2= 30 m.

The simulated vertical electric fields at r_2= 30 m are compared to the corresponding measured fields. The simulated fields are evaluated based on the current parameters using the proposed method. The results show that the simulated field in the presence of the ground reflection factor is in better agreement with the corresponding measured field compared to other methods of simulating the field.

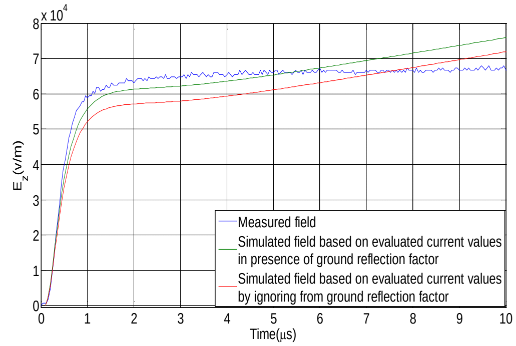

Fig. 7. Comparison between simulated vertical electric fields and the corresponding measured field at r_2= 30 m.

Figures 6 and 7 demonstrate that the ground reflection factor has a direct effect on the values of the electromagnetic fields due to the lightning channel and the additional reflected currents act as new sources along the lightning channel to create the electromagnetic fields. Therefore, by ignoring the ground reflection factor, an error will be entered into calculations. The proposed method can evaluate the full shape of the lightning return stroke currents using the measured electromagnetic field directly in the time domain while all field components and ground reflection factor are taken into consideration compared to previous methods. Likewise, the ground resistivity parameter can be entered into account by using equation (9) that considers on the relation between the ground impedance and ground resistivity [29]. It should be mentioned that $\rho_g = \frac{z_{ch}-z_g}{z_{ch}+z_g}$ [30, 31],

$$z_g = \frac{\rho}{2\pi l}\ln(\frac{4l}{r} - 1) \tag{9}$$

where, ρ is ground resistivity, l is the depth of rod (connection point), r is the radius of rod (connection point).

The proposed algorithm can be used to prepare a lightning current data bank, which can be used for studies into the effects of lightning on power systems, buildings and humans and for setting an appropriate protection level for a power system. Moreover, the method can consider a wide range of lightning occurrences using local measured electromagnetic fields and LLS compared to direct measuring methods that can consider only limited occurrences.

VI. CONCLUSION

In this paper, an inverse procedure algorithm is proposed to evaluate the full shape of lightning return stroke currents at different heights along a lightning channel in the time domain and it considers the all electromagnetic field components and the effect of the ground reflection factor on the fields. Moreover, the proposed algorithm is applied to a set of measured electromagnetic fields that have been obtained from a triggered lightning experiment and the results discussed accordingly. The proposed method can be used for preparing a lightning current data bank that can be very useful for studies into the effects of lightning on power systems and for setting the appropriate protection level for power systems and buildings.

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