Simulations of the Global Electrical Circuit coupled to local Potential Gradient measurements

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Simulations of the Global Electrical Circuit coupled to local Potential Gradient measurements

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Abstract. There are several models describing the Global Electric Circuit of the Earth's atmosphere. Here it is used the common model and parameters of Global Electric Circuit to couple it with a local circuit less studied in literature. The first objective is to test different voltage sources describing thunderstorm activity and compare the output, Potential Gradient, with the known *Carnegie Curve*. Two sets of parameters are used, the first one from values found in literature and the second one from values tweaked to get the best agreement between the simulated Potential Gradient and the *Carnegie Curve*. This study is a first step in simulations regarding the coupling of the Global Electric Circuit (primary) to local electric circuit (secondary). One of the main objectives is to estimate the aerosol load on the local resistor in case of aerosol events, e.g. fires.

1. Introduction

The existence of a Global Electric Circuit (GEC) was first recognised by the observation of the so called *Carnegie curve* based on a global daily variation of the surface Potential Gradient (PG) aboard of the Carnegie cruises [1]. For that reason, different models have been elaborated to understand the GEC proprieties [3, 4] and its relation with climate [5]. Nevertheless, scarce attempts have been made to perform simulations coupling the GEC primary circuit to a secondary circuit describing local PG measurements. Such simulations are of considerable interest because, for instance, in polluted regions the daily variation of PG differs drastically from the *Carnegie curve* [6]. Since it is expected that GEC would, in principle, impose a similar global daily variation, a deviation from the *Carnegie curve* could only be a result from local variations of the electrical components defining the secondary local circuit. If the proposed simulations were successful they would enable the separation of the global effects from local ones on real PG data. It would allow, for example, the estimation of the electric resistance load caused by atmospheric pollution from PG measurements in polluted environments like large cities [6] and severe pollution events like fires [7].

In this work, a method is described to couple a local circuit to the global one describing GEC. It is assumed that changes in the local circuit would not affect considerably the GEC. The model is presented and adjusted to reproduce the *Carnegie curve*.

2. Global Electric Circuit Simulations

Two main parts compose the electric circuit considered here. The first part englobes the components defining the primary circuit corresponding to GEC: V_s corresponds to the voltage generated by thunderstorm daily activity, R_s is the resistor associated with the thunderstorms region, R_{FW} is the resistor corresponding to fair-weather (FW) regions which closes the circuit in parallel with the Ionosphere-Earth (IE) capacitor, C_{IE}. This primary (global) circuit is coupled to a secondary circuit; which corresponds to the local circuit where the PG measurements take place. It is composed by R_{FT}, the resistor of the free-troposphere (FT) and R_{BL}, the resistor corresponding of the planetary boundary layer (BL). To account for space-charge density accumulation below the boundary layer [2] a capacitor, C_{BL}, is inserted in parallel with the R_{BL}. The diagram of the circuit is presented in Figure 1.

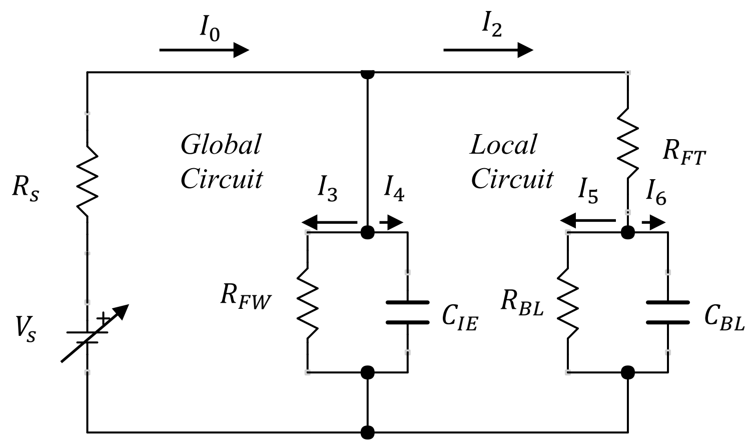

Figure 1 Circuit model and corresponding parameters.

2.1. Circuit equations

Using Kirchhoff's laws on the circuit of Figure 1 and the notation $I_n = \dot{Q}_n$ (where $\dot{Q}_n$ represents the time derivative of the *n* charge) it is obtained the following system of differential equations:

$$
\begin{aligned}
&-V_s + R_s\dot{Q}_0 + R_{FW}\dot{Q}_3 = 0;\\
&-R_{FW}\dot{Q}_3 + {Q_4}/{C_{IE}} = 0;\\
&-{Q_4}/{C_{IE}} + R_{BL}\dot{Q}_5 + R_{FT}\left(\dot{Q}_5 + \dot{Q}_6\right) = 0;\\
&{Q_6}/{C_{BL}} - R_{BL}\dot{Q}_5 = 0;\\
&\dot{Q}_0 - \dot{Q}_2 - \dot{Q}_3 - \dot{Q}_4 = 0;\\
&\dot{Q}_2 - \dot{Q}_5 - \dot{Q}_6 = 0.
\end{aligned}
\tag{1}
$$

Having V_{BL} (voltage drop at R_{BL}) as the secondary voltage output, $V_{BL} = {Q_6}/{C_{BL}}$, it is need to calculate Q_6 from Eq. (1). The numerical method used was the algorithm *ode45* from MATLAB®, which is based on an explicit Runge-Kutta (4,5) formula, with a relative and absolute tolerance of 10^{-6} [8]. A remark must be made here to explain the use of $I_n = \dot{Q}_n$; this is because such transformation converts the system of equations in (1) into a system of first order differential equations possible to integrate numerically.

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3. Results and discussion

The voltage source, representing the thunderstorms, V_s, was modulated in two different ways: 1) based on the *Carnegie curve, C_c*; 2) based on the *Ionosphere Potential*, I_P, modelled in [5]. For both cases the curves were divided by its mean and multiplied by V_0, the amplitude of the estimated voltage source for the global thunderstorm activity. The expressions are:

$$V_S^{Cc} = V_0 \times {C_c}/{\overline{C_c}}$$
$$V_S^{Ip} = V_0 \times {I_P}/{\overline{Ip}}. \qquad (2)$$

Two sets of parameters were used for the different components of the circuit. Firstly, parameters according to the literature [2]: V_0 = 100 MV, R_s = 100 kΩ, R_{FW} = 200 Ω, R_{BL} = 300 PΩ, R_{FT} = 25 PΩ, C_{IE} = 1 F and C_{BL} = 0.01 pF. Secondly, parameters tweaked to get a closer agreement between the simulations and the observed *Carnegie Curve*: V_0 = 110 MV, R_s = 80 kΩ, R_{FW} = 200 Ω, R_{BL} = 500 PΩ, R_{FT} = 25 PΩ, C_{IE} = 0.7 F, C_{BL} = 0.01 pF. The values of the simulated PG were found from V_{BL} by dividing it by the height of the boundary layer, h ~ 2000 m. The results obtaining are presented in Figure 2, as shown:

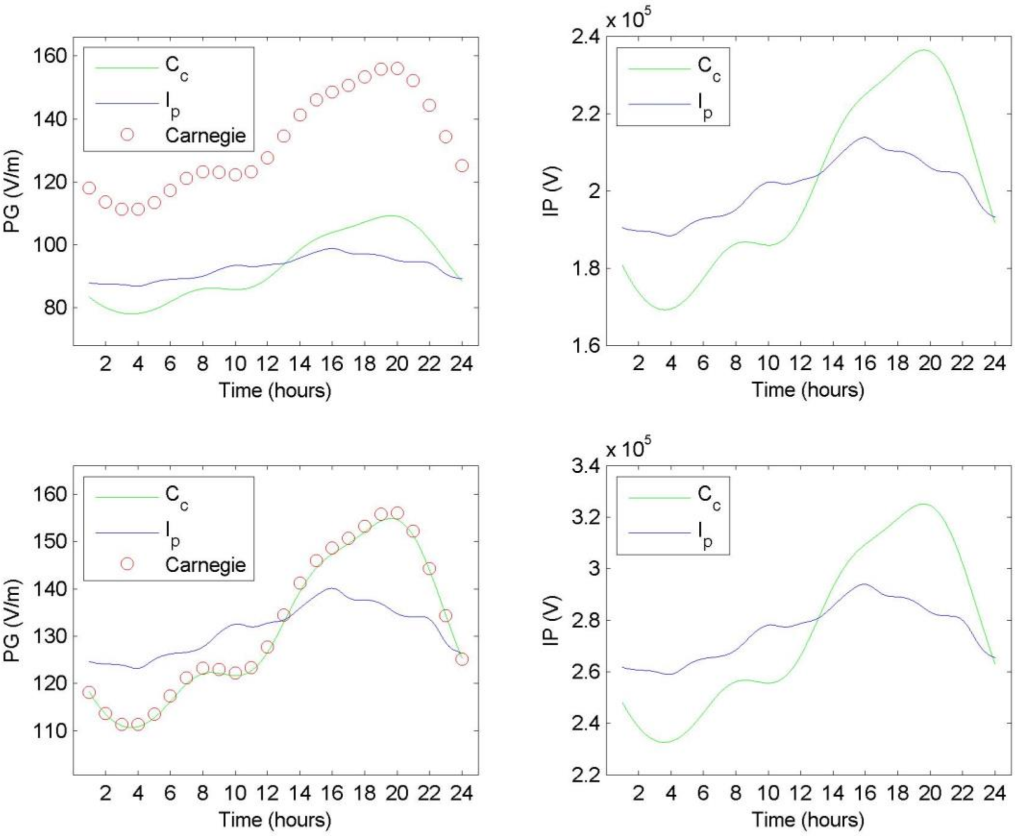

Figure 2 (Upper left): PG values simulated with the first set of parameters; (Upper right): Ionosphere Potential derived from the thunderstorms voltage source and resistance for the first set of parameters; (Bottom left): PG values simulated with the second set of parameters; (Bottom right): Ionosphere Potential derived from the thunderstorms voltage source and resistance for the second set of parameters.

It is seen that the input modulation shapes drastically the form of PG, as expected. On the one hand, using V_S^{Cc} with the typical values in the literature [3, 4] there is a remarkable difference between the observed *Carnegie Curve* and the simulated data. Using I_p modulation, V_S^{Ip}, the results show even a larger deviation because not only the maximum does not correspond to the one of daily variation, but also the PG amplitude is rather low. This results in a very poor similarity regarding *Carnegie Curve*. On the other hand, tweaking the parameters for both modulation cases, V_S^{Cc} and V_S^{Ip}, a perfect match between the simulated PG and the *Carnegie Curve* is found for the first case (as expected), but still a very poor agreement is found with the *Carnegie Curve* for the second one. The discrepancy between the PG simulated with V_S^{Ip} (expected to realistic describe the Ionosphere Potential) and the *Carnegie Curve* is noteworthy. Tentatively it can be argued that this is because of daily variation of R_{BL} associated with the daily dynamics of the boundary layer. With the present model such dynamics can be easily introduced in the simulations allowing R_{BL} to vary during the numerical integration. This is, in fact, a strong point of the present circuit simulations.

4. Conclusions

In the present work a method is described to couple the common model for the Global Electric Circuit (primary circuit) to a Local Circuit (secondary circuit) resembling real PG measurements. Though it is a preliminary approach, a significant discrepancy was found between the PG simulated with modeled Ionosphere Potential and the Carnegie Curve. Future work would involve different aspects and a major one is to test the contribution of thunderstorm activity as voltage or current source. One of the main objectives is to estimate the aerosol load on the local resistance in case of aerosol events, e.g. fires [7].

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