AN ELECTRICAL MODEL FOR DESCRIBING MARX GENERATORS

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Abstract

A numerical model for the equivalent circuit of a Marx type discharge is presented. The treatment includes the effect of finite closure time of the switches which drive the generator. The role of stray capacities in the generation of several oscillations (usually ascribed to "noise") is discussed. The results of numerical calculations for simple configurations are presented.

1. Introduction

In pulsed, high voltage discharges it is usually observed in the initial part of the measured magnitudes (like dI_L/dt, the temporal derivative of the current I_L circulating on a load with impedance Z_L), complex high frequency components superimposed to the expected temporal behavior. This phenomenon is commonly ascribed to noise pick-up (or resonances) in the measuring system. Marx generators behave also in this way and, in an effort to clarify the source of these high frequency components, we have developed a numerical model which yields the evolution of the electrical magnitudes in this kind of generators. In what follows, preliminary results will be presented and discussed.

2. Model and results

For simplicity, we will consider a two stage Marx generator, discharging on a load impedance Z_L through a switch S_L (see Fig. 1).

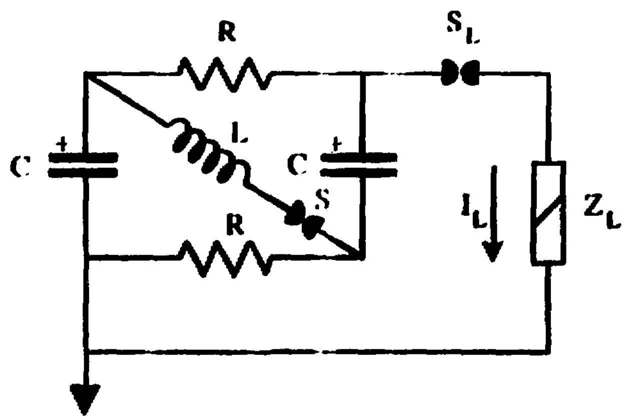

Fig. 1: Standard two stage Marx generator.

Both capacitors (capacity C) are externally charged up to the voltage V_o through the resistances R, and the switches S and S_L control the Marx erection and its discharge on the load, respectively. For a proper operation of the circuit, R » $(L/C)^{1/2}$ (L being the inductance associated with S and connections), so that when S begins its closing action the branches containing the R's can be considered as open circuits. To simulate the real behavior of the switches, we will treat them as "black box" elements, with voltage drops following a Fermi-Dirac-like function. This representation has been employed in previous works [1,2]. A time delay Δt between the closing of S_L and S is allowed for the model. The simplest conceivable equivalent circuit is shown in Fig. 2, where V_S and V_{SL} indicate the Fermi-Dirac functions quoted above, and L is the inductance associated with S. Note that a stray capacity (C_{SL}) associated with S_L has been included. The presence of this capacity (however small) is essential for a proper description of the voltage erection of the circuit, because it provides a path for the discharge current while S_L remains open.

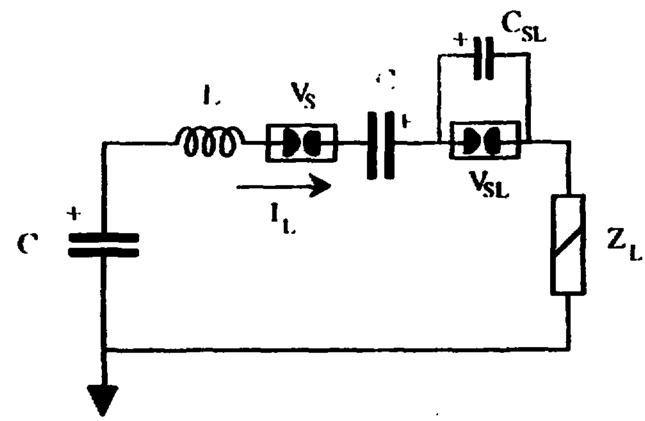

Fig 2: Equivalent circuit to model a two-stage Marx generator.

Kirchhoff's law for the circuit of Fig. 2 writes

$$2V_o - \frac{2}{C}\int_0^t I_L\,dT = L\frac{dI_L}{dT} + V_S + V_{SL} + V_{Z_L}$$

where according to the model chosen for simulating the behavior of the switches, we have employed the following expressions for V_S and V_{SL}

$$V_S = \frac{V_o[1 + \exp(-B_S T_S)]}{1 + \exp[B_S(T - T_S)]}$$

and

$$V_{SL} = \begin{cases} V_o + \dfrac{1}{C_{SL}}\displaystyle\int_0^T I_L\,dT & T \le \Delta T \\[2ex] \dfrac{2\,V_{SL}(\Delta T)}{1 + \exp[B_{SL}(T - \Delta T)]} & T \ge \Delta T \end{cases}$$

Both B_S and B_{SL} are related to the closure speed of the switches: 4.4 / B_S is the time required for V_S to fall from 0.9 V_o to 0.1 V_o (the equivalent holds for V_{SL}). The parameters T_S and ΔT are the "instants" at which the corresponding switches are closing. Solutions of the abowe equations have been found; as an example, in Fig. 3 we show dI_L/dT (in V_o/L units) as a function of the time T (in $(LC)^{1/2}$ units), for the case $C_{SL} = 10^{-5}$ C (that is, C_{SL} values in the pF range), L = 1 and $Z_L = (L/C)^{1/2}$ (purely resistive load). Besides, S_L is assumed to operate by overvoltage its voltage drop reaches $2V_o$, and with $\Delta t\,(LC)^{-1/2} = \Delta T = 0.1$. The closure speeds of the switches has been chosen as $B_S = B_{SL} = 100$, with $T_S = 0.01$.

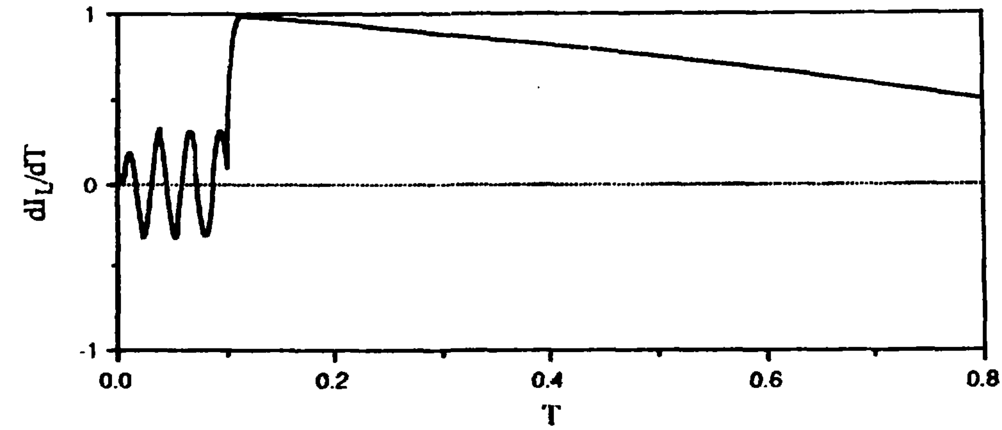

Fig 3: Tipical waveform of dI_L/dT obtained from the circuit of Fig 2.

As can be seen, dI_L/dT grows up from 0 during the closure time of S (i.e. while C_{SL} charges from V_o up to $2V_o$ (in the time interval $0 \le T \le 0.01$ in the example)), then dI_L/dT has oscillations around 0 while S_L remains open ($T < 0.1$), and finally the main discharge begins and dI_L/dT evolves according with what must be expected for a simple RLC series circuit, i.e. a damped sinusoid with a nondimensional period of $2\pi(7/4)^{1/2}$ for the chosen values of the parameters of this example. Also it can be noted that the high frequency oscillations can be easily predicted as resonances of an L C_{SL} circuit in the present example. In more involved cases, the frequency of these oscillations can also be predicted after a small amount of simple algebra.

In a real Marx generator, many other stray capacitances can arise taking into account that during the erection, conductors initially grounded are allowed to charge up to high voltages. The determination of these stray capacitances depends on the geometrical details of the actual device under study, and a full discussion of this subject exceed the scope of the present work. However, due to the fact that is common practice in Marx devices to locate both switches as close as possible (so that the UV emission from the first helps in the triggering of the second), a stray capacitance C' between S and S_L is likely to exist.

In Fig. 4 we show a modified equivalent circuit including C', and an inductance L' which takes into account a partition of the total series inductance.

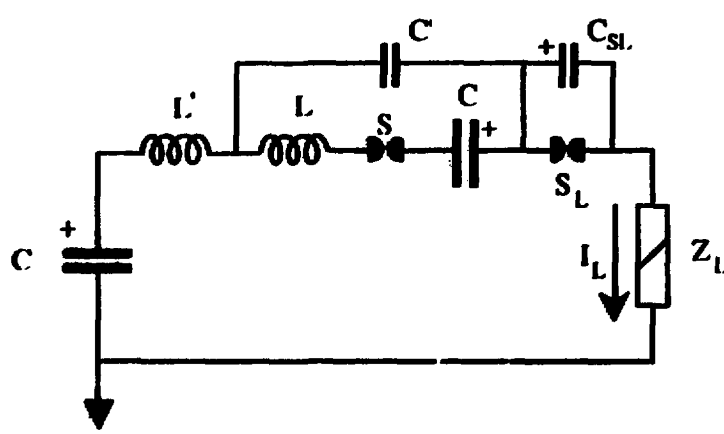

Fig 4: Equivalent circuit to model a two-stage Marx generator with a stray capacitance C" between switches.

In Fig. 5, dI_L/dT as a function of the time is given, for the same set of values of the parameters used in Fig. 3 and with $C' = C_{SL} = 10^{-5}$ C and $L' = L$. Now, higher frequency oscillations (both with S_L open or closed) appear, with periods which can be analytically obtained from a frequency analysis of the circuit and which are in good agreement with those obtained from the numerical calculations. It can be noted that during Δt, the curve of dI_L/dT has high frequency oscillations superimposed to a fundamental one.

In more elaborated models (with more stages or more stray elements, for instance) one must expect more complex spectral structures. Another point of interest to comment is the amplitude with which the high frequency oscillations can be excited. It is not possible to give an answer to this question in an annalitic way, but as a rule, one can say that the higher are the closure speed of the switches, the larger will be the amplitude of the excited harmonics.

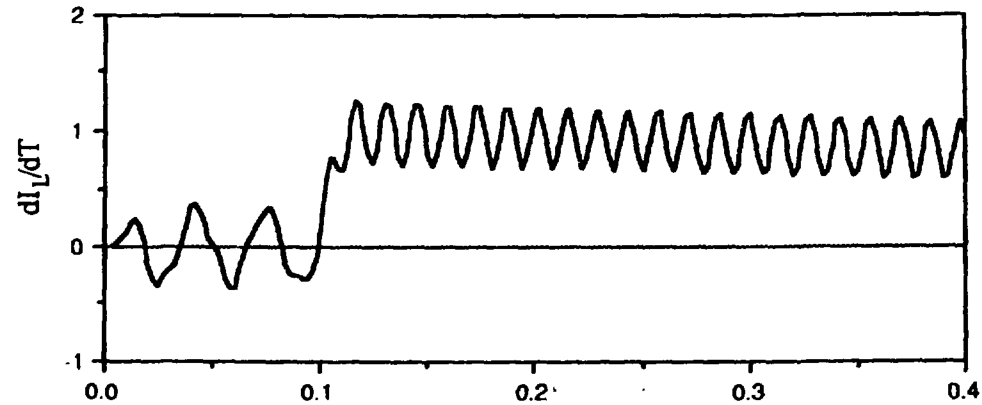

Fig 5: Tipical waveform of dI_L/dT obtained from the circuit of Fig 4.

3. Final remarks

It must be noted that the circuit of Fig. 4 does not contain all the stray elements which should be included for reproducing a measured signal. In fact, besides stray capacitances between switches one can add stray capacitances between the capacitors of the Marx, but this procedure should be made for the particular geometrical arrangement of each device. In particular, work in this direction is under way for the Marx generator of the Plasma Physics Laboratory of the Pontificia Universidad Católica de Chile, and the results of such study will be presented elsewhere.

As a final remark, we have shown that a proper electrical model for a Marx discharge requires the inclusion of several stray elements for reproducing high frequency resonances and the erection of the generator. Besides, the inclusion of finite closure times of the switches is also necessary for obtaining the amplitude of these harmonics.

Aknowledgements

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References

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[2] Bruzzone, H., Kelly, H., Moreno, C., IEEE Trans. Plasma Sci. (in press).