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Construction of Solitary Wave Solutions of Modeled Equations in a Nonlinear Hybrid Electrical Line

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Abstract

In this paper, we are using a hybrid electrical line meaning it is constituted by nonlinear inductors and nonlinear capacitors to derive two new set of nonlinear partial differential equations which govern the dynamics of solitary waves in the obtained lines. We therefore construct solitary wave solutions of the two set of equations by using direct and effective mathematical methods like that of Bogning-Djeumen Tchaho-Kofane [16-21]. This has permitted to discover that it is simultaneously propagated in one of the hybrid lines a set of two solitary waves of type (Kink; Kink) and in the other hybrid electrical line a set of two solitary waves of type (Pulse; Pulse) when the conditions we have elaborated are respected.

Keywords

Hybrid Electrical Line, Construction, Soliton Solution, Solitary Wave, Nonlinear Partial Differential Equation, Kink, Pulse

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1. Introduction

Years ago, solitary waves have left from a stage of simple water waves to the propagation of solitons in optical fibers [1]. Due to the simple fact that those solitary waves are defined as waves capable of propagating on a long distance without changing its shape and speed; it has come to our mind the idea that if such a signal is use in engineering of information through a hybrid electrical line, it will withstand better on different dissipation factors. We have therefore in this light decided to render analytical definitions of nonlinear magnetic flux linkage of the inductors and nonlinear charge of the capacitors; then we have applied them to model two new set of nonlinear partial differential equations which govern the dynamics of the set of two solitary waves in each of those lines. To construct the set of two solitary wave solutions in each set of nonlinear partial differential equations, we have first of all gotten inspiration on the solving methods presented in [2-15]. Next, we have decided to apply the new Bogning-Djeumen Tchaho-Kofane method [16-21] giving the fact that it facilitates the construction of solitary wave solutions of nonlinear partial differential equations by the identification of basic hyperbolic function coefficients through a direct and effective manner. This has permitted to obtain for each set of equation a set of two solitary wave solutions of type (Kink; Kink) and a set of two solitary wave solutions of type (Pulse; Pulse). The work presented in this paper is divided as follows: In part 2, we present the general modeling of a nonlinear hybrid electrical line. In part 3, we construct the set of two solitary wave solutions of type (Kink; Kink). In part 4, we construct the set of two solitary wave solutions of type (Pulse; Pulse). We finally present the conclusion in part 5.

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2. General Modeling of Nonlinear Hybrid Electrical Line

Let's consider a nonlinear hybrid electrical line as presented in figure 1 and which is constituted by identical networks; the network order n is constituted of an inductor whose magnetic flux linkage ϕ_n change in nonlinear manner in term of current i_n that flow through the inductor; a resistor of value R in series branch with the inductor; a capacitor whose charge q_n changes in nonlinear manner in terms of voltage u_n across that capacitor; another capacitor with conductance G in parallel with the capacitor.

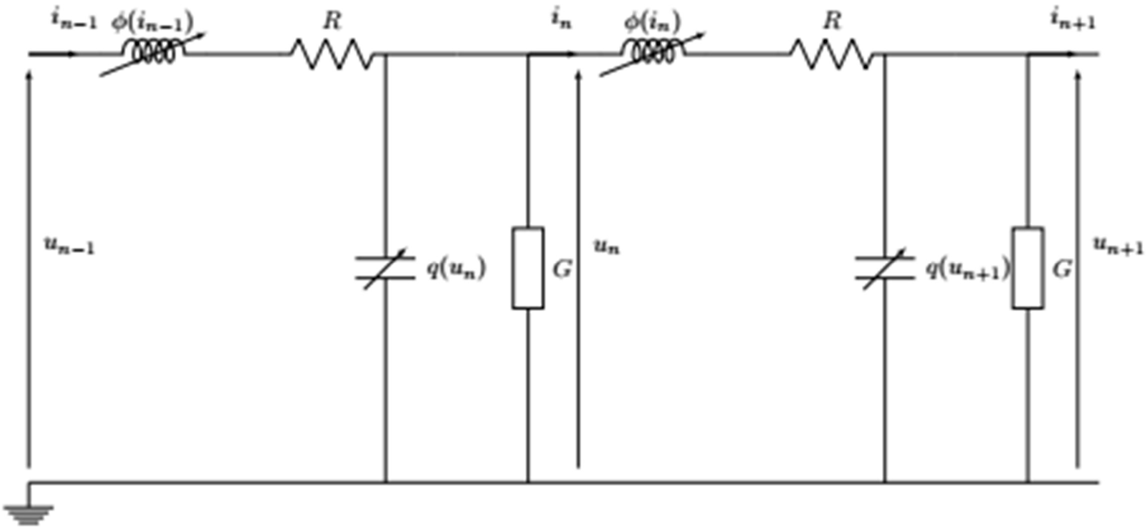

Figure 1. Presentation of a nonlinear hybrid electrical line.

Applying Kirchhoff laws in the circuit presented in figure 1, we obtain the following equations:

$$u_n - u_{n+1} = \frac{\partial \phi_n}{\partial t} + Ri_n , \tag{1}$$

$$i_{n-1} - i_n = \frac{\partial q_n}{\partial t} + Gu_n . \tag{2}$$

To obtain the continuum model, the left hand member of equations (1) and (2) have to be approximated by a partial derivative relative to $x = nh$ which is the distance measured from the beginning of the line. h is the distance which separates two consecutives nodes and is equivalent to the spatial sampling derivative period. By using Taylor expansion of u_{n+1} closely to u_n and i_{n-1} closely to i_n and considering the terms till second order as follows:

$$u_{n+1} = u_n + \frac{h}{1!}\frac{\partial u_n}{\partial x} + \frac{h^2}{2!}\frac{\partial^2 u_n}{\partial x^2} , \tag{3}$$

$$i_{n-1} = i_n - \frac{h}{1!}\frac{\partial i_n}{\partial x} + \frac{h^2}{2!}\frac{\partial^2 i_n}{\partial x^2} . \tag{4}$$

Considering equations (3) and (4), equations (1) and (2) can be rewritten as:

$$\begin{cases} \frac{h^2}{2}\frac{\partial^2 u_n}{\partial x^2} + h\frac{\partial u_n}{\partial x} + \frac{\partial \phi_n}{\partial t} + Ri_n = 0, \\ -\frac{h^2}{2}\frac{\partial^2 i_n}{\partial x^2} + h\frac{\partial i_n}{\partial x} + \frac{\partial q_n}{\partial t} + Gu_n = 0. \end{cases} \tag{5}$$

We can therefore present the general model of nonlinear hybrid electrical line of figure 1 by the set of two partial differential equations written as:

$$\begin{cases} \frac{h^2}{2}\frac{\partial^2 u(x,t)}{\partial x^2} + h\frac{\partial u(x,t)}{\partial x} + \frac{\partial \phi(i(x,t))}{\partial t} + Ri(x,t) = 0, \\ -\frac{h^2}{2}\frac{\partial^2 i(x,t)}{\partial x^2} + h\frac{\partial i(x,t)}{\partial x} + \frac{\partial q(u(x,t))}{\partial t} + Gu(x,t) = 0. \end{cases} \tag{6}$$

3. Construction of a Set of Two Solitary Wave Solutions of Type (Kink; Kink) Relative to General Differential Equation (6)

We define respectively the nonlinear charge $q(u(x,t))$ of the capacitors and the nonlinear magnetic flux linkage $\phi(i(x,t))$ of the inductors under the analytical shape given below:

$$\begin{cases} q(u(x,t)) = A_1 u(x,t) + A_2 u^2(x,t) + A_3 \ln\left(u^2(x,t) - A_0^2\right), \\ \phi(i(x,t)) = B_1 i(x,t) + B_2 i^2(x,t) + B_3 \ln\left(i^2(x,t) - B_0^2\right). \end{cases} \tag{7}$$

With $\left|u(x,t)\right| > \left|A_0\right|$, $\left|i(x,t)\right| > \left|B_0\right|$. A_1, A_2, A_3, B_1, B_2 and B_3 are non-zero real numbers whose conditions of choice will be elaborated. Substituting $q(u(x,t))$ and $\phi(i(x,t))$ of (7) in the set of differential equations (6) we obtain the set of two nonlinear partial differential equations written as:

$$\begin{cases} \left(\frac{h^2}{2} i^2(x,t) - \frac{h^2 B_0^2}{2}\right)\frac{\partial^2 u(x,t)}{\partial x^2} + \left(-hB_0^2 + hi^2(x,t)\right)\frac{\partial u(x,t)}{\partial x} \\ +\left(-B_1 B_0^2 + \left(2B_3 - 2B_2 B_0^2\right) i(x,t) + B_1 i^2(x,t) + 2B_2 i^3(x,t)\right)\frac{\partial i(x,t)}{\partial t} + Ri^3(x,t) - RB_0^2 i(x,t) = 0, \\ \left(-\frac{h^2}{2} u^2(x,t) + \frac{h^2 A_0^2}{2}\right)\frac{\partial^2 i(x,t)}{\partial x^2} + \left(-hA_0^2 + hu^2(x,t)\right)\frac{\partial i(x,t)}{\partial x} \\ +\left(-A_1 A_0^2 + \left(2A_3 - 2A_2 A_0^2\right) u(x,t) + A_1 u^2(x,t) + 2A_2 u^3(x,t)\right)\frac{\partial u(x,t)}{\partial t} + Gu^3(x,t) - GA_0^2 u(x,t) = 0. \end{cases} \tag{8}$$

Let us construct solution of a set of nonlinear partial differential equations (8) under the analytical shape as shown below:

$$\left(u(x,t) = a\tanh\left(kx - vt\right); i(x,t) = b\tanh\left(kx - vt\right)\right). \tag{9}$$

Where a, b, k and v are non-zero real numbers which will be determined in terms of the hybrid electrical line parameters. Replacing $u(x,t)$ and $i(x,t)$ of (9) in the set of nonlinear partial differential equations (8), we obtain the set of two equations below:

$$\begin{cases} \left(h^2 b^2 ak^2 + 2B_2 b^4 v\right)\frac{\sinh\left(kx - vt\right)}{\cosh^5\left(kx - vt\right)} + \left(B_1 b^3 v - akhb^2\right)\frac{1}{\cosh^4\left(kx - vt\right)} \\ +\left(Rb^3 - RbB_0^2\right)\frac{\sinh\left(kx - vt\right)}{\cosh\left(kx - vt\right)} \\ +\left(-Rb^3 + h^2 B_0^2 ak^2 - h^2 b^2 ak^2 - 2B_2 b^4 v + 2B_2 b^2 B_0^2 v - 2B_3 b^2 v\right)\frac{\sinh\left(kx - vt\right)}{\cosh^3\left(kx - vt\right)} \\ +\left(-B_1 b^3 v + B_1 B_0^2 bv - akhB_0^2 + akhb^2\right)\frac{1}{\cosh^2\left(kx - vt\right)} = 0, \\ \left(-h^2 a^2 bk^2 + 2A_2 a^4 v\right)\frac{\sinh\left(kx - vt\right)}{\cosh^5\left(kx - vt\right)} + \left(A_1 a^3 v - bkha^2\right)\frac{1}{\cosh^4\left(kx - vt\right)} \\ +\left(Ga^3 - GaA_0^2\right)\frac{\sinh\left(kx - vt\right)}{\cosh\left(kx - vt\right)} \\ +\left(-Ga^3 - h^2 A_0^2 bk^2 + h^2 a^2 bk^2 - 2A_2 a^4 v + 2A_2 a^2 A_0^2 v - 2A_3 a^2 v\right)\frac{\sinh\left(kx - vt\right)}{\cosh^3\left(kx - vt\right)} \\ +\left(-A_1 a^3 v + A_1 A_0^2 av - bkhA_0^2 + bkha^2\right)\frac{1}{\cosh^2\left(kx - vt\right)} = 0. \end{cases} \tag{10}$$

The set of two equations (10) is valid if and only if each of its basic hyperbolic function coefficients is zero. This permit us to obtain the set of ten equations written as follows:

$$\begin{cases} h^2b^2ak^2+2B_2b^4v=0, \\ B_1b^3v-akhb^2=0, \\ Rb^3-RbB_0^2=0, \\ -Rb^3+h^2B_0^2ak^2-h^2b^2ak^2-2B_2b^4v+2B_2b^2B_0^2v-2B_3b^2v=0, \\ -B_1b^3v+B_1B_0^2bv-akhB_0^2+akhb^2=0, \\ -h^2a^2bk^2+2A_2a^4v=0, \\ A_1a^3v-bkha^2=0, \\ Ga^3-GaA_0^2=0, \\ -Ga^3-h^2A_0^2bk^2+h^2a^2bk^2-2A_2a^4v+2A_2a^2A_0^2v-2A_3a^2v=0, \\ -A_1a^3v+A_1A_0^2av-bkhA_0^2+bkha^2=0. \end{cases} \tag{11}$$

Solving the set of equation (11) we obtain the solution given in (12) with different conditions relative to the set of nonlinear partial differential equations (8) which model the dynamics of the set of two solitary waves of type (Kink; Kink) in the hybrid electrical line:

$$a=A_0,\ b=B_0,\ k=\frac{2A_0A_2}{A_1h},\ v=\frac{2A_2B_0}{A_1^2},\ A_3=\frac{-GA_0A_1^2}{4A_2B_0},\ B_1=\frac{A_1A_0^2}{B_0^2},\ B_2=\frac{-A_0^3A_2}{B_0^3},\ B_3=\frac{-RA_1^2}{4A_2},$$

$$\left(u(x,t)=A_0\tanh\left(\frac{2A_0A_2}{A_1h}x-\frac{2A_2B_0}{A_1^2}t\right);i(x,t)=B_0\tanh\left(\frac{2A_0A_2}{A_1h}x-\frac{2A_2B_0}{A_1^2}t\right)\right). \tag{12}$$

4. Construction of a Set of Two Solitary Wave Solutions of Type (Pulse; Pulse) Relative to General Differential Equation (6)

We define respectively the nonlinear charge $q(u(x,t))$ of the capacitors and the nonlinear magnetic flux linkage $\phi(i(x,t))$ of the inductors under the analytical shape given below:

$$\begin{cases} q(u(x,t))=A_1u(x,t)+A_2u(x,t)\sqrt{1-\left(\frac{u(x,t)}{A_0}\right)^2}+A_3\arctan\left(\sqrt{\frac{u^2(x,t)}{A_0^2-u^2(x,t)}}\right), \\ \phi(i(x,t))=B_1i(x,t)+B_2i(x,t)\sqrt{1-\left(\frac{i(x,t)}{B_0}\right)^2}+B_3\arctan\left(\sqrt{\frac{i^2(x,t)}{B_0^2-i^2(x,t)}}\right). \end{cases} \tag{13}$$

Where $|A_0|>|u(x,t)|$, $|B_0|>|i(x,t)|$. A_1, A_2, A_3, B_1, B_2 and B_3 are non-zero real numbers whose condition of their choice will be elaborated. Substituting $q(u(x,t))$ and $\phi(i(x,t))$ of (13) in a set of general differential equation (6), we obtain the set of two nonlinear partial differential equations written as:

$$\begin{cases} h^2 B_0\sqrt{B_0^2-i^2(x,t)}\dfrac{\partial^2 u(x,t)}{\partial x^2}+2hB_0\sqrt{B_0^2-i^2(x,t)}\dfrac{\partial u(x,t)}{\partial x} \\ +\left(2B_1B_0\sqrt{B_0^2-i^2(x,t)}-4B_2i^2(x,t)+2B_3B_0+2B_2B_0^2\right)\dfrac{\partial i(x,t)}{\partial t} \\ +2RB_0 i(x,t)\sqrt{B_0^2-i^2(x,t)}=0, \\ -h^2A_0\sqrt{A_0^2-u^2(x,t)}\dfrac{\partial^2 i(x,t)}{\partial x^2}+2hA_0\sqrt{A_0^2-u^2(x,t)}\dfrac{\partial i(x,t)}{\partial x} \\ +\left(2A_1A_0\sqrt{A_0^2-u^2(x,t)}-4A_2u^2(x,t)+2A_3A_0+2A_2A_0^2\right)\dfrac{\partial u(x,t)}{\partial t} \\ +2GA_0u(x,t)\sqrt{A_0^2-u^2(x,t)}=0. \end{cases} \tag{14}$$

Let us construct the solution relative to the set of nonlinear partial differential equation (14) under the analytical shape given below:

$$\left(u(x,t)=a\,\mathrm{sech}\left(kx-vt\right);i(x,t)=b\,\mathrm{sech}\left(kx-vt\right)\right) \tag{15}$$

Where a, b, k and v are non-zero real numbers which will be determined in terms of the hybrid electrical line parameters. Replacing $u(x,t)$ and $i(x,t)$ of (15) in the set of nonlinear partial differential equation (14), we obtain the set of two equations as follows:

$$\begin{cases} \sqrt{A_0^2-\dfrac{a^2}{\cosh^2\left(kx-vt\right)}}\left(\begin{array}{l}\left(2GaA_0-h^2A_0bk^2\right)\dfrac{1}{\cosh\left(kx-vt\right)} \\ +\left(-2hbkA_0+2avA_0A_1\right)\dfrac{\sinh\left(kx-vt\right)}{\cosh^2\left(kx-vt\right)} \\ +2h^2A_0bk^2\dfrac{1}{\cosh^3\left(kx-vt\right)}\end{array}\right) \\ +2avA_0A_3\dfrac{\sinh\left(kx-vt\right)}{\cosh^2\left(kx-vt\right)}+2aA_2A_0^2v\dfrac{1}{\cosh^2\left(kx-vt\right)}-4a^3vA_2\dfrac{\sinh\left(kx-vt\right)}{\cosh^4\left(kx-vt\right)}=0, \\ \sqrt{B_0^2-\dfrac{b^2}{\cosh^2\left(kx-vt\right)}}\left(\begin{array}{l}\left(2RbB_0+h^2B_0ak^2\right)\dfrac{1}{\cosh\left(kx-vt\right)} \\ +\left(-2hakB_0+2bvB_0B_1\right)\dfrac{\sinh\left(kx-vt\right)}{\cosh^2\left(kx-vt\right)} \\ -2h^2B_0ak^2\dfrac{1}{\cosh^3\left(kx-vt\right)}\end{array}\right) \\ +2bvB_0B_3\dfrac{\sinh\left(kx-vt\right)}{\cosh^2\left(kx-vt\right)}+2bB_2B_0^2v\dfrac{1}{\cosh^2\left(kx-vt\right)}-4b^3vB_2\dfrac{\sinh\left(kx-vt\right)}{\cosh^4\left(kx-vt\right)}=0. \end{cases} \tag{16}$$

We realize that to be able to transform the hyperbolic functions of equation (16) to the basic hyperbolic functions as recommended by the new Bogning-Djeumen Tchaho-Kofane method [16-21], we must consider $A_0=a$; $B_0=b$ such that:

$$\begin{cases} \sqrt{A_0^2-\dfrac{a^2}{\cosh^2\left(kx-vt\right)}}=a\tanh\left(kx-vt\right), \\ \sqrt{B_0^2-\dfrac{b^2}{\cosh^2\left(kx-vt\right)}}=b\tanh\left(kx-vt\right). \end{cases} \tag{17}$$

Replacing $\sqrt{A_0^2-\frac{a^2}{\cosh^2(kx-vt)}}$ and $\sqrt{B_0^2-\frac{b^2}{\cosh^2(kx-vt)}}$ of (17) in the set of equation (16) we obtain:

$$\begin{cases} \left(2Ga^2A_0-h^2A_0abk^2+2avA_0A_3+2aA_2A_0^2v\right)\frac{\sinh(kx-vt)}{\cosh^2(kx-vt)} \\ +\left(-2hbkA_0a+2a^2vA_0A_1\right)\frac{1}{\cosh(kx-vt)} \\ +\left(2h^2A_0abk^2-4a^3vA_2\right)\frac{\sinh(kx-vt)}{\cosh^4(kx-vt)}+\left(2hbkA_0a-2a^2vA_0A_1\right)\frac{1}{\cosh^3(kx-vt)}=0, \\ \left(2Rb^2B_0+h^2B_0abk^2+2bvB_0B_3+2bB_2B_0^2v\right)\frac{\sinh(kx-vt)}{\cosh^2(kx-vt)} \\ +\left(-2hbkB_0a+2b^2vB_0B_1\right)\frac{1}{\cosh(kx-vt)} \\ +\left(-2h^2B_0abk^2-4b^3vB_2\right)\frac{\sinh(kx-vt)}{\cosh^4(kx-vt)}+\left(2hbkB_0a-2b^2vB_0B_1\right)\frac{1}{\cosh^3(kx-vt)}=0. \end{cases} \tag{18}$$

The set of two equations (18) is valid if and only if each of its basic hyperbolic function coefficients is zero. This brings about the set of eight equations given below:

$$\begin{cases} 2Ga^2A_0-h^2A_0abk^2+2avA_0A_3+2aA_2A_0^2v=0, \\ -2hbkA_0a+2a^2vA_0A_1=0, \\ 2h^2A_0abk^2-4a^3vA_2=0, \\ 2hbkA_0a-2a^2vA_0A_1=0, \\ 2Rb^2B_0+h^2B_0abk^2+2bvB_0B_3+2bB_2B_0^2v=0, \\ -2hbkB_0a+2b^2vB_0B_1=0, \\ -2h^2B_0abk^2-4b^3vB_2=0, \\ 2hbkB_0a-2b^2vB_0B_1=0. \end{cases} \tag{19}$$

Solving the set of equation (19), we obtain the solution presented in (20) with different conditions relative to the set of nonlinear partial differential equations (14) which is a set of two solitary waves of type (Pulse; Pulse) which is propagated simultaneously in the modeled hybrid electrical line:

$$a=A_0,\ b=B_0,\ v=\frac{2B_0A_2}{A_1^2A_0},\ k=\frac{2A_2}{hA_1},\ A_3=\frac{-GA_1^2A_0^2}{2B_0A_2},\ B_1=\frac{A_0^2A_1}{B_0^2},\ B_2=\frac{-A_0^2A_2}{B_0^2},\ B_3=\frac{-RA_1^2A_0}{2A_2},$$

$$\left(u(x,t)=A_0\,\mathrm{sech}\left(\frac{2A_2}{hA_1}x-\frac{2B_0A_2}{A_1^2A_0}t\right);i(x,t)=B_0\,\mathrm{sech}\left(\frac{2A_2}{hA_1}x-\frac{2B_0A_2}{A_1^2A_0}t\right)\right). \tag{20}$$

5. Conclusion

At the end of this work, where we have modeled a hybrid electrical line by the set of two nonlinear partial differential equations which have had each, a set of two solitary wave solutions; it is necessary to point out that the results obtained will first of all enable us in the field of physics and engineering of telecommunication, the manufacturing of new transmission lines notably two hybrids electrical lines whose magnetic flux linkage of inductors and charge of capacitors of one change in nonlinear manner defined in (7), and the other change in nonlinear manner defined in (13). In addition, these results will permit an amelioration of the quality of signals which will be displaced in the two hybrid electrical lines. In fact, these signals are on the one hand a set of two solitary waves of type (Kink; Kink) obtained in (12) and on the other hand the set of two solitary waves of type

(Pulse; Pulse) obtained in (20), Which by their definition are propagated on longer distances maintaining their shape and speed by resisting best to the dissipation factors. Finally, in a purely mathematical domain, the results obtained have enabled us to define in (8) and (14) two new set of nonlinear partial differential equations which have respectively for exact solutions the set of two solitary waves given by (12) and the set of two solitary wave given by (20); this by increasing the field of mathematical knowledge. In order to bring up new ideas on the stability of the two sets of solitary waves obtained, it is necessary for us to study next their modulational instability before carrying out a practical exercise where we will experiment the applicability and the perfection of the two new hybrid electrical lines.

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