



A new survey to the nonlinear electrical transmission line model

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ABSTRACT

In this paper, we find new travelling wave solutions to the nonlinear electrical transmission line model. Exponential function method is applied. This model is used to the voltage behaviors in electrical transmission lines. Under a suitable choice of control parameters, we plot the figures along with contour surfaces of new solutions by using computational programs such as Mathematica, Maple and Matlab. Some information about the behavior of voltage on the electrical lines is extracted. The hyperbolic, periodic or singular properties are reported.

1. Introduction

In modern century, energy transfer systems (ETS) play an important role in applied science such as engineering, physics, optics and so on. Such models are based on the network line with various parameters. Many scientists studied on the various forms of ETS. Furthermore, with the help of newly developed tools for network line, new ETS were explored. Moreover, many new real world problems including network line and ETS were symbolized by using mathematical models (Chikalova-Luzina, Samosvat, Vyatkin, & Zegrya, 2019). One of such problems is the nonlinear electrical transmission line model in (2 + 1) dimensions. Kumar et al. have investigated the complex structures of nonlinear transmission line model (Kumar, Seadawy, & Chowdhury, 2018). Pelap & Faye have presented the new soliton solutions of electrical transmission line model (Pelap & Faye, 2005). Further, researches of electrical model were presented by Marquie et al. with theoretical applications (Marquie, Bilbault, & Remoissenet, 1995). They focused on the nonlinear behavior of the electrical lattice model. Moreover, they submitted some important simulations of electrical lattice behavior. Ciancio et al. presented the important properties of wave propagation in thermo visco elastic model (Ciancio, Ciancio, & Farsaci, 2007) and a hybrid model for tumor-immune system (Ciancio & Quartarone, 2013). Ciancio et al. investigated the thermo mechanical model in elastic media (Ciancio, Ciancio, & Farsaci, 2008). Seadawy searched for ion-acoustic waves in a magnetized and in quantum plasma (Seadawy, 2014, 2016, 2017). Dusunceli and his team observed the high-order linear com-

plex differential equations with variable coefficients (Dusunceli, 2017). Some important properties of the fractal distribution of primes and prime-indexed were observed by Cattani and Ciancio (2016). Bulut studied on the Cahn-Allen model, generalized double Sinh-Gordon and K(m,n) equation (Bulut, 2017, 2013, 2015). Many other nonlinear partial differential equations (Antuñña, Guirao, & López, 2021, 2020, 2014; Baskonus & Bulut, 2015; Baskonus & Cattani, 2018; Baskonus, Bulut, & Sulaiman, 2019; Bienvenue, Gambo, Mibaille, Hammouch, & Houwe, 2019; Khalique, 2018; Cattani, 2012; Cattani, 2003, 2003; Cattani, Pierro, & Altieri, 2012; Cattani, Sulaiman, Baskonus, & Bulut, 2018, 2018; Demir & Sungu, 2009; Eskitascioglu, Aktaş, & Baskonus, 2019; Hammouch, Mekkaoui, & Agarwal, 2018; Ilhan, Esen, Bulut, & Baskonus, 2019; Kaya & Yokus, 2012; Moleleki, Motsepa, & Khalique, 2018; Sulaiman, Bulut, Yokus, & Baskonus, 2019; Touchent, Hammouch, Mekkaoui, & Unlu, 2019; Uddin, Hafez, Hammouch, & Baleanu, 2020, 2021) used to symbolize important physical properties of real word problems were investigated.

One of such models is the (2 + 1)-dimensional nonlinear electrical transmission line model (NETLM) defined as (Tala-Tebue & Zayed, 2018; Tala-Tebue, Tsobgni-Fozap, Kenfack-Jiotsa, & Kofane, 2014)

$$v_{tt} - \alpha(v^2)_{tt} + \beta(v^3)_{tt} - \omega_0^2 \delta_1^2 v_{xx} - \omega_0^2 \frac{\delta_1^4}{12} v_{xxxx} - \omega_0^2 \delta_2^2 v_{yy} - \omega_0^2 \frac{\delta_2^4}{12} v_{yyyy} = 0, \quad (1)$$

where $\alpha, \beta, \omega_0, \delta_1, \delta_2$ are real constants with non-zero. $v = v(x, y, t)$ is dependent function of x, y, t . Eq. (1) is used to symbolize the voltage in

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electrical transmission line and also is used to describe the wave propagation in the network line. In Tala-Tebue and Zayed (2018), Tala-Tebue et al. investigated new jacobi elliptic function properties of Eq. (1).

This paper is organized as follows. The main properties of the method are given in Section 2. In Section 3, we apply the exponential function method (EFM) to the NETLM. We present a comprehensive conclusion in the last section.

2. General properties of EFM

In this section, exponential function method is presented in detail.

Step 1: Let's consider the nonlinear partial differential equation as

$$P(u, u_x, u_y, u_t, u^2, u_{xx}, \dots) = 0, \tag{2}$$

in which $u = u(x, y, t)$ is an unknown function, P is a polynomial in u . Taking the travelling wave transformation (Baskonus & Bulut, 2015)

$$u(x, y, t) = U(\xi), \quad \xi = k(x + y - ct), \tag{3}$$

$$\begin{aligned} \frac{\partial u}{\partial x} &= kU', \\ \frac{\partial u}{\partial y} &= -cU', \\ \frac{\partial u}{\partial t} &: \end{aligned} \tag{4}$$

where k, c are real constants and non-zero, Eq. (2) can be converted into nonlinear ordinary differential equation (NODE) as following,

$$NODE(U, U', U'', U''', \dots) = 0, \tag{5}$$

where $NODE$ is a polynomial of $U = U(\xi)$.

Step 2: We suppose the test function of solution formula to Eq. (5) as

$$U = \sum_{i=0}^N A_i [\exp(-\Omega(\xi))]^i = A_0 + A_1 \exp(-\Omega(\xi)) + \dots + A_N \exp(-N\Omega(\xi)), \tag{6}$$

in which A_i ($0 \leq i \leq N$) are real-constants with non-zero. Here, $\Omega = \Omega(\xi)$ satisfies the following differential equation

$$\Omega' = \mu \exp(\Omega) + \exp(-\Omega) + \lambda. \tag{7}$$

Eq. (7) has of the following results

Family-1: If $\mu \neq 0, \lambda^2 - 4\mu > 0$,

$$\Omega(\xi) = \ln \left(\frac{-\sqrt{\lambda^2 - 4\mu}}{2\mu} \tanh \left(\frac{\sqrt{\lambda^2 - 4\mu}}{2} (\xi + c_1) \right) - \frac{\lambda}{2\mu} \right), \tag{8}$$

Family-2: When $\mu \neq 0, \lambda^2 - 4\mu < 0$,

$$\Omega(\xi) = \ln \left(\frac{\sqrt{-\lambda^2 + 4\mu}}{2\mu} \tan \left(\frac{\sqrt{-\lambda^2 + 4\mu}}{2} (\xi + c_1) \right) - \frac{\lambda}{2\mu} \right), \tag{9}$$

Family-3: When $\mu = 0, \lambda \neq 0$, and $\lambda^2 - 4\mu > 0$,

$$\Omega(\xi) = -\ln \left(\frac{\lambda}{\exp(\lambda(\xi + c_1)) - 1} \right), \tag{10}$$

Family-4: When $\mu \neq 0, \lambda \neq 0$, and $\lambda^2 - 4\mu = 0$,

$$\Omega(\xi) = \ln \left(-\frac{2\lambda(\xi + c_1) + 4}{\lambda^2(\xi + c_1)} \right), \tag{11}$$

Family-5: When $\mu = 0, \lambda = 0$, and $\lambda^2 - 4\mu = 0$,

$$\Omega(\xi) = \ln(\xi + c_1), \tag{12}$$

being $A_0, A_1, A_2, \dots, A_N, c_1, \lambda, \mu$ are real-constants and non-zero.

Step 3: Setting Eqs. (3), and (4) into Eq. (2), we find a polynomial of $e^{-\Omega(\xi)}$ with various power. Considering all the coefficients of same power of $e^{-\Omega(\xi)}$ to zero gives a system of algebraic equations. By solving this system, we can obtain the solutions to the Eq. (2).

3. Application of EFM

In this section, we apply EFM to the Eq. (1) as following. Let's consider the travelling wave transformation formula

$$v = v(x, y, t) = V(\xi), \quad \xi = k(x + y - ct), \tag{13}$$

where k, c are real constants and non-zero. Substituting Eq. (13) into Eq. (1), we obtain following nonlinear ordinary differential equation

$$\begin{aligned} [c^2 - \omega_0^2 \delta_2^2 - \omega_0^2 \delta_1^2] k^2 V'' - 2\alpha k^2 c^2 [V V']' + 3\beta k^2 c^2 [V^2 V']' \\ - [\omega_0^2 \delta_1^4 + \omega_0^2 \delta_2^4] \frac{k^4}{12} V^{(4)} = 0. \end{aligned} \tag{14}$$

If we integrate this model twice by getting to zero of integration constants, Eq. (14) can be rewritten as

$$12[c^2 - \omega_0^2 \delta_1^2 - \omega_0^2 \delta_2^2] V + 12\beta c^2 V^3 - 12\alpha c^2 V^2 - k^2 [\omega_0^2 \delta_1^4 + \omega_0^2 \delta_2^4] V'' = 0. \tag{15}$$

Balancing among V'' and V^3 , we obtain the value of N as

$$N = 1, \tag{16}$$

which produces the text function of solution as

$$V = A_0 + A_1 \exp(-\Omega), \tag{17}$$

with

$$\begin{aligned} V' &= A_1 e^{(-\Omega)} (-\mu e^{\Omega} - e^{(-\Omega)} - \lambda), \\ V'' &= \dots, \\ &: \end{aligned} \tag{18}$$

where $A_1 \neq 0$. Using Eqs. (17) and (18) into Eq. (15) gives a system of algebraic equations. Solving this system gives many new travelling wave solutions to the Eq. (1) as following cases.

Case-1. If

$$\begin{aligned} A_0 &= \frac{\alpha + \sqrt{\alpha^2 + 9\beta^2 \mu A_1^2}}{3\beta}, \quad c = 3 \frac{\sqrt{-\beta(\omega_0^2 \delta_1^2 + \delta_2^2 \omega_0^2)}}{\sqrt{2\alpha^2 - 9\beta}}, \\ \lambda &= \frac{2\sqrt{\alpha^2 + 9\beta^2 \mu A_1^2}}{3\beta A_1}, \quad k = \frac{3i\sqrt{6\beta} A_1 \sqrt{\omega_0^2 \delta_1^2 + \delta_2^2 \omega_0^2}}{\sqrt{(2\alpha^2 - 9\beta)(\omega_0^2 \delta_1^4 + \delta_2^4 \omega_0^2)}}, \end{aligned} \tag{19}$$

we find the new complex solution to the Eq. (1) under the terms of Family-1 being $\mu \neq 0, \lambda^2 - 4\mu = \frac{4(\alpha^2 + 9\beta^2 \mu A_1^2)}{9\beta^2 A_1^2} - 4\mu > 0$, as

$$v_1 = \frac{\alpha + \sqrt{\rho}}{3\beta} + \frac{6\beta \mu A_1^2}{-2\sqrt{\rho} - \varphi \tanh \left(c_1 \kappa + i\tau \kappa x + i\tau \kappa y - 3i\tau \kappa \frac{\sqrt{-\beta(\omega_0^2 \delta_1^2 + \delta_2^2 \omega_0^2)}}{\sqrt{2\alpha^2 - 9\beta}} t \right)}, \tag{20}$$

where $\varphi = \sqrt{4\rho - 36\beta^2 A_1^2 \mu}$, $\tau = \frac{3\sqrt{6\beta} A_1 \sqrt{\omega_0^2 \delta_1^2 + \delta_2^2 \omega_0^2}}{\sqrt{(2\alpha^2 - 9\beta)(\omega_0^2 \delta_1^4 + \delta_2^4 \omega_0^2)}}$, $\kappa =$

$$\frac{1}{2} \frac{\sqrt{4\rho - 36\beta^2 A_1^2 \mu}}{3\beta A_1}, \quad \rho = \alpha^2 + 9\beta^2 \mu A_1^2.$$

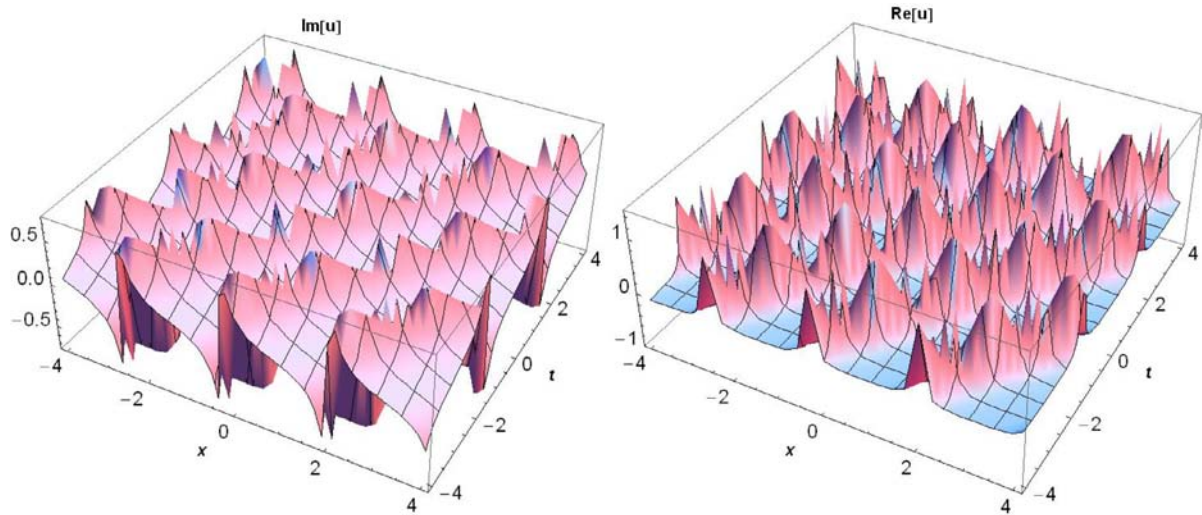


Fig. 1. The 3D graphs of Eq. (20).

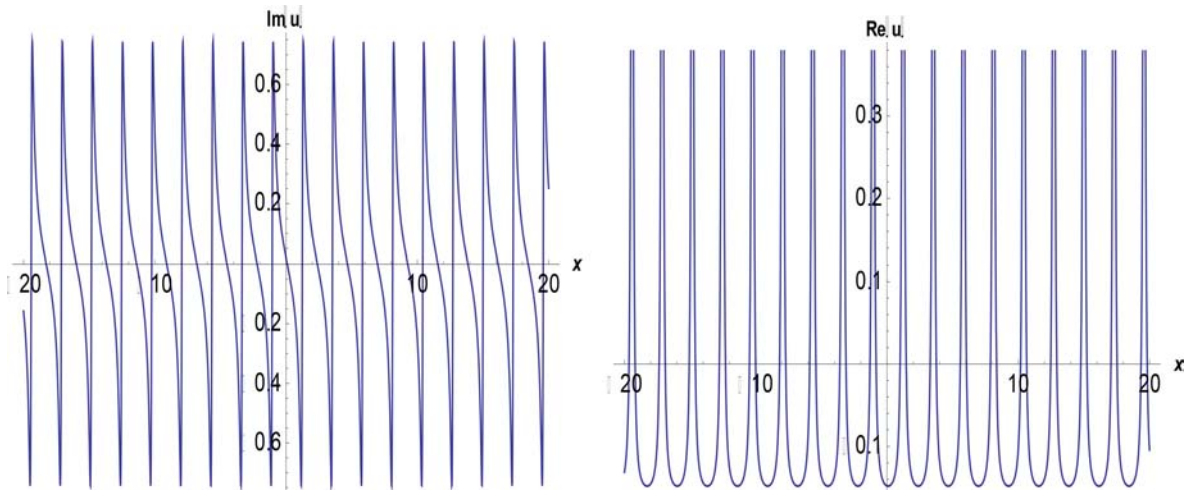


Fig. 2. The 2D graphs of Eq. (20).

Case-2. When

$$c = -3 \frac{\sqrt{-\beta(w_0^2 \delta_1^2 + \delta_2^2 \omega_0^2)}}{\sqrt{2\alpha^2 - 9\beta}}, \quad A_1 = \frac{i\sqrt{\beta A_0(2\alpha - 3\beta A_0)}}{\sqrt{3\beta}\sqrt{\mu}},$$

$$k = \frac{3\sqrt{2}\sqrt{\beta A_0(2\alpha - 3\beta A_0)}\sqrt{w_0^2 \delta_1^2 + \delta_2^2 \omega_0^2}}{\sqrt{(2\alpha^2 - 9\beta)\mu(w_0^2 \delta_1^4 + \delta_2^4 \omega_0^2)}}, \quad \lambda = \frac{2i\sqrt{\mu}(\alpha - 3\beta A_0)}{\sqrt{6\alpha\beta A_0 - 9\beta^2 A_0^2}}, \quad (21)$$

these produce another new dark complex solution to the Eq. (1) under the terms of Family-1 which $\mu \neq 0$, $\lambda^2 - 4\mu = -4\mu - \frac{4\mu(\alpha - 3\beta A_0)^2}{6\alpha\beta A_0 - 9\beta^2 A_0^2} > 0$, as

$$v_2 = A_0 + 2i\vartheta \left(-2i\beta\sqrt{3\mu}\zeta - \beta\psi\sqrt{3} \tanh\left(\frac{1}{2}c_1 v + \frac{1}{2}\varpi v x + \frac{1}{2}\varpi v y + \frac{3}{2}\varpi v t \zeta\right) \right)^{-1}, \quad (22)$$

where $\varpi = \frac{3\sqrt{2}\sqrt{\beta A_0(2\alpha - 3\beta A_0)}\sqrt{w_0^2 \delta_1^2 + \delta_2^2 \omega_0^2}}{\sqrt{(2\alpha^2 - 9\beta)\mu(w_0^2 \delta_1^4 + \delta_2^4 \omega_0^2)}}$, $\psi = \sqrt{-4\mu - \frac{4\mu(\alpha - 3\beta A_0)^2}{6\alpha\beta A_0 - 9\beta^2 A_0^2}}$, $v = \sqrt{-4\mu - \frac{4\mu(\alpha - 3\beta A_0)^2}{6\alpha\beta A_0 - 9\beta^2 A_0^2}}$, $\zeta = \frac{(\alpha - 3\beta A_0)}{\sqrt{6\alpha\beta A_0 - 9\beta^2 A_0^2}}$, $\zeta = \frac{\sqrt{-\beta(w_0^2 \delta_1^2 + \delta_2^2 \omega_0^2)}}{\sqrt{2\alpha^2 - 9\beta}}$, $\vartheta = \sqrt{\mu\beta A_0(2\alpha - 3\beta A_0)}$.

Case-3. Considering other coefficients as

$$c = 3 \frac{\sqrt{-\beta(w_0^2 \delta_1^2 + \delta_2^2 \omega_0^2)}}{\sqrt{2\alpha^2 - 9\beta}}, \quad A_1 = -\frac{i\sqrt{\beta A_0(2\alpha - 3\beta A_0)}}{\sqrt{3\beta}\sqrt{\mu}},$$

$$k = -\frac{3\sqrt{2}\sqrt{\beta A_0(2\alpha - 3\beta A_0)}\sqrt{w_0^2 \delta_1^2 + \delta_2^2 \omega_0^2}}{\sqrt{(2\alpha^2 - 9\beta)\mu(w_0^2 \delta_1^4 + \delta_2^4 \omega_0^2)}}, \quad \lambda = \frac{-2i\sqrt{\mu}(\alpha - 3\beta A_0)}{\sqrt{6\alpha\beta A_0 - 9\beta^2 A_0^2}}, \quad (23)$$

we obtain the another novel complex dark solution to the Eq. (1) with the terms of Family-1 which $\lambda^2 - 4\mu = -4\mu - \frac{4\mu(\alpha - 3\beta A_0)^2}{6\alpha\beta A_0 - 9\beta^2 A_0^2} > 0$, as

$$v_3 = A_0 - 2i\vartheta \left(2i\beta\sqrt{3\mu}\zeta - 2\beta\psi\sqrt{3} \tanh(c_1\psi - \varpi\psi x - \varpi\psi y + 3\varpi\psi t \zeta) \right)^{-1},$$

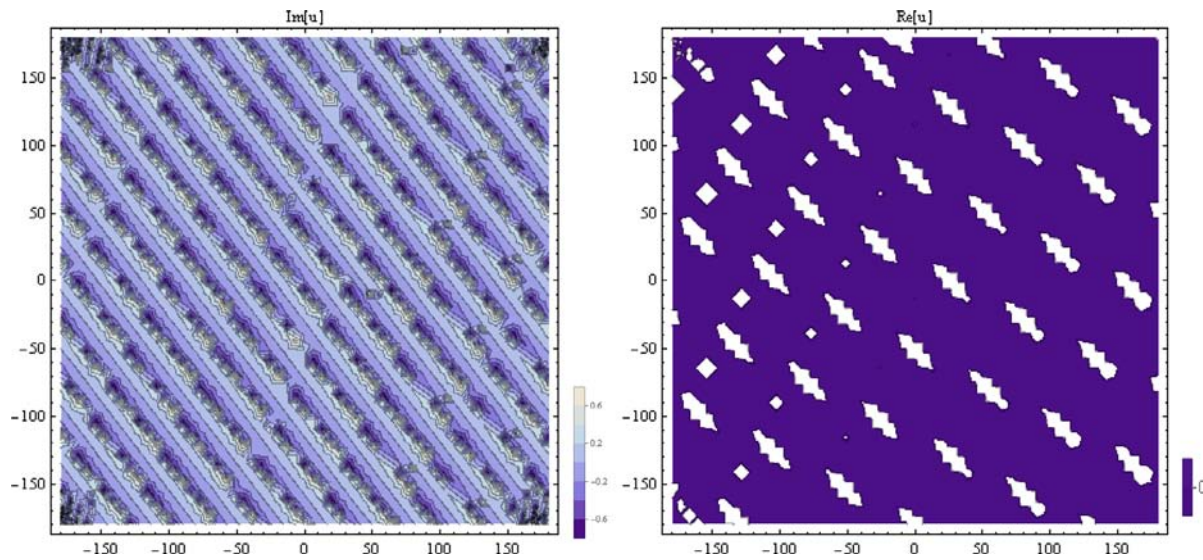


Fig. 3. The contour graphs of Eq. (20).

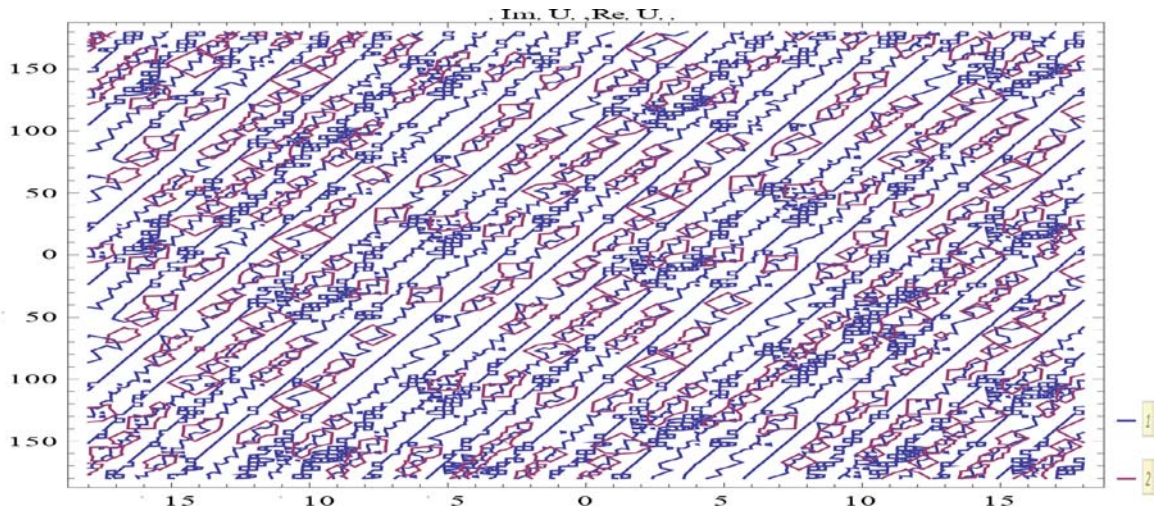


Fig. 4. The compilation of contour graphs of both side of Eq. (20).

where

$$\begin{aligned} \varpi &= \frac{3\sqrt{2}\sqrt{\beta A_0(2\alpha - 3\beta A_0)}\sqrt{w_0^2\delta_1^2 + \delta_2^2\omega_0^2}}{\sqrt{(2\alpha^2 - 9\beta)\mu(w_0^2\delta_1^4 + \delta_2^4\omega_0^2)}}, \\ \psi &= \frac{1}{2}\sqrt{-4\mu - \frac{4\mu(\alpha - 3\beta A_0)^2}{6\alpha\beta A_0 - 9\beta^2 A_0^2}}, \\ \zeta &= \frac{(\alpha - 3\beta A_0)}{\sqrt{6\alpha\beta A_0 - 9\beta^2 A_0^2}}, \\ \zeta &= \frac{\sqrt{-\beta(w_0^2\delta_1^2 + \delta_2^2\omega_0^2)}}{\sqrt{2\alpha^2 - 9\beta}}, \vartheta = \sqrt{\mu\beta A_0(2\alpha - 3\beta A_0)}. \end{aligned}$$

4. Conclusions

In this study, we have successfully applied EFM to find new complex, dark, and hyperbolic function solutions to the Eq. (1). Entirely

(24)

new travelling wave solutions were obtained. Under a suitable choosing of parameters, we plotted the Figs 1,2,5,6,9,10 and contour surfaces (3,4,7,8,11). The strain conditions for family-1 were also presented.

From the Figs. 1,2,5,6,9,10, physically, it can be observed that voltage levels with wave propagation in nonlinear electrical transmission line have the same travelling wave properties. From contour surfaces (3,4,7,8,11), it can be observed that these voltage levels have periodical and travelling wave behaviors in electrical transmission line in high and lower point. Moreover, contour surfaces have also the similar wave propagation in the network line.

These results are entirely new wave propagation by comparing with the existing results in literature. From these results, it can be said that EFM is a powerful and efficient mathematical tool to solve other nonlinear models arising in nonlinear sciences.

Declaration of Competing Interest

No conflict of interest exists in the submission of this manuscript, and manuscript is approved by all authors for publication.

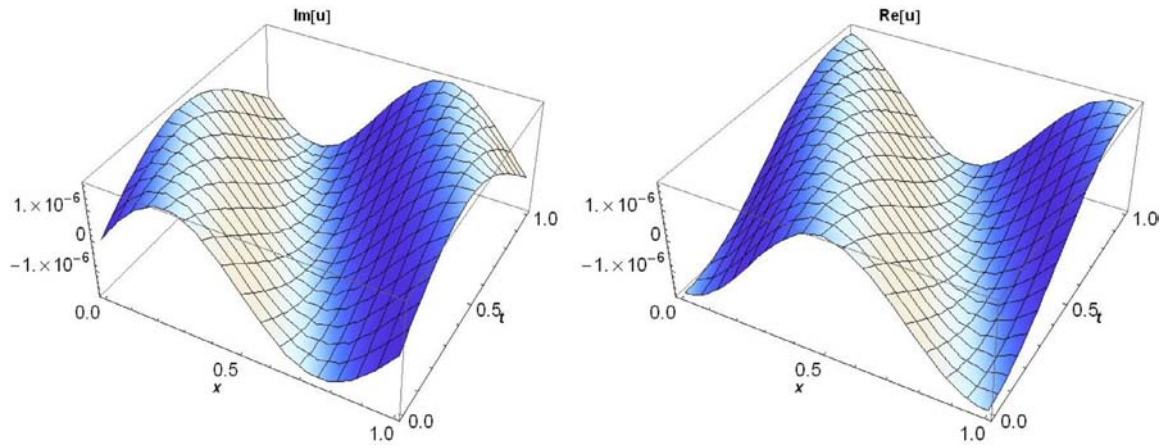


Fig. 5. The 3D graphs of Eq. (22).

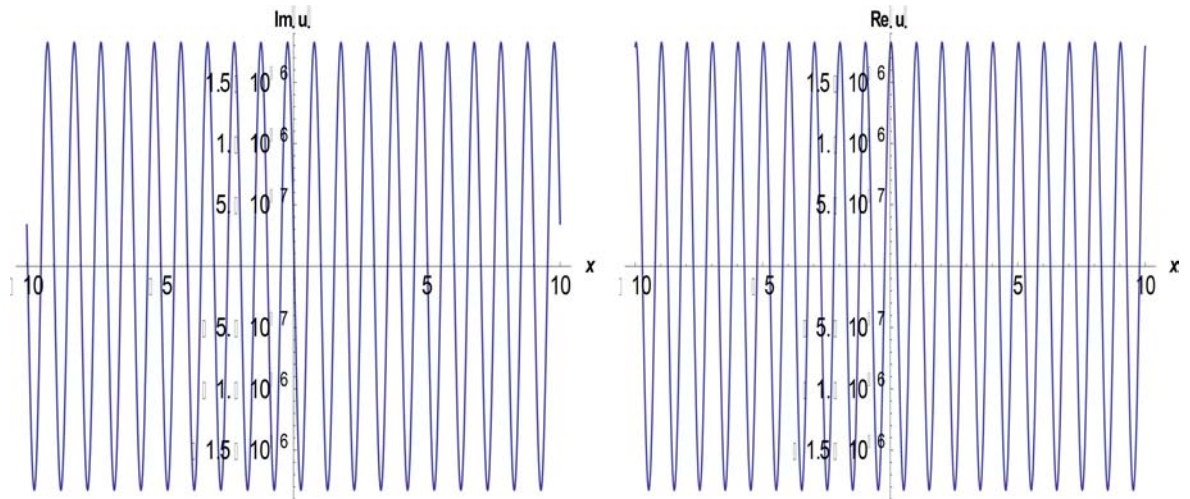


Fig. 6. The 2D graphs of Eq. (22).

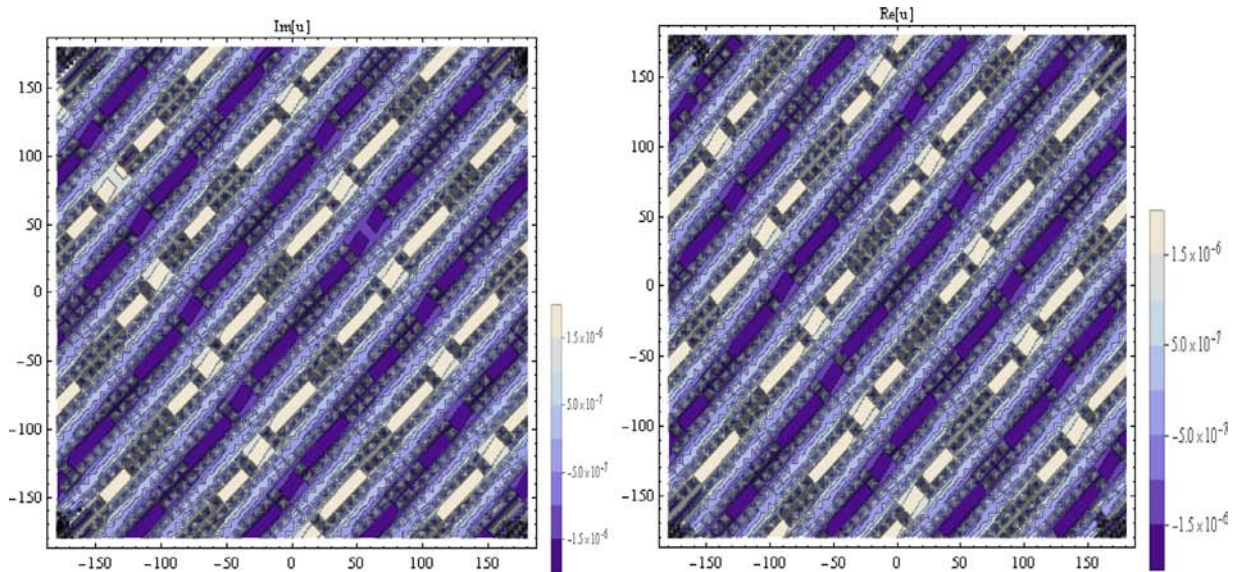


Fig. 7. The contour graphs of Eq. (22).

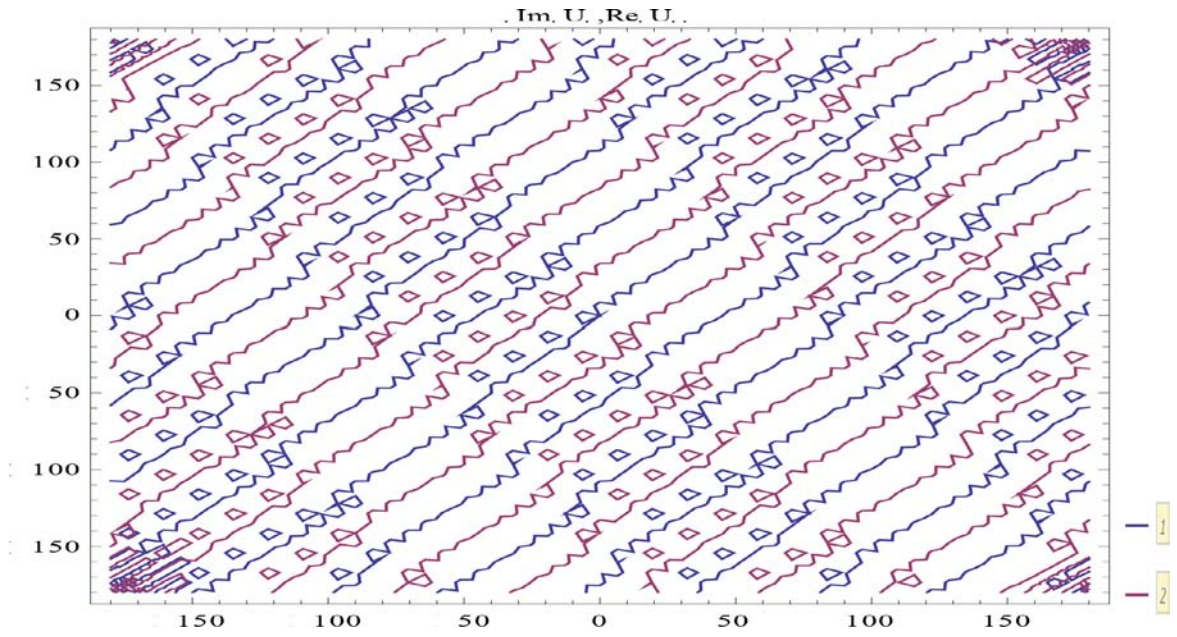


Fig. 8. The compilation of contour graphs of both side of Eq. (22).

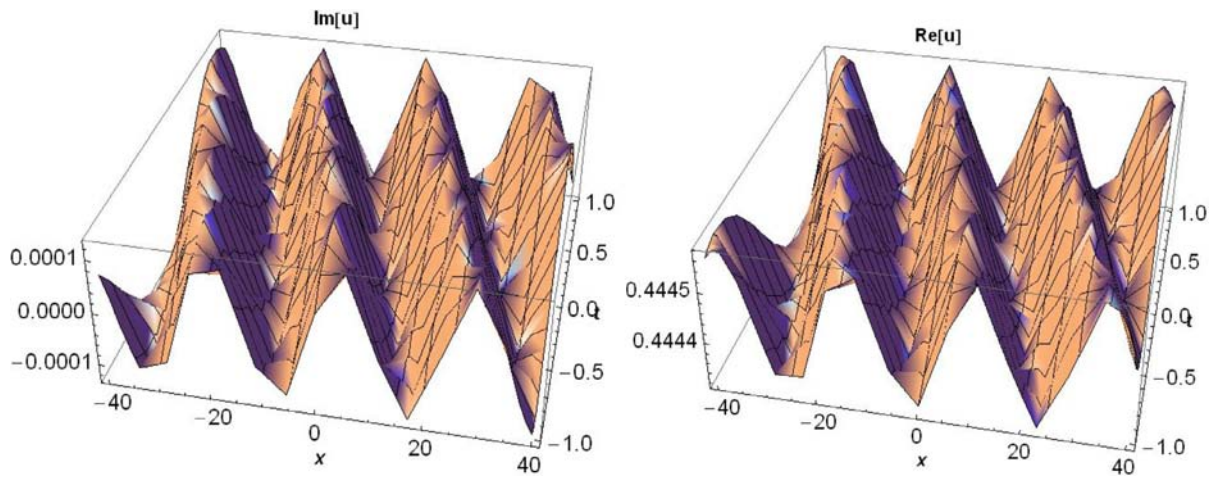


Fig. 9. The 3D graphs of Eq. (24).

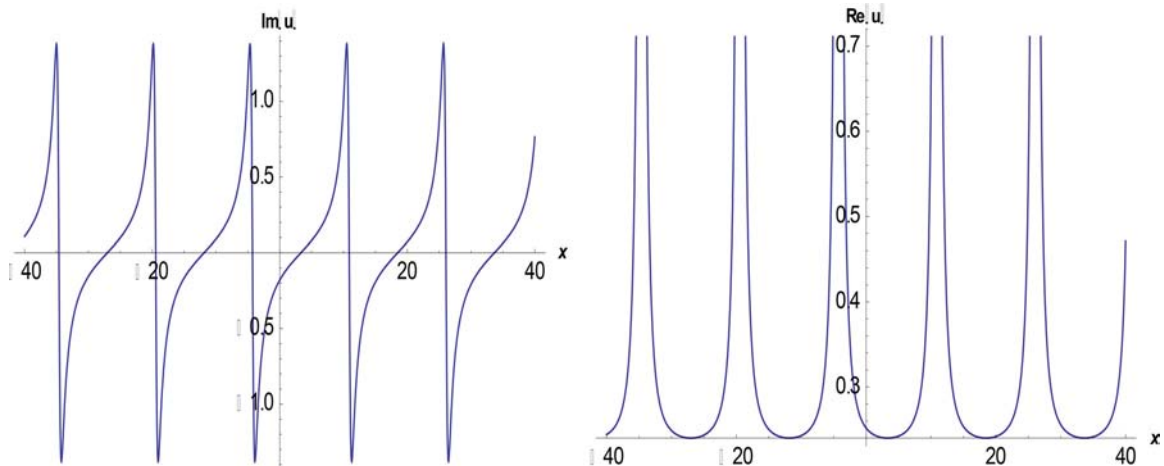


Fig. 10. The 2D graphs of Eq. (24).

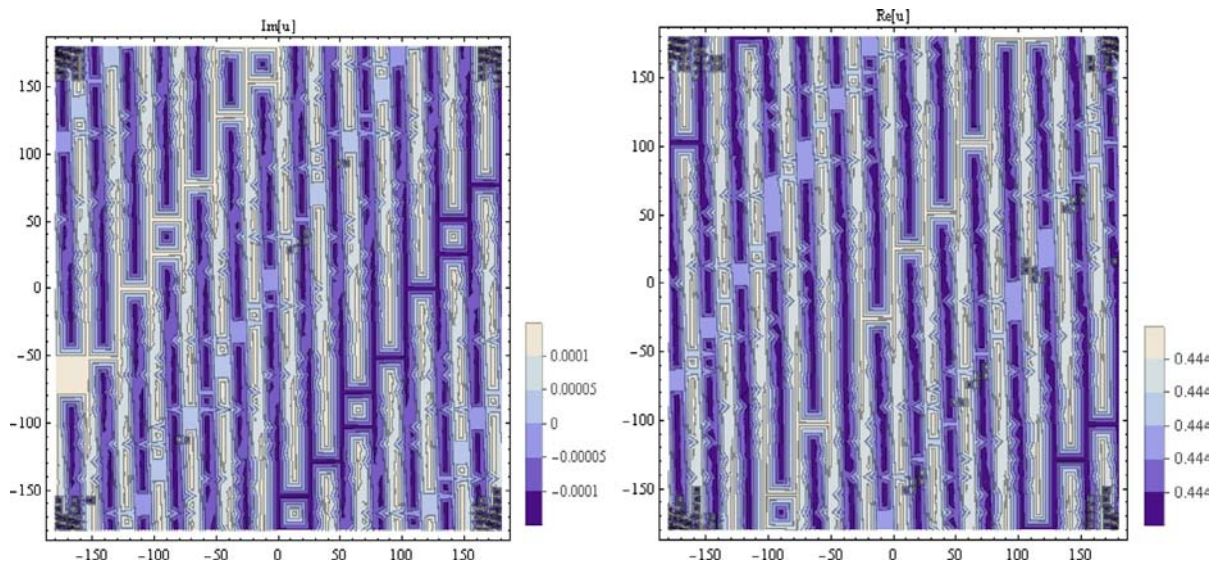


Fig. 11. The contour graphs of Eq. (24).

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