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Analysis and Modeling of Power Systems Transmission Line Transient by Matlab Simulink

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Abstract

In this paper, the transmission line (TL) is modeled and analyzed in the transient state with the aid of Matlab Simulink Program. The results are compared with the different types of TL models to approach the compromise state of the system with very high degree of accuracy, simplest circuit configuration, and least significant error. The selected system for application was Iraqi Northern Regional Grid (IRNG). Another points to be explained, the results give the difference between using the distributed parameter TL and lumped parameter TL across sending-end voltage, receiving-end voltage, and TL current.

الخلاصة:

تم نمذجة وتحليل خط النقل باستخدام برنامج Matlab Simulink وقورنت النتائج مع نماذج أخرى متعددة للوصول إلى أدقها. طبقت هذه الطريقة على شبكة العراق الشمالية وقد أظهرت النتائج اختلافاً عند استخدام الثوابت الموزعة في التحليل عن تلك التي تستخدم الثوابت المجمعة من خلال ملاحظة فولتيات الإرسال والاستلام وكذلك تيار الخط.

List of Symbols

Vs = Sending end voltage.
Vr = Receiving end voltage.
Is = Sending end current.
Ir = Receiving end current.
Es = Supply voltage.
A, B, C, and D = TL constant.
Z= input impedance.
N = Number of π section.
υ = Constant.
ℓ = line length.
Zc= characteristic impedance.
γ = Propagation constant = $\alpha + j\beta$.

1. Introduction

The main object of this paper is to study the TL in the transient state by including different TL models. The effect of (source, C.B., and Transformer) impedance (**Z**) is also embodied in the modeling of the studied system including Vs, Vr, and Is.

Previously, the transmission line has been represented by one π section or more than one π section, according to the line length. This representation gives inaccurate results in the transient simulation that is used in the design, control, and analysis of power systems. So, it is necessary to know the behavior of TL in transient condition, to get high accuracy in the results, which is the scope of this paper.

J.R.Smith has proposed a method [1], to determine the number of π sections or the length per π section that is used in transient studies. Another newly made method is that presented by John J. Jrainger and Stevenson in which the determination of Vs, and Vr in the transient state [2]. In this work the new modified method is adopted based on methods given in Refs. [1-6]. This analysis especially for long TL as it is in fact one of the serious problem in system

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modeling. INRG is the system under investigation wills includes different types of TL depending on its length, so that loaded Mosul Dam - Baiji long TL is chosen for this investigation. In this work, a new technical for representation of TL by Matlab Simulink [7] is used due to is accurate results.

2. Frequency Characteristics of TL

The real transmission line [1] shown in Fig.(1) has length ℓ and resistance, inductance and capacitance per unit length R, L, and C, respectively and has characteristic impedance Zc, propagation constant γ, and the following tow-port network equation[6]:

$$\begin{bmatrix} Vs \\ Is \end{bmatrix} = \begin{bmatrix} A & B \\ C & D \end{bmatrix} \cdot \begin{bmatrix} Vr \\ Ir \end{bmatrix} \qquad \ldots(1)$$

where:

$A(j\omega) = \cosh(\gamma\ell)$; $B(j\omega) = Z_c \sinh(\gamma\ell)$

$C(j\omega) = \sinh(\gamma\ell)/Z_c$; $D(j\omega) = \cosh(\gamma\ell)$

and, $Z_c = [(R+j\omega L)/j\omega C]^{1/2}$;

$\gamma = [(R+j\omega L)j\omega C]^{1/2}$

So the TL frequency characteristics are relationships of A, B, C, D as shown in equation (1) in term of frequency ω. The TL can be represent by multiple π lumped parameter [1] as shown in Fig.(2).

Obviously, the line shown in Figure (2) can also be represented by a two-port network equation:

$$\begin{bmatrix} Vs' \\ Is' \end{bmatrix} = \begin{bmatrix} A' & B' \\ C' & D' \end{bmatrix} \cdot \begin{bmatrix} Vr' \\ Ir' \end{bmatrix} \qquad \ldots(2)$$

From values of A', B', C' and D', which belong to equation (2), it could be found that the frequency characteristics which is used to compare with equation (1) to find the percentage error which depends on the number of π sections. Appendix (A) shown how those values were calculated, A', B', C',D' and number of π sections percentage error.

2.1 Computation of parameters and Analysis of TL

Taking the Mosul Dam- Baiji TL parameters as shown in Table (1). $A(j\omega)$, $C(j\omega)$ can be obtained using equation (2). If the number of π sections is given, the amplitudes of A' and C' together with ЄA and ЄC in terms of frequency ω can be computed. Some of the computed results are shown in Fig.(3), Fig.(4), and Table (2). Fig.(5) is a flow chart shows how those constants were calculated.

From Figures (3) and (4), it could be seen that:

1. The amplitudes of A and C are vary periodically with frequency; the amplitudes of A and C are vary approximately in accordance with the cosine and sine respectively.
2. If the number, N, of π sections is large enough, the amplitudes of A' and C' are also vary periodically with frequency in coincidence with A and C respectively, but the range decreases with the increase of frequency. Consequently, the variation periods of A' and C' differ from those of A and C.
3. The differences between A',A and C',C vary directly with frequency and inversely with the number of π sections.

By using methods given in Fig.(5) and appendix (A) the results for Mosul Dam – Baiji TL, where found and given in table (2). Where for transient simulation time equal to 6.5msec and the number of π sections N=2 with error about 3%.

This approach to analyzes the TL is similar to that used for deriving the steady-state voltage and current relation for the long line with distributed constant. To measure the distance x along the line from the sending end to the differential element of length Δx, as shown in Fig.(3) the voltage *v* and current *i* are function of both *x* and *t* so that there is a need to use partial derivatives [2]. The voltage is expressed by $v = f(x - \upsilon t)$,where $\upsilon = 1 / \sqrt{LC}$ Ref.[2-6].

From the differential equations of the TL [2], we can represent the TL by Matlab Simulink as shown in Fig.(4).

3.1 Voltage Profiles

In practical, power lines in the steady state are affected by **Surge Impedance Loading (SIL)** during small load conditions up to multiples of SIL, depending on line length and line compensation, and during heavy load conditions [5, 6]. Fig.(5) shows voltage profiles of lines with a fixed sending-end voltage magnitude Vs for line lengths ℓ up to a quarter wavelength. This figure is for loading conditions:

1. The voltage profile at no load, $Vr=Vs/\cosh(\gamma\ell)$, assuming that $\gamma = \alpha + j\beta$.
2. The voltage profile at SIL is flat, Vr=Vs.
3. The voltage profile at full load, Vr= certain value.
4. The voltage profile at short circuit, Vr=0.

Fig.(5) summarizes these results, showing a high receiving-end voltage at no load and a low receiving –end voltage at full load. This voltage regulation problem becomes more severe as the line length increases, to solve this problem shunt compensation methods are used Ref [5, 6]. In the transient state the profiles of voltage is complex, which is the scope of this paper.

4. Simulation Procedure

In this work, the analysis of TL procedure used to perform the simulation by the proposed model would be presented here. The simulation have been made with the use of the step-by-step solution with (dt=0.0005) and the simulation time period is (Tmax=0.04 sec). The used program is Matlab version 6.0 (2000) to which fast solutions could be obtained with the complex numbers.

5 Simulation Results

Simulations were performed for a model system, Fig.(7),with the given parameters in table (1).

The result features are taken voltage in p.u. versus time in second for the following cases, 2π lumped parameter, 4π lumped parameter, and 10π lumped parameter those three cases are given in the same figure. Three cases of switching transient of an equivalent voltage source being suddenly closed on a long TL , 247km 400kV, with the receiving-end open are simulated. The input impedance is taken as pure resistance or pure inductance and the results for voltage wave of sending and receiving ends are shown in Fig.(9) to Fig.(12). The current profile also has been taken. And its given in Fig.(13).

7 Conclusion

This paper presents a new result with the inclusion (Z) effect (source impedance, C.B. impedance, and Transformer impedance), which are lumped in one impedance (Z). The sending end voltage and receiving end voltage waves are given for Z=R or Z=jX, the influence of this change of impedance can be seen from the comparison of voltage waves for the two cases. Factors influencing the discrepancies between the distributed and lumped parameters models are investigated over the voltage and current profile. The π section lengths of the line models used in different transient cases are given in the results, Number of π section can be determined with any frequency range.

It could be seen that increasing number of π section gives higher degree of accuracy. This proposed method is for three phase TL.

Appendix A:

In order to find those values, A', B', C' and D', there are two ways those are:

1- By relating Fig.(2) and equation (2) to get equation (A1) which gives Table (A1).

$$\begin{bmatrix} Vs \\ Is \end{bmatrix} = \begin{bmatrix} Ao & Bo \\ Co & Do \end{bmatrix} \cdot \begin{bmatrix} Ao & Bo \\ Co & Do \end{bmatrix} \cdot \begin{bmatrix} Ao & Bo \\ Co & Do \end{bmatrix} \cdots\cdots \begin{bmatrix} Ao & Bo \\ Co & Do \end{bmatrix} \cdot \begin{bmatrix} Vr \\ Ir \end{bmatrix} \quad \ldots(A1)$$

In case of using one π section the following expressions could be obtained:

$$\begin{aligned} Ao &= Do = 1 + 0.5ZY \\ Bo &= Z \\ Co &= Y(1 + 0.25ZY) \quad \ldots(A2) \\ Do &= Ao \end{aligned}$$

Where $Z = R\ell/N + j\omega L\ell/N$, $Y = j\omega C\ell/N$ and N the numbers of the used π sections . The parameters those given in Table (A1) may defined as:

At N=1 A1 = Ao, B1 = Bo, C1 = Co and D1 = Ao.
At N=2 $A2 = Ao^2 + BoCo$, $B2 = 2\,AoBo$, $C2 = 2\,AoCo$ and D2 = A2.
At N=3 $A3 = Ao^3 + 3AoBoCo$, $B3 = 3Ao^2Bo + Bo^2Co$, $C3 = 3Ao^2Co + Co^2Bo$ and D3 = A3.
At N=4 $A4 = Ao^4 + 6Ao^2BoCo + Bo^2$, $B4 = 4Ao^3Bo + 4AoBo^2Co$, $C4 = 4Ao^3Co + 4AoBoCo^2$ and D4 = A4.

2- The frequency characteristics also could be obtained from Vs', Vr' and Is' with the second terminal of the line is open circuited:

$$\begin{aligned} A'(j\omega) &= \frac{Vs'(j\omega)}{Vr'(j\omega)} \\ C'(j\omega) &= \frac{Is'(j\omega)}{Vr'(j\omega)} \quad \ldots(A3) \end{aligned}$$

and when any one of the three variables Vs', Vr', and Is' is known, e.g. Vr' the other two variables can be determined.

It is obvious that the substitution of the distributed parameter model by the multiple π models assures an introduction of a significant error. This error is defined as:

$$\begin{aligned} \varepsilon_A &= \frac{\max\{|A(j\omega)| - |A'(j\omega)|\}}{\max\{|A(j\omega)|\}} \\ \varepsilon_C &= \frac{\max\{|A(j\omega)| - |A'(j\omega)|\}}{\max\{|A(j\omega)|\}} \quad \ldots..(A4) \\ \varepsilon &= \max\{(\varepsilon_A, \varepsilon_C)\} \end{aligned}$$

Where ω is the frequency with a variation range of $0 < \omega < \omega_m$

In the previous equations those contain A(jω) and C(jω) are uniquely depend on ω, while A'(jω) and C'(jω) are depend on ω in addition to the number, N, of π sections. Consequently, the error ϵ will be very small in case of the large value of N. So according to the predicted permissible error ϵ_p and frequency range, the number, N, of π sections could be obtained.

It is necessary to point out that only the errors of the amplitudes of A' and C' are considered here, as the errors of the phase angles of the related A' and C' are small enough and varies in the same sense of amplitude variation. Such that the amplitude errors would be depended merely and that of phases' are neglected.

References

1. J. R. Smith and W. W. Bell, " Selection of Transmission Circuit Models for Power

System Transient Studies", IEE Proc. C, Vol 131, No 1, PP 1-4, 1984.

2. John J. Grainger and William D. Stevenson ," Power System Analysis", McGraw-Hill,Inc. 1994.
3. J.Arrilaga and C.P.Arnold," Computer analysis of power systems", John Wiley & Sons Ltd. 1990.
4. Peter W. Sauer and M. A. Pai , " Power System Dynamics and Stability" , Prentice Hall Inc. 1998.
5. T. J. E. Miller , "Reactive Power Control in Electric System" , John Wiley & Sons Ltd. 1982.
6. J. D. Glover and M. Sarma , "Power System Analysis & Design", PWS publishing Company 1994.
7. Matlab Works Inc. " Simulink (Dynamic System Simulation for MATLAB)", version 6.0, 2000.

Table (1) Mosul Dam – Baiji Transmission Line parameters

Voltage (Kv)	Mvab	R (Ω / km)	X (Ω / km)	C (μF / km)	l (km)
400	100	0.034	0.315	0.02	247

Table (2) Representation of Mosul Dam – Baiji TL resluts.

Frequency range (Hz)	l(km)	N	ϵ_P(%)	ϵ_A(%)	ϵ_C(%)	ϵ(%)
0 - 150	247	2	3.2	1.1	3.16	3.16
0 – 500	247	4	8	3.5	7.825	7.825
0 - 1000	247	10	10	9.91	9.9	9.91
0 - 1500	247	20	10	9.1	8.52	9.1
0 - 1500	247	30	0	0	0	0

Table (A1) The relationship between No. of π sections and the values of A'. B'. C'and D'.

No. of π sections	N= 1	N= 2	N=3	N=4	………	$N \rightarrow \infty$
A'	A1	A2	A3	A4	………	$\cosh(\gamma l)$
B'	B1	B2	B3	B4	………	$Z_c \sinh(\gamma l)$
C'	C1	C2	C3	C4	………	$\sinh(\gamma l)/Z_c$
D'	D1	D2	D3	D4	………	$\cosh(\gamma l)$

Fig.(1)The distributed parameter model of a transmission line.

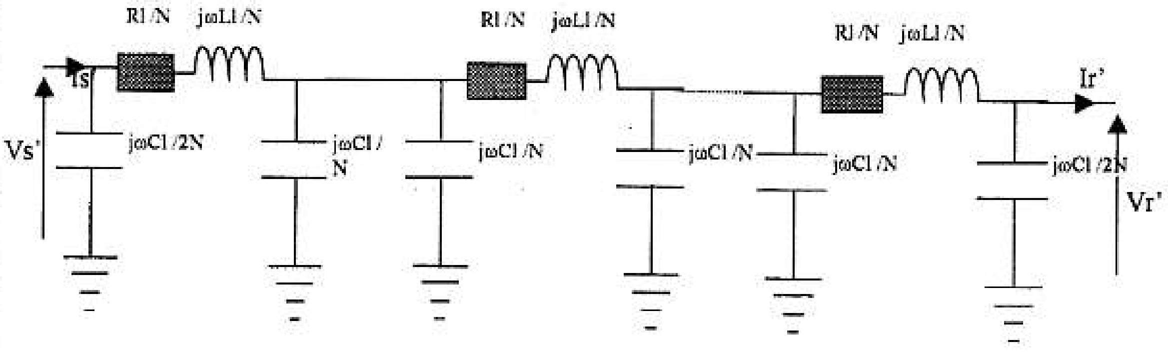
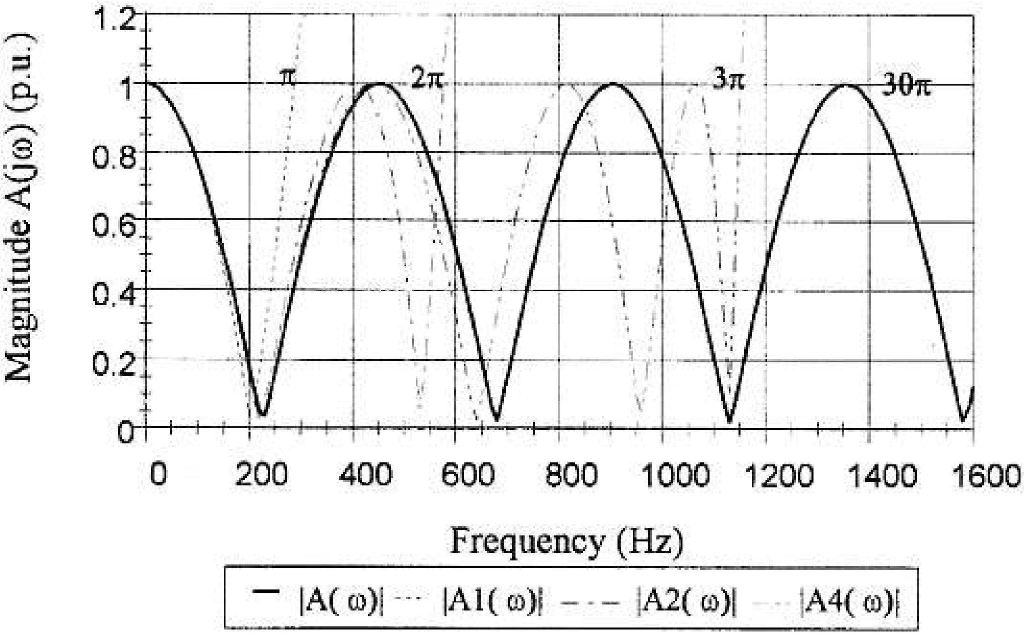
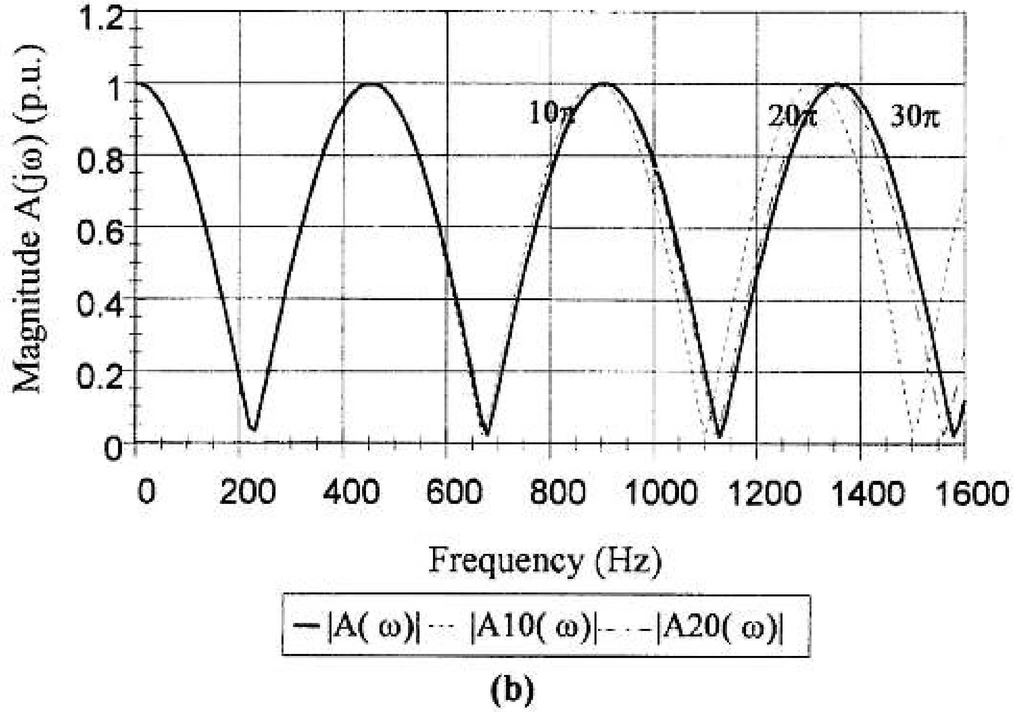


Fig.(2) The multiple π lumped parameter model of a transmission



(a)



(b)

Fig.(3) Frequency characteristics of A(jω) , magnitude vs. frequency ω, for the TL that parameters as given in Table (2); where:

(a) Numbers of π sections (N =1,2,4,30).

(b) Numbers of π sections (N =10,20,30).

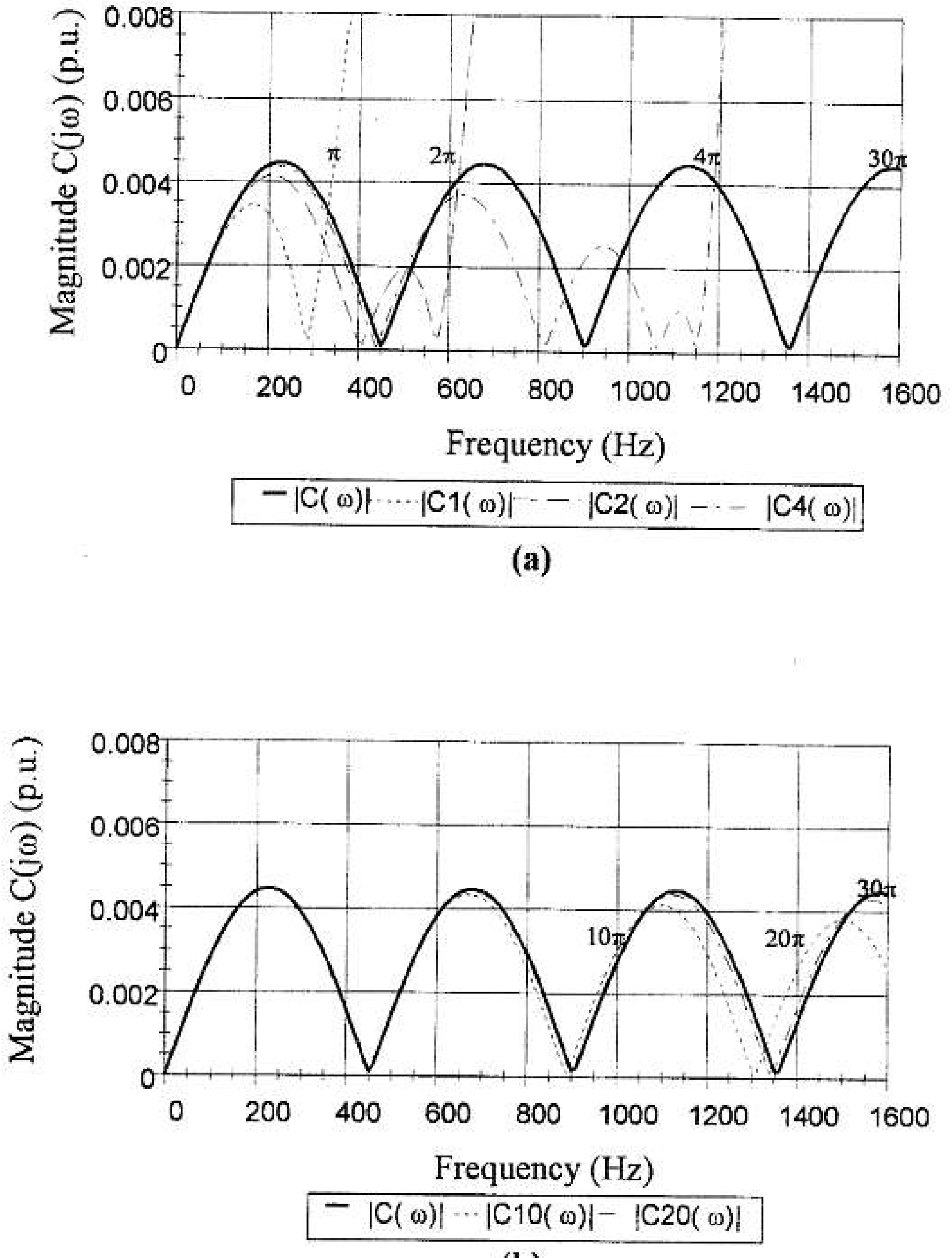


Fig.(4) Frequency characteristics of C(jω) , magnitude vs frequency ω, for the TL that parameters as given in Table (2) ; where:

(a) Numbers of π sections (N =1,2,4,30).

(b) Numbers of π sections (N =10,20,30).

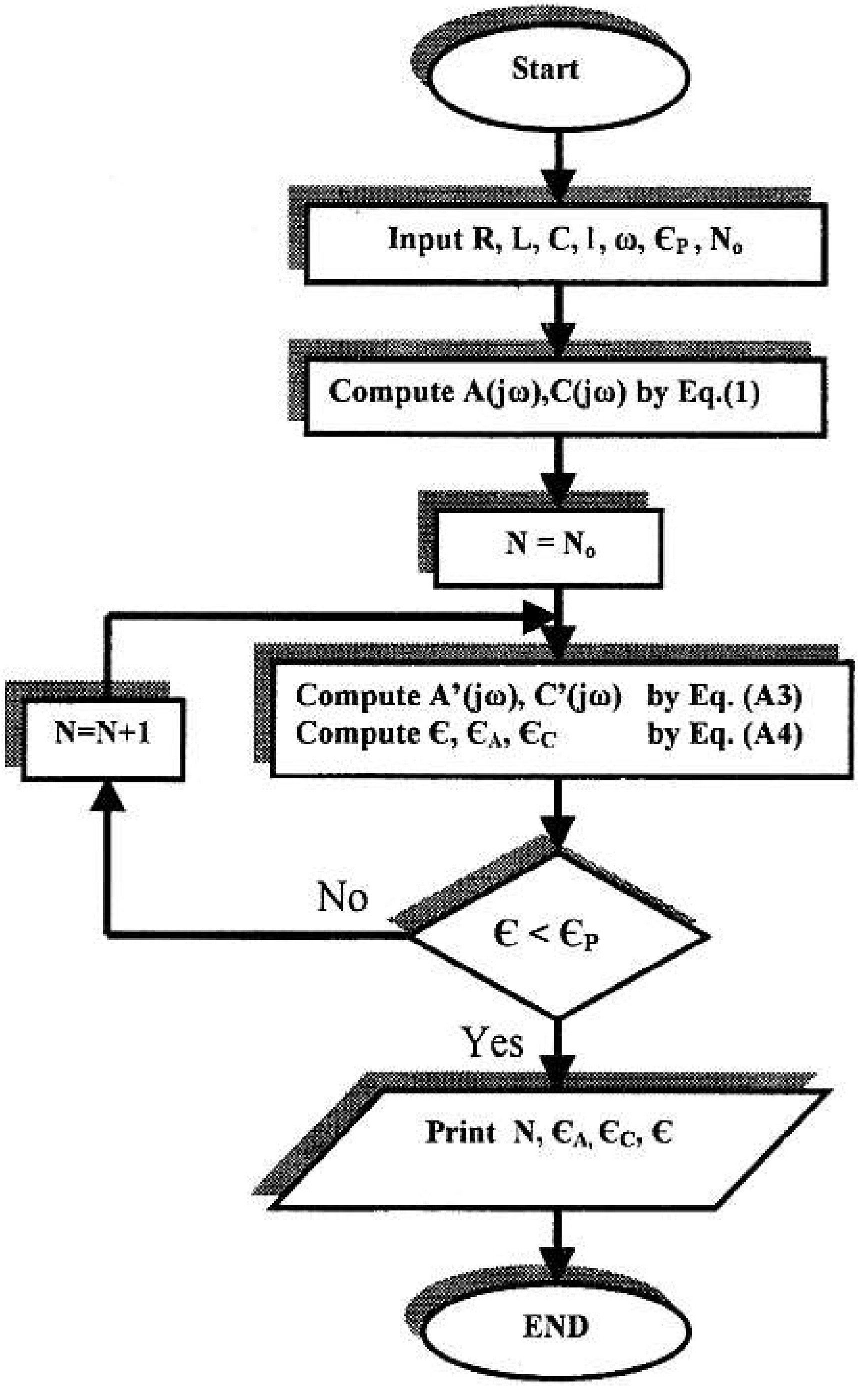


Fig.(5) Flow Chart for Determining N.

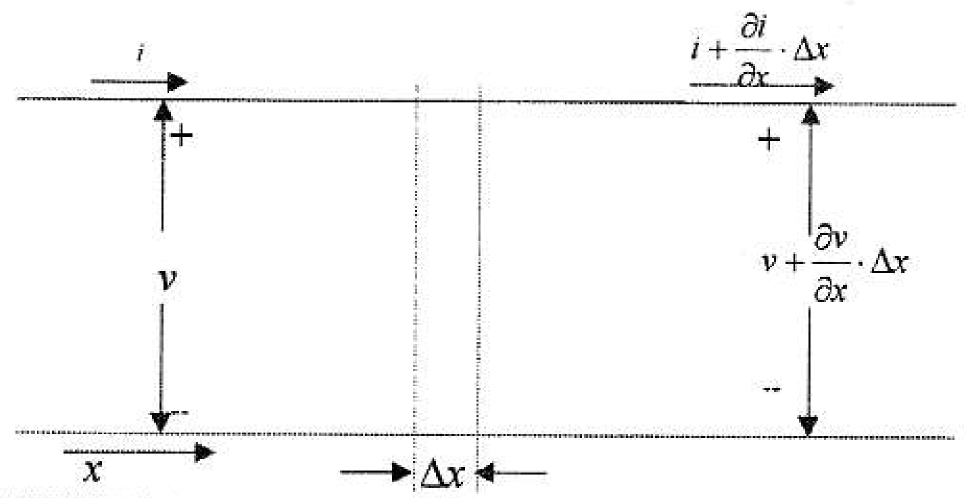


Fig.(6) Schematic diagram of an element section of a transmission line. Voltage (*v*) and current (*i*) are function of both *(x)* and *(t)*. The distance *(x)* is measured from the sending end of the line.

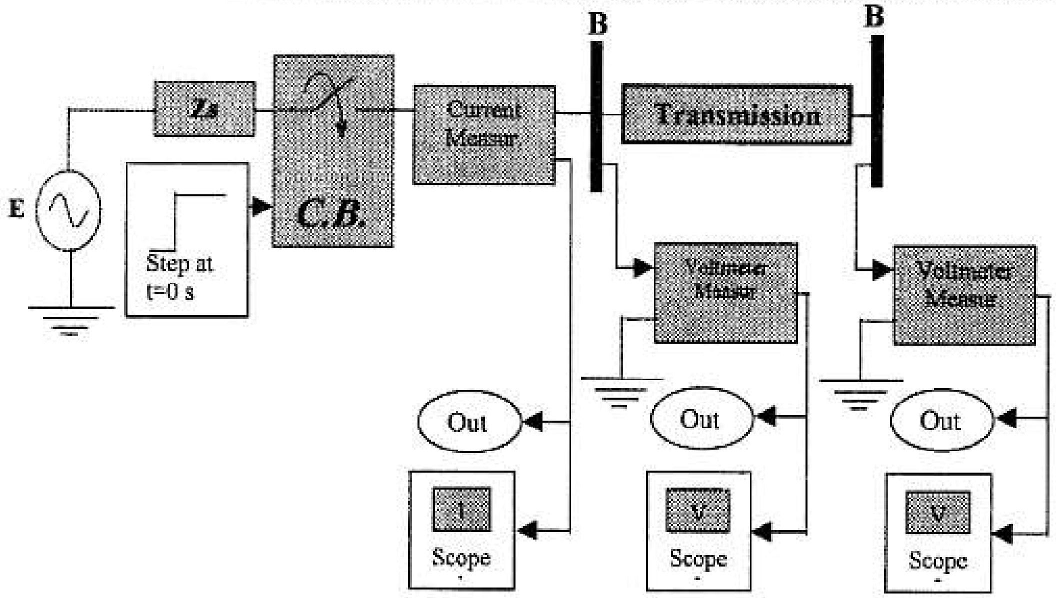


Fig.(7) Block diagram of an element section of a transmission line which is represented by Matlab Simulink .

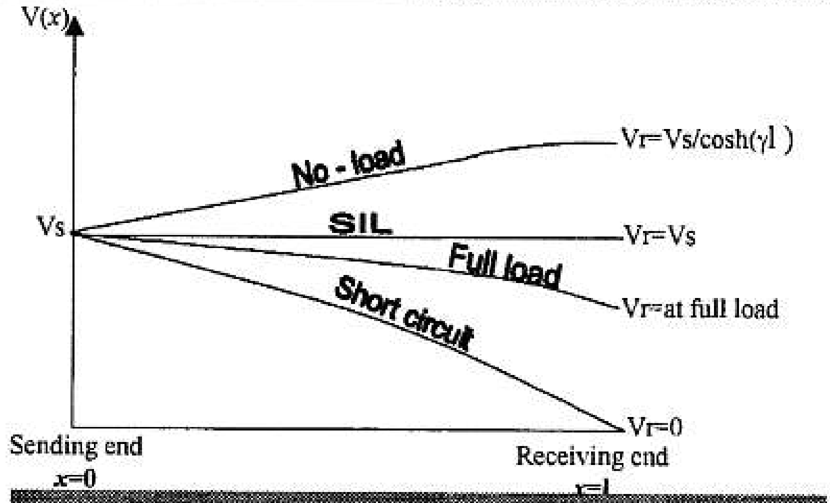
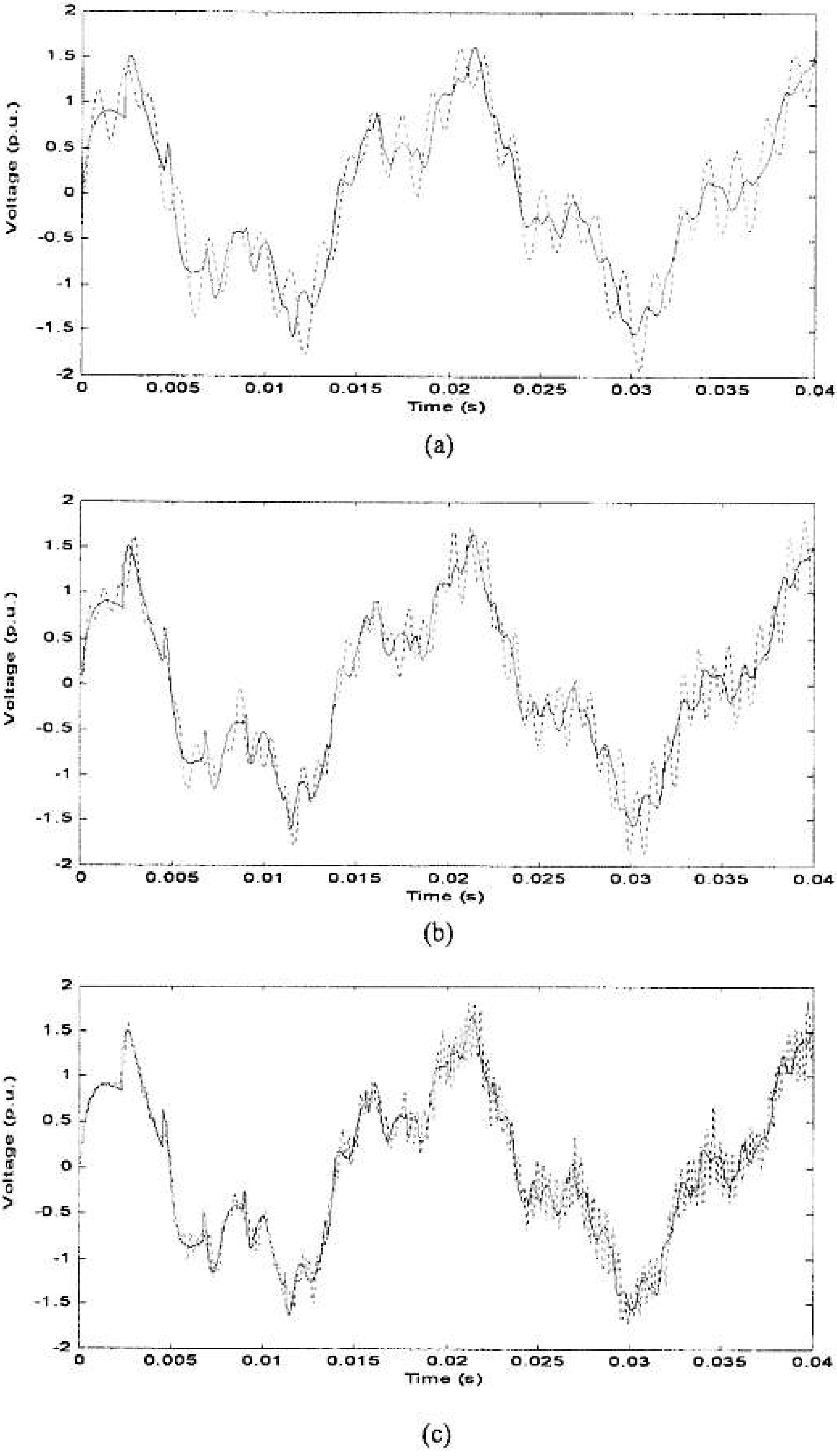


Fig.(8) Voltage profiles with fixed sending-end voltage for line lengths up to quarter wavelength.



(a)

(b)

(c)

Fig.(9) Sending-end voltage with receiving-end open (Z=jX): (a) 2π lumped parameter and distributed parameter models; (b) 4π lumped parameter and distributed parameter models; (c) 10π - - - - - -lumped parameter and ——— distributed parameter models.

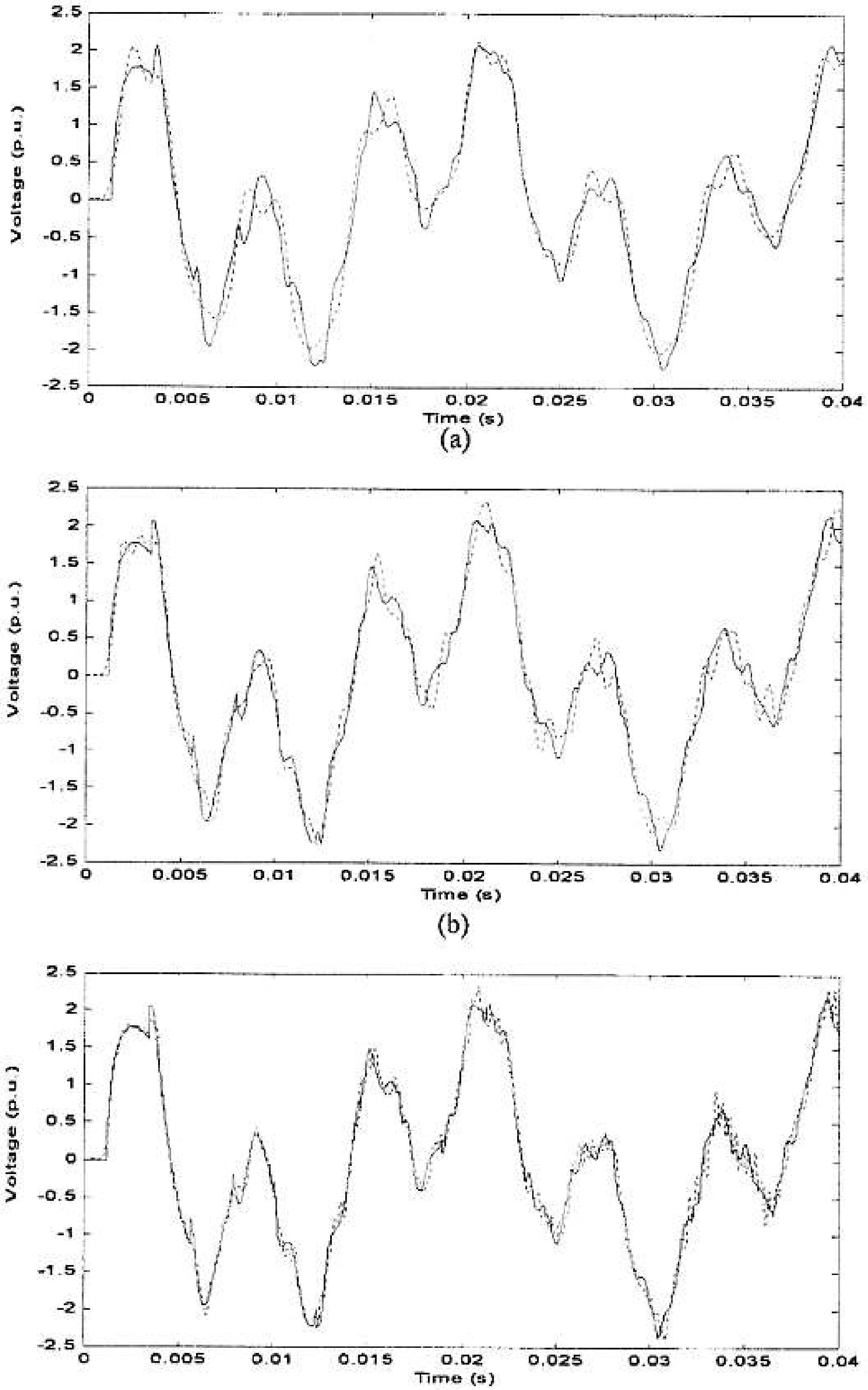
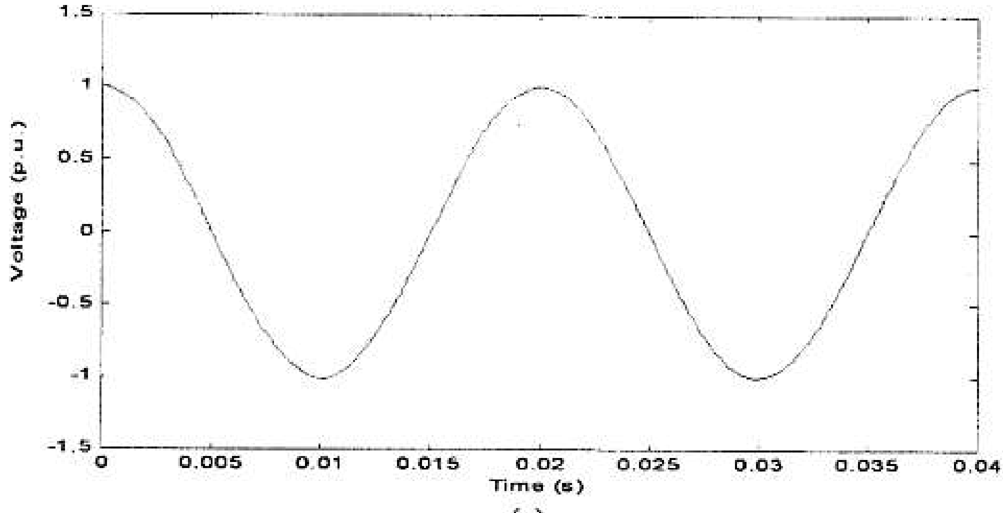
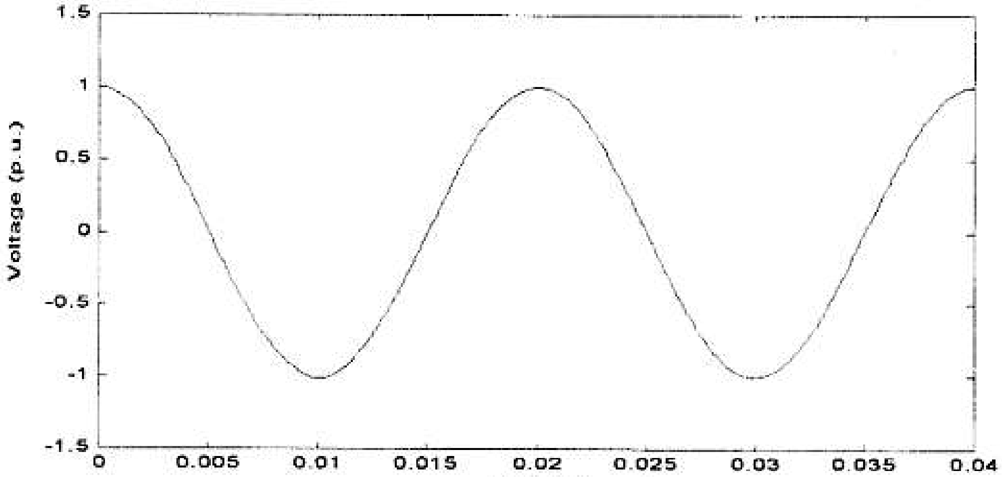


Fig.(10) Receiving-end voltage with receiving-end open (Z=jX): (a) 2π lumped parameter and distributed parameter models; (b) 4π lumped parameter and distributed parameter models; (c) 10π - - - - - -lumped parameter and ———— distributed parameter models.



(a)



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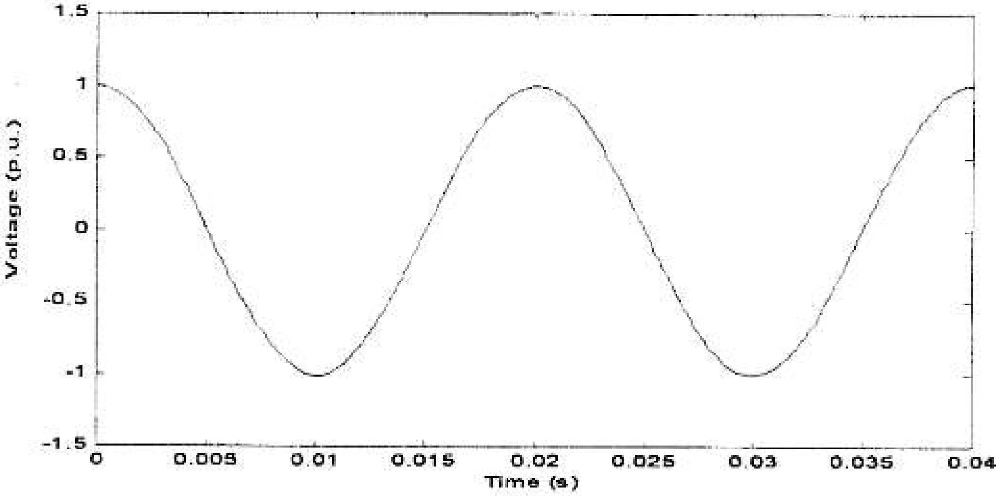


(c)

Fig.(11) Sending-end voltage with receiving-end open (Z=R) : (a) 2π lumped parameter and distributed parameter models; (b) 4π lumped parameter and distributed parameter models; (c) 10π ------lumped parameter and ——— distributed parameter models.

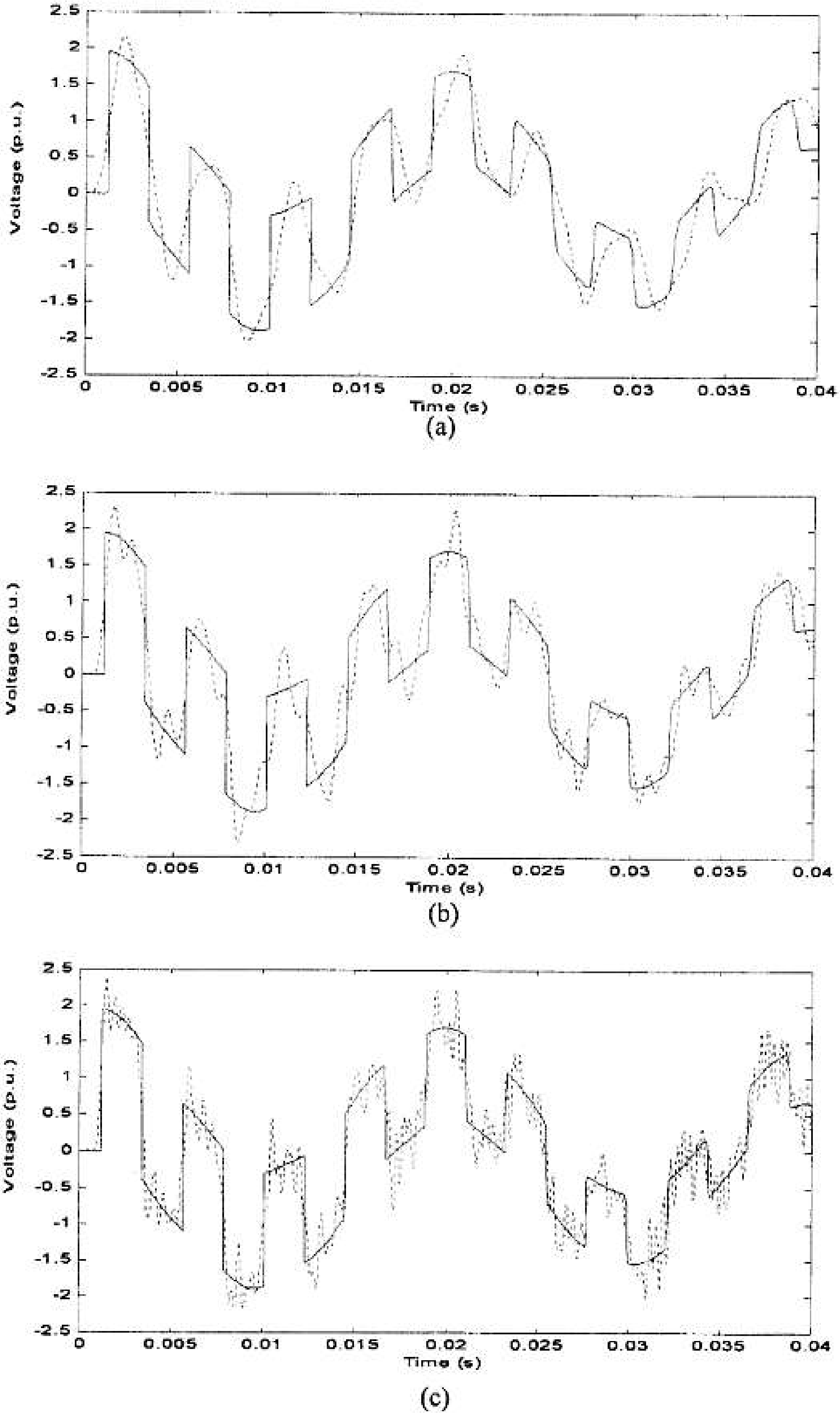
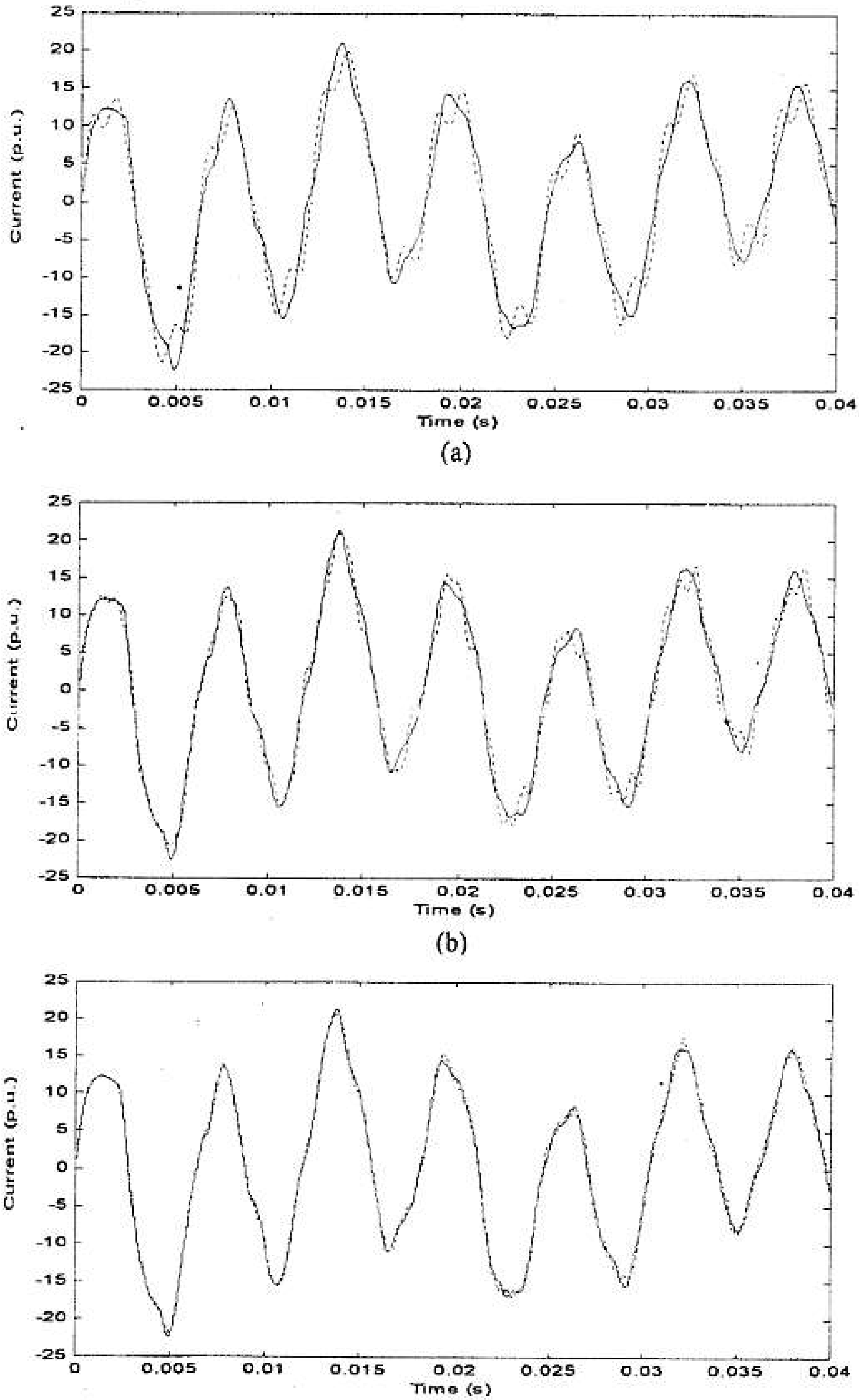


Fig.(12) Receiving-end voltage with receiving-end open (Z=R): (a) 2π lumped parameter and distributed parameter models; (b) 4π lumped parameter and distributed parameter models; (c) 10π ------ lumped parameter and ——— distributed parameter models.



(a)

(b)

(c)

Fig.(13) sending-end current with receiving-end open (Z=jX): (a) 2π lumped parameter and distributed parameter models; (b) 4π lumped parameter and distributed parameter models; (c) 10π - - - - - -lumped parameter and ——— distributed parameter models.