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A study on a Cabtyre Cable for a Transient Condition

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Abstract: **The cabtyre cables are widely used in power distribution systems. It is necessary to have an accurate cable models to predict switching or lightning surges. Transient characteristics on the cabtyre cable are measured. The cabtyre cable frequency characteristic of characteristic impedance and propagation constant are studied and discussed for aerial mode. It is found for the aerial mode-2 cable characteristic impedance can be represented by RL series circuit. The attenuation increases as the frequency increases. This study supports to develop a generalized frequency dependent cabtyre cable model.**

Key words: cabtyre cable, EMTP, frequency dependence

I. INTRODUCTION

A cabtyre cable has been used in household appliances and industrial machines with rated voltage 400/220/110 Volts. Analytical study on 3-core cabtyre cable is carried out employing matrix analysis [2]. The cable impedance is assumed to be identical to that of i.e. an overhead conductor. The relative permittivity ε_r of the cabtyre cable insulator is unity i.e. $\varepsilon_r = 1$. The cable admittance is calculated using the formula for a pipe type overhead cable [1]. The dielectric loss is included in the calculation using $\tan\delta(=0.025)$ and a complex permittivity ε.

Transient measurements are carried out to evaluate frequency dependence effect of characteristics impedance and propagation constant. The comparative study is carried out to study the influence of the frequency dependence of the parameters.

II. WAVE PROPAGATION ON CABTYRE CABLE

Transient measurements are carried out for wave propagation on the cabtyre cable with receiving end open-circuited and short-circuited. Fig.1 shows a circuit diagram for an aerial mode (mode-2) with a pulse generator (PG) whose internal resistance $R_{in} = 51\ \Omega$. Similar methodology is applied for another aerial mode (mode-1) and earth return mode (mode-0).

The two cores are short-circuited at sending as well as at receiving end. A pulse generator (PG) is used as a source voltage. A current is evaluated from a source voltage $v_o(t)$ and a sending end voltage $v_s(t)$ using eq. (1). All the voltages are measured by an oscilloscope (Tektronix DPO 4104, 1GHz) and voltage probes (Tektronix serial No. p6139A).

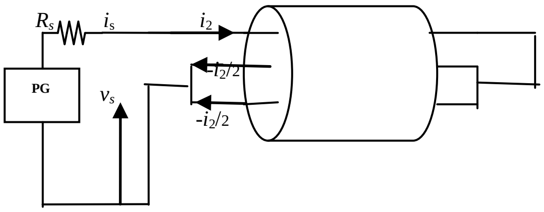
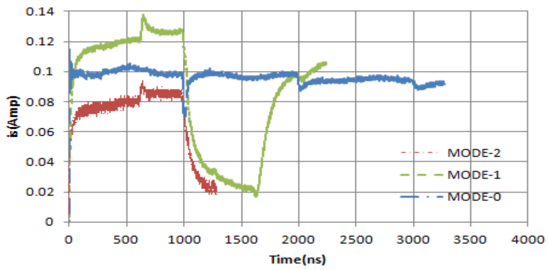
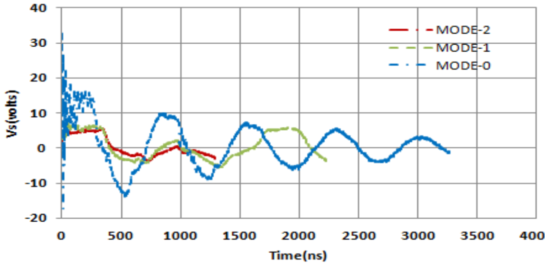


Fig.1 Test circuit for Mode 2

$$i_s(t) = \frac{v_o(t) - v_s(t)}{R_s} \qquad (1)$$



(a) Sending-end current $i_s(t)$



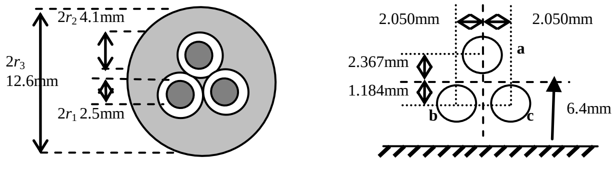
(b) Sending- end voltage $v_s(t)$
Fig. 2 Measured results for all modes

Fig.2 shows measured result for all three modes with short circuited at the receiving end. The travelling velocity is measured as v = 171 m/µs. The permittivity of insulator of the cabtyre cable is obtained by the formula as shown in eq. (2).

$$v = \frac{1}{\sqrt{\mu\varepsilon}} = \frac{1}{\sqrt{\mu_o \varepsilon_o \varepsilon_r}} = \frac{C_o}{\sqrt{\varepsilon_r}} \qquad (2)$$

$$\therefore \varepsilon_r = \frac{C_o^2}{v^2} = \frac{(300 \times 10^6)^2}{\left(171 \times 10^6\right)^2} = 3.07$$

III. TRANSIENT CALCULATION WITH CONSTANT PARAMETER LINE



(a) Cross-section (b) Overhead conductor approximation
Fig .3 A cabtyre cable FUJI E.W.C. V.C.T. 3.5mm^2, 3 core, 30.2

Fig.3 shows the detailed view of the cabtyre cable. A computer program calculating a cabtyre cable parameters are developed using Maple computer code. The program outputs data as shown in APPX-I (A) of a distributed parameter line model of Electro-Magnetic Transient Program (EMTP) [3].

An EMTP simulation is carried out in order to confirm validity of the developed mathematical model on the basis of physical parameters. The transient response of the circuit illustrated in Fig.1 is simulated by the EMTP using cable parameters calculated at 1MHz. The floating voltage source in Fig.1 is converted to two current sources by Norton theorem for the EMTP simulation which is based on a nodal analysis method as shown in Fig.4

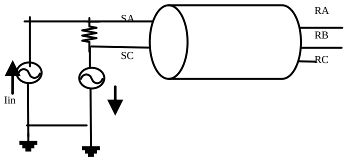
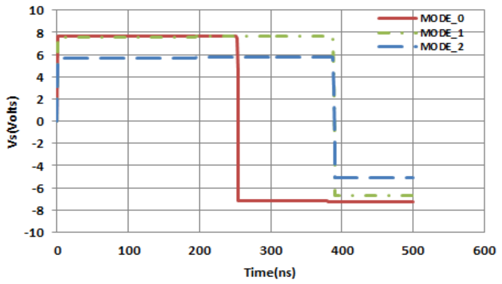
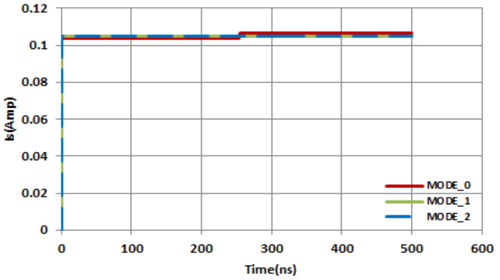


Fig. 4 EMTP branch card for mode-1 and mode-2



(a) Sending- end voltage $v_s(t)$



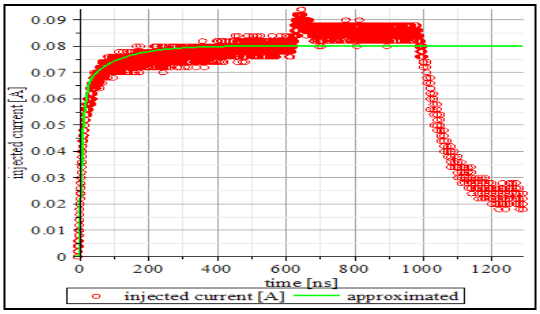
(b) Sending- end current $i_s(t)$
Fig. 5 Simulation result for all modes

Fig.5 shows simulation results for sending end voltage and current for the all modes. From the simulated results characteristics impedance for three modes are Z_0=78 Ω , Z_1=78 Ω and Z_2=55 Ω. Velocities of three modes are v_o= 238.73 m/μs, v_1 and v_2 = 155.67 m/μs.The theoretical and EMTP simulated results agree with each other. However, the transient response calculated by a line model using constant parameters at a frequency cannot reproduce measured waveform.

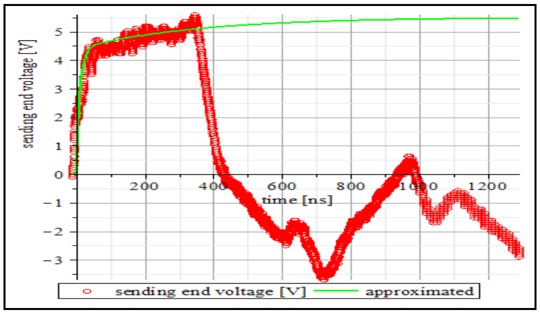
IV. FREQUENCY DEPENDENT EFFECT

The frequency dependent effects are an important factor in transient analysis. As conductors of the cable are twisted, the cable can be considered as a transposed line. Therefore there is no frequency dependent effect on the transformation matrix. For the accurate modeling of the cable, it requires evaluation of the frequency dependent effect on propagation and characteristics impedance (admittance) should be expressed by the functions in a frequency domain. This is achieved through a curve fitting algorithm which calculated poles and zeros of the function. Each illustrated measured sending end voltage and current is approximated by a double exponential function.

The characteristic impedance of a cabtyre cable including its frequency dependent effect is obtained based on exponential curve fitting upto twice of travelling time.



(a) Sending end current approximation



(b) Sending end voltage approximation v_s upto 2τ
Fig.6 Characteristics impedance approximation

Fig.6 shows the curve fitting to measured data for an aerial mode. The detailed procedure is shown in a flow chart in APPX-I(B). The approximation result is obtained in terms of poles and residues with infinite characteristics admittance.

Characteristics admittance parameters: $y_o(s)$

$$0.01817595499-\frac{0.003377716987}{8.6\,10^{-9}s+1}+\frac{0.003570073678}{1.000\,10^{-7}s+1}+\frac{0.003822857140}{-2.82120\,10^{-7}s-1}$$

Similarly, another important frequency dependent parameter is wave deformation obtained using lattice diagram method [4].

$$v_S(t)=v_o(t)(1+\theta_1)\theta_2\,v_o(t-2\tau)\ 2\tau<t<4\tau\text{(in time domain)}$$

$$v_S(s)=v_o(s)(1+(1+\theta_1)\theta_2\,e^{-2\gamma\ell}\ 2\tau<t<4\tau\text{(in frequency domain)}$$

where $\Theta_1$and Θ_2 are reflection coefficients at sending and receiving end respectively. The propagation characteristic of the travelling wave $e^{-\gamma l}$ can be obtained by solving above equation.

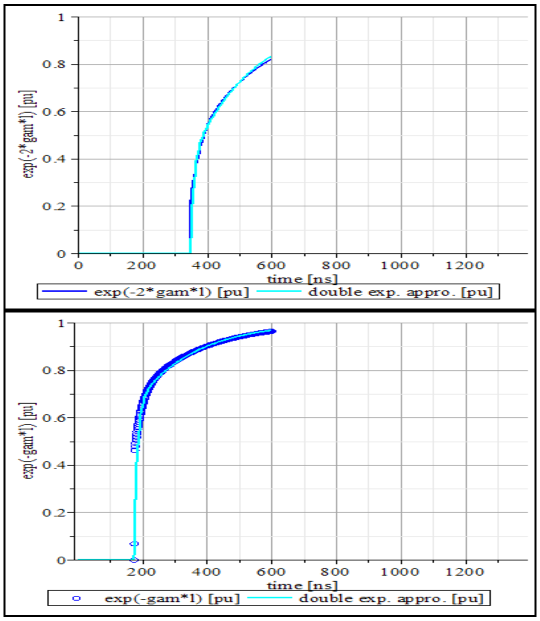


Fig.7 Wave propagation approximation

Fig.7 illustrate the step response of the travelling wave, $£^{-1(}e^{-\gamma l/s).}$ The response is approximated by the following function.

$$f(t)=u(t-\tau)-p_1e^{\left(\frac{t-\tau}{\tau_1}\right)}-(1-p_1)e^{\left(\frac{t-\tau}{\tau_2}\right)}$$

The parameters for aerial mode are:
A=1, p_1=0.65, t_1=10.0e-9, t_2=180e-9, τ =175e-9

The approximation of the voltage gives wave propagation parameters. The coefficient p1 is residue and inverse of the time constants τ_1 and τ_2 are poles of the approximated function in a frequency domain.

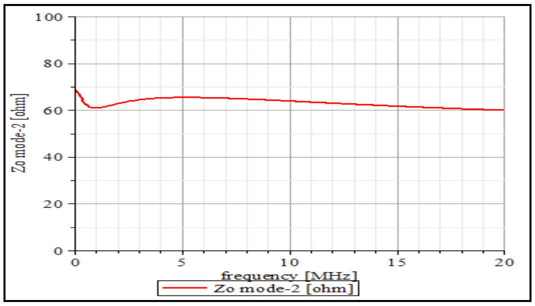
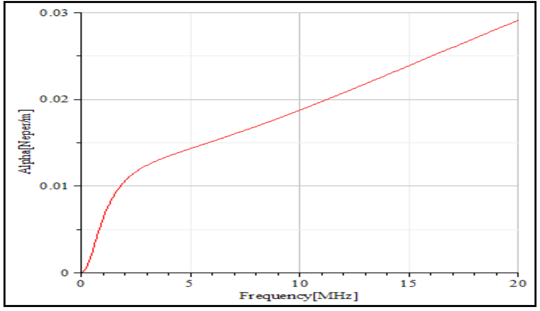
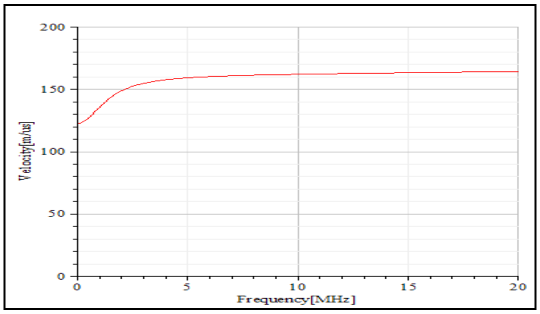


Fig.8 Characteristics impedance

Fig.8 shows variation of characteristic impedance with frequency. In a low frequency region less than 10 MHz the characteristics impedance is about 64Ω and it decreases as increase in frequency and set to 55Ω i.e.mode-2 impedance.



Attenuation



(a) Velocity

Fig.9 Propagation constant

The propagation constant is complex number. The real and imaginary parts express the attenuation and the phase shift, respectively. Fig. 9 shows the frequency dependent characteristics of the propagation constant. The attenuation is increasing as frequency increases. The propagation speeds approaching to $C_o/\sqrt{\varepsilon_r}$. The frequency dependent characteristic of the propagation constant distorts the travelling wave as shown in Fig.9 (b)

V. CONCLUSION

In this paper, a program for calculating parameter of a cabtyre cable is developed at a frequency. However, the transient response calculated by a line model using constant parameters at a frequency cannot reproduce measured waveform. The frequency dependence transient measurements of wave propagation characteristics on the cabtyre cable are carried out. It is found for the mode-2 cable characteristic impedance can be represented by RL series circuit. The attenuation increases as the frequency increases. This study supports to develop a generalized frequency dependent cabtyre cable model.

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APPX -I

A. EMTP Line Constant Routine for Cabtyre Cable [4] without frequency dependent

An EMTP line constant routine is developed by Maple code at 1MHz frequency as below:

```
$VINTAGE, 1
C [BUS1][BUS2][BUS3][BUS4][     R    ][    Zs    ][    vel   ][   Leng   ] 1[]
-1NODES1NODER1              1.91591e-027.35360e+012.38007e+08-3.02000e+01103
-2NODES2NODER2              6.64588e-027.29082e+011.55281e+08-3.02000e+01103
-3NODES3NODER3              4.98441e-025.46812e+011.55281e+08-3.02000e+01103
C  TI(1,1) ][  TI(1,2) ][  TI(1,3) ][  TI(1,4) ][  TI(1,5) ][  TI(1,6) ]
 3.33333e-01 1.00000e+00-5.00000e-01 {Real}
 0.00000e+00 0.00000e+00 0.00000e+00 {Imaginary}
 3.33333e-01 0.00000e+00 1.00000e+00 {Real}
 0.00000e+00 0.00000e+00 0.00000e+00 {Imaginary}
 3.33333e-01-1.00000e+00-5.00000e-01 {Real}
 0.00000e+00 0.00000e+00 0.00000e+00 {Imaginary}
$VINTAGE, 0
```

B. Curve fitting flow chart for Cabtyre Cable [4] with frequency dependent