WAVE PROPAGATION CHARACTERISTICS ON A COVERED CONDUCTOR

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ABSTRACT

A wave propagation characteristic is very significant to investigate a transient voltage and insulation design of a cable. This paper carries out an experiment and a simulation of wave propagation characteristics on an insulation covered conductor in comparison with a bare conductor. The simulations are carried out using Electro Magnetic Transient Program (EMTP) and Finite Difference Time Domain (FDTD) method. The measured results and simulated results are compared for bare and covered conductors. It has been found that in the case of the covered conductor, the characteristics impedance in the simulation result is less by few percent from that of the bare conductor. The EMTP and FDTD simulations reasonably agree with the measured and theoretical results when the cell size and its number in the FDTD are appropriate.

KEYWORDS: *Wave Propagation, Bare Conductor, Covered Conductor, EMTP, FDTD*

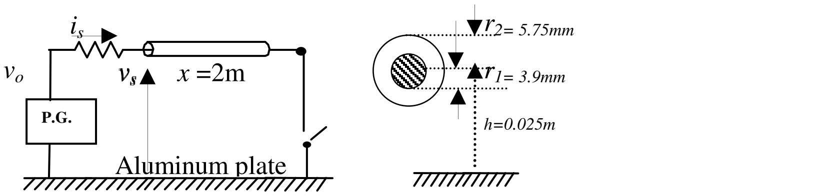
I. INTRODUCTION

Network companies are faced with increasing demands to supply energy without any disruptions. This challenge can be tackled by increasing reliability of the network. Covered conductors (CCs) provide a cost-effective method to increase overhead line reliability. The predominant practice throughout the world is to use bare conductors for overhead distribution circuits. By proper conductor spacing in air and support insulators adequate insulation between phase to phase and phase to ground is achieved. But due to long forest area and snow fall countries like UK , France, Finland, Sweden, Norway, Australia etc have converted there distribution system from bare conductor to covered conductor to get reliable service to customer. Covered conductors consist of a conductor surrounded by a covering made of insulating material as protection against accidental contacts with other covered conductors and with grounded parts such as tree branches, etc. There are significant advantages and disadvantages to using bare conductor, the same is true for covered conductor. The research [6 - 8] is going on proper fault detection and necessary measures in present of covered conductor. This paper has investigated the wave propagation characteristics of a covered conductor based on experimental results. To support the experimental results, EMTP and FDTD simulations and an analytical study were also carried out.

II. EXPERIMENTAL OBSERVATIONS

Fig.1 illustrates an experimental setup for measuring characteristic impedance and the travelling wave velocity of an overhead cable. For investigation 2 m length bare and covered conductor is used. A pulse generator (PG) is used as a source voltage. A current is evaluated from a source voltage (v_o) and a sending end voltage (v_s). All the voltages are measured by an oscilloscope (Tektronix DPO 4104, 1GHz) and a voltage probe 2500V pk (Tektronix Type no p6139A, Freq. Band 500 MHz).

2.1 Experimental Setup

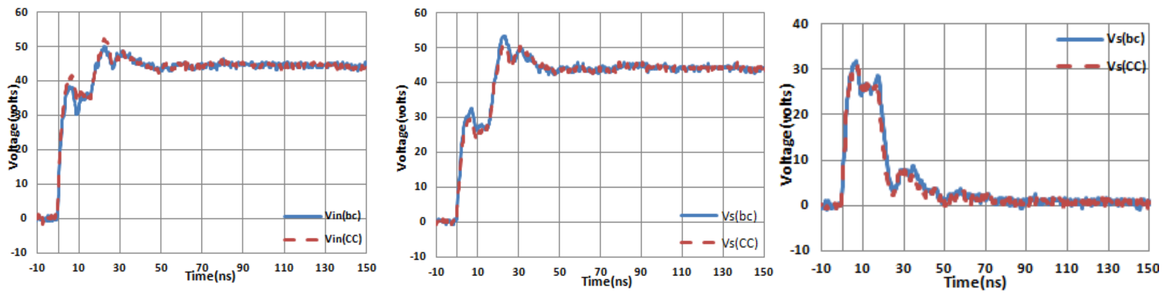


(a) Experimental circuit (b) Cross-section of Covered Conductor

Fig.1. Experimental setup

2.2. Measured Result

Fig.2 shows measured results of the v_s(t) in the case of open circuit and short circuit conditions at the receiving end.



(a)Input Voltage (b) Voltage at v_s(t) open circuit (c) Voltage $v_s(t)$ at *short circuit*

Fig.2. Measured results of voltage v_s of a bare and covered conductor

III. Numerical Simulations

3.1. EMTP SIMULATION

Electro Magnetic Transient Program (EMTP) [1] is straightforward for a circuit analysis. Required input data for the simulation are easily obtained by the EMTP Cable Parameters [2] or Line Constants [3].

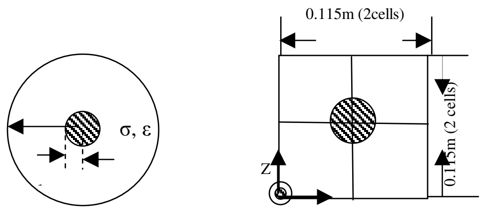
3.2 FDTD SIMULATION

3.2.1FDTD

A numerical electromagnetic analysis (NEA) is becoming a very powerful approach to solve a transient which cannot be handled by a circuit–theory based approach such as the EMTP. The NEA is a direct solution of Maxwell's equations expressed in a discrete representation so that various incident, reflected and scattered fields can be calculated by digital computers. The discretized Maxwell equations in time domain form the foundation of the Finite Difference Time Domain (FDTD) method to the solution of electromagnetic propagation problems [4]. VSTL developed by CRIEPI [5] is adopted in this paper.

3.2.2 MODEL CIRCUIT

Fig. 3 (a) illustrates the cross section of a 2m long covered conductor surrounded by a cylindrical sheath. The radius of the bare conductor and the surrounding sheath are a and b, respectively. The relative permittivity and the conductivity of the medium between the bare and the sheath conductor are assumed to be εr and, σ respectively. Fig. 3 (b) shows a bare conductor surrounded by a sheath conductor having a square cross section of 11.5 X 11.5 mm to be analyzed using the FDTD method.



(a) (b)

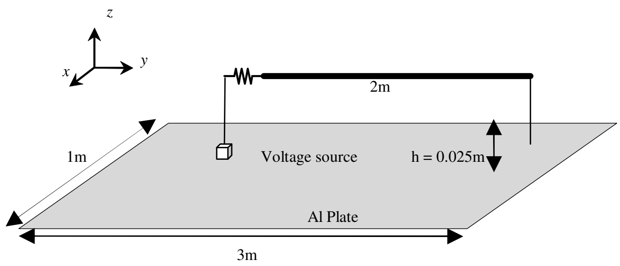
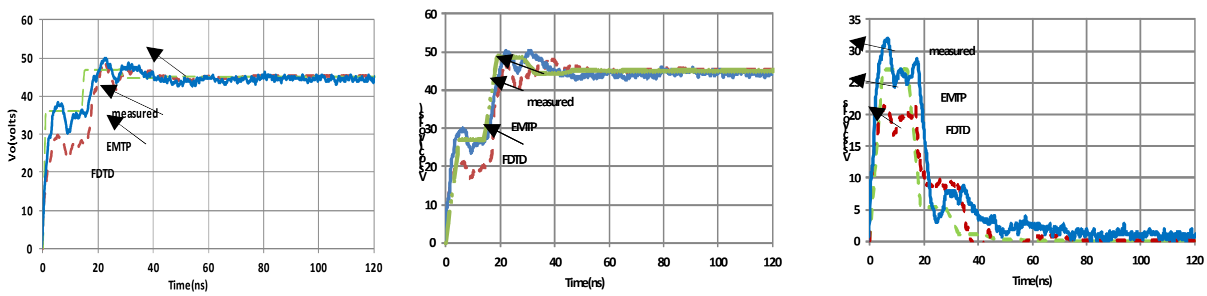


Fig.3.A bare conductor and the surrounding sheath representation **Fig.4** FDTD simulation model

The analytical space is composed of four enclosed cells around the conductor. This conductor system is represented with cell size Δs = 0.0125 m. The FDTD simulation model is as illustrated in Fig.4. The simulation is carried out for the experimental circuit with open-circuited and short-circuited receiving end conditions. The response is calculated up to 120 ns with a time increment of 20 ns.

IV. Comparative Results



(a) Input Voltage $v_o(t)$ (b) Voltage at $v_s(t)$ open circuit (c) Voltage $v_s(t)$ at short circuit

-------- Measured———— EMTP -.-.-.-.-. FDTD

Fig.5 Comparison of EMTP and FDTD simulation with measured results

Fig. 5 shows results of FDTD simulation in comparison with measured and EMTP simulation results.

V. Discussion

5.1. Evaluation of surge impedance and velocity [1, 2]

5.1.1 Analytical calculation

(a) Bare conductor

The characteristic impedance of a bare conductor is calculated from physical dimensions in Fig.1 as follows:

$$Z_s = 60\,ln\left(2 * h/_{r1}\right) = 153.03\Omega$$

(b) With covered conductor

Assuming εr = 3, the surge impedance Zs and velocity c are evaluated by formulas described in Appendix. It gives Zs = 144.94Ω and c = 284.09m/μs

5.2. Measured results

The following formula is often used to evaluate an approximate value of surge impedance Z_s

$$Z_s = v_s/i_s \quad (1)$$

$$i_s = (v_o - v_s)/R \quad (2)$$

$$c = x/\tau \quad (3)$$

where v_s = sending end voltage in time domain

i_s = sending end current in time domain
x = length of cable

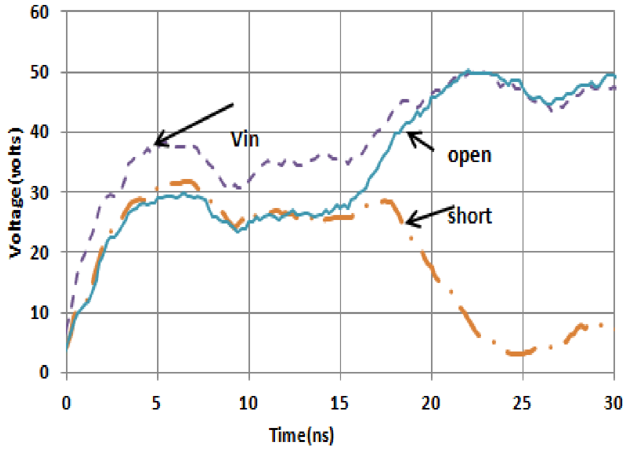


Fig.6. Comparison of measured voltages at node *s* for Open circuit and Short circuit

Zs and c are evaluated by eqs. (1) and (3) from Fig.7 which is the same as Fig. 2 upto 2τ.
Z_s = 163.47Ω and c = 285.71m/μs

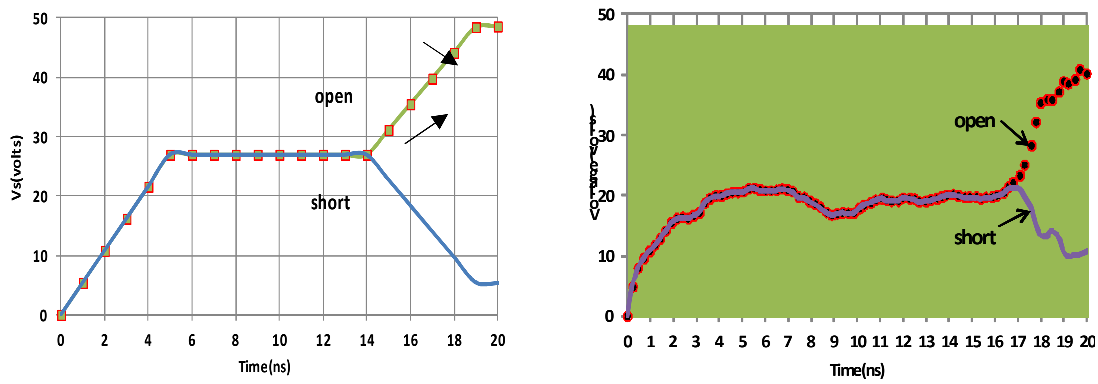
TABLE I: Propagation velocity c and Surge impedance Z_s

conductor	measured		analytical	
	c (m/μs)	Zs (Ω)	c (m/μs)	Zs (Ω)
bare	285.71	163.47	300	153.03
covered	285.71	158.36	284.09	144.94

It is observed that there is a minor difference of the surge impedance between the bare conductor and the covered conductor. Table I gives a comparison of the surge impedance measured and calculated analytically. It can be observed from Table 1 that the difference of Z_s is 3.2% between bare conductor and covered conductor. Theoretical error is 9.24%. The measured velocity is almost equal in magnitude for both conductors.

5.3 EMTP and FDTD Simulation

Using EMTP and FDTD simulation method theoretical and measured results for covered conductor is investigated. Fig. 7(a) shows open and short circuited sending end voltages by EMTP, it is view of Fig.3 up to 2τ and Fig. 7(b) is FDTD simulation of Fig.6 up to 2τ.



(a) EMTP Simulated voltage up to 2τ (b) FDTD Simulated voltage upto 2τ

Fig.7 Sending end voltage v_s(t)

Fig.8 shows measured bare conductor and covered conductor result for surge impedances as well EMTP and simulated results. For covered conductor, EMTP simulated surge impedance is 153.28Ω and measured result is 158.36Ω.The error is 3.2%.

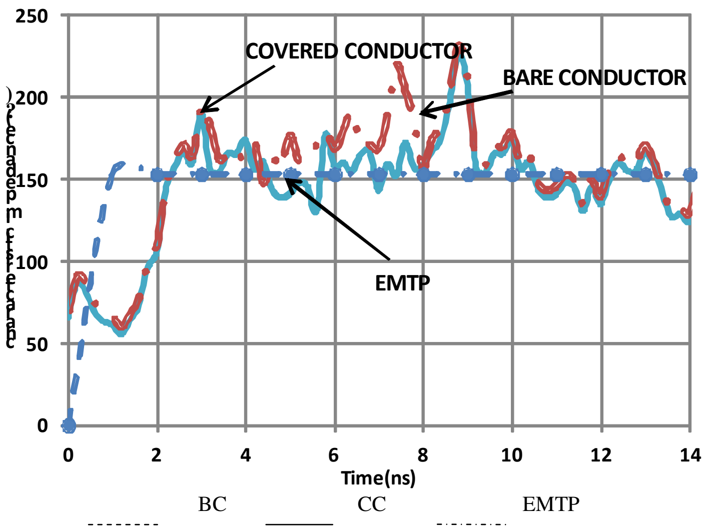


Fig.8 Comparison of Surge impedance

FDTD simulation is carried out for different cell sizes. The summary of result is as shown in Table II.

TABLE II : Surge Impedance [Ω] by FDTD

case	Height	Virtual height (m)	Cell Size (m)	Zs(Ω)	% Error
1	h/2	0.025	0.0125	126.52	25.16
2	h	0.05	0.025	153.79	2.971
3	3h/2	0.075	0.0375	168.22	-5.86
4	2h	0.1	0.05	183.02	-13.4

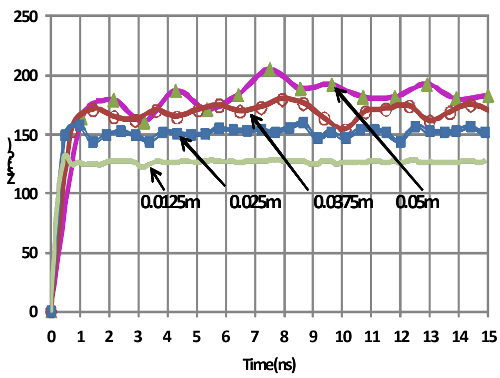


Fig.9 FDTD simulation of surge impedance

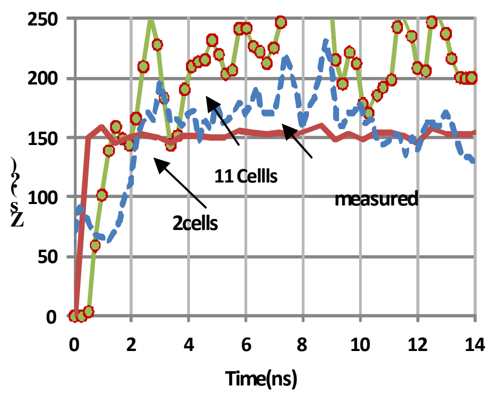


Fig.10 Comparison of Surge impedance for no of cells

A significant difference is observed in the surge impedance measured and FDTD simulated at cell size equal to half of the actual configuration height. The measured results are Zs = 158.36Ω and Zs = 126.52Ω by FDTD method, respectively. The error equals to 25%. There is two possibility of this inaccuracy, one is data sampling, as 10000 points are sampled to 200 points and another is that the cell size used for FDTD simulation is very small i.e. 0.0125m. To check the validity of simulation is carried out for different cell sizes. It is observed for cell size equal to actual configuration height is reasonably agreed with measured value. While other approximated results are not acceptable. The variation in surge impedance due to different cell size is plotted as shown in Fig.9.Finite Difference method used techniques in electromagnetic with unstructured grids for electrical and magnetic field quantities. Two cells are considered from ground, i.e. one for source and one for lead wire, problem may occur when trying to modeling across different time scales and space in a simulation. In general lead wire is represented by 10cells , for further verification 1 cell for source and 10 cells are considered for lead wire while simulation. When Δs = 0.025m, virtual height = 0.275m which is far greater than actual height. The simulated result is as show in fig.10.

VI. CONCLUSION

This paper has investigated the wave propagation characteristics of a covered conductor based on experimental results. To support the experimental results, EMTP and FDTD simulations and an analytical study were also carried out. From the investigations in the paper, the following remarks are obtained.

(1) The surge impedance of a covered conductor is different only by few percent in comparison with that of a bare conductor in a measured result. It is estimated that this difference is caused by the permittivity of an insulator.

(2) The transient response simulated by FDTD method somehow reproduces a measured waveform.

(3) The FDTD simulation is carried out with different cell sizes. The surge impedance simulated by the FDTD with the cell size of Δs =h is reasonably agree with the measured. The other conditions do not give satisfactory result.

(4) The surge impedance becomes 283Ω, which is far greater than the measured value, when the FDTD is used with virtual height equals 0.275 i.e. no of cells equal to 11 from ground.

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APPENDIX:

In lossless condition (R = G = 0), no attenuation, i.e.α=0

$$Zs = \sqrt{\frac{L}{C}}\ \Omega \qquad and \quad velocity = \frac{1}{\sqrt{LC}}\ \ m/\mu s \qquad (1)$$

(A) For an overhead conductor

$$L = \frac{\mu_o}{2\pi} ln\frac{2h}{r}\ \text{H/m} \qquad C = \frac{2\pi\varepsilon_o}{ln\frac{2h}{r}}\ \text{F/m} \qquad (2)$$

$$\therefore\ Zs = 60\, ln\frac{2h}{r}\ \Omega \qquad velocity = \frac{1}{\sqrt{\mu_o\varepsilon_o}} = \ 300\ m/\mu s \qquad (3)$$

(B) For a covered conductor

$$L = \frac{\mu_o}{2\pi} ln\frac{2h}{r}\ \text{H/m} \qquad C = P^{-1} \qquad (4)$$

$$P = P_o + P_i \qquad \text{where} \quad P_i = \frac{1}{2\pi\varepsilon_o\varepsilon_r} ln\left(r_2/r_1\right), P_o = \frac{1}{2\pi\varepsilon_o} ln\left(2h/r_2\right) \qquad (5)$$

$$C = \frac{2\pi\varepsilon_o}{ln\left(\left(\frac{2h}{r_2}\right)\left(\frac{r_2}{r_1}\right)^{1/\varepsilon_r}\right)} \qquad (((\qquad (6)$$

$$\therefore\ Zs = \frac{\mu_o}{4\pi^2\varepsilon_o} ln\left[\frac{2h}{r_1} + \left(\frac{2h}{r_2}\right)\left(\frac{r_2}{r_1}\right)^{1/\varepsilon_r}\right]\ \Omega \qquad velocity = \frac{1}{\sqrt{\mu_o\varepsilon_o}} \frac{ln\left(\frac{2h}{r_1}\right)}{\sqrt{ln\left(\frac{2h}{r_2}\right)\left(\frac{r_2}{r_1}\right)^{1/\varepsilon_r}}}\ \ m/s \qquad (7)$$

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BIOGRAPHIES

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