THE EFFECTS OF INTERCONNECTIONS AND BRANCHED NETWORK IN THE BROADBAND POWERLINE COMMUNICATIONS

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Abstract

The frequency responses of a single-phase powerline channel with interconnections are derived. Different loading at different branches is considered. The results indicate that there are significant attenuations and distortions as the number of branches are increased. Broadband signal with pulse width smaller than the channel delay spread causes a series of pulses at the receiver. The small impedances at the terminations cause severe distortions. As the number of interconnections at the same point increases the signal from the source to that point increases in negative sides, which has implications to electromagnetic interference.

I. INTRODUCTION

Several techniques have been presented in literature to model the transfer characteristics of powerline network in the presence of interconnections and loads, with a view to use them for broadband powerline communications [1][2][3][4]. The model, which is most common is the one developed in [1], which is top down approach. The model extracts the data from measurements. The model was extended in [2] to formulate the bottom top model by deriving the parameters from the actual network and take into consideration the load connected. However, the model being developed in [1] and computational analysis extended in [2] is commonly used, because it is easy to use and it corresponds somehow with measurements. Although the model is popular, there are some drawbacks. The first drawback is the high computational cost in estimating the delay, the amplitude and the phase associated with each path. Since the model is in time domain, it is necessary to take into consideration the very high number of paths associated with all the possible reflections from unmatched terminations along the line [5]. Since the consideration of paths is individual thinking when it comes to real powerline network, which consists of complicated interconnections and branches it is very difficult to use the same method and come up with the uniform results. Four, when it comes to electromagnetic compatibility analysis the model cannot be used to determine the distribution of current along the transmission line. In this method the transfer characteristics of powerline channel have been developed where the uniformity of the results can be obtained. The derivation has been based on the reflection and transmission factors, taking into consideration the loads, distances and interconnection nodes. In addition the formula can be extended to determine the current distribution at any given distance. In this paper the effects of interconnections and branched network have been investigated.

II. SIGNAL PROPAGATION IN THE POWERLINE NETWORK

A. Powerline with one Interconnection

Consider a transmission line shown in fig 1, Vs being the source impedance, AB and BC are transmission lines with characteristics impedance Z_1 and Z_2 respectively while Z_{L2} is the load impedance. When transmission lines is excited with a pulse at point A, the signal v^+ will propagate to B. The signal, which will propagate, is given by $v^+e^{-\gamma_1 l_1}$, the parameter v^+ is a terminal voltage, g_1 is propagation constant and l_1 is arbitrary length the signal has travelled towards B. The incident wave at point B is given by $v^+e^{-g_1 L_1}$; the parameter L_1 is the length of transmission line 1. On reaching point B two waves will image, the first will be reflected back to A, the second wave will travel towards C. The incidence wave at C will generate two waves, the first will travel towards the load and another wave will be reflected back towards node B. In general in the first instant there will be three waves between nodes B and C. The first is the first direct wave, second is the wave reflected at node C and the third wave is the wave reflected at B back to C. The trend of reflections at all points will continue until all signals have been attenuated. In addition the waves reflected at point B during the first instant on reaching node A will propagate back and course another trend. It has been derived that the general trend of voltage signal received at receiver two taking into consideration all factors is given by $V_2 = \sum_{M=1}^{L} T_L a_{21} V_{21}$. The parameter T_L is a load transmission factor, $a_{21} = r_s^{M-1} r_{12}^{M-1} e^{-g_1(2(M-1)L_1)}$; M is the reflection point between node A and node B and V_{21} is given by equation 1. The parameter $b_2 = \mathrm{T}_{12} e^{-g_1 L_1} v^+$, $b_{21} = \frac{\mathrm{B}_{21}}{1-\mathrm{B}_{21}} + \frac{\mathrm{B}_{21}\mathrm{A}_{21}}{1-\mathrm{B}_{21}\mathrm{A}_{21}} + \frac{\mathrm{B}_{21}\mathrm{A}_{21}^{\;2}}{1-\mathrm{B}_{21}\mathrm{A}_{21}^{\;2}} + \frac{\mathrm{B}_{21}\mathrm{A}_{21}^{\;3}}{1-\mathrm{A}_{21}\mathrm{B}_{21}^{\;3}} + ..,$ $A_{21} = r_{L2} r_{21} e^{-g_2 2L_2}$ and $B_{21} = \left(e^{-g_1 2L_1} \mathrm{T}_{12} e^{-g_2 2L_2}\right) r_{L2} T_{21} r_s$ the parameters r_{21}, r_s, r_{12} are reflection factors from transmission line 2 to transmission line 1, at the source and transmission line 1 to transmission line 2 respectively. T_{12} and T_{21} are transmission factors. L_2 and l_2 are length of transmission line 2 and arbitrary length the signal have travelled respectively .

$$V_{21} = (1+b_{21}) b_2 e^{-g_2 l_2} + \sum_{N=1}^{L} (1+b_{21}) b_2 r_{21}^{N-1} r_{L1}^{N} e^{-g_2(2NL_2 - l_2)} + \sum_{N=1}^{L} (1+b_{21}) b_2 r_{21}^{N} r_{L1}^{N} e^{-g_2(2NL_2 + l_2)} \quad (1)$$

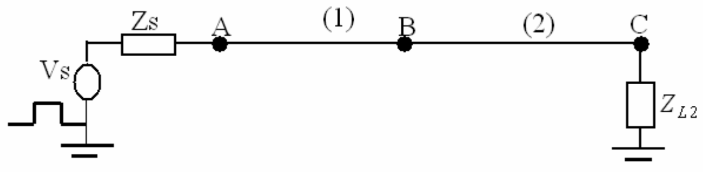

Fig 1: Transmission line with one interconnection

The transfer function $H_2(f)$ is the ratio of received signal and transmitted signal at the input of the transmission line, that is $H_2(f) = \frac{V_2}{v^+}$. Considering the received signal, the transfer function can be represented as $H_2(f) = \sum_{m=1}^{L} T_L a_{21} H_{21}(f)$. The parameter $H_{21}(f)$ is as shown in equation (2) and $b_3 = \mathrm{T}_{12} e^{-g_1 L_1}$.

$$H_{21} = (1+b_{21}) b_3 e^{-g_2 l_2} + \sum_{N=1}^{L} (1+b_{21}) b_3 r_{21}^{N-1} r_{L1}^{N} e^{-g_2(2NL_2 - l_2)} + \sum_{N=1}^{L} (1+b_{21}) b_3 r_{21}^{N} r_{L1}^{N} e^{-g_2(2NL_2 + l_2)} \quad (2)$$

B. Powerline with one Interconnection and Branch

Fig. 2 shows a transmission line with one interconnection and a branch, with parameters L_1, L_2 and L_3 being the lengths of transmission line and l_1, l_2 and l_3 being arbitrary distance the signal has traveled from the source to branch, loads 2 and load 3 respectively. The parameters Z_{L2} and Z_{L3} are load impedances.

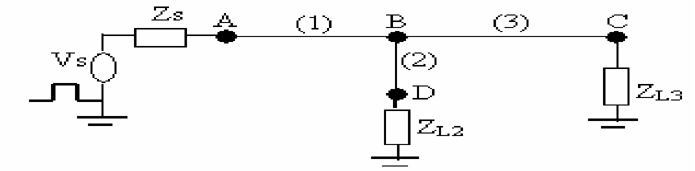

Fig 2: Transmission line with one interconnection and Branch

Assuming that the loads are not terminated in their characteristics impedances, the received signal at load two (Z_{L2}) is the contribution from transmission lines 1 and 3. The signals towards load 2 from transmission line 1(V_{21}) and 3 (V_{23}) can be represented by $V_2 = \sum_{M=1}^{L} (a_1 V_{21} + a_{23} V_{23})$. The parameter $a_{23} = r_{L3}^{M-1} r_{32}^{M-1} e^{-g_3(2(M-1)L_3)}$ whereby each parameter of transmission line 1 is replaced by transmission line 3 $b_{132} = \mathrm{T}_{13}\mathrm{T}_{23} r_{L3} e^{-g_1 L_1} e^{-g_3(2L3)} v^+$, $\mathrm{B}_{23} = r_{L3} r_{L2} \mathrm{T}_{23} \mathrm{T}_{32} e^{-g_3(2L_3)} e^{-g_1(2L_2)}$, $\mathrm{A}_{23} = r_{L3} r_{23} e^{-g_2(2L_2)}$ and $b_{23} = \frac{\mathrm{B}_{23}}{1-\mathrm{B}_{23}} + \frac{\mathrm{B}_{23}\mathrm{A}_{23}}{1-\mathrm{B}_{23}\mathrm{A}_{23}} + \frac{\mathrm{B}_{23}\mathrm{A}_{23}^{\;2}}{1-\mathrm{B}_{23}\mathrm{A}_{23}^{\;2}} + \frac{\mathrm{B}_{23}\mathrm{A}_{23}^{\;3}}{1-\mathrm{A}_{23}\mathrm{B}_{23}^{\;3}} + \ldots.$

$$V_{23} = (1+b_{23}) b_{132} e^{-g_2 l_2} + \sum_{N=1}^{L} (1+b_{23}) b_{132} r_{23}^{N-1} r_{L1}^{N} e^{-g_2(2NL_2 - l_2)} + \sum_{N=1}^{L} (1+b_{23}) b_{132} r_{23}^{N} r_{L1}^{N} e^{-g_2(2NL_2 + l_2)} \quad (3)$$

The transfer function $H_2(f)$ is the ratio of received signal at load 2 from load 3 and transmitted signal at the input terminal. Considering the received signal, the transfer function can be represented as $H_2(f) = \sum_{M=1}^{L} T_L \left(a_{21} H_{21}(f) + a_{23} H_{23}(f)\right)$. The parameter $H_{23}(f)$ is as shown in equation (4), whereby

$b_{133} = \mathrm{T}_{13}\mathrm{T}_{23} r_{L3} e^{-g_1 L_1} e^{-g_3(2L3)}$.

$$H_{23} = (1 + b_{23}) b_{133} e^{-g_2 l_2} + \sum_{N=1}^{L} (1 + b_{23}) b_{133} r_{21}^{N-1} r_{L1}^{N} e^{-g_2(2NL_2 - l_2)} + \sum_{N=1}^{L} (1 + b_{23}) b_{133} r_{21}^{N} r_{L1}^{N} e^{-g_2(2NL_2 + l_2)} \quad (4)$$

C. Powerline with a number of Branches and Interconnections

For a transmission line with a number of branches connected at the same point the signal along the region from the source to the interconnection point can be represented by $H_m(f) = \sum_{M=1}^{L} \sum_{n=1}^{N_T} \mathrm{T}_L a_{mn} H_{mn}(f)$, $m \neq n$, N_T is the total number of transmission lines connected at the same node and m=1 means transmission line with source signal. The received signal will be the transmission signal to the load depending on the load impedance. The parameter T_L is the load transmission factor; $a_{mn} = r_{Ln}^{M-1} r_{nm}^{M-1} e^{-g_n(2(M-1)Ln)}$ and $H_{mn}(f)$ is as in equation (5). In the general equations m means the reference load where the transfer function is referred, for example if the reference is load 3 then m will be equal to 3 and n is the transmission line which contributes signals to the load. For example in fig. 3 if the reference is load 3, then n=1 and 2. The parameters $b_{1nm} = \mathrm{T}_{1n}\mathrm{T}_{mn} r_{Ln} e^{-g_1 L_1} e^{-g_n(2L_n)}$, $b_{mn} = \frac{\mathrm{B}_{mn}}{1-\mathrm{B}_{mn}} + \frac{\mathrm{B}_{mn}\mathrm{A}_{mn}}{1-\mathrm{B}_{mn}\mathrm{A}_{mn}} + \frac{\mathrm{B}_{mn}\mathrm{A}_{mn}^{2}}{1-\mathrm{B}_{mn}\mathrm{A}_{mn}^{2}}$......

$\mathrm{A}_{mn} = r_{Lm} r_{mn} e^{-g_m(2L_m)}$ and $\mathrm{B}_{mn} = r_{Lm} r_{Ln} \mathrm{T}_{mn} \mathrm{T}_{nm} e^{-g_n(2L_n)} e^{-g_m(2L_m)}$.

$$H_{mn} = (1 + b_{mn}) b_{1nm} e^{-g_m l_m} + \sum_{N=1}^{L} (1 + b_{mn}) b_{1nm} r_{mn}^{N-1} r_{Lm}^{N} e^{-g_m(2NL_m - l_m)} + \sum_{N=1}^{L} (1 + b_{mn}) b_{1nm} r_{mn}^{N} r_{Lm}^{N} e^{-g_2(2NL_m + l_m)} \quad (5)$$

For transmission line as shown in fig. 3, the same methodology as before can be used. The channel transfer function can be calculated as the ratio of the received signal at the receiving end to the terminal voltage. This can be given by $H_m(f) = \prod_{n=1}^{M_T} \sum_{M=1}^{L} \sum_{n=1}^{N_T} T_L a_{mn} H_{mn}(f)$. The channel impulse response $h_m(t) = \prod_{n=1}^{M_T} \sum_{m=1}^{L} \sum_{n=1}^{N_T} T_L a_{mn}(t) h_{mn}(t)$ can be obtained by taking Inverse Fast Fourier Transform (IFFT) of the frequency domain transfer function $H(f)$ where the parameter M_T is the total number of cascading nodes in series. For example fig 3 has two nodes (node B & C). Since the derivation has considered three cables, then the terminal conditions are needed to be able to deal with cascaded lines. In this the case of fig. 3, in the region BC line small lengths have to be considered and terminated it into characteristics impedances, the output at that node will be the input signals to other part. In addition the source reflection factor is r_{21} .

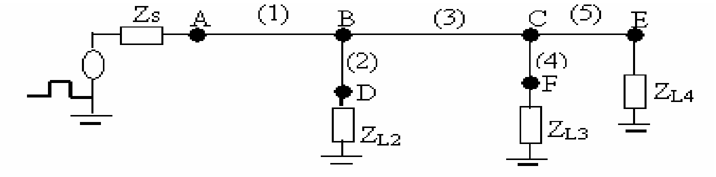

Fig 3: Transmission line with one interconnection and Branch

III. MODEL VERIFICATION WITH ATP-EMTP

For verification purposes the transmission line, which is used in Tanzania Power network, is considered. The inductance, capacitance, resistance and conductance were calculated as $\mathrm{L} = \frac{\mu}{\pi} \cosh^{-1}(\frac{\mathrm{D}}{2\mathrm{a}})$, $\mathrm{C} = \frac{\pi\varepsilon}{\cosh^{-1}(\mathrm{D}/2\mathrm{a})}$, $\mathrm{R} = \frac{1}{\pi \mathrm{a}} \sqrt{\frac{\pi \mathrm{f} \mu}{\sigma}}$ and $\mathrm{G} = 2\pi \mathrm{f} \mathrm{C} \tan\delta$ respectively the parameter μ is the permeability in free space; D is a cable parameter, a is a radius of a conductor, ε permitivity in free space and σ is a conductivity of a material. The characteristics impedance was calculated as in $\mathrm{Z} = \sqrt{\frac{\mathrm{R} + \mathrm{j}\omega \mathrm{L}}{\mathrm{G} + \mathrm{j}\omega \mathrm{C}}}$ [6] and the reflection and transmission factors are calculated as in [1][2]. Since the cable in Tanzania network is overhead transmission line and the separation between is free space the conductance is assumed to be zero. The propagation constant is calculated as in $\gamma = \alpha + \mathrm{j}\beta = \sqrt{(\mathrm{R} + \mathrm{j}\omega\mathrm{L})(\mathrm{G} + \mathrm{j}\omega\mathrm{C})}$ where α is attenuation constant, β phase factor and δ is depth factor. By using that formula the calculated characteristics impedances are 496.6134Ω. Let us simulate a case corresponding to fig. 3. Note that for confirming the validity of the proposed model simulations are also carried out with ATP-EMTP [7]. From fig. 3, the transmitter is located at point A and receivers connected at point E (Receiver 3) and F (Receiver 2). The lengths of AB, BC, BD, CF and CE are 60m, 100m, 200m, 200m and 100m respectively. Two types of loading were considered. Firstly all points were terminated in their characteristics impedances. Secondly load 2 was terminated in 50Ω while the other points were terminated in their characteristics impedances. The simulation results are as in fig. 4, and the results comparable with corresponding ATP-EMTP simulations.

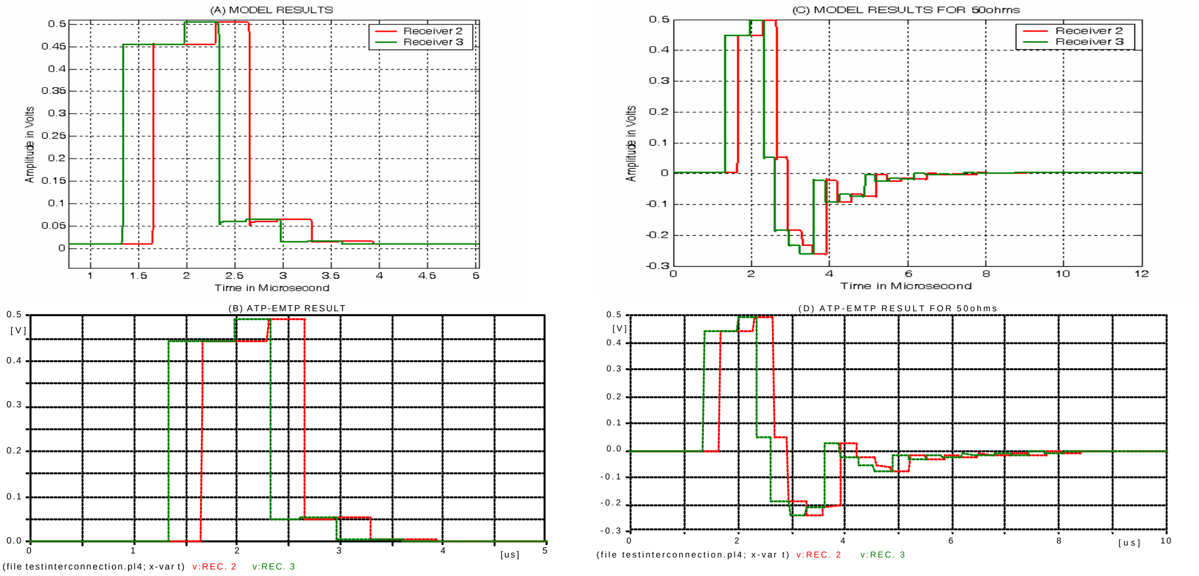

Fig 4: Simulation Results: (A) Model Results for all terminated in Characteristics impedance (B) ATP-EMTP Results for (A) (C) Model Results terminated in 50Ω (D) ATP-EMTP Results for termination in 50Ω.

IV. CONCLUSSION

In this paper the modeling procedure of powerline channel have been presented. The parameter required have been derived from the powerline network topology and loading. The model used has indicated to come up with good results, hence can be used satisfactorily to characterize powerline network and overcome all limitations, which have been observed in [1] and [2]. In powerline network, the small impedances at the terminations cause severe distortions. As the number of interconnections at the same point increases the signal from the source to that point increases in negative sides, which has implications to electromagnetic interference. By using this model in powerline network considering ten interconnections, and delay spread smaller than the determined delay spread, series of pulses were observed at the receiving terminal. When the numbers of interconnections were increased at the same point the reflected signals were increased in negative part, which can have implications in EMC.

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