Incidence Angle Impact on EM Wave-Line Coupling

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Abstract— For an EM plane wave coupling with a horizontal conductor above ground, the induced current reaches a maximum for small incidence angles. A transmission line analysis shows that this is due to in-phase adding of excited waves along the line.
Keywords- EMP; Transmission line; EM Wave Coupling.

I. INTRODUCTION

This study supports the threat evaluation for EMP impact on power lines and connected components. The current induced by a plane wave incident on a horizontal line above a lossy ground is computed as a function of the incidence angle ψ, as in Fig. 1 (case of zero incidence azimuthal angle, that yields the largest current). Solutions from both fully EM analysis, and from transmission line theory are well known (e.g. [1], [2], respectively).

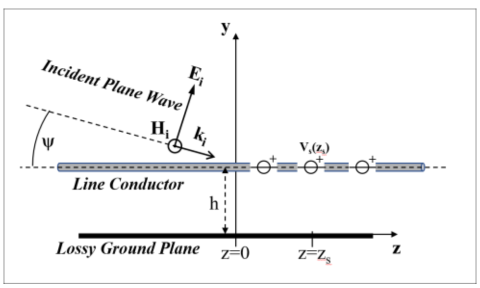

Figure 1. Incident wave on line above ground

II. INDUCED CURRENT ON THE LINE

Following [2], the impact on the infinite line from the external field (incident wave plus ground reflection) can be represented by a distributed set of voltage sources (Fig. 1). In the conventional phasor notation, for a single lumped voltage source V_s in $z=z_s$, the current on an infinite line above ground is [2]

$$I_{line}(z) = \begin{cases} \frac{V_s(z_s)}{2Z_c} e^{-j\gamma(z-z_s)}, z \geq z_s \\ \frac{V_s(z_s)}{2Z_c} e^{j\gamma(z-z_s)}, z \leq z_s \end{cases} \triangleq V_s(z_s)\alpha(z,z_s) \qquad (1)$$

where γ and Z_c are, respectively, the propagation constant and characteristic impedance. A distributed voltage source can be considered as the equivalent to a harmonic incident wave of amplitude E_0. This leads to a field component $E_c(z)$ on the conductor expressed as (with $e^{-j\omega t}$ suppressed)

$$E_c(z) = E_0 \sin(\psi)\left(e^{jh\sin(\psi)k_0} - R_v e^{-jh\sin(\psi)k_0}\right)e^{-jz\cos(\psi)k_0}$$

where $k_0=\omega/c$ and R_v is the ground reflection coefficient. Thus, if $V_s(z_s)$ in (1) is replaced by a source distribution $dV_s(z_s)=E_c(z_s)dz$, the line current can be written as

$$I_{line}(z) = \int_{-\infty}^{z} \frac{e^{j\gamma(z-z_s)}}{2Z_c} E_c(z_s)dz_s + \int_{z}^{\infty} \frac{e^{-j\gamma(z-z_s)}}{2Z_c} E_c(z_s)dz_s \qquad (3)$$

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III. CURRENT VS. INCIDENCE ANGLE

Approximations of the integral in (3) with finite line length L, and then through series representing a discrete source distribution are then considered as

$$I_{line}(z) \cong \int_{-L}^{L} \alpha(z,z_s)E_c(z_s)dz_s \cong \sum_{n=-N}^{N} \alpha(z,\mathrm{n}\Delta)E_c(\mathrm{n}\Delta)\Delta \qquad (4)$$

where $\Delta=L/N$, and then $z_s=n\Delta$ and α was defined in (1).

The L=∞ line current in (3) is computed analytically and plotted in Fig. 2 vs. the angle ψ, with the same open-termination geometry and lossy ground as in [1]. As in [1] (that uses a different normalization and a fully EM model), the peak occurs at $\psi_{max} \approx 6.7°$. Fig. 2 shows also a good agreement with the responses in (4), for both a finite L, (of several wavelengths at 500 kHz as in [1]), and with the series approximation with N=50.

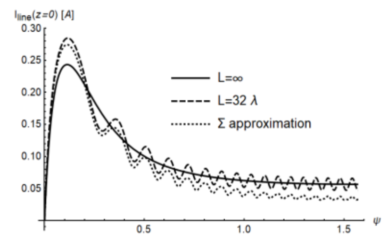

Figure 2. Line current amplitude vs. incidence angle ψ

To study the peaked response, (4) is re-written in terms of the current contributions ΔI: $I_{line}(z) \cong \sum_{n=-N}^{N} \Delta I(z,\mathrm{n}\Delta)$.

In Fig. 3, the real part of the phasor ΔI is plotted vs. z, in the vicinity of $z=0$, for five $z_s=n\Delta<0$ sources. This shows how the peak of Fig. 2 is formed: at $\psi=\psi_{max}$ the current contributions add closer in phase (thus leading to an overall larger current), while for $\psi=2.5\psi_{max}$ there is a larger spread leading to partial cancellations of the contributions.

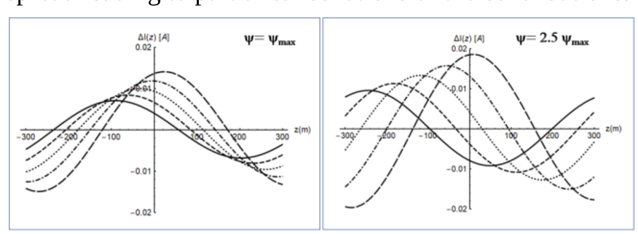

Figure 3. Current waveform spread at ψ=ψmax vs. larger ψ

This was verified for other angles and locations of the sources. Also, for larger frequencies the peak in Fig. 2 has a lower amplitude, and shifts to slightly lower angles.

IV. CONCLUSIONS

The peaking of the wave-line coupling at small incidence angles is due to a selective superposition of the traveling waves induced on the line. The finite length line analysis that was presented is also effective to study realistic, short-duration pulses.

REFERENCES

[1] Olsen, R. G., D. C. Chang, IEEE Trans. on Antennas and Propagation, AP-22 (4), 586 (1974)
[2] Tesche, F. M., M. Ianoz and T. Karlsson, EMC Methods and Computational Models. Wiley Interscience, New York 1997