Spatial Perturbation of Extremely Low-Frequency Electric Fields by the Human Body under Overhead Power Lines

Maros Smondrk, Roman Radil, Milan Smetana, Ladislav Janousek
Department of Electromagnetic and Biomedical Engineering
Faculty of Electrical Engineering and Information Technology, University of Zilina
Zilina, Slovakia
{maros.smondrk, roman.radil, milan.smetana, ladislav.janousek}@uniza.sk

Peter Bojda, Lubos Skurcak
Department of Science, Research, Development and Analysis, VUJE, a.s
Trnava, Slovakia
{peter.bojda, lubos.skurcak}@vuje.sk

***Abstract*—This paper presents a boundary analysis of extremely low-frequency (ELF) electric field perturbations caused by a human body under high-voltage overhead transmission lines (OHL). In the 50/60 Hz quasi-static regime, the human body acts as a lossy conductor, significantly distorting the ambient electric field. While the literature over the last decade thoroughly covers internal dosimetry (induced currents and SAR), there is a distinct research gap regarding the definition of the external boundary where the field returns to its unperturbed, free-space state. This paper establishes a mathematical methodology to define this "safe distance" utilizing both scalar magnitude and complex vector deviations combined with a 99.0% statistical percentile compliance criterion. A case study comparing a 400 kV OHL at structural height and realistic LiDAR-measured height is performed. The results demonstrate that a horizontal clearance of 2.3 m and a vertical clearance of 1.7 m are highly robust and sufficient for standard 5% EMC engineering margins. Conversely, high-precision applications requiring 1% field integrity must significantly expand their exclusion zones, requiring a protective envelope of at least 5.2 m horizontally and 3.6 m vertically under the worst-case OHL height condition.**

***Index Terms*—Extremely Low Frequency (ELF), Electric Field Perturbation, Human Phantom, Transmission Lines, Numerical Dosimetry.**

I. Introduction

Exposure of the general public and occupational personnel to extremely low-frequency (ELF) electric fields (E-fields) generated by high-voltage overhead transmission lines (OHL) remains a focal point of electromagnetic compatibility (EMC) and environmental safety standards, such as those set by ICNIRP and IEEE ICES [1]. Under typical 400 kV OHLs, the ambient E-field at the ground level can reach several kV per meter.

At the power-line frequency of 50 Hz (or 60 Hz), the wavelength of the electromagnetic wave is approximately 6000 km. Consequently, the physical interaction between the OHL and a human body located on the ground is governed entirely by quasi-static electrostatic coupling. In this regime, biological tissue is characterized by high relative permittivity ($\varepsilon_r \approx 10^4 - 10^5$) and moderate conductivity ($\sigma \approx 0.1 - 0.2$ S/m). This electrical profile renders the human body highly conductive relative to the surrounding air ($\sigma_{\text{air}} \approx 10^{-14}$ S/m). As a result, the human body behaves similarly to a grounded conductor. It draws E-field lines toward its surface, creating significant local field enhancements (hotspots) near the head and shoulders, while simultaneously shielding the region immediately below and behind the torso.

The bulk of the research from the last decade focused on high-resolution internal dosimetry. Standardized models, such as the IT'IS Foundation's Virtual Population (e.g., Duke, Ella) [2], have been used to calculate induced fields. Under a 50 Hz power line, King et al. [3] demonstrated that the internal E-field is highly dependent on posture and ground contact. Similarly, Chakaroth et al. [4] performed finite element method (FEM) simulations to evaluate the current density inside a multi-layered human model, showing that the maximum internal fields are located in the neck and ankles due to cross-sectional narrowing. However, these papers focus exclusively on the internal volume of the phantom, leaving the external free-space perturbation unquantified. Several authors investigated the external E-field enhancement factor ($k_e = E_{\text{surface}}/E_{\text{ambient}}$). Research by Yamazaki et al. [5] showed that the E-field at the top of the head of a standing human model is enhanced by a factor of 4.5 to 5.5 compared to the unperturbed ambient field. Modenese et al. [6] studied how this enhancement is affected by nearby grounded objects. While these studies quantify the field at the boundary interface (skin-to-air), they do not map the spatial decay of the perturbation as a function of distance from the phantom.

Defining this external boundary is critical for calibrating field sensors, designing exposure setups, and validating free-space assumptions in power line corridors. Thus, this paper