Investigation of SLF-EMF effects on Human Body using Computer Simulation Technology

MW Aslam[1*], H Ali[2], MAU Rehman[3], MAUR Bajwa [4]

[1, 2, 3] Research Scholar, Institute of Electrical Engineering and Computer Science, Albert Einstein 22, 18059 Rostock University of Rostock, Mecklenburg Vorpommern, Germany
[4] Lecturer, Department of Mechatronics and Control Engineering, UET Lahore, Pakistan

---

Abstract - Energy and healthcare are fundamental needs of the human life. In 19th century, after the invention of AC (Alternating Current), the engineers and scientist profile multiple advantages of AC compared to DC (Direct Current). They also did investigated its direct exposure to living things and then create some standard of safety. With the passage of time when the energy transfer techniques were more developed and AC voltages in transmission lines raised. This directly affected to the EMF (Electromagnetic field). The EMF got stronger and chances of EM fields to affect the living things e.g. human body shoot up. The strength of EMF directly linked to the amount of power passing through the power/transmission line. The current induced in human body investigated using the CST [4] software. The EMF on living tissues observed and monitored by ICNIRP standard.

Key Words: Low Frequency, Electromagnetics, CST Studio, Transmission Line, anisotropy.

1. INTRODUCTION

Computer based simulations [9] are most advance way to pre investigate the complicated behaviour of systems. The idea behind work to reinvestigate the behaviour of electromagnetic effects, current induces in the body, using advance simulations and finer meshing.

In this work, The simulations are taken places on anisotropic human body model (self-designed), which undergone the direct exposure of EM field due to 750kV/50Hz AC transmission lines [10] using CST EM Studio®.

For designing the human body, reference taken by [2] where they investigate the comparison of anisotropic and isotropic tissues under Electrostatic fields using FIT. In addition, the [1] where they investigate the induced EM fields and currents using different numerical techniques.

The electric and Magnetic field strength on the human model using FIT technique calculated through Computational Simulations. A major concern was to investigate electro-quasistatic simulation and maximum strength of exposure to electric, magnetic and electromagnetic fields on the human body and compare it with ICNIRP [7]. And conformed the amount of current induced lies below the harmful level.

1. MODELLING

1.1 Tower

The simulation domain is consisting of two 750 kV transmission line towers. Both are at the distance of 400m from each other and connected by three power lines. These power lines are not straight. They are band toward the centre. At the midpoint, the height of the wires is 16.2m (the minimum height from the ground).

1.1.1 Material

A high voltage power line, in general, designed with two physical properties. Firstly, they should be able to transmit a massive amount of energy and secondly, they should be so strong so that they can bear a large amount of tension. So for this reason, they are made of copper and steel 80+20% or 60+40% ratio.

The tower has to bear all the weight of these large power lines so it should be physically strong enough and to be a particularly large. That could give the distance between the lines. Usually made of steel or sometimes some other alloys mixed to enhance the properties.

1.1.2 Design

Rather than the complex design with "L" and "T" shape metals in the simulation design, we shape it bit simpler and round the edges

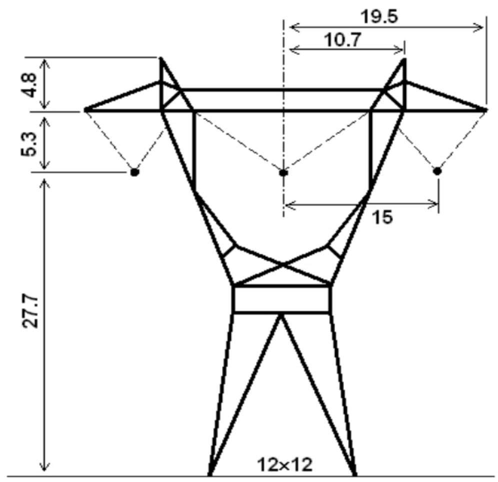

Figure 1 Tower Geometry [2,8]

The physical lengths and width in simulation kept same, as it should be in real physical design so that model performs approximately same behavior as real in simulation

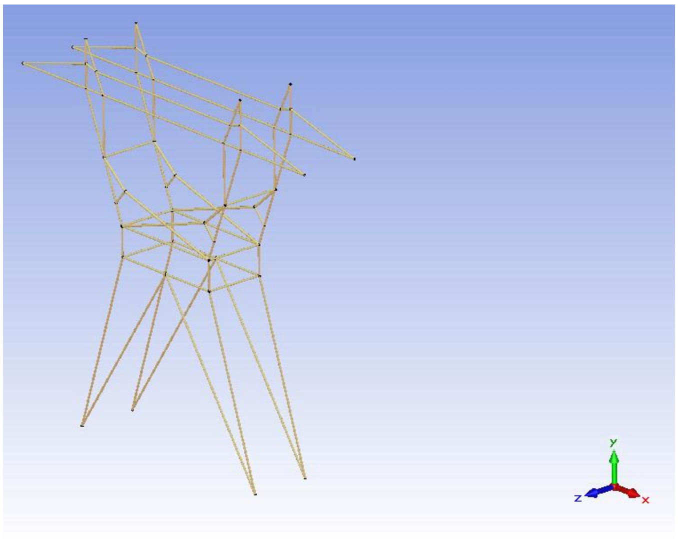

Figure 2 Tower Design in CST Studio

PEC material used for tower design in CST, so that field induced in tower ignored and keep away the complexity because the major focus is the investigation of fields on the human body.

1.2 TRANSMISSION LINE

The Dimensions used in this paper based on common three-phase transmission configuration, as explained in the picture below. The configuration line is flat horizontal. Height for all three lines is same from ground H1 = H2 = H3, each has height of 16.7m from the human body. The normal horizontal phase separation, between the conductor, is 15m. The diameter of each conductor is 44cm.

For the purpose of the investigation a balanced three-phase system with nominal 750kV, 50 Hz transmission assumed. The current on each wire is 666.66 A so, the resulting power P_{Total} we can calculate by the following method

$$P_1 = P_2 = P_3 = V \cdot I \cdot \cos(\theta)$$

Cos (θ) the power factor, although we PEC conductor is being used having zero impedance. The cos factor is ignored. For a stable, three phase system,

$I_1 = I_2 = I_3$ then the power will be $P_{Total} = 3 \cdot V \cdot I$

1.2.1 Effect of Shield Wire

The addition of shield on the transmission line has a little effect either the ground level field or the conductive surface of the wire. Studies shows that the shield keeps wire more protective and strengthen it against climate changes. With the addition of shield, the field is reduced approximately near to <1%. For calculations, Shielding for wire had been ignored a sake of simplicity.

1.3 Human Body

The Human body is most complex natural structure. In simulation software [11], it is complicated to design the model exactly the same way as the body could be complicated. A fine approximation is used the professional models like HUGO[3]. These models are made of different anisotropic and isotropic materials. These materials consists of different electric and magnetic properties. By analysing the different tissues, cells of the human body and their behaviour in different fields we created own human body design.

1.3.1 Material

The designing work done under consideration of the complexity of human body. All the electromagnetic properties like epsilon, omega and physical properties closely taken for simulation. Each metrical in our design like blood tissues, grey brain, bones, had unique properties, which taken by the research work [6]. The materials properties also mentioned in the table below.

Materials	Epsilon	Mue	Rho
Blood	61.21	1	1058
Bone	57.56	1	1850
Brain	38.73	1	1038
Muscle	54.92	1	1047
Skin	41.16	1	1125

Table 1 Human tissues properties[2,13]

These materials are uniquely independent and truly isotropic if we consider them one by one. Human body model as one (a mixture of different isotropic materials [12]) randomly taken as anisotropic [6].

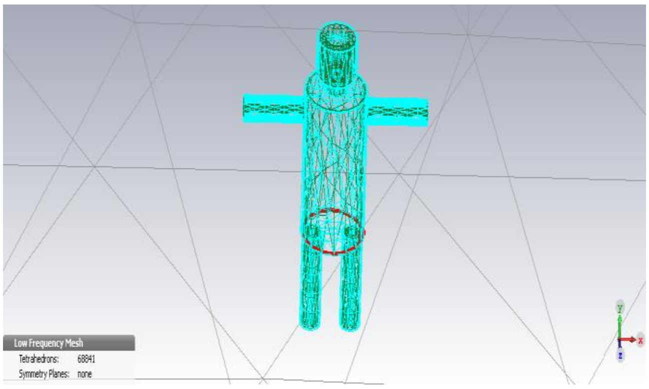

Figure 3 Mesh formation of Human Body

1.3.2 Design

Approximations used while designing the human body due to its complexity and limited or no access to the redesigned model. After analysing different methods and approximation techniques, cylindrical layers of tissue (materials) depends on which part is taking into consideration

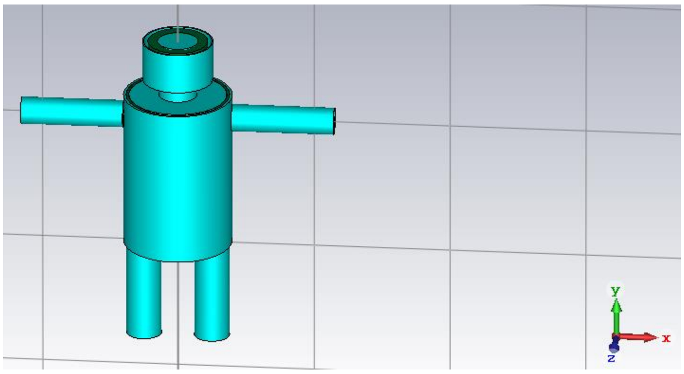

Figure 4 Explaining the Human body

It give us two approaches, we can observe the EM absorbing behaviour isotopically (each material separately) and anisotropic (absorbing for the whole body as one unit).

2. SIMULATION METHOD

2.1 Design

In CST studio ® due to the large size of the model and the long transmission line, we cannot perform the whole simulation at one time with the human body model.

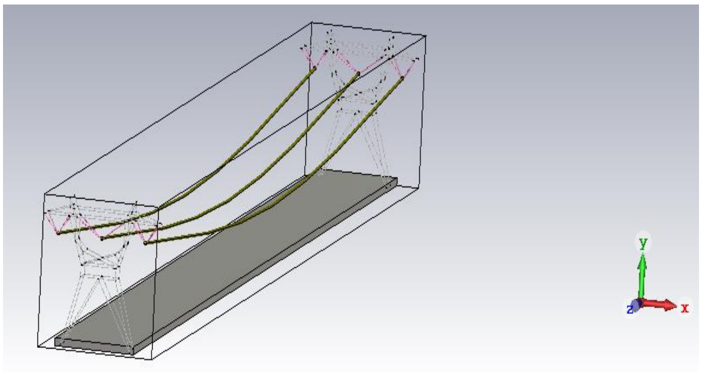

Figure 5 System model

Therefore, we remove the human body from the model and then discretize it into a large number of grid nodes (automatically) in the CST EM Studio ®. Then, we simulate the design in electrostatic problem solving with OBC. From this large size grid, we took the potential at the same position and where we have to place the human body and then we took a new design, which represents equality of the specific section (where the human body is) of the whole domain.

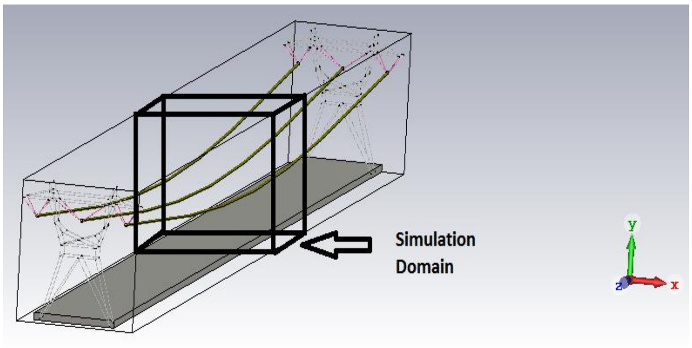

Figure 6 Domain selection for Simulation

This section consists of finer grids and fully anisotropic bodies. The simulation results in the visualisation of the computed fields.

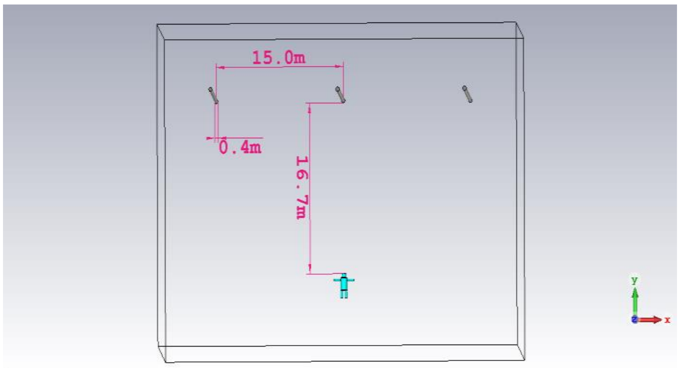

Figure 7 Physical distances in Simulation zone

2.2 Excitation of sources

The case under analysis having three phase balanced transmission system. The unit is operating at 750kV /50Hz. To excite our system we use a lumped element approach. Current path (A, B, C) for each Phase (phase 1, phase 2, phase 3) was established at the nominal line current value of 666.66 A with each phase at 120^{o} differ from another one.

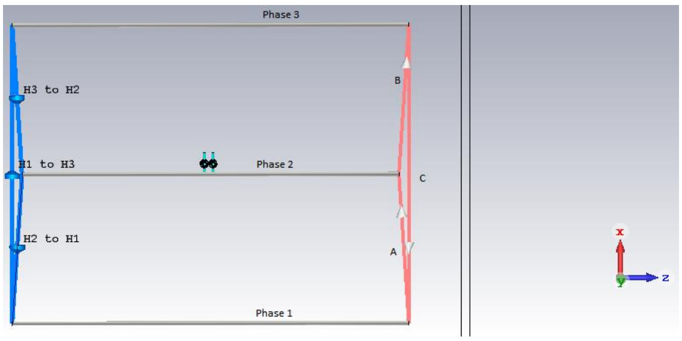

Figure 8 Excitation Approach

To obtain the rated voltage level the second end of the phase wire attached to a lumped element, these elements war purely resistive because of the simplicity as shown in the figure8 we were having three lumped elements for the three given phases. Each lumped element having the value of 1125 ohm. With Ohm's law, we got the voltage of 750kV on each line with the power of 500MW on each phase of the transmission network.

2.3 Computational Parameters

Due to the limitation of our software and capacity of the computer, we must have to limit our model with some boundaries. It results in the use of limited resources in computer and gives finer results using less calculation time. In this application, study of our structure cannot be limited to any domain and goes to infinity. Nevertheless, we cannot cover the whole domain with grids so we use OBC. Since we are dealing with the 50 Hz, It is a low-frequency application for CST EM Studio®, so the solver used under this condition is low-frequency domain solver, with full wave equation solver instead of the electrostatic and magnetoquasistatic solver. The mesh type is tetrahedral with 86970 tetrahedrons.

2.3 Electrostatic Simulation

Electrostatic fields are applicable only point charge, stationary charges (non-conducting materials) means there is no flow of charges, no current. The Poisson Equation calculates electric fields and the displacement currents

$$\nabla \cdot D = \rho$$

Epsilon is the rank two tensor (diagonal quantity) of electric permittivity. Phi is electric potential and row is the charge density. After discretizes it into the FIT the approximation free equation form is

$$\tilde{S} M_{\varepsilon} \tilde{S}^T \phi_E = q$$

S divergence operator, M material operator, S^T= - G discrete gradient operator, the discrete potential is denoted by ϕ_E and discrete charge density q.

2 .4 Electro-Quasistatic Simulation (EQS)

A three-phase AC with 50 Hz of frequency, the electromagnetic field has a wavelength of $3x10^8$ m/s that is very high in case of a person so that quasistatic assumption fulfilled. For predominantly electric field, time derivative of magnetic flux B neglected but to take the consideration of displacement current. Regarding the time harmonics of EQS fields, Maxwell equation combined to

$$\nabla \left(i\omega \underline{\varepsilon} + \underline{\sigma} \nabla \times \underline{\varphi} \right) = \nabla \cdot \underline{\boldsymbol{J}_i}$$

The propagation medium (air) taken as anisotropic due to the epsilon and theta having now charge in motion. Electric field amplitude defined as gradient of scalar potential

$$\boldsymbol{E} = -\nabla \cdot \underline{\varphi}$$

With of the human body, we did two simulations.

-Both feet touching the ground.

-Both feet are in the air

With respect to dielectric properties of tissue, we use the same human body as described earlier with the given EM properties

3. RESULTS

With EQS we compare the analysis of inducing a current in the human body in different cases (both feet on the ground, both feet above the ground) the maximum value of the current density induced in the body is mentioned in the table below.

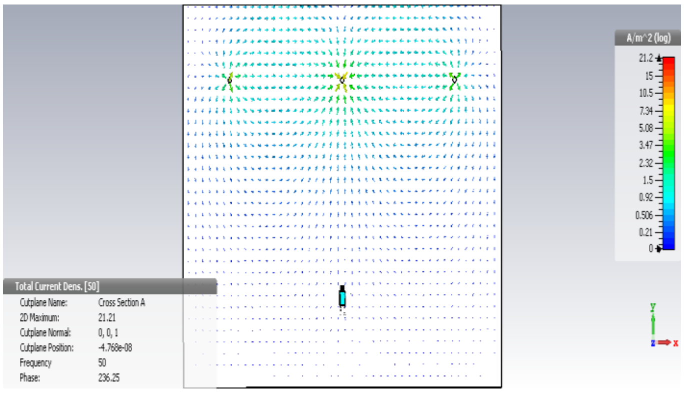

Figure 9 Current Density

	Head	Arm	Knee
Both feet in the Ground	0.4536	0.8745	1.15
Both feet in air	0.3954	0.4769	1.6125

Table 2 Maximum Current Densities found in Human Body

*Values are in [mA/m²]

4. CONCLUSION

A major concern of this project was to check the safety of this design that either this particular system of HV transmission in the open air is much safer for the public or it can harm their life. Especially the case when a person is moving on his feet below from the HVAC line. We observe that the quantity of current induced in the body at given conditions in blow then the values, which were mention in the ICNIRP [7]

Exposure characteristics	Frequency range	Current density for head and trunk (mA m^{-2}) (rms)
Occupational exposure	up to 1 Hz	40
	1–4 Hz	40/*f*
	4 Hz–1 kHz	10
	1–100 kHz	*f*/100
	100 kHz–10 MHz	*f*/100
	10 MHz–10 GHz	—
General public exposure	up to 1 Hz	8
	1–4 Hz	8/*f*
	4 Hz–1 kHz	2
	1–100 kHz	*f*/500
	100 kHz–10 MHz	*f*/500
	10 MHz–10 GHz	—

Table 3 ICNIRP Standard of safety [7]

ACKNOWLEDGEMENT

I would like to thank Dr Thomas Flisgn for his help to complete this work and special thanks to Dr Prof. Rienen for her support toward completion of this work.

REFERENCES

[1] Dawson, T. W., & Stuchly, M. A. (1998). Effects of skeletal muscle anisotropy on human organ dosimetry under 60 Hz uniform magnetic field exposure. Physics in medicine and biology, 43(5), 1059.

[2] Motrescu, V. C., & Rienen, U. V. (2005). Computation of currents induced by ELF electric fields in anisotropic human tissues using the Finite Integration Technique (FIT). Advances in Radio Science, 3(BK), 227-231.

[3] Motresc, V. C., & Rienen, U. V. (2005). Computation of electrostatic fields in anisotropic human tissues using the Finite Integration Technique (FIT). Advances in Radio Science, 2(12), 309-313.

[4] CST EMStudio™, CST GmbH, Bad Neuheimer Str. 19, D-64289, Darmstadt, Germany.

[5] Deno, D. W., & Zaffanella, L. E. (1982). Field effects of overhead transmission lines and stations. Transmission Line Reference Book: 345 kV and Above, 365-379.

[6] Van Rienen, U. (2012). Numerical methods in computational electrodynamics: linear systems in practical applications (Vol. 12). Springer Science & Business Media.

[7] ICNIRP. (1998). Guidelines for limiting exposure to time varying electric, magnetic, and electromegnatic fields (up to 300GHz). Health Physics, 74(4), 494-522.

[8] EHV tower geometries and line characteristics in transmission line reference :Book 365 kV and above, 2nd ed., (Palo Alto, A: EPRI), 30-168,1982

[9] Balay, S., Gropp, W. D., McInnes, L. C., and Smith, B.: PETSc – Efficient Management of Parallelism in Object Oriented Numerical Software Libraries, Modern Software Tools in Scientific Computing, Birkhauser Press, 163–202, 1997

[10] Deno, D. and Zaffanella, L.: Field effects of overhead transmission lines and stations, in: Transmission Line Reference Book: 345 kV and Above, 2nd edn., (Palo Alto, CA: EPRI), 365–79, 1982.

[11] Sachse, F. B., Wolf, M., Werner, C., and Meyer-Waarden, K.:Extension of Anatomical Models of the Human Body: ThreeDimensional Interpolation of Muscle Fiber Orientation Based on Restrictions, Journal of Computing and Information Technology, vol. 6 no. 1, 95–101, 1998

[12] Sachse, F. B., Werner, C., Meyer-Waarden, K., and Dossel, O.:Comparison of Solutions to the Forward Problem in Electrophysiology with Homogeneous, Heterogeneous and Anisotropic Impedance Models, Biomedizinische Technik, vol. 42, 277–280,1997

[13] Gabriel, S., Lau, R. W., and Gabriel, C.: The dielectric properties of biological tissues: III. Parametric models for the dielectric spectrum of tissues, Phys. Med. Biol. 41, 2271–2293, 1996b