

Effect of Electromagnetic Fields from Power Lines on Metallic Objects and Human Bodies

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Abstract This paper investigates the interference between electromagnetic field produced by high voltage power lines and living organisms and metallic objects underneath the transmission lines such as ships, at rivers crossing, and vessels passing under or near to power lines. Metallic pipelines buried in the same corridor are affected with many factors, namely: the power line configuration, separation distance between transmission line and pipeline, separation distance between conductors, the transmission line tower height, existence of the earth wire, the sequence of the power supply, the length of corridor and the fault conditions. The equations of magnetic fields of the transmission lines and the density of currents induced in the human bodies and metallic ships surface were introduced. The induced voltage on the neighbouring pipelines was calculated. A computer program was developed to model and simulate the magnetic fields produced by power lines. The program calculates the current density induced in objects underneath or in the neighbourhood of the transmission line. The results obtained using the developed program illustrated to be consistent with previous literature results. The obtained results showed to be satisfactory and consistent with the experimental ones.

Keywords Human Bodies, Electromagnetic Fields, Metallic Objects, Power Line

1. Introduction

It is common that electromagnetic fields produced by transmission lines causes dangerous effects on both living organisms and any metallic objects. If the human bodies are projected to high levels of magnetic fields the main effect of interferences is the production of electric currents within the body. Electric and magnetic fields differ, in their effects, when they pass across the body of living organisms at low frequencies. An electric field directed on an unshielded person discharges to ground while the magnetic field permeates the body inducing a magnetic flux that generates secondary electric fields inside the body and then induce currents density that causes a change in protein, DNA syntheses, enzyme activity, heart dysfunction and possible nervous effects. While metallic structures near to transmission lines are subjected to interference arising from inductive, capacitive and resistive coupling as in [1]. Inductive coupling arises when the structure is placed in a time varying magnetic field. Capacitive coupling only affects structure located above ground since these have a capacitance to both the transmission line and to the earth as in [2,3]. Resistive coupling between a transmission line and metallic pipeline is only relevant during ground fault when

significant levels of currents flow into the ground.

This interference with metallic objects causes corrosion of the object material or risks for people entering in contact with these objects. In case of cathodic protection of metallic objects magnetic interference may produce mal-operation. This paper studies the inductive interference to the human bodies and metallic objects and the factors affecting the interference. It simulates the process using the developed computer program.

2. Theoretical Analysis

2.1. The Magnetic Field Density Produced from Power Lines

2.1.1. A 500 kV Horizontal Configuration

This line consists of three conductors lying on the horizontal plane. Using the centre conductor as the reference point o , s is the distance of the two other conductors from centre line and I is the conductors current. The magnetic field density B in Tesla can be found as in (1), [4].

$$B = \frac{\mu_0 s I}{2\pi R} \left[\frac{3R^2 + (s^2)}{(R^4 - 2R^2 s^2 \cos 2\phi_r + s^4)} \right]^{1/2} \quad (1)$$

Where R is the distance from any point of interest and the centre point of power line o , ϕ_r is the angle between the vector R and the horizontal central line as shown in figure. 1.a.

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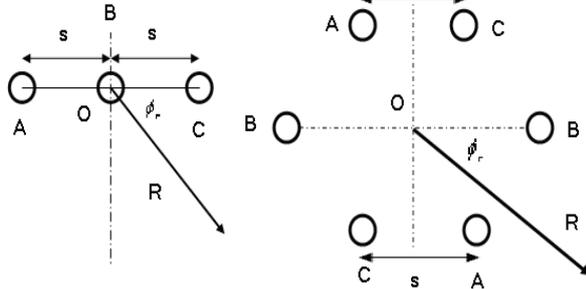


Figure 1. Conductors arrangement on transmission lines, (a) Horizontal single circuit configuration (b) Double circuit configuration

2.1.2. A 220kV Double Circuit Line Configuration

This configuration is considered as a low reactance double circuit line with balanced and equal currents on the two circuits as shown in figure.1.b.

The magnetic field density B in Tesla can be found as in (2),[4].

$$B = \frac{\mu_0}{2\pi} \frac{3\sqrt{2}I_s^2 R [R^4 + s^4]^{1/2}}{(R^{12} - 2R^6 s^6 \cos 6\phi_r + s^{12})^{1/2}} \quad (2)$$

2.2. The Induced Electric Field and Current Density

For any structure may be considered as a homogeneous cylinder, the magnetic field will induce an electric field E in the structure, according to Faradays law, is given as in (3),[5,6].

$$E = \left(-\frac{\partial B}{\partial t} \right) * \left(\frac{r}{2} \right) \quad (3)$$

Where

r : radial distance from the centre of the cylinder to the point where E is evaluated.

E : vector lines in a plane perpendicular to B and is oriented tangentially to circles of radius r .

$$E = -j\omega B * \left(\frac{r}{2} \right) \quad (4)$$

For the structure conductivity σ the current density J in A/m² can be found as in (5), (6),[5].

$$J = \sigma * E \quad (5)$$

$$J = \pi * r * f * \sigma * B \quad (6)$$

2.3. Induced Voltage on Pipeline

The mutual impedance with earth return in Ω/m between pipeline and phase conductors of transmission line, which carry an ac current of frequency 50 Hz, can be found using Carson's formula as in (7). where δ in meter is the depth of the earth return path with soil resistivity ρ in $\Omega.m$, space permeability μ_0 , angular frequency ω and distance between pipeline and phase conductors D_{ph-p} can be found as in (8),[7].

$$Z_{ph-p} = (\mu_0 * \omega / 8) + j((\mu_0 * \omega / 2\pi) * \ln(\delta / D_{ph-p})) \quad (7)$$

$$\delta = 1.85 / \sqrt{\omega * (\mu_0 / \rho)} \quad (8)$$

Two conditions can be considered:

1. Without overhead earth wire - At normal conditions: The induced voltage V_p on pipeline due to full load currents

I_A, I_B, I_C with mutual impedances between phases A,B and C and pipeline Z_{AP}, Z_{BP}, Z_{CP} is given as in (9),[8].

$$V_p = I_A Z_{AP} + I_B Z_{BP} + I_C Z_{CP} \quad (9)$$

At fault conditions: The induced voltage V_p on pipeline due to fault current I_{fault} for a single line to ground fault is given as in (10),[9].

$$V_p = I_{fault} * Z_{ph-p} \quad (10)$$

2. With overhead earth wire - At normal conditions: The impedance of earth wire with earth return Z_E for the earth wire resistance R_E and geometric mean radius of R_{GM} is given as in (11),[7].

$$Z_E = R_E + (\mu_0 * \omega / 8) + j((\mu_0 * \omega / 2\pi) * \ln(\delta / R_{GM})) \quad (11)$$

The mutual impedance between the phase conductor, earth wire and the pipeline is given as in (12),[9].

$$Z_{ph-E-p} = Z_{ph-p} - ((Z_{E-p} * Z_{ph-E}) / Z_E) \quad (12)$$

Then the induced voltage V_p on the pipeline is given as in (13),[9].

$$V_p = I_A Z_{A-E-p} + I_B Z_{B-E-p} + I_C Z_{C-E-p} \quad (13)$$

At fault conditions: Considering earth wire at fault conditions there are a shielding factor K that can be found as in (14),[9].

$$K = 1 - ((Z_{ph-E} * Z_{p-E}) / (Z_E * Z_{ph-p})) \quad (14)$$

The induced voltage V_p on the pipeline at fault condition is given as in (15),[9].

$$V_p = I_{fault} * K * Z_{ph-p} \quad (15)$$

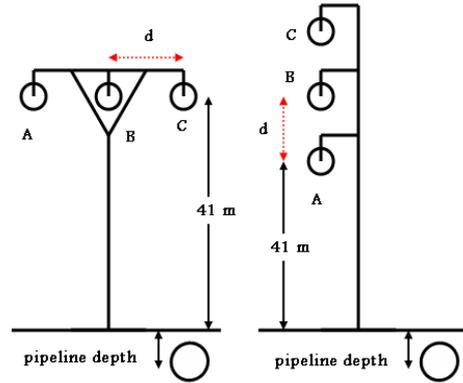


Figure 2. Different interference system with (a) Horizontal, (b) Vertical

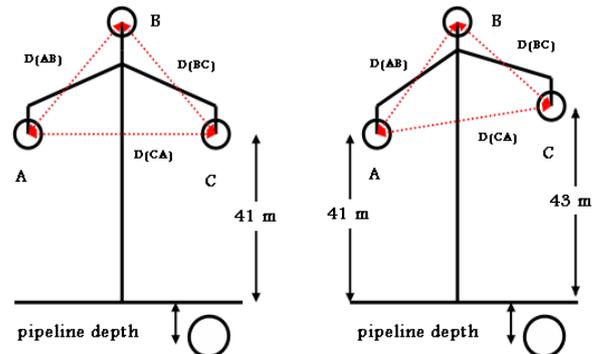


Figure 3. Different interference system with (a) Triangle equilateral, (b) Triangle with different spacing configurations

3. Simulation and Modeling of System

3.1. Magnetic Field Density from Power Lines

3.1.1. A 500 kV Horizontal Configuration

According to The separation distance between conductors of $s=11\text{m}$, the height of tower is $h=37.5\text{m}$ and the conductor current of $I=650\text{A}$. then by using equation (1) the magnetic field density can be seen in figure.4.

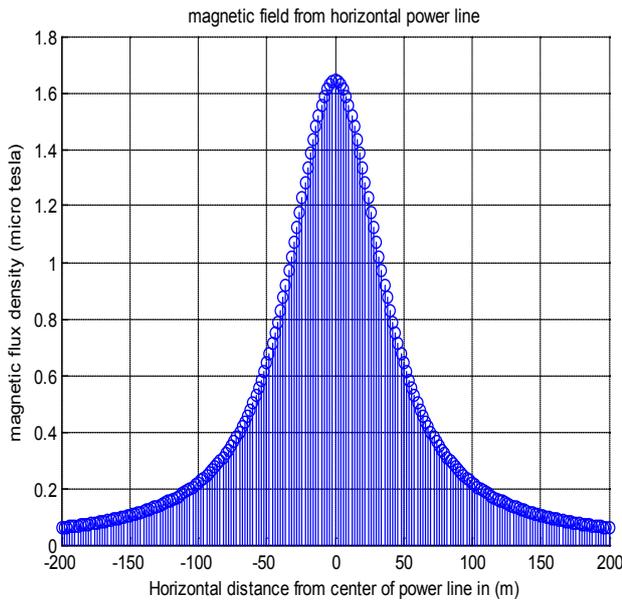


Figure 4. Magnetic field density from 500kv horizontal configuration

3.1.2. A 220kV Double Circuit Power Line Configuration

According to The distances between conductors $s=6\text{m}$, height of tower $h=41\text{m}$ and the conductors current $I=1000\text{A}$. Then by using equation (2) the magnetic field density can be seen in figure.5.

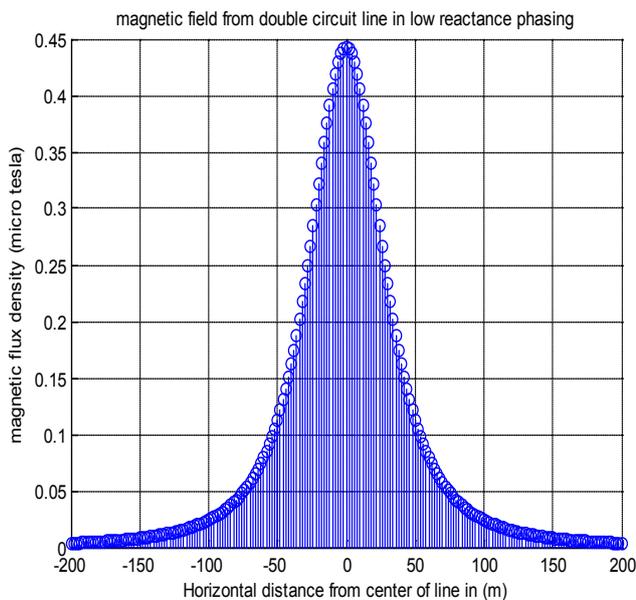


Figure 5. Magnetic Field Density From 220kV Double Circuit Configuration

Figures. 4,5. show that the magnetic flux density produced from 220kV double circuit line configuration is less than that from 500kV horizontal configuration single circuit. This is due to the fact that the magnetic field produced from each conductor of the double circuit will be balanced by other ones. This will reduce the net magnetic field seen by any object.

3.2. Current Density Induced in Human Body

The current density in A/m^2 induced due to electric field which is produced from the magnetic field can be determined using equation (6). For a person having a head of radius $=0.1\text{m}$ and body of radius $=0.3\text{m}$ and body conductivity $\sigma=0.2\text{ S}/\text{m}$, the current density for different distances from the 500kV horizontal single circuit transmission line can be seen in figure.6.

The results of current density for different distances from 220kV double circuit transmission line can be seen in figure.8.

Figures. 6,8 show that the induced current density on human body in case of single circuit is greater than that of a 220kV double circuit. This is due to the magnitude of magnetic field density.

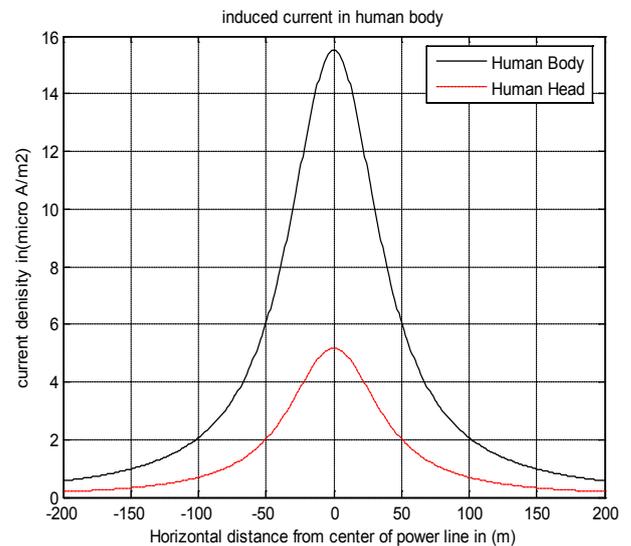


Figure 6. Induced current in human bodies due to 500kV power line

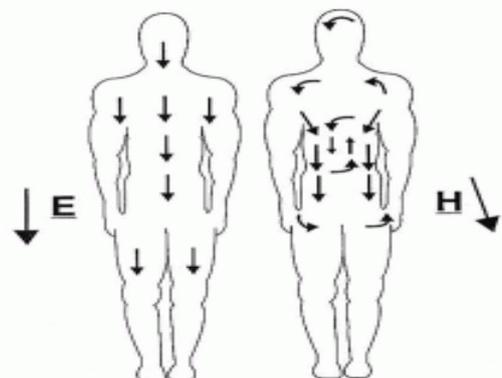


Figure 7. The Human electric and magnetic field

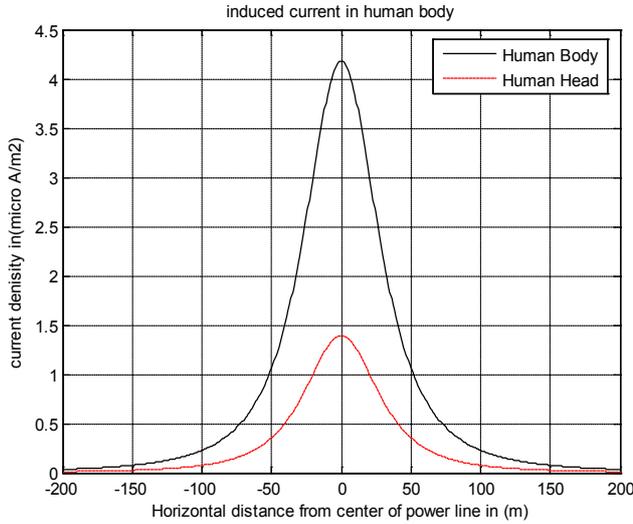


Figure 8. Induced current in human bodies due to double circuit power line

3.3. Induced Current on Metallic Ships and Vessels Underneath Power Line

By applying the same method on ships and vessels such as missile boats of radius=9m, destroyer of radius=29.5m, cargo of radius=23.5m, frigate of radius=11.5m and Aircraft carrier ships of radius=47.5m which are subjected to electromagnetic fields from 500kV horizontal single circuit power lines crossing over rivers or canals with $s=11m$, $h=140m$, $I=650A$ and the conductivity of metallic material $\sigma=0.3 \cdot 10^6 S/m$ the results of current density can be seen in figure.9.

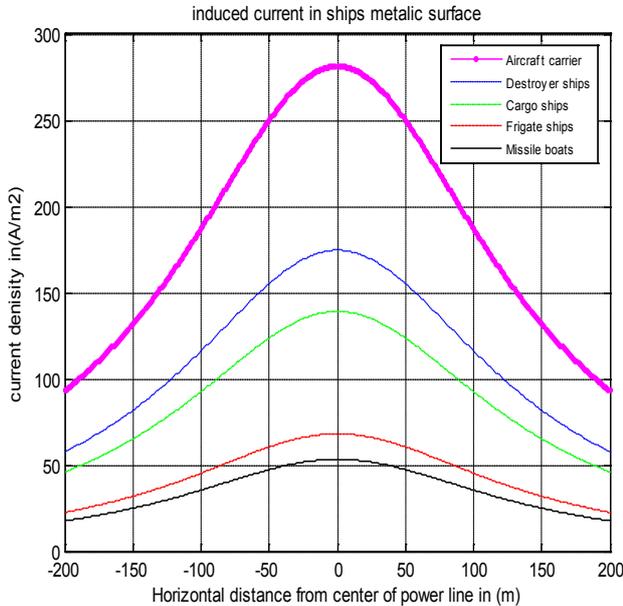


Figure 9. Induced current in ships surface due to horizontal power line

By applying this method on ships and vessels which are subjected to electro magnetic field from 220kV double circuit power lines crossing over the rivers with $s=6m$, $h=140m$ and $I=1000A$ the results of current density can be seen in figure.10.

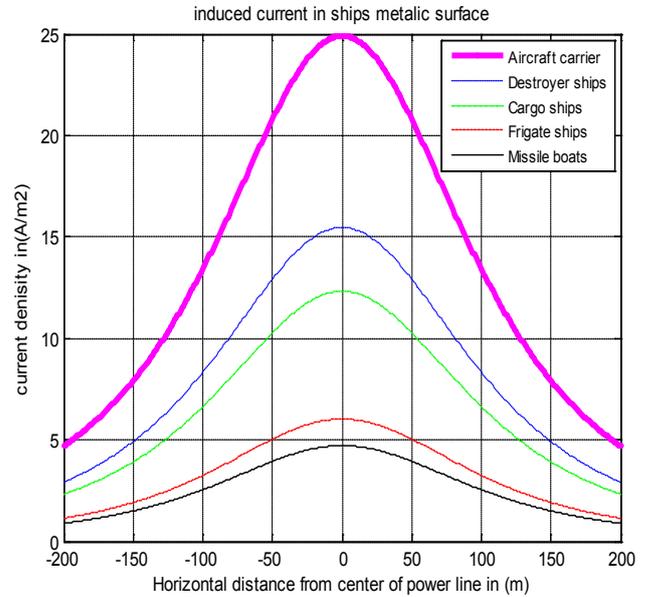


Figure 10. Induced current in ships surface due to double circuit power line

Figures. 9, 10 shows that induced current density on ships and vessels under or near to high voltage power lines are subject to high amount of current density. Fortunately these currents can be dissipated in the earth water the ships or vessels is navigating in. the larger the surface area of that ship (hull) the quicker the dissipation of current.



Figure 11. The destroyer ships as a homogeneous cylinder

3.4. Interference with Pipelines and the Factors Affecting It

3.4.1. Power Line Configuration

The induced voltages on pipelines are significantly dependent on the configuration of the power line. The electro magnetic fields produced by the overhead line phases, generally balance each other and significantly reduce the net field seen by the pipeline and then affect the magnitude of the induced voltage on pipeline[10].

Figures. 2, 3 show different configurations of 220 kV, transmission line with a phase current $I=1000A$ at normal conditions, distance between conductors $d=6m$, length of parallelism of pipeline $L=10km$ and soil resistivity of $100 \Omega.m$.

Figure. 12 shows that the vertical configuration caused the height magnitude of induced voltage for the first 40m

separation distance between the centre of power line and the pipeline than any other configuration[11]. This is due to the high density of the resultant electromagnetic field EMF produced from the vertical power line than the others and still has the higher magnitude than the delta configuration until reaches 80m. Then as we move laterally away from the centre, the vertical configuration gives the lower magnitude of induced voltage than the other configurations; the delta configuration causes a medium value of induced voltage between vertical and horizontal configurations.

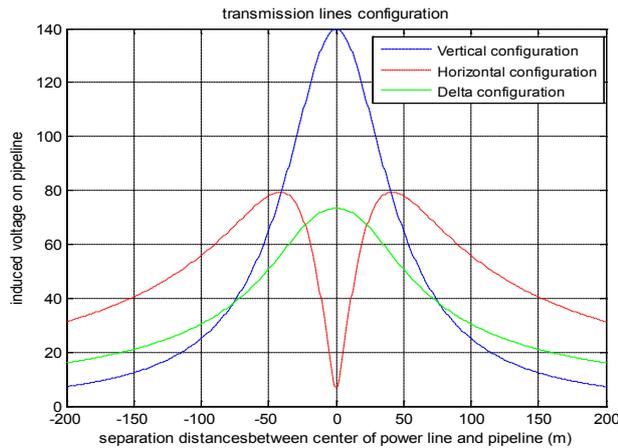


Figure 12. Different power line configurations

It can be seen that the horizontal configuration caused a smaller amount of induced voltage, from 0m to 25m separation distance. From 40m although its value decays with increasing distance but it is higher than all other configurations.

3.4.2. Distance between Power Line and Pipeline

Figure. 12 illustrated that, for all configurations, as the separation horizontal distance from power line increases the magnitude of the induced voltage on pipelines decrease.

3.4.3. Distance between Conductors

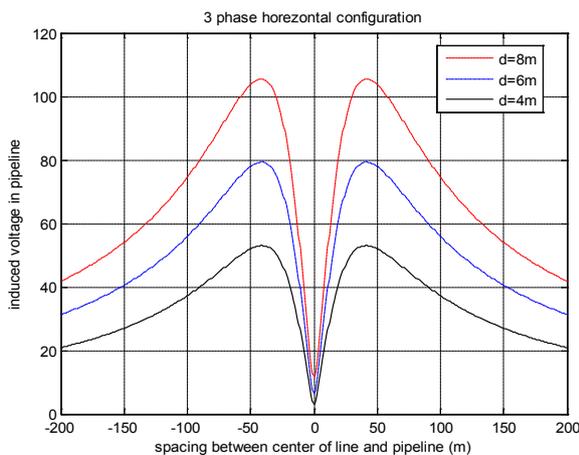


Figure 13. Different separation distance between conductors for horizontal configurations

1- For a 220 kV horizontal configuration - The induced

voltages on pipelines, for different separation distance between conductors as $d = 4m, 6m$ and $8m$, is indicated in figure.13.

2- For a 220 kV vertical configuration - The induced voltage on pipeline was calculated for different separation distances between conductors $d = 4m, 6m$ and $8m$ is shown in figure. 14.

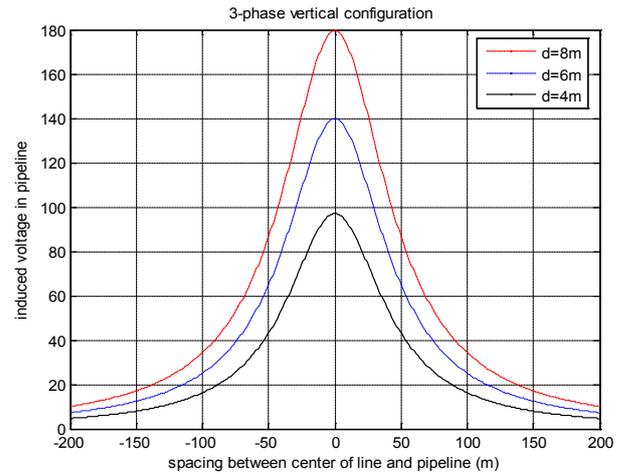


Figure 14. Different separation distance between conductors for vertical configurations

It can be concluded that as the separation distance between lines increase the induced voltage increases for any configurations. This is due to the fact that the outer phase gets nearer to the pipeline which enhances this phenomenon. Also, it may be due to the fact that the mutual effect of the two neighbour conductors is reduced as they get separated from each other.

3- For a 220 kV delta configuration - For the 3-phase 220 kV delta configuration there are two configurations triangle equilateral and triangle with different spacing as shown in figure. 3.a,b.

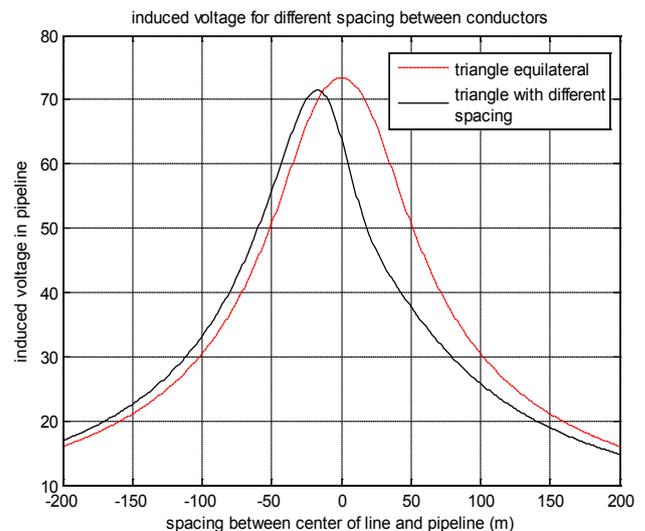


Figure 15. Different separation distance between conductors for delta configurations

Figure. 15. indicated a symmetrical curve at the centre line

of the power line for the triangle equilateral configuration.

The triangle which has different spacing shows the height of the hump of the curve at the left hand side is higher than that at right hand side.

This is because when the pipe line was placed at left side of power line it is more affected by phases A and B which C is much more far out of it, which has a separation distance of 6m. When it is placed at right hand side of the power line it is more subjected to phases C and B, with separation distance of 4.3m.

3.4.4. Height of Towers

For the studies 220 kV horizontal system with $d=6m$ and the height of tower is $h=41m, 38m$ and $35m$. Figure. 16 shows that as the height of the tower increases the net electromagnetic field EMF seen by the pipeline decreases, then the induced voltage on pipeline decreases. This is the general trend for all power line configurations.

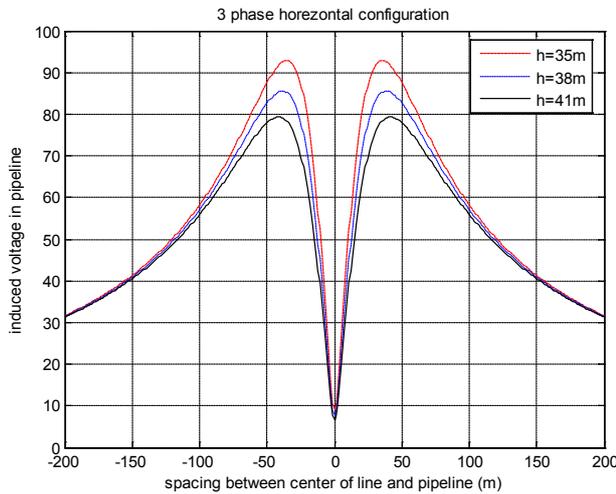


Figure 16. Different height of towers for horizontal configurations

3.4.5. Existing of the over Head Earth Wire OHEW

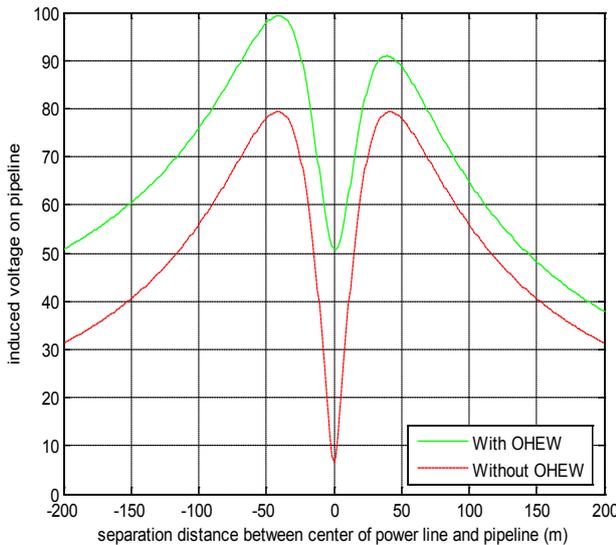


Figure 17. Power line with and without OHEW

The OHEW will break the magnetic field balance of the system and leads to higher induced voltage on the pipeline at normal condition[9].

- Triton 37/3.75 AAC which has R_{GM} of 0.00982m and resistance of $0.0869 \Omega /km$ can be using as OHEW.

As the resistance of earth wire increases the mutual impedance increases according to equation (12). And then the total induced voltage increases according to equation (13) this is consistent with figure. 17.

3.4.6. Sequence of the Power Line Phases

The phase sequence of three phases, with earth wire affects directly the height of the maximum induced voltage value, depending on the position of the pipeline, this is clear in figures 17, 18. for positive sequence of the phases (ABC) if the pipeline is situated at right of the power line the induced voltage on the pipeline is different from that if it was situated at left hand side of power line for the same distances as shown in figure. 17. While for negative sequence of the phases (ACB) the induced voltage on pipeline is the opposite to the positive sequence case as shown in figure. 18.

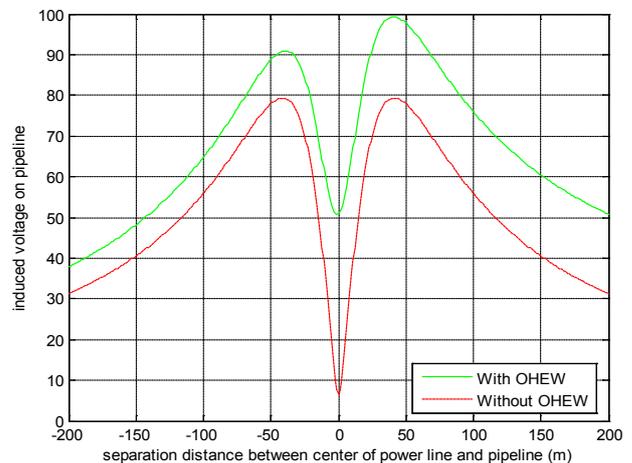


Figure 18. Power line with and without OHEW

3.4.7. Length of System Parallelism

The magnitude of induced voltage on pipeline is affected by the parallelism section of the pipeline and power line.

For the same 220 kV horizontal configuration the separation between pipeline and power line is 50m and the length of system parallelism are $L=5km, L=10km, L=20km$ and $L=30km$.

The maximum induced voltage occurs at the two ends of the pipeline because of the strong discontinuity of the EMF at these two points and the minimum induced voltage occurs at the midpoint of pipeline because the induced EMF in the pipeline on both sides of this point has the same magnitude and of opposite direction resulting in a minimum induced voltage on this point.

Figure. (19) shows the induced voltage along the pipeline for different length of parallel section. As the parallel section increases, the induced voltage on pipeline increases too [12,13].

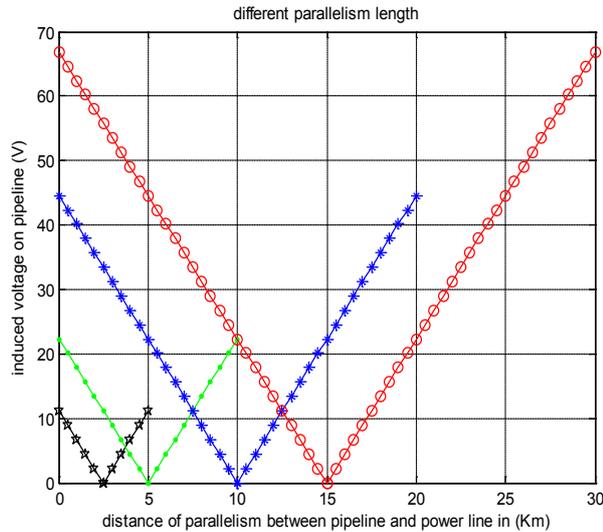


Figure 19. Different length of system parallelism

3.4.8. Fault Conditions

For any configuration the fault condition causes higher induced voltage on pipeline according to the magnitude of the $I_{\text{fault}} = 5000\text{A}$ as in [14].

Under the fault condition the existence of the OHEW will reduce the impact on the induced voltage on the pipeline due to the resistance of the OHEW affects directly the value of the induced voltage as in [15]. This is attributed to the size of the conductor. The OHEW with large size induces the smallest voltage. This can be verified using the different types of OHEW as in [9]:

1. Triton 37/3.75 AAC with R_{GM} of 0.00982m and resistance of 0.0869 Ohms/km.
2. Pluto 19/3.75 AAC with R_{GM} of 0.00676m and resistance of 0.168 Ohms/km.
3. Leo 7/2.5 AAC with R_{GM} of 0.00244m and resistance of 1.02 Ohms/km.

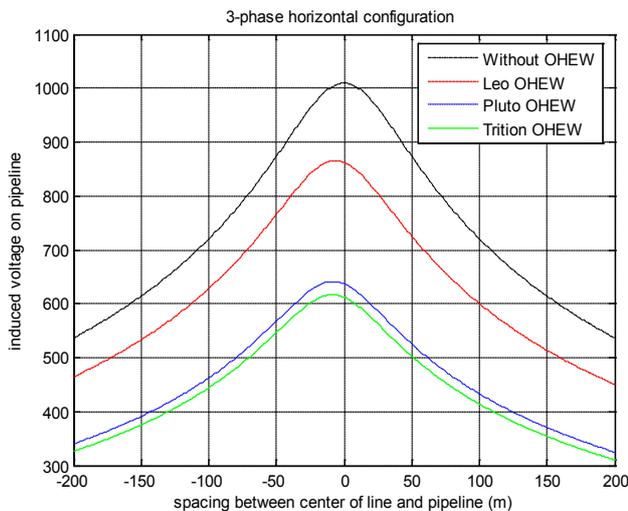


Figure 20. Power line at fault condition

From figure.20, it is clear that the triton OHEW produces the least induced voltage and vice versa.

4. Conclusions

This paper has explained and analysed the interference between high voltage transmission lines and human bodies, metallic ships and pipelines which have different factors that affect the interference.

Modelling and simulation of induced current density on human bodies, metallic ships surface and the induced voltages on pipelines for various configurations of power lines is investigated.

The magnetic field of over head transmission line with different configurations was determined using Ampere law.

A computer program was developed to calculate the values of the induced current density and induced voltages. This developed program showed to be very effective and with least running time. This method was compared with the results obtained using EMTP and showed to be more accurate and having a smaller running time.

The electromagnetic field interference is significantly dependent on the power line configurations, separation distance between transmission line and objects underneath, separation distance between conductors of transmission line, the transmission line tower height, existence of the earth wire, the sequence of the power supply, the length of system parallelism and fault conditions.

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