International Journal of Engineering Innovation & Research
Volume 2, Issue 6, ISSN: 2277 – 5668

Magnetic Field Calculation Around 230kV Bundled Transmission Lines

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***Abstract* – Transmission lines are strategically important components of any power system. Power transmission lines are considered as one of the major sources of magnetic field. In recent years some people are concerned that daily exposure to magnetic fields may cause health problems. The rapid increase of electric energy utilization led to the reality that countries need to upgrade and develop existing and new transmission and distribution lines which resulted in the transmission lines to become inside the urban areas. Nowadays, bundled transmission lines are used for transmitting huge units of power over long distances. These bundled transmission lines can produce magnetic fields more than simple transmission lines. In this paper, theoretical studies of the magnetic fields produced by bundled transmission lines are described. First, a prepared software package for magnetic field calculation is developed in MATLAB. Then, magnetic field distributions under 230kV bundled power transmission lines are investigated.**

***Keywords* – Magnetic Field, Bundled Conductors, Transmission Line, Software Package, MATLAB.**

I. Introduction

Magnetic fields are produced by electric currents, which can be macroscopic currents in wires, or microscopic currents associated with electrons in atomic orbits. So, magnetic fields are produced wherever electricity or electrical equipment is in use. Magnetic fields are very widely used throughout modern technology, particularly in electrical engineering and electro mechanics. But, magnetic fields of power transmission lines cause electrical currents inside the body. So, some people are concerned that daily exposure to magnetic fields may cause health problems [1-2]. Nowadays, bundled transmission lines are used for transmitting huge units of power over long distances. So, bundled transmission lines are considered one of the major sources of magnetic field. Therefore, Accurate calculating of magnetic field under bundled transmission lines is very important for assessment of the interaction of these fields with life forms at the ground level under power lines. In order to calculate the magnetic field under power transmission lines many studies have been done. Many studies have been carried out to evaluate the magnetic fields beneath different power lines which are considered as major sources of induction [3-5].Two recent studies were published which investigated the magnetic field distributions under parallel transmission lines [6-7]. In [8], magnetic field distribution under crossing power lines using a three-dimensional magnetic field computational technique is investigated. In this paper, theoretical studies of the magnetic fields produced by bundled transmission lines are described. First, a prepared software package for magnetic field calculation is developed in MATLAB. Then, magnetic field distributions under 230kV bundled power transmission lines are investigated.

II. Bundled Transmission Lines

A bundled conductor is formed by two or more than two sub-conductors in each phase as shown in figure 1. These are used for transmitting huge units of power over long distances. In a bundled conductor, the sub-conductors are separated from each other by a constant distance, whereas in the case of composite conductors, the sub-conductors are placed in close proximity so that they touch each other. The overall diameter of bundled conductor increases due to filler material or air space in between the sub-conductors.

Fig.1. Bundled conductor arrangements

The advantages of bundled conductors are:

- Reduced corona loss due to larger cross-sectional area;
- reduced interference with telecommunication systems;
- Improved voltage regulation.
- Increase the more power transmitting

III. Magnetic Field Calculation of Power Transmission Line

Magnetic fields are created only when there is an electric current, the motion of electric charges (electrons) in a conductor, such as a wire [9-10]. The magnitude of a magnetic field is proportional to the current flow through an electric line, not the voltage. As the current increases, so does the magnetic field. So, the bundled Transmission Line can produce relatively high magnetic fields. In the literature, magnetic field data are presented in either units of Gauss (G) or Tesla (T). A milligauss (mG) is equal to one-thousandth of a Gauss (G). One Tesla is equal to 10,000 Gauss. A micro tesla (μT) is equal to one-millionth of a Tesla or 10 mG.A useful law that relates the magnetic field along a closed loop to the electric current passing through the loop is Ampere's Law that first discovered by André-Marie Ampere in 1826. Equation (1) could describe the content of this concept [9-10].

International Journal of Engineering Innovation & Research
Volume 2, Issue 6, ISSN: 2277 – 5668

$$\oint B.dl = \mu_0 I \quad (1)$$

Where, the line integral is over any arbitrary loop, I is the current enclosed by that loop and r is the distance from the center of the wire.

The magnetic field of an infinitely long straight wire can be obtained by applying Ampere's law. The magnetic field generated by a single wire is equal to the following equation.

$$\vec{B} = \frac{\mu_0 I}{2\pi r}\vec{a}_\varphi \quad (2)$$

In Cartesian coordinate system, $\vec{a}_\varphi$ and r can be rewritten as follows:

$$a_\varphi = -\frac{y-y_n}{R}\vec{a}_x + \frac{x-x_n}{R}\vec{a}_y \quad (3)$$

$$r = \left[(x_n - x)^2 + (y_n - y)^2\right]^{\frac{1}{2}} \quad (4)$$

So, equation (2) can be rewritten as follows:

$$B = B_x.\vec{a}_x + B_y.\vec{a}_y \quad (5)$$

$$B_x = \frac{\mu_0 I}{2\pi r}\left(-\frac{y-y_n}{r}\right) \quad \& \quad H_y = \frac{\mu_0 I}{2\pi r}\left(\frac{x-x_n}{r}\right) \quad (6)$$

$$|B| = (B_x^2 + B_y^2)^{\frac{1}{2}} \qquad \theta = Arc\tan\left(\frac{B_y}{B_x}\right) \quad (7)$$

Finally,

$$B = |B|\angle\theta \ (8)$$

Based on Ampere's Law Magnetic field of power transmission line in any point can be calculated as following equations [9]:

$$B_{xa} = \frac{-\mu_0(I_{ra} + j\,I_{ia})(y_a - y_n)}{2\pi} * \left[\frac{1}{(x_n - x_a)^2 + (y_n - y_a)^2}\right] \quad (9)$$

$$B_{ya} = \frac{\mu_0(I_{ra} + j\,I_{ia})(x_a - x_n)}{2\pi} * \left[\frac{1}{(x_n - x_a)^2 + (y_n - y_a)^2}\right] \quad (10)$$

Equations (9) and (10) can be rewritten as follows:

$$B_{xa} = B_{rxa} + j\,B_{ixa} \quad (11)$$

$$B_{ya} = B_{rya} + j\,B_{iya} \quad (12)$$

So,

$$B_{rx} = B_{rxa} + B_{rxb} + \cdots \quad (13)$$

$$B_{ix} = B_{ixa} + B_{ixb} + \cdots \quad (14)$$

$$B_{ry} = B_{rya} + B_{ryb} + \cdots \quad (15)$$

$$B_{iy} = B_{iya} + B_{iyb} + \cdots \quad (16)$$

Then, the real and imaginary values of the magnetic field can be calculated.

$$B_x = B_{rx} + j\,B_{ix} \quad (17)$$

$$B_y = B_{ry} + j\,B_{iy} \quad (18)$$

And finally, the amplitude of magnetic field can be calculated as follows:

$$|B| = \left(|B_x|^2 + |B_y|^2\right)^{\frac{1}{2}}$$
$$|B_x| = \left(|B_{rx}|^2 + |B_{ix}|^2\right)^{\frac{1}{2}} \quad (19)$$
$$|B_y| = \left(|B_{ry}|^2 + |B_{iy}|^2\right)^{\frac{1}{2}}$$

IV. Magnetic Field of Three-Phase Transmission Lines

Three-phase electric power is a common method of current electric generation, transmission, and distribution. It is a type of poly phase system and is the most common method used by electrical grids worldwide to transfer power. Three-phase systems can produce a magnetic field that rotates in a specified direction. In a three-phase system, three circuit conductors carry three alternating currents (of the same frequency) which reach their instantaneous peak values at one third of a cycle from each other. Current of phases in these systems can be expressed as follows [10]:

$$I_a = I_m\cos(\omega t + \varphi_a)$$
$$I_b = I_m\cos(\omega t + \varphi_b)$$
$$I_c = I_m\cos(\omega t + \varphi_c)$$
$$\varphi_b = \varphi_a - 120 \quad (20)$$
$$\varphi_c = \varphi_a + 120$$

The effective values of currents can be calculated using following equations.

$$I_{ra} = \frac{I_m}{\sqrt{2}}\cos(\varphi_a)$$
$$I_{ia} = \frac{I_m}{\sqrt{2}}\sin(\varphi_a)$$
$$I_{rb} = \frac{I_m}{\sqrt{2}}\cos(\varphi_b)$$
$$I_{ib} = \frac{I_m}{\sqrt{2}}\sin(\varphi_b) \quad (21)$$
$$I_{rc} = \frac{I_m}{\sqrt{2}}\cos(\varphi_c)$$
$$I_{ic} = \frac{I_m}{\sqrt{2}}\sin(\varphi_c)$$

According the equations (9) and (10), magnetic field induced using phases a, b and c at an arbitrary point $N(x_n, y_n)$ can be calculated using following equations.

$$H_x = H_{xa} + H_{xb} + H_{xc} \quad (22)$$

$$H_y = H_{ya} + H_{yb} + H_{yc} \quad (23)$$

Where

$$|H_x| = \left[\begin{matrix}(H_{rxa} + H_{rxb} + H_{rxc})^2 + \\ (H_{ixa} + H_{ixb} + H_{ixc})^2\end{matrix}\right]^{\frac{1}{2}} \quad (24)$$

$$|H_y| = \left[\begin{array}{l} (H_{rya} + H_{ryb} + H_{ryc})^2 + \\ (H_{iya} + H_{iyb} + H_{iyc})^2 \end{array} \right]^{\frac{1}{2}} \quad (25)$$

And finally

$$|H_n| = \left(|H_x|^2 + |H_y|^2 \right)^{\frac{1}{2}}$$

$$\theta = Arctg\left(\frac{|H_y|}{|H_x|} \right) \quad (26)$$

$$H_n = |H| \angle \theta$$

V. Magnetic Field of Bundled Three-Phase Transmission Lines

A bundled conductor is formed by five sub-conductors in each phase is shown in figure 2.

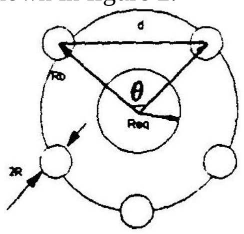

Fig.2. Cross section of 5 bundled line

In this figure, Rb is bundle radius, R is radius of each sub-conductors and d is distance between two sub-conductors. For bundled conductors the following equation is correct:

$$R_b = \frac{d}{[2(1-\cos\theta)]^{\frac{1}{2}}} \quad (27)$$

$$\theta = \frac{360}{n}$$

Where, n is the number of sub-conductors. So, a conductor with a radius equal to Req can be replaced instead of bundled conductors.

Req can be calculated using following equation:

$$\text{Re}q = R_b \left(\frac{n\,R}{R_b} \right)^{\frac{1}{n}} \quad (28)$$

So, a bundled Transmission line can be simulated with a simple line.

VI. Prepared Software Package

MATLAB is currently available on popular computer for engineering applications. A new software package for magnetic field calculation is prepared based on above equation and developed in MATLAB. Several parameters such as number of sub-conductors, bundleradius, radius of each sub-conductor, current of wires, height of transmission towers, and diameter of wires and position of the phases in transmission towers are input data of software package. By using input data and based on equations (1) to (28) magnetic field around bundled three phase's systems at a constant height from the ground or in a fixed-width of the transmission tower can be calculated.

VII. Calculation of Magnetic Field Around 230kV Bundled Transmission Lines

In Iran, several line configurations are installed for 230kV voltage level. The design, shown in Figure 3 is typical Lattice-type structure for most of 230kV lines that are used in Iran. These figures present the line conductor configurations and dimensions of the employed 230 kV lines.

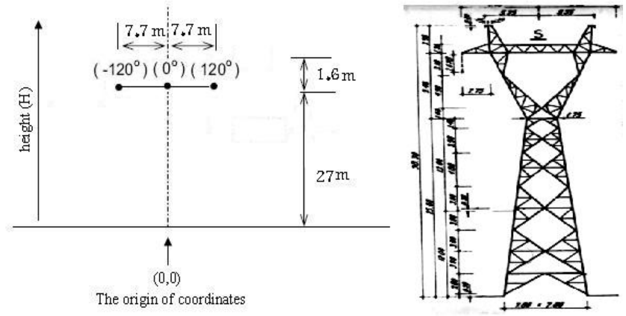

Fig.3. Line conductor configuration of 230 kV lines

The design, shown in Figure 3, is a typical Lattice-type structure for most of 230 kV lines that are used in Iran. The measured data for this case is tabulated in Table 1 for I=1000A and Table 2 for I=2000 A. The measurement data are collected in relatively flat area of about 1 m height. The conductor used is 795 mm2 bundled with two conductors with spacing of 18 inches, which is the standard conductor for 230 kV lines in Iran.

The measurement data in relatively flat area of about 10 m and 20 m height for I= 1000A are listed in Table3 and Table 4.

In this section, the magnetic fields are obtained for tower configuration shown in Fig. 3. The results of the magnetic field (in μT) obtained from the different cases of study. From these tables we can conclude that:

- Several parameters such as number of sub-conductors, bundle radius, radius of each sub-conductor, current of wires, height of transmission towers, and diameter of wires and position of the phases in transmission towers are effective parameters on amplitude of Magnetic field.
- Magnetic fields under or near bundled transmission lines have adverse health effects if the field value is higher than the minimum safe value.
- Magnetic field rapidly decreases when the distance from the center of the wire increases.
- The results of this study confirm the environmental pollution of the magnetic field produced near transmission lines

Table1: Magnetic Field (μT) Measurement for I=1000 A

	Distance (m) From Center of the Tower							
	-10	-5	-2	0	1	3	5	15
Magnetic Field (μT)	3.3	3.58	3.66	3.7	3.67	3.64	3.57	2.88

Table 2: Magnetic Field (μT) Measurement for I=2000 A

	Distance (m) From Center of the Tower							
	-10	-5	-2	0	1	3	5	15
Magnetic Field (μT)	6.6	7.16	7.33	7.4	7.35	7.27	7.15	5.76

Table 3: Magnetic Field (μT) Measurement (I=1000 A and H=10m)

	Distance (m) From Center of the Tower							
	-10	-5	-2	0	1	3	5	15
Magnetic Field (μT)	6.53	7.55	7.85	7.92	7.90	7.77	7.50	5.15

Table 4: Magnetic Field (μT) Measurement (I=1000 A and H=20 m)

	Distance (m) From Center of the Tower							
	-10	-5	-2	0	1	3	5	15
Magnetic Field (μT)	20.47	27.77	28.97	29.18	29.11	28.63	27.67	11.37

VIII. Conclusions

Bundled transmission lines are strategically important components of any power system. These transmission lines are considered as one of the major sources of magnetic field that cause electrical currents inside the body. So, Accurate calculating of magnetic field under bundled transmission lines is very important for assessment of the interaction of these fields with life forms at the ground level under power lines. In this paper, theoretical studies of the magnetic fields produced by bundled transmission lines are described. First, a prepared software package for magnetic field calculation is developed in MATLAB. Then, magnetic field distributions under 230kV bundled power transmission lines are investigated.

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