Magnetic Field of 1200kv Transmission Line by FEM & MATLAB

Akibahemad Arora, Anuradha Deshpande

Abstract: ***With rapid industrial and commercial growth and flourishing population, power demand is increasing rapidly. Modern methods of UHV transmission lines are important to transmit bulk amount of power more efficiently in comparison to earlier methods of transmission. 1200 KV UHV transmission line is India future and therefore forthcoming project to tackle this situation. However as line to line voltage level increases, complexity of the transmission line increases. But, with higher level of line to line voltage, complexity of transmission line increases. ROW is one of the major concerns with transmission lines. Many parameters need to take care in designing; one of them is a magnetic field distribution at surroundings of transmission line. India has initiated to expand its UHV range to 1200kv. Paper suggest magnetic field of three configurations of the 1200KV line. Horizontal and vertical configuration test lines have been installed. Analysis has been done by two methods finite element method and***

(Method of images) analytical method. FEM is used to solve partial differential equations. Results from both methods have been compared. 3D electric field analysis of configuration also performed. Plotted results are compared with ICNIRP standards and safety limits defined. Adverse effects of excess magnetic field is also discussed. Biological effects of electromagnetic field on people, animals and plants are also discussed. Thus paper aimed at magnetic field calculation and verification with respect to standard. It also helps to utilize less right of way. The subject is under broad development due to its advantages over lower voltage levels and holds significance in future as well.

Keywords : Analytical Method, Finite Element Method

(FEM), International commission on non-ionizing radiation protection (ICNIRP). Magnetic field, Right Of Way (ROW).

I. INTRODUCTION

To transmit bulk amount of electrical power economically over a long distance, research and test facilities are being built in several countries. Initial work started in the 1970s and research and development work is still continued to gather the vast amount of technical information necessary to design transmission lines above 1000 kV AC. Experimental lines and ultra-high voltage (UHV) test stations were built in several countries. This paper highlights the glimpses of establishment of major UHV projects, in general, and that of 1200 kV Indian project in particular [1-2].

India generates surplus power in northeast states and in eastern region. While northern, southern and western regions are mainly load centers of India [2]. So, to transmit large amount of energy over distant load centers, large transmission corridors are required.

Therefore, India initiated with 1200kv voltage range in UHV transmission line. Test substation have been installed at Bina,for research and development which uses two configurations for test lines which are S/C horizontal configuration and D/C vertical configuration

Also, At present, Wardha to Aurangabad line is operating at 400kv voltage level, will be upgraded to 1200kv level[5].

By 1200kv UHV transmission line, it is possible to transmit 6000-8000 MW power over long distance, which is 2 to 3 times power carrying capacity of 765kv UHV transmission line. It also reduces the power loss/km and optimizes Right of Way (ROW) [5]. The UHV system increases the associated electric and magnetic fields (EMF) and hence, needs to be examined for its impact on design of lines, on behaviour of humans, animal and plants in and around the power lines [6].

Magnetic field depends on current flowing through conductors. As per CIGRE WG 36.01 analytical method is used for magnetic field analysis. In this paper magnetic field is calculated and compared for both configurations by finite element method and analytical method [7].Experimental results are under test.

II. SYSTEM DATA AND METHODOLOGY

A. SYSTEM DATA

A design specification of 1200kv transmission lines is given in table I.

Table I Line Parameters

Description	Notation	Value	Units
Number of sub-conductors in a bundle	N	8	Nos.
Bundle Radius	R	0.6	m
Sub conductor spacing	B	0.46	m
Diameter of sub-conductor	d	4.63	cm
Conductor height above ground at a tower	H	37	m
Conductor height above ground at midspan	Hm	24.3	m
Phase spacing	S	27	m
Bundle conductor type	Bersimis/moose		

In this paper, twoconfigurations of a line have been discussed, which are single circuit horizontal, configuration and double circuit vertical configuration [8].

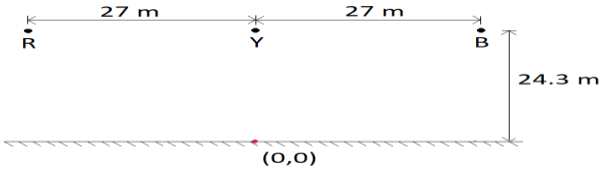


Fig. 1.S/C Horizontal configuration

Revised Manuscript Received on October 15, 2019

Mrs. Anuradha Deshpande, Associate Professor, Department of Electrical Engineering, The M.S. University of Baroda, Vadodara, India.
Email:a.s.deshpande-eed@msubaroda.ac.in
Mr. Akibahemad Arora, PG Student, Department of Electrical Engineering, The M.S. University of Baroda, Vadodara, India.
Email:akib.arora.aa@gmail.com

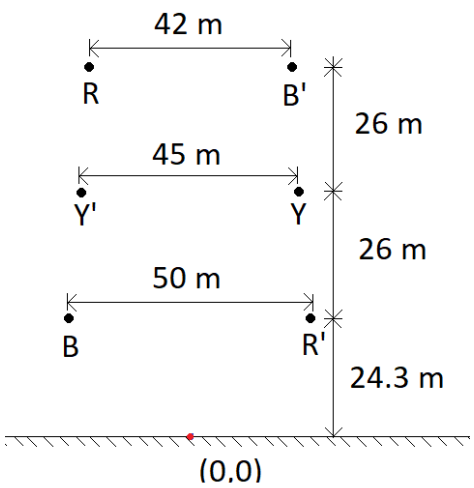


Fig.2.D/C Vertical configuration

From data, geometrical representation of octacorebersimis bundle conductor looks like as in figure 3. From data equivalent radius of conductor can be given by (1).

$$r_{eq} = R\left(\frac{Nr}{R}\right)^{\frac{1}{N}} = 0.518\, m \quad (1)$$

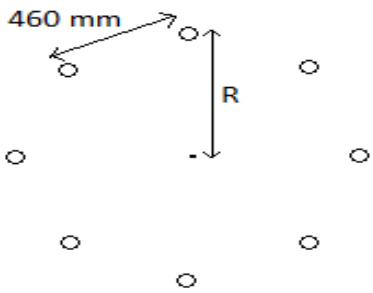


Fig. 3.octacorebersimis bundle conductor.

B. METHODOLOGY

Magnetic field produced due to current, as per the Maxwell-ampere law magnetic field intensity correlates with current density as given in (2)& (9).

$$\nabla \times H = J \quad (2)$$

Magnetic flux density depends on permeability of material. Relation between magnetic field intensity and magnetic flux density can be given as in (3) and it also given by curl of magnetic vector potential as in eq(4)

$$B = \mu H \quad (3)$$

$$B = \nabla \times A \quad (4)$$

By combining (2), (3), (4) magnetic vector potential can be correlated with current density as in (5), called poisson's equation for magnetic field. For analysis cross section of line has been considered, x axis stands for ground surface, y axis stand for height above ground surface, lines are assumed to be parallel with z-axis. So, direction of current density is taken in z direction, which is shown in (5).

$$\nabla \times \left(\frac{1}{\mu}\nabla \times A_z\hat{z}\right) = J_z\hat{z} \quad (5)$$

There will be many value which satisfies (5). To get unique solution gauge condition needs to be applied, which is given as in (6).

$$\nabla . A = 0 \quad (6)$$

Final equationobtained by combining (5) and (6) equation can be written as (7).

$$-\frac{\partial}{\partial x}\left(\frac{1}{\mu}\frac{\partial A_z}{\partial x}\right) - \frac{\partial}{\partial y}\left(\frac{1}{\mu}\frac{\partial A_z}{\partial y}\right) = J_z \quad (7)$$

C FINITE ELEMENT METHOD

In this section basic steps of the finite element method to formulateand solve magnetic field problems [9-10] is discussed.

D DOMAIN DISCRITIZATION

The first step of a finite element analysis is to divide the domain area into small elements. Figure 4 shows quadratic triangular element. For magnetic problems magnetic vector potential equation at each node is given in (8). By (9) magnetic potential at any location within an element can be written in the form of magnetic vector potential at six nodes. This equation called interpolation equation aregiven as (9).

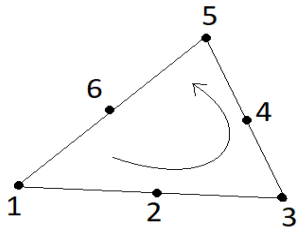


Fig.4. Quadratic type triangular element

$$A_{(x_1,y_1)} = a + bx_1 + cy_1 + dx_1^2 + ex_1y_1 + fy_1^2 \quad (8)$$

$$A = \sum_{i=1}^{6} N_{i(x,y)} A_i \quad (9)$$

E FORMULATION OF FUNCTIONAL EQUATION

Functional equation is formulated as per Ritz method. Functional equations for i[th] element can be written as (10). It shows integration within the area of an element. A represents magnetic vector potential at six nodes of an element and J stands for current density.

$$F^e(A^e) = \frac{1}{2}\iint\left[\frac{1}{\mu}\left(\frac{\partial A^e}{\partial x}\right)^2 + \frac{1}{\mu}\left(\frac{\partial A^e}{\partial y}\right)^2 - 2JA^e\right]d\Omega \quad (10)$$

To solve (10) it needs to be differentiated with respect to magnetic vector potential at all nodes, which equals to zero. From (9) value of vector potential can be put in (10) to make it into a matrix form equation. Expanded version of that equation can be written as in (11), where M stands for all number of nodes in domain area.

$$\frac{\partial F(A)}{\partial A_i} = \sum_{j=1}^{M}\iint\left[\left\{\frac{1}{\mu}\left(\frac{\partial N_i}{\partial x}\right)\left(\frac{\partial N_j}{\partial x}\right) + \frac{1}{\mu}\left(\frac{\partial N_i}{\partial y}\right)\left(\frac{\partial N_j}{\partial y}\right)\right\}A_j - JN_i\right]d\Omega \quad (11)$$

F. BOUNDARY CONDITIONS

For magnetic problem two boundary conditions have been used. One is Dirichlet condition and second is Neumann condition. Dirichlet conditions are current flow density in phase conductors, assuming balanced full load condition. Full load current is 3800 ampere and equivalent radius of conductor 0.518 meter. Dirichlet conditions for conductors are given as in (12).

Dirichlet conditions:

1. Current density in R-

phase conductor: $\frac{3800}{\pi(0.518)^2}$ = =4507.89 Amp/m^2

2. Current density in Y- phase conductor =4507.89$\angle -120°$ Amp/m^2 (12)
3. Current density in B- phase conductor =4507.89$\angle 120°$ Amp/m^2

Practically transmission lines are in air medium which is unbounded, but for analysis bounded geometry is required. For that line is bounded by big size of rectangle.Neumann condition is applied to boundaries of rectangle, which is given as in (13). Where$\hat{n}$,stands for normal vector to boundary surface and A for current density at boundary point.

Neumann condition:

$$\hat{n} \times A = 0 \quad (13)$$

III. ANALYTICAL METHOD

For understanding method for magnetic field calculations three phase configuration of line geometry has been considered as shown in figure 5. Here h shows height of the conductors from ground surface and s stands for phase to phase spacing. Three phases are represented by a, b, and c and images of conductor due to ground effect are represented as a', b' and c'[6].

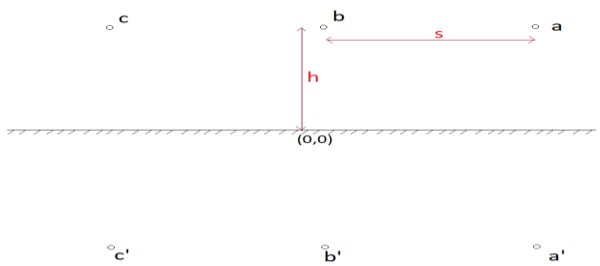


Fig. 5.3-phase horizontal configuration

Suppose I amperes are flowing through conductors. At point P magnetic field is required to be calculated. Figure 6 shows simple explanation of magnetic field due to phase "a" to that at point P.

Directions of magnetic field intensity due to conductor "a" and image of conductor a' can be found by right hand thumb rule. Magnitude of field intensity can be given by (14).

$$H = \frac{I}{2\pi D}$$

$$H' = -\frac{I}{2\pi D'} \quad (14)$$

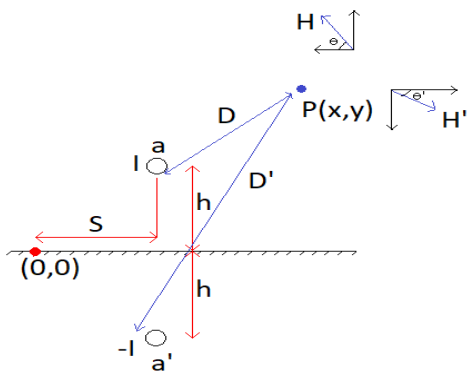


Fig.6. magnetic field intensity at point P due to phase "a"

By separating horizontal and vertical configuration, total magnetic field due to a phase conductor at point P can be written asin equation (15) and (16).

$$H_h = H\cos\theta + H'\cos\theta'$$
$$= \frac{I}{2\pi}\left(\frac{y+h}{(x-s)^2+(y+h)^2} - \frac{y-h}{(x-s)^2+(y-h)^2}\right) \quad (15)$$

$$\mathbf{H_v = H\sin\theta + H'\sin\theta'}$$
$$= \frac{I}{2\pi}\left(\frac{x-s}{(x-s)^2+(y-h)^2} - \frac{x-s}{(x-s)^2+(y+h)^2}\right) \quad (16)$$

Now, in same manner horizontal components for all three phases can be found. Three variables can also be defined for locating part in (15), these are given as (17)

$$K_a = \frac{y-h}{(x-s)^2+(y+h)^2} - \frac{y+h}{(x-s)^2+(y-h)^2}$$
$$K_b = \frac{y-h}{(x)^2+(y+h)^2} - \frac{y+h}{(x)^2+(y-h)^2} \quad (17)$$
$$K_c = \frac{y-h}{(x+s)^2+(y+h)^2} - \frac{y+h}{(x+s)^2+(y-h)^2}$$

Now, horizontal component of magnetic field at point P due to three phases can be written as shown in (18).

$$H_{ht} = \frac{1}{2\pi}(I_aK_a + I_bK_b + I_cK_c) \quad (18)$$

In balanced load condition current magnitude is same in all three phases with 120 degree phase difference, which can be written as in (19). By solving (19) into overall magnitude can be written as in (20). Similarly vertical component of magnetic field can be calculated, variables defined by J term for vertical components can be given as in (21). Total magnetic field intensity of vertical component can be given as in (22).

$$H_{ht} = \frac{I}{2\pi}(K_a\angle 0° + K_b\angle -120° + K_c\angle 120°) \quad (19)$$

$$|H_{ht}| = \frac{I}{2\pi}\left(K_a^2 + K_b^2 + K_c^2 - K_aK_b - K_aK_c - KcKb1/2\right) \quad (20)$$

$$J_a = \frac{x-s}{(x-s)^2+(y+h)^2} - \frac{x-s}{(x-s)^2+(y-h)^2}$$
$$J_b = \frac{x}{(x)^2+(y+h)^2} - \frac{x}{(x)^2+(y-h)^2} \quad (21)$$
$$J_c = \frac{x+s}{(x+s)^2+(y+h)^2} - \frac{x+s}{(x+s)^2+(y-h)^2}$$

$$|H_{vt}| = \frac{I}{2\pi}\left(J_a^2 + J_b^2 + J_c^2 - J_aJ_b - J_aJ_c - J_cJ_b\right)^{1/2} \quad (22)$$

Total magnetic field at point P can be given as in (23). Magnetic flux density correlates with a magnetic field intensity as in (3). Unit of magnetic flux density is in tesla, which can be converted into mG.

$$H = (H_{ht}^2 + H_{vt}^2)^{1/2} \text{ A/m} \quad (23)$$

IV. RESULTS AND DISCUSSION

A magnetic field is calculated and plotted for two configurations of a 1200kV transmission line. Magnetic field is plotted, up to some distance from reference point on ground surface. It is repeated forvarious heights from the ground surface and 2m, 4m, 6m, 8m and 10m above from the ground surface.

The Analysis is performed by considering the minimum height of conductors in a span. COMSOL Multi Physics is used for analysis by technique of FEM and MATLAB is also used for analysing the same details. Figure 7 and figure 8 shows magnetic field of horizontal configuration of 1200kv transmission line by FEM and Mat Lab respectively.

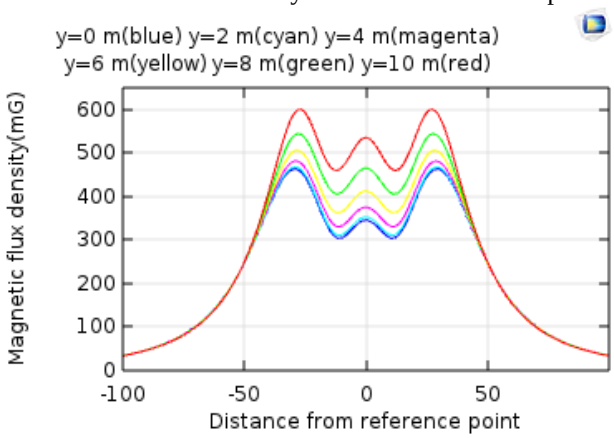


Fig.7. Magnetic field distribution for S/C horizontal configuration by FEM

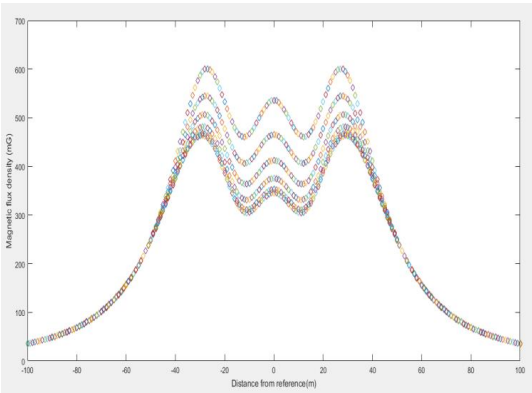


Fig.8. Magnetic field distribution for horizontal configuration by Analytical method

In same manner figure 9 and figure 10 shows magnetic field results by Comsol and Mat Lab for vertical configuration.

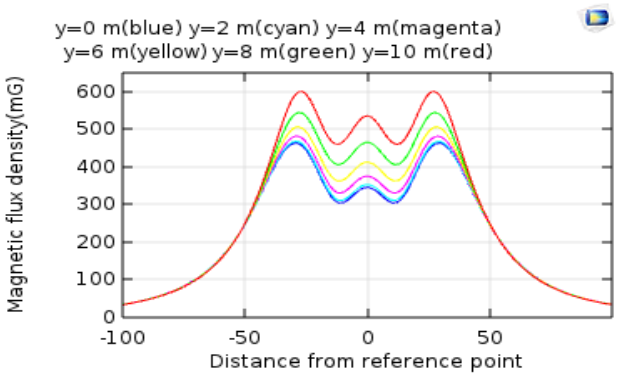


Fig.9. Magnetic field distribution for D/C vertical configuration by FEM

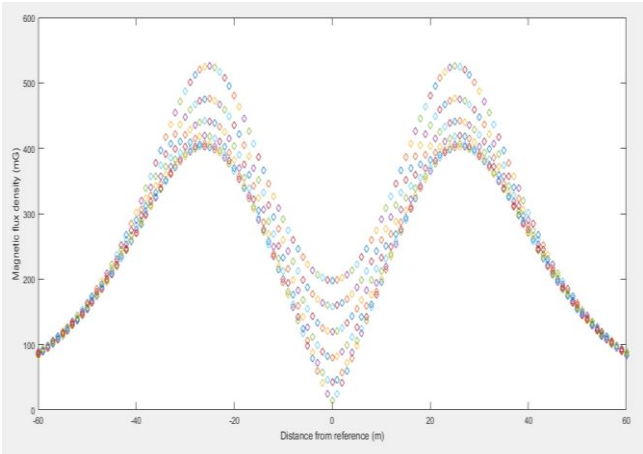


Fig.10. Magnetic field distribution for vertical configuration by Analytical method

Table 2 and table 3 shows comparison of results obtained by two methods. It is clear that FEM can be used for magnetic field analysis. Practically ground surface is not flat everywhere. Transmission lines are not straight lines throughout it length. For practical and more realistic cases Finite element method is very useful. It simplifies complexity of problem by dividing into elements.

Table2. Comparison of results for horizontal configuration

Location from the reference point	Magnetic flux density(mG)		
	Horizontal configuration		
	By FEM	By Mat Lab	Percentage error
(-50,10)	249.9209	250.5	-0.23%
(-25,8)	534.273	534.8	-0.09%
(0,6)	412.5707	412.9	-0.08%
(25,4)	465.6701	466.3	-0.16%
(50,2)	247.325	248	-0.27%
(0,0)	345.3331	345.6	-0.08%

Table3. Comparison of results for vertical configuration

Location from the reference point	Magnetic flux density(mG)		
	Vertical configuration		
	By FEM	By Mat Lab	Percentage error
(-50,10)	163.638	163.1	0.33%
(-25,8)	475.516	475.6	-0.02%
(0,6)	119.3387	119.3	0.03%
(25,4)	418.5359	418.5	0.01%
(50,2)	154.9238	154.1	0.53%
(0,0)	14.6754	14.54	0.93%

As per ICNIRP standards magnetic flux density above 2000mG is harmful for human, animals and plants. Magnetic fields are basically energy reservoirs with an energy density, which is given as

$$e = \frac{B^2}{2\mu_0} \text{ Joule/m}^3 \qquad (21)$$

This energy is known to influence tissues in the human body in everyday activities.Some of the effects are known to be beneficial such as being used medically for healing broken bones. But most are harmful and pose health hazards among which includes cancer of many types, like leukaemia or blood cancer, lymphoma, nervous disorders leading to brain damage such as Alzheimer disease, breast cancer in both femaleThe study of health hazards associated with power-frequency (50 and 60 Hz) magnetic fields has gained world-wide importance in medical, biological, physics and engineering fields and is the subject of intensive study, including the magnetic-field radiation from UHV lines and distribution lines [6].

V. CONCLUSION

From above calculation it is clear that for given design magnetic flux density is in limit when compared with ICNIRP standards. There will be no harmful effects on human beings, animals, plants. By comparison between COMSOL and FEM it can be concluded that results by finite element method are also accurate. COMSOL multi physics can be used for many applications in electromagnetic field analysis with more complexities. Comsol finite element calculation is in direct comparision with matlab results. Also paper suggests that horizontal configuration results are better than vertical configuration. Thus, paper has successfully estimated magnetic field strength of 1200 kv UHV transmission line.

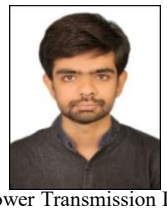
ACKNOWLEDGEMENT

Thanks to the electrical engineering department, Faculty of technology and Engineering, MSU-Baroda, Vadodara, India

REFERENCES

1. CIGRÉ Brochure 362 WG A3.22: 'Technical requirements for substation equipment exceeding 800 kV – field experience and technical specifications of substation equipment up to 1200 kV', December 2008, ISBN: 978-285873-049-0
2. SatyadharmaBharti, SatyaPrakashDubey, "No-load performance study of 1200 kV Indian UHVAC transmission system", High Voltage IET, Vol. 1, Issue. 3, pp. 130–137, 2016.
3. "India to have world's highest power transmission line", THE HINDU Business Line Newspaper, December 04, 2013.
4. "PowerGrid to launch India's first 1200-kv station" Business Standard, January 20 2013.
5. http://www.powergridindia.com/shri-i-s-jha-cmd-powergrid-inaugurates-commencement-power-flow-through-1200kv-national-test-station
6. R.D. Begamudre, "Extra High Voltage AC Transmission Engineering", New Age, International Publication, 3rd Edition, 2006.
7. Zhenya Liu, "Ultra-High Voltage AC/DC Grids", Acadamic Press Publication-Elsevier, 2015.
8. H.K. Agarwal, K. Mukherjee, A.K. Pal and P.Barua, "Design and Development of 1200KV Transmission Line and Substation Insulation Hardware Fittings Clamps& Connectors", CIGRE India journal Vol.1 issue 2, pp.10-18, 2012.
9. JIAN-MING JIN, "The Finite Element Method in electromagnetics", Third Edition, IEEE Press, Willey Publication.
10. Matthew N. O. Sadiku, "Numerical Techniques in Electromagnetics", Second Edition, CRC Press.
11. Aliyu Ozovehe, Maina Ibrahim, Ali Hamdallah,}" Analysis of Electromagnetic Pollution due to High voltage Transmission Lines." Journal of Energy Technologies and Policy, ISSN 2225-0573(online), vol.2, No.7, 2012.
12. International Commission on Non ionizing radiation protection guidelines for limiting exposure to time varying electric and magnetic fields. (1Hz to 100Hz), Health physics 99(6):818-836;2010.
13. COMSOL Multiphysics User's guide, May 2012
14. Book on ," Electrical Power Systems," sixth Edition, New Age Internstional Publishers.
15. Manash Jyoti Baishya, Dr NKKishore, and Dr. Satyajit Bhuyan," Calculation of Electric and Magnetic field safety limits under UHV AC Transmission Lines," Eighteenth National Power System Conference (NPSC) 18-20 Dec 2014.
16. R M RADWAN, M M Samy, S. Akef," Calculation of Electric Fields Underneath Ultra High Voltage Transmission Lines," Proceedings of the 17th Middle East Power Conference, 16-18 Dec 2015.
17. Mahadev G Unde, Bansidhar E Kushare," Analysis of electromagnetic fields of 1200 KV UHV-Ac Transmission Lines," 5th international Conference on Computational Intelligence and Communication Networks, 27-29 Sept, 2013.
18. Puneeth Bhurat, Dundru Sridhar, Dharmesh Yelamanchi, Jitin Pauly, Vasudev N,"1200KV Transmission Line Corona Effects And Electro magnetic Fields," International Conference on high voltage engineering and technology, January 2015,
19. M Trlep, A Hamler, M Jesenik, and B. Stumberger," Electric Field Distribution under Transmission Lines Dependent On Ground surface,"IEEE Transactions on Magnetics, Vol 45, No3, March 2009.

AUTHOR'S PROFILE:



Akibahemad Arora,is a Post Graduate student of Master of electrical power engineering during academic year 2018-19 at department of electrical and electronics engineering, Faculty of Technology & Engineering, M S University of Baroda, Vadodara,
390001. Gujarat, India His M E dissertation is titled Electromagnetic Field Analysis Of 1200kv Power Transmission Line. He has presented a paper titled," Analysis of the Electric Field of the 1200KV power transmission line using the Finite element Method at the IEEE sponsored 4th International Conference on Communication and electronics Systems (ICCES 2019) organized by PPG Institute of Technology during 17-19, july 2019 at Coimbatore, India.

She is holding a degree of Post graduation as on today, of The Maharaja Sayajirao University of Baroda. Author has guided many undergraduate projects and post graduate dissertation. She was awarded best paper award at Energy, Economy and Environment 2008 conference held at Calicut.She has professional membership of IE(India), ISTE, Society for power engineers, etc.She has many publications published in National and International Journals of repute. She has published a book titled,"Transient Analysis of Series Circuit."