Advances in UHV Transmission and Distribution
Prof. B Subba Reddy
Department of High Voltage Engg (Electrical Engineering)
Indian Institute of Science, Bangalore

Lecture – 27
Electric and magnetic fields, mitigations techniques

Good morning we were discussing about the electromagnetic fields. Whether this electromagnetic fields which are caused by the transmission lines could be harmful for the human and also the animals. So, this is a interesting topic and concerned topic for the research as well as for the utilities. So, during 19 nineties most of the EMF that is a electromagnetic field research was focused on low frequency exposures.

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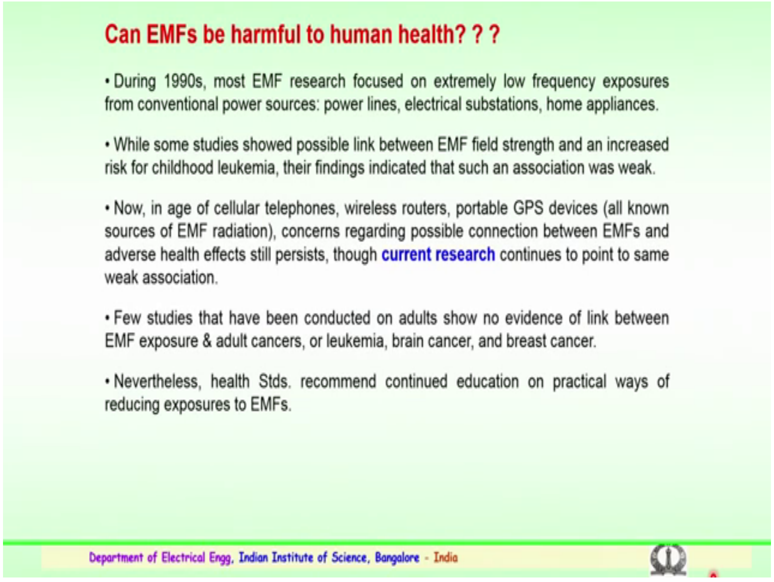

Particularly from the conventional power sources from the power lines or generating from the electrical substations, or could be of the home appliances like the micro ovens refrigerators air conditioner units so on.

So, some of the studies have a showed a possible link could be between the electromagnetic field a strength and a increased risk of a childhood leukemia. But this findings indicated that such an association was very weak. So, there were no concrete proof that the magnetic fields generated by the appliances and the electrical power lines do support the a theory of a causing harmfulness to the human life. So, with the age of cellular technology so, several of the wireless routers being used in the cellular networks a likewise the portable GPS devices. So, the concerns regarding the possible connections between the electromagnetic fields and the adverse health effects still persists among the people, though current research continuous to point to the same a weak association.

Some of the studies have been conducted on the humans show no evidence of any link between the electromagnetic field exposure and the cancer related or a leukemia pertaining to the human a decease like brain cancer breast cancer so on nevertheless the international health standards recommend and also the continued education on the practical ways of reducing the exposures particularly to the electromagnetic fields is very important. And people should be told about the importance and also to see that a minimum exposure to the electromagnetic field is necessary for the health issues.

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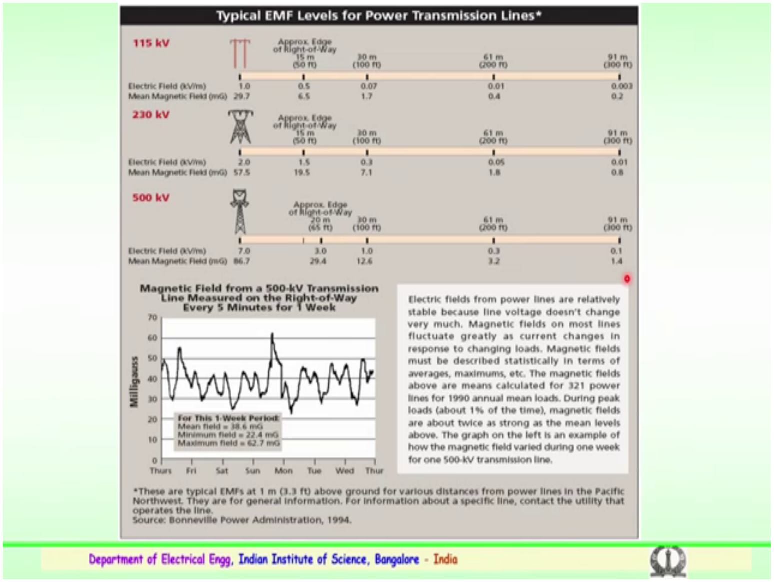

So, typically when you see the transmission towers you have both the electric field and the magnetic field in the vicinity of the power transmission lines. The here are few of the examples for various voltage levels 115, 230 and the 500 kilovolts, where you see that these are the towers and the distance from the towers, you can see that both the electric and magnetic field electric field in kV per a meter and magnetic field in a milligauss the values are very clearly given here say in example of a 500 kV transmission system.

You can see the electric field the kV 7 kV per a meter being at the midpoint of the tower, or very near to the conductor, as the distance increases from the tower you can see the values of the electric field and the magnetic field getting reduced initially 7 kV per meter being the electric field and 86.7 milligauss being a magnetic field near the high voltage tower.

So, it reduces as the distance decreases or you go further away from the tower, say 91 meters approximately around 300 feet you see the electric field reducing to 0.1 meter and the magnetic field reducing to 1.4 a milligauss. So, this is information for various electric and magnetic field pertaining to the transmission higher transmission levels. So, the electric fields from the power lines are relatively stable because, the voltage does not change. So, all the transmission a lines which are operating at that particular voltage see at 765 kV level the voltage level fluctuation will be very less.

So, the line because of the voltage level being maintained the electric fields, will be relatively stable. But the magnetic fields on the lines may fluctuate greatly, because this is due to the current changes in the response to the charging load. So, as the load which is being supplied by the transmission which is being supplied to the load, when the loads change the current magnitudes change drastically, because of a this the magnetic fields which are there should be of concern and must be described statistically because in terms of averages or other maximum or a minimum values which the fluctuation depends upon the load aspects.

So, the magnetic fields above the main normally calculated for a various transmission a lines. And it could be monitored and a measurements could be done. So, various values for the different transmission systems are being given here.

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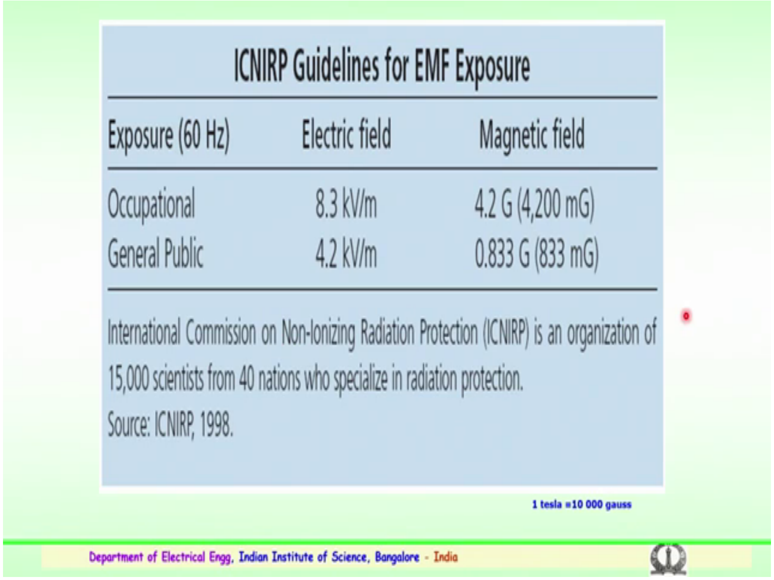

As mentioned earlier, the international commission on non ionizing a radiation protection which is a organization on comprising of more than 15000 scientist from more than forty nations, specialized in radiation protection how come to a common platform, and they have frame the guidelines a pertaining to the electromagnetic fields exposure where the severity of the magnetic field and the electric field near the people particularly were working in the transmission or distribution or in the substation utilities, should not be exposed with the specified values.

So, here are some of the guidelines which have been framed by the association of ICNIRP you can see here the exposure say for a 60 hertz power frequency supply 60 or 50 hertz you in the country it is 50 hertz. So, in some of the countries they follow 60 hertz supply. So, the guidelines mention that is a occupational the people who are working in the utilities say in the substations, or say people who are exposed for the a transmission or the substation electric and magnetic field were working in the utilities or people who are involved in that, they should not be exposed or more than 8.3 a kV per meter in case of electric field, and in case of a magnetic field the maximum exposure should not be more than 4.2 or 4 4200 a milligauss this is a value.

And in case of a general public it the values of electric field it should not increase by 4.2 kilovolt per meter or 0.8 a 3, 3 gauss or 833 milligauss. These are the some of the guidelines which have been framed and it is a necessary to be adopted for the safe a healthiness of the humans over a working in the utilities or in the transmission companies. So, electric field and above the 1 gauss or a 1 tesla is equal to 10000 gauss.

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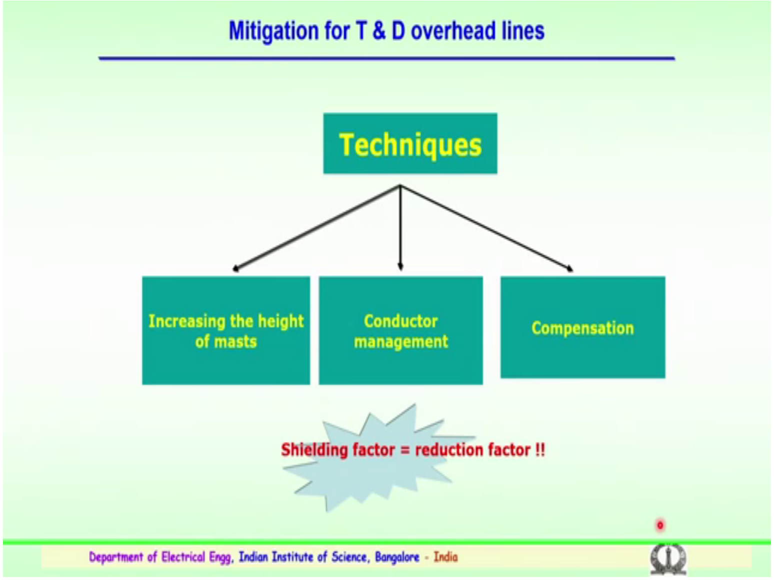

This is one point to be noted. So, which is a electromagnetic fields are measured in terms of a gauss. So, 1 tesla is equal to 110000 gauss

So, the mitigation of the electric and magnetic fields is very, very important. And particularly concerning the transmission and distribution systems could be over volt overhead lines or a substations the proper mitigation techniques have to be employed ah. So that a proper shielding factors or shielding has to be taken care. So, that it could be reduced for the people who are working in the substation or in the a transmission sector. So, various techniques are being employed for the EHV and a UHV transmission and the substation aspects

So, one of the technique is to increase the height of the mast. Height of the mast is the tower mast where it is increased and the clearances are more. So, with the clearances the electric field kV per meter come down and also the magnetic fields are will get reduced on the people who are working on the earth ground level. Second being the conductor a management again we will be discussing about these aspects in a detail. So, with the help of the conductor proper conductor management, the mitigation could be done or reduced electric field and magnetic fields could be reduced with the proper a conductor management. And third being the compensation techniques.

So, again various a compensation techniques could be used to see how these could be reduced. The shielding factor is one of the important aspects to see that a proper shielding will help to reduce the fields.

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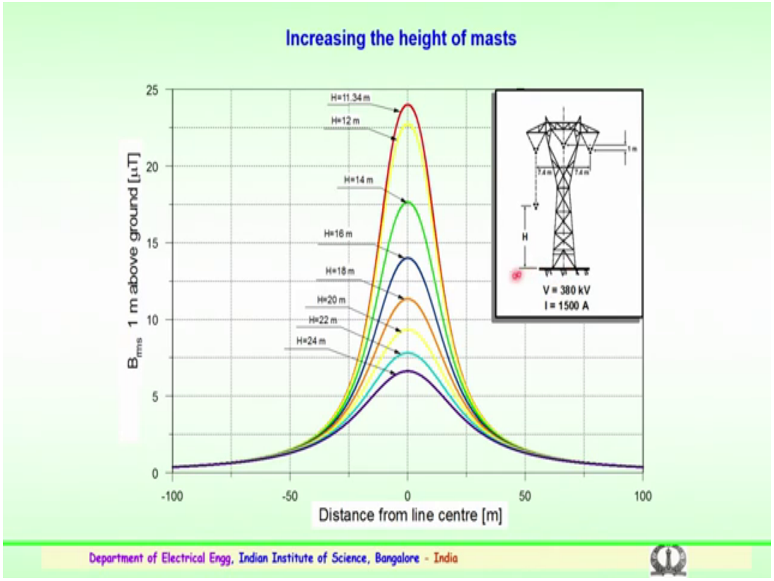

This graph shows you the effect of the mast a like increasing the mast increasing the height of the mast. You see the reduction for various heights, you can see like when the conductor is consider the tower with the conductor here a 3 conductor bundle here.

So, this height whatever the clearances from the ground, say this clearances from the ground, typically transmission system of 380 kilovolts is considered here, with the current carrying capability of 1500 amps for the conductor and the simulation of electric field is carried out a for various a heights. And you can see as the clearance increases and the electric field were reduces that is a distance from the center is considered here.

You can see for various height and that is one meter above the ground. The micro tesla that is a magnetic fields which are could be generated, because of the 1500 a carrying capability or the conductors. So, the height from a 11.34 meters that is a h is considered at 11.34 meters to 12 14 and up to 24 meters, you can very clearly see as the height decreases, the magnetic field increases. You can see the values typically for a 11 meter clearance height with a conductor being charge at 1500 amps for a voltage level of 380 kV a system; the magnetic field could be somewhere 23 to 24 micro tesla. As the distance increases the micro the magnetic fields gets reduced you can see for a 14 meter

16 20 so on at a height of 24 meter you can see the reduction from the 23 micro tesla to approximately around 6 to 7 micro tesla.

So, this shows that increasing mass or the clearances could bring down the magnetic fields particularly the magnetic fields near the ground surface on the near the tower a high voltage or the extra high voltage tower which are carrying more power.

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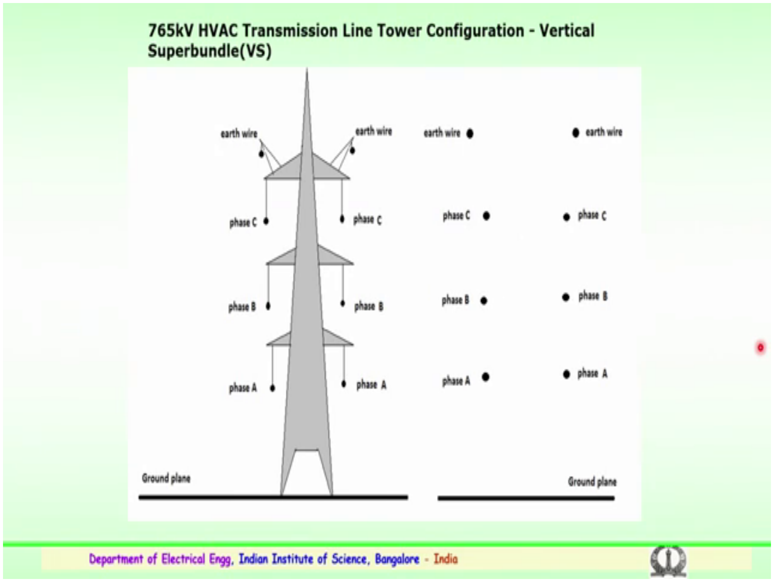

And also it should be noted that magnetic fields as mentioned earlier, mainly depend on the current or caring capability of the conductors, your magnetic field will be more only when the current or is very high. So, when the voltage is very high current is less so magnetic fields of or mod of much a concern a electric field as of a concern.

So, the magnetic fields as a power transfer goes high and the current load is higher and then the magnetic fields are the magnitude of the magnetic fields also go high. So, this is again a typical 765 kV transmission a line a tower configuration for the vertical a super bundle. You can see 2 circuit is here A B C, and again here A B C. And you have a 2 earth wires and lightening on the tower schematic here, this is a ground plane intentionally the earth wires are connected here. And you see the A B C and the phases are change and it is a proper transpose is done to see that the advantages for transmission is better and also reduction of the electric and magnetic fields to a certain extent in case of the conductor carrying more current.

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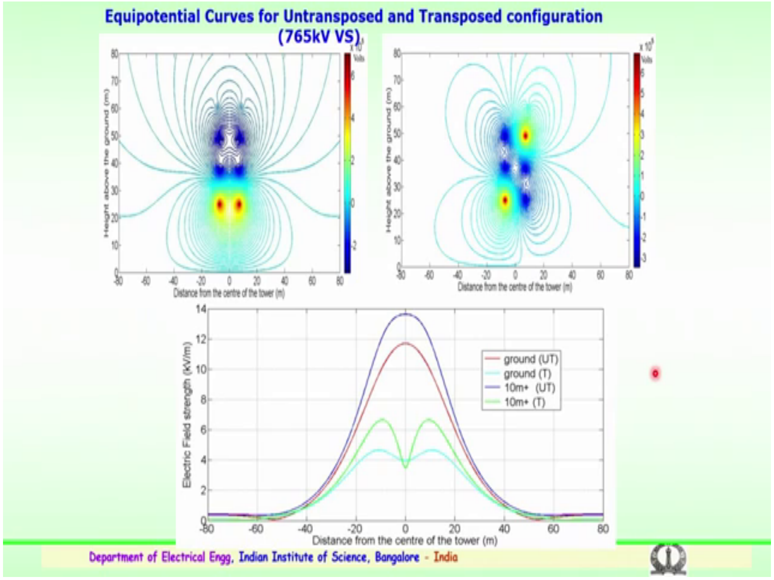

So, is there some of the things we some of the magnetic field and electric field values which have been simulated in the using developed software. So, for a 765 kV the curves have been shown both for the untransposed, this is for the untransposed normal tower 765 and this is for the transposed tower you can see height above the ground verses the distance from the center of the tower.

These are the equipotential plots which given indication, and this gives the electrical a field strength from the center of the tower. You can very clearly see here we have try to plot both for untransposed and also the transposed. You can see the colour red color which is been shown here is for the untransposed part, and this is for the ground he is the transposed apart.

So, compared to the transposed and untransposed, the electric field strength reduces this is one of the management of the conductors placement and going in for your transposed conditions. So, very important one of the mitigation very important mitigation technique which is being flowed in the transmission system.

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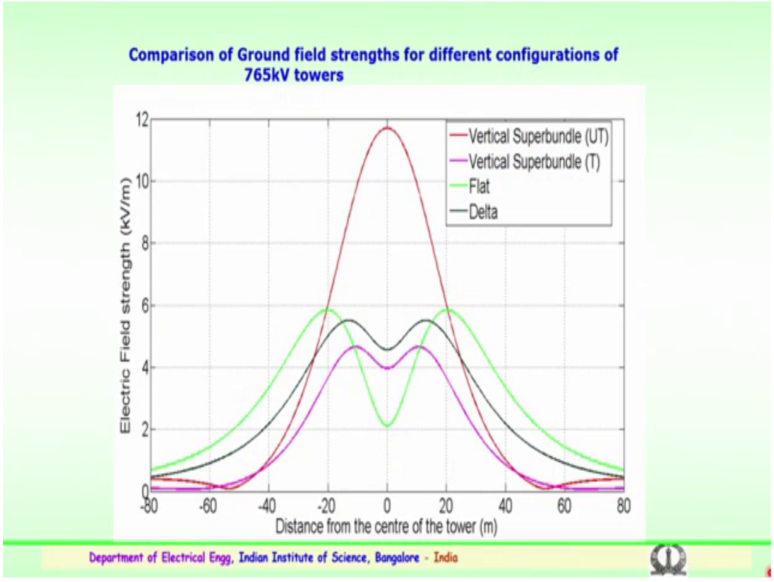

Again comparing for the ground field strengths electric field strengths, for different configuration again for the 765 towers, you can see that for various towers we have carried out the simulations. This simulations results very clearly show that for the different towers and also for the transposition and a untransposed ah, conditions that is a vertical super bundle type untranposed and vertical tower with a transport system, and also for a flat tower and a delta type of configuration.

So, 4 type of a configuration studies have been done, and here you can see the electric field kV per meter verses the distance from the center of the tower. Very clearly you can see when the line is transposed when the conductors have transposed the levels of electric field stress reduces this is again in case of delta the pink color shows for the vertical super bundle whereas, for a untransposed you can see that the electric field strength is very, very high near to 11 or a 12 kV per meter, for the same tower with the transposition you come it comes down to 4.

So, it reduces by one third value. So, the very clear conclusion that the transposition going in for transposition will be the better option for a reducing the electric fields.

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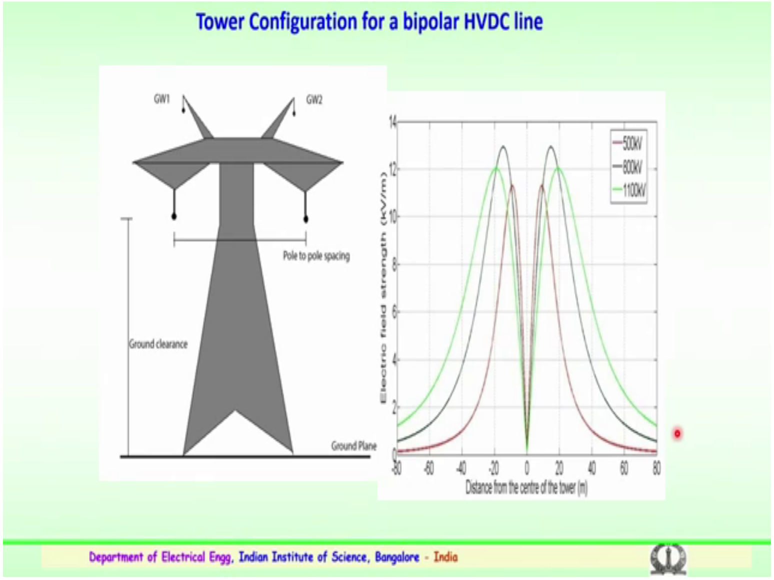

This is a similar study conducted for the tower configuration for a bipolar HDVC transmission lines for a various voltage levels, a 500 kV 800 and 1000 kV lines from the data which is being obtained in the literature for the tower details have been the data for the tower details have been obtained from the utility and also from the literature.

You can this is a again a schematic of the HDVC a transmission tower, you can see the ground clearances if the conductors are connected is above polar to line DC line this GW 1 and GW 2 are the ground wire connections a 1 and 2 for a tower. This as is a ground plane and the distance between the 2 conductors will give the pole to pole spacing that as for the standards for 500, 800 and 1100 kV, have been taken into consideration while estimating the electric fields.

So, for the DC we have try to estimate the electric fields for a EHV and a UHV DC lines. So, here you can see for a 500, 800 and a 1100 kV a estimations were carried out for a bipolar HDVC line. You can see the 500 kV HDVC line given in the red line, a shows red curve shows a approximately 11 kV per meter electric field similarly, for a 800 kV it is a 13 kV and for a 1100 kV system it is a 12 kV per meter again it depends on the height of the clearances which have been given and the tower pole to pole spacing and the ground clearance very important. So, the values which are estimated have been compared with the actual dimensions of the available data from the literature and the simulations have been carried out.

So, for the 500 800 and 1000 kV you see the fields could lie anywhere between a 11 to a 13 kV per a meter considering the distances.

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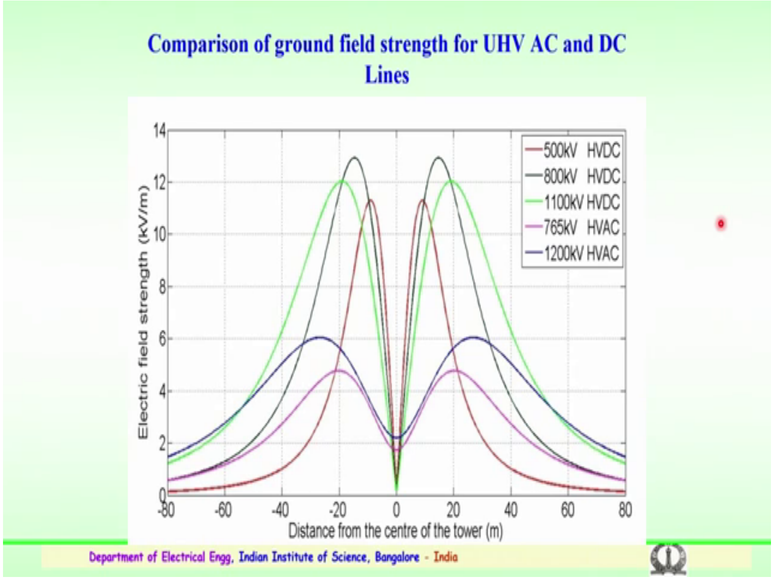

So, similarly comparison for the ground field strength, for both a ultra high voltage AC and DC transmission lines was estimated, and a comparison is made here. You can very clearly see the comparison conducted for both ultra high voltage AC and DC lines, for the electric field strength this y axis shows the electric field strength verses the distance a from the center of the tower.

So, for high voltage AC and the DC you can see the comparison, the red color gives the high voltage DC 500 kV a line which gives approximately the 11 kV per a meter which we have seen in the previous case, again the 800 kV being 13 kV per meter. For HVAC you can see the fields are substantially less here around 4, 4 to 5 kV per a meter.

And in case of a 12080s hardly around 6 kV per meter. These are done with the proper going in for the transposition of the conductors, again this would reduce drastically. For comparing the 1100 kV HDVC and 1200 kV HVAC or 800 kV HDVC and 765 kV HDVC, you can see the electric fields will be definitely higher in case of HDVC, slightly higher and for HVAC with the proper transposing fields will be lesser.

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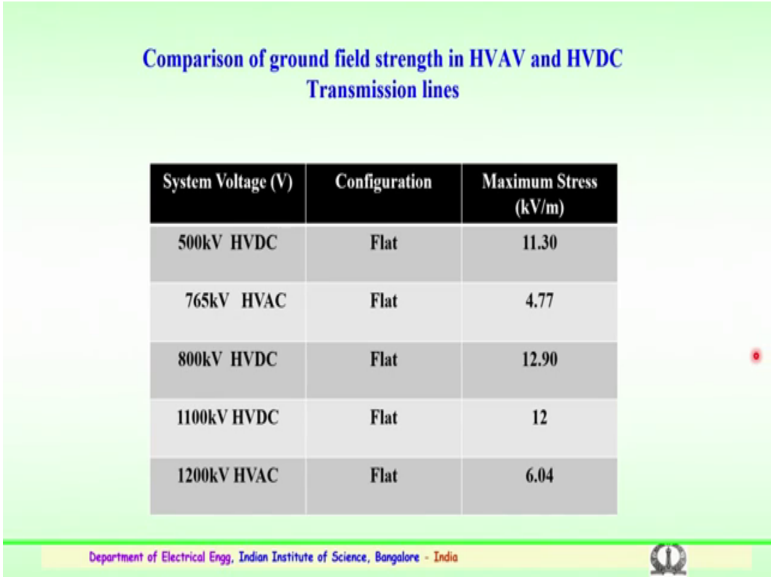

System Voltage (V)	Configuration	Maximum Stress (kV/m)
500kV HVDC	Flat	11.30
765kV HVAC	Flat	4.77
800kV HVDC	Flat	12.90
1100kV HVDC	Flat	12
1200kV HVAC	Flat	6.04

So, again a comparison of the ground magnetic sorry, strength for high voltage AC and HDVC, this gives the summary of the system details that from 500 kV a DC 765 AC up to 1200 kV AC both for AC and DC. The for various towers the flat type of towers what was the maximum stress which was obtained a kV per meter are shown here in case of a 500 it is summarized is 11.30, 765 kV it is 4.77 one third reduction in comparison with the 800 kV DC a lines.

Similarly, for 1100 kV a HDVC it is 12 and 1100 kV a 1200 kV HVAC it is 6. So, almost a 50 percent of the fields which have been or the maximum stress which have been seen in case of DC comparatively lesser in case of AC.

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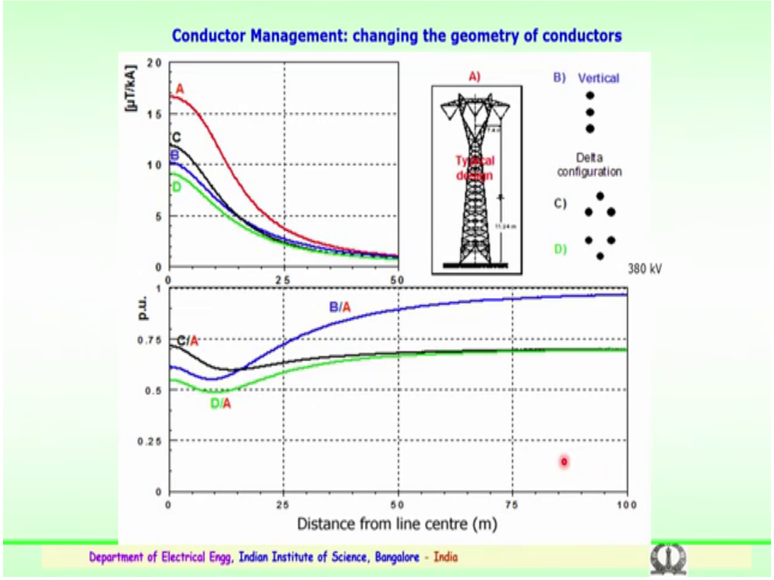

The second point the one was the clearances a height, the as mentioned earlier the conductor management a very important, this we have also seen that is a conductor going in for the different configuration. And also the conductors being going in for a transposition this will help in the reduction of files fields electric fields.

So, here or a magnetic fields you can see a small example here example of a the design of a vertical type of tower or a delta configuration type of all the conductors are managed and conductors are connected this will be helpful. So, a various options have been shown here see, example this is a one type of a arrangement where the conductors have been connected and this is the clearances b is the vertical conductors placement like as shown here.

Third being the delta configuration in a rectangular sorry equilateral triangle type, and the D being the inverted equilateral triangle. The placement of the conductors is being modified and the studies have been carried out to see the fields the behavior. You can see here for the magnetic fields that is a microtesla per k kiloamp. So, it depends what is the current rating of the or the load which is being carried by this conductors.

So, for various current rating in terms of kiloamp the microtesla is been estimated that is a magnetic field is estimated, and you see a particularly of this configuration the magnetic fields are higher. And going in for a either vertical or a delta or a inverted equilateral triangle type of a arrangement of the conductors could lead to the better performance of the line or also the magnetic fields getting a reduced. So, this is how it is being shown here. And this gives the per unit verses the distance from the center of the values.

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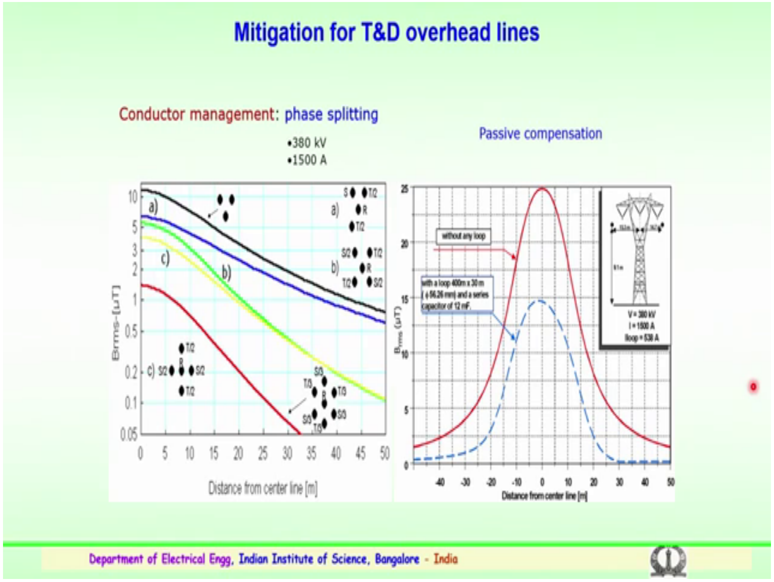

So, the further the conductor management again, there is a one more option which is being done like the face a splitting. So, face splitting a typical example is shown here, for a 300 kV a transmission line carrying a current of 1500 amps, and you can see for various configuration how the performance of the magnetic fields from the center is shown for various configuration A B and C, you can see how the configuration is given here. So, that this will improve the performance and gives a better information to the utility engineers who could plan to see how properly the conductor management could be made for a reducing the magnetic fields or the electric fields.

This is a one more method of going in for passive compensation. Here you can see that the distance from the center again here the magnetic field reduction is seen with a loop or particularly for a using a series capacitor of 12 a microfarad, this is without loop the magnetic field could be slightly higher. So, various types of a mitigation techniques are being employed in the by the utilities for the shielding by a metallic materials.

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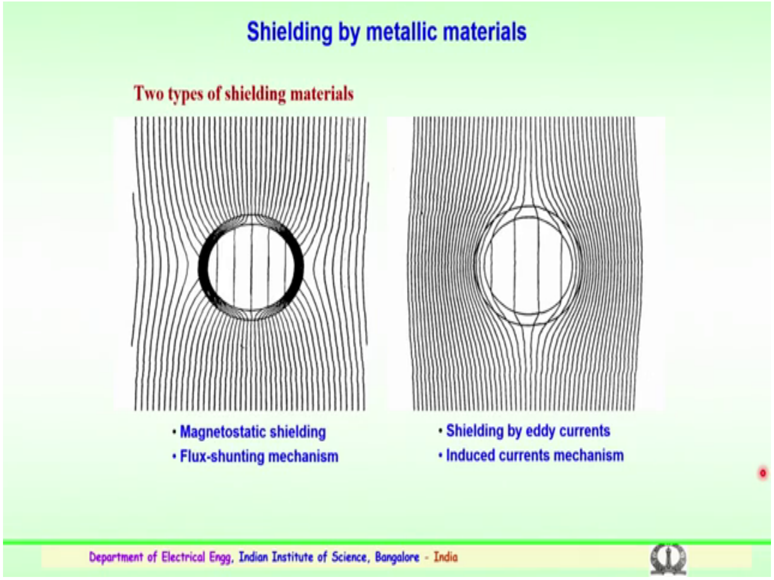

So, the now a materials play a very important role. So, either shielding of this magnetic fields could be made by using a magneto static shielding or using a flux a shunting mechanism where typically using a proper metallic a materials where the magnetic flux which comes in the vicinity could be diverted because of a using a proper shielding mechanism. So, either shielding by eddy currents or by induced current mechanism or going in for magneto static shielding will help in a reducing the magnetic fields ah.

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(Pure) ferromagnetic shielding

Material	Initial Relative Permeability $\mu_{r,ini}$	Maximum Relative Permeability $\mu_{r,max}$
Iron, 99.8% pure	150	5000
Steel, 0.9% C	50	100
Low Carbon Steel (LCS)	300 - 400	2000
Ultra Low Carbon Steel (ULC)	250	1100
Hot rolled Ultra Low Carbon Steel (HR ULC)	250	2000 to 5000
Silicon steel (Si 3%) - Grain oriented (GO)		40,000
78 Permalloy (μ-material)	8,000	100,000

Department of Electrical Engg, Indian Institute of Science, Bangalore - India

Going in for a magnetic or a pure a magnetic shielding aspects. Here again the various materials are available with a different relative permeability that is a initial and high permeability maximum permeability values are also specify.

So, various materials like iron steel low carbon steel ultra carbon hot rolled ultra low carbon silicon steel and permalloy which is also known as micro material, some of this magnetic shielding using this materials are also been tried out to reduce the Fields.

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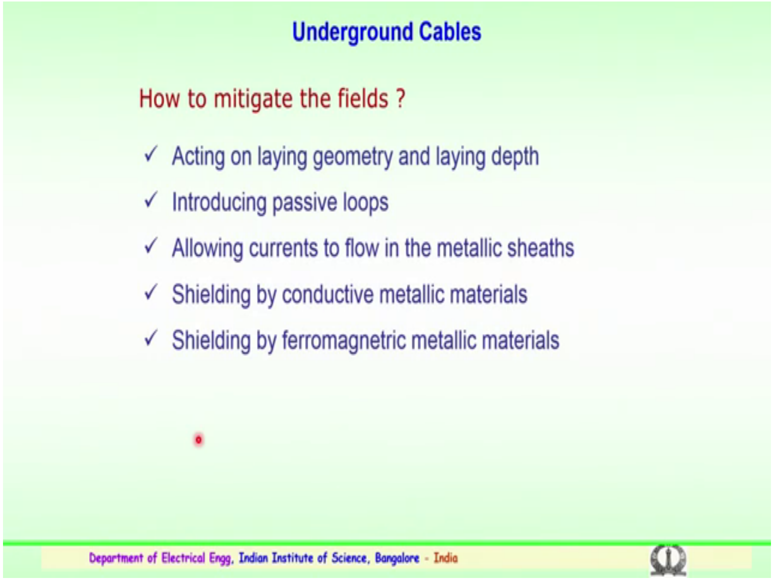

How to mitigate the fields particularly for the underground cables? For the overhead conductors we have seen, for the underground cabling we again it depends on laying geometry in the cable, how it is laid and what is the depth of the cable trench which is being adopted for the voltage and the dimension of the cable.

So, here also introducing passive loops could help in reducing the magnetic fields also allowing currents to flowing the metallic sheets on the cables. Mean shielding by conductive metallic materials will again further help introducing the magnetic fields of the underground cables, and shielding by the for a magnetic metallic materials will also help to reduce the fields.