Power System Analysis
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Lecture - 6
Transmission Line Capacitance (Contd.)

Welcome to lesson 6 on Power System Analysis. In this lesson, we are going to discuss Transmission Line Capacitance which we were discussing in lessons 5. We are continuing with it.

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Here, what we will do is, we will consider the effect of earth on transmission line capacitance. Actually when we have this transmission lines, the phase conductors are in above the ground in over a transmission system. And the distance between the phase conductors and ground are of the same magnitude. And therefore, the earth which acts as a equipotential surface. Thus effect the electric field lines and thereby the capacitors.

So, we need to consider the effect of earth. And calculating the capacitance for transmission lines. So, in these lessons we will discuss, how the earth or the ground affects the capacitance of a single phase transmission line, and how it affects the three phase transmission line.

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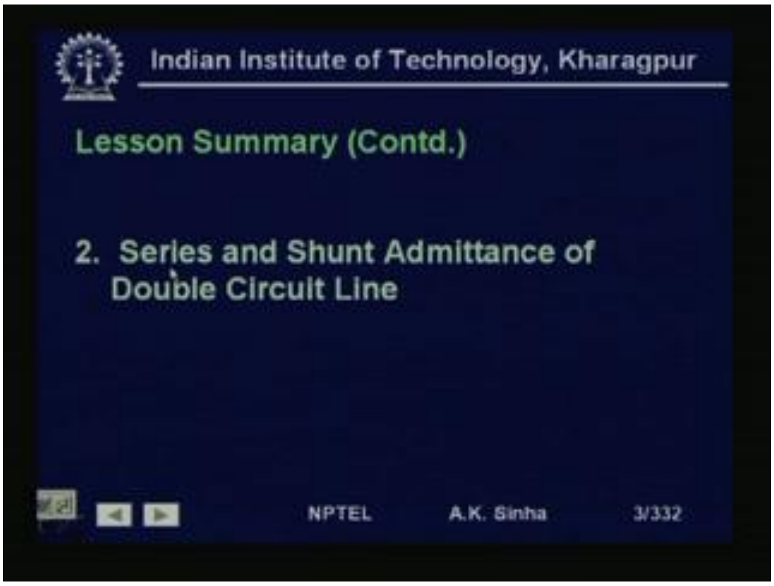

Then, we will talk about a double circuit line. And we will talk about how we calculate the series, and shunt impedance of the double circuit line. In fact, when we have a double circuit line the two circuits are somewhat close to each other. That is the three phase conductors of one circuit and the three phase conductors of the other circuit, are most of the time placed on the same tower. And therefore, they are in quite close proximity.

And because of which the both the magnetic field lines, as well as electric field line do get effected by the currents flowing in the other circuit. And the voltages present in the phase conductors in the other circuit. Therefore, for a double circuit line, we have the mutual effects. Because of the two circuits and that needs to be considered. And we will see how we take care of this, in this lesson. Well, we will first start with the effect of earth on transmission line capacitance.

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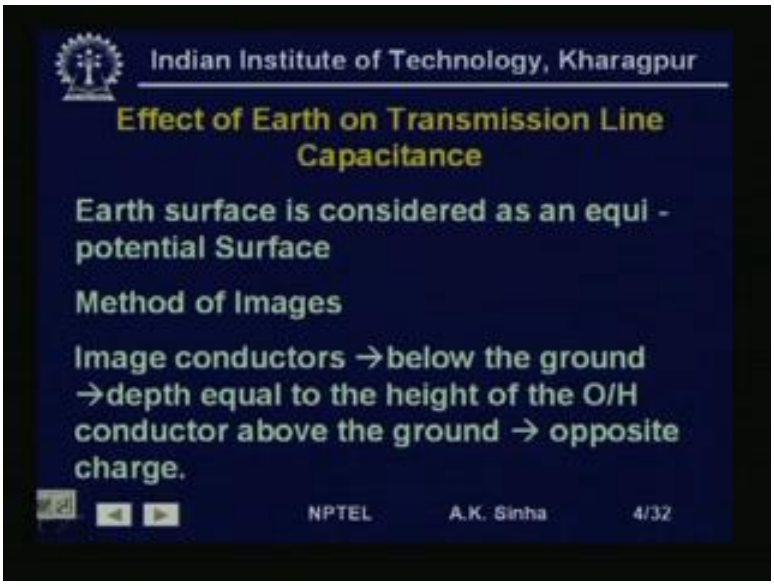

Now, as I said earlier, we consider the earth surface as an equipotential surface. Now, the earth surface may not be a plane. It may be undulating, it may not be horizontal, it may incline. But, for our purpose of calculation we will always consider that to be a horizontal plane surface.

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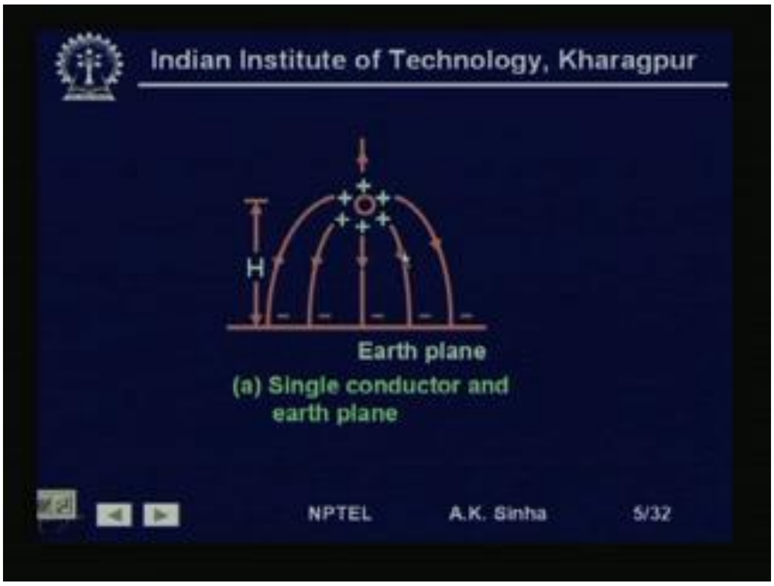

Now, if we see that there is a conductor as shown here. The phase conductor, which is charged with positive charge q per meter length, then the lines of electrical lines or field line should be radiating from this in radial direction. But, because the earth is acting as an equipotential surface. So, these field lines will bend and go to the negative potential on the earth. So, the effect of earth is to change the configuration of the electric field lines. And thereby, this will affect the capacitance of the conductor system. Now, how do we take care of this effect. Well, what we do is, we use what we call as method of images.

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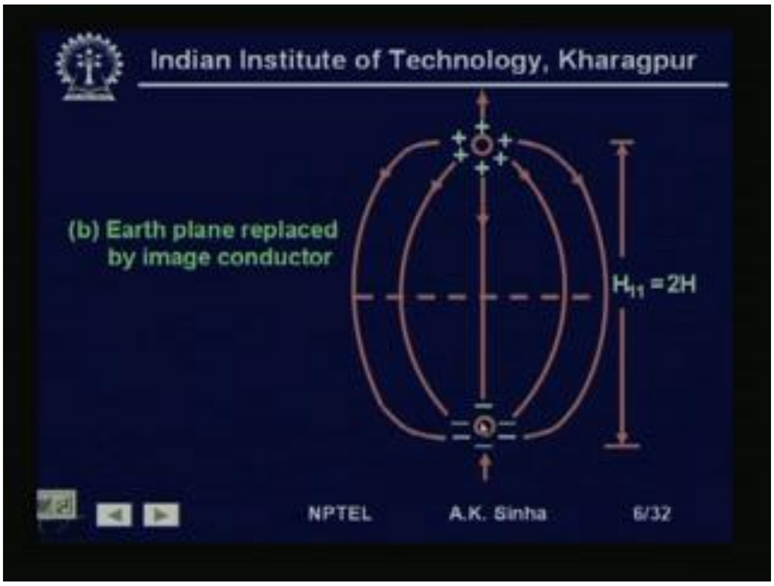

Now, in this what we do is, we consider a conductor directly below the overhead conductor in the ground at a distance; which is equal to the height of the conductor above the ground. That is we are considering an image of this conductor below the ground. So, this is a mirror image of this conductor. And the charge on the image conductor is opposite of that of the overhead conductor. Now, if you see, if you have such a system, then the field lines will look like as shown here.

Now, these field lines if you see are very much similar to if we had as just this conductor, and the ground and consideration. Therefore, what we find as that, that if we take another conductor with an opposite charge. And place it below the ground, just below the ground of this conductor at a distance, which is equal to the height of the conductor above the ground.

Then, the field lines created are exactly same as that, if this conductor as above that earth surface. That is the effect of earth can be taken care of by this kind of a situation. So, the method of images basically consist of considering image conductors below the ground at a depth; equal to the height of the overhead conductor above the ground. And the charge on this image conductor is of the opposite polarity. So, if we do this then we have a system which is consistent of the same effect as that of the earth. Now, we will try to use this for calculating the capacitance of a single phase line.

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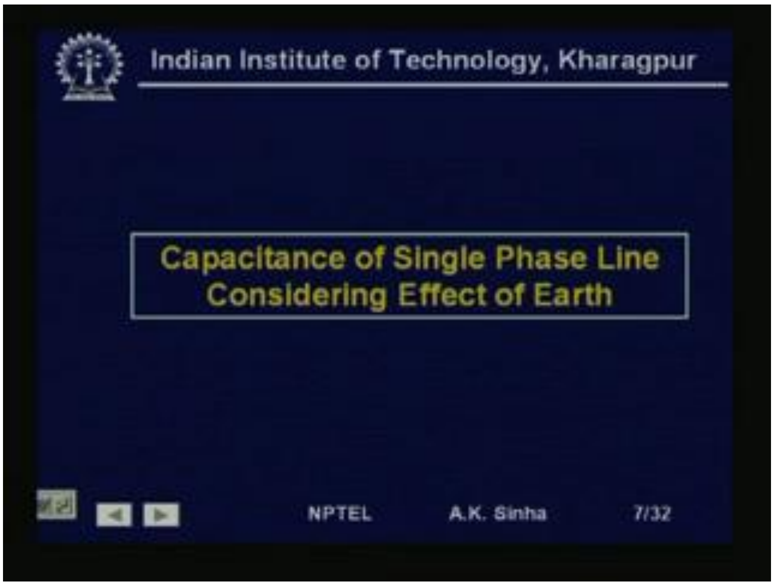

So, capacitance of a single phase line considering the effect of earth.

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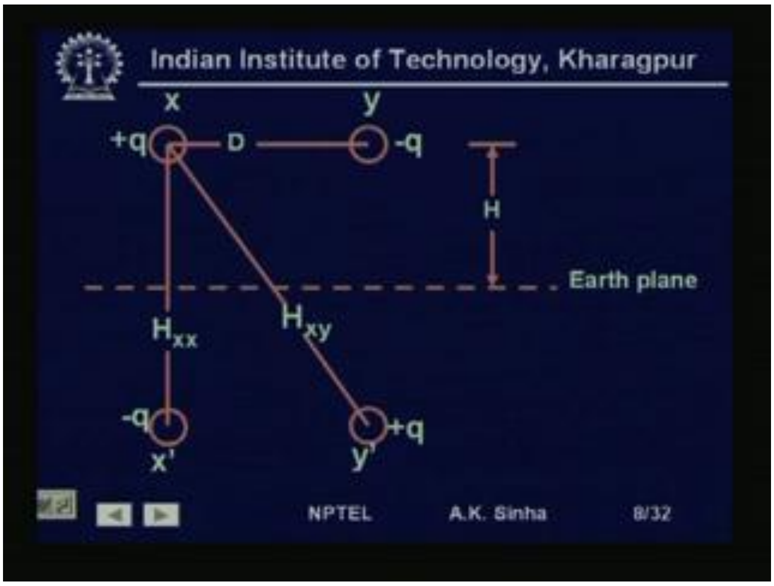

Now, here we have a single phase line with two conductors x and y. Placed at a distance D, the conductors have a radius of r x and r y. The charge on conductor x is q coulombs per meter and charge on conductor is minus q coulombs per meter, because conductor y in a single phase system will be acting as a return conductor. That is current flowing in x will be returning through conductor y. Now, this system of conductors single phase 2 conductors are above the ground at a height of H meters.

So, if we have to now take the effect of ground or earth. Then, what we have to do is, we have to consider image conductor x dash, which is placed directly below the conductor x. At a distance equal to H below the ground, that is the distance between conductor x. And it is image H x x will be equal to 2 H. And the charge on this image conductor x dash will be minus q coulombs per meter.

Similarly, we will consider the image conductor for conductor y, as y dash which will be placed directly below the conductor y at a distance of 2 H. That is at a distance H below the ground directly under conductor y. And the charge on this conductor y dash will be equal to plus q per coulomb per meter. So, now with this system we would like to find out the voltage between the two conductors x and y.

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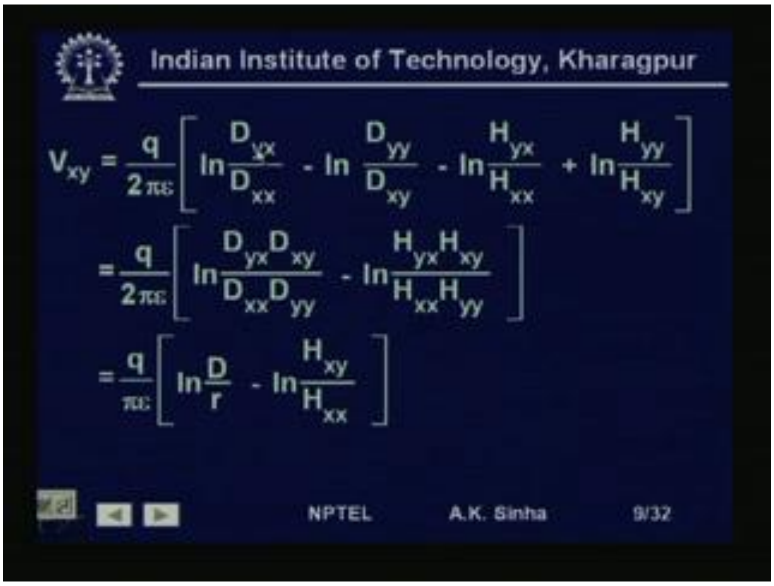

We can write this voltage from the earlier lesson, that we have had. We can write this voltage V x y is equal to q by twice pi epsilon into log n D y x. That is the distance of the conductor b to conductor a divide by D x x. That is the distance of conductor a to conductor a, that is conductor x to conductor x. So, in similar way we will write for the charge on conductor y, considering the charge on conductor y.

We will have the relationship q by twice pi epsilon minus q by twice pi epsilon D y y. That is the distance of conductor y to conductor y itself divided by distance of conductor x from y. Now, due to the image conductor x dash, we will have the effect on the voltage given by q by minus q by twice pi epsilon log n H y x. That is distance of image conductor x to conductor y. And H x x that is divided H x x, that is the distance between x and the image conductor x.

For the charge on the conductor y dash, we will have the term q by twice pi epsilon log n H y y divided by H x y. Now, if we consider all these terms together. And arrange them, then we will get this as equal to q by twice pi epsilon log n D y x into D x y divided by D x x into D y y. That is this minus log n D y y by D x y can be written as plus log n D x y by D y y. And then we can add these two together that will get me log n D y x into D x y divided by D x x into D y y.

Similarly, considering these two conductors, this if we make it as negative then this becomes H x y by H y y. So, this will be minus log n H x y by H y y. Therefore, if we add these two, then we will get minus log n H y x into H x y divided by H x x into H y y. Now, considering the symmetry of the figure, that we have H x x will be equal to H y y and H x y will be equal to H y x. Also D x x is equal to r x and D y y is equal to r y and if both the conductor have the same radius, then we will have that equal to r.

Therefore, this can become as D y x and D x y are basically equal to D. So, this becomes q by twice pi epsilon log n D square by r square, which can be written as this square can be taken out. So, this will have 2 here and 2 will cancel with this 2. So, it will become q by pi epsilon log n D by r. In the similar H x y is equal to H y x. So, this becomes equal to H x y square and H x x is equal to H y y which is equal to H x x square, therefore this square term can be taken here. So, 2 will cancel with this 2 here, so we get q by pi epsilon minus log n H x y by H x x. So, this way we have calculated the voltage between the 2 phase conductors x and y for a single phase line.

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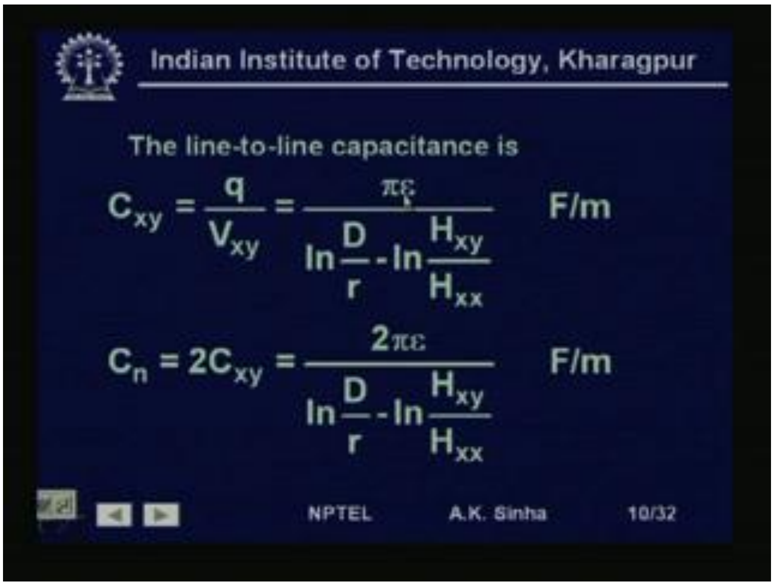

Once we have got this voltage, we can calculate the line to line capacitance as C x y is equal to q by V x y. So, now this is simply q divided by V x y, that we have calculated this will come out to be pi epsilon by log n D by r minus log n H x y by H x x farad per meter. Now, as we had seen earlier, the capacitance to neutral or capacitance to ground will be equal to twice C x y, because the earth surface or the ground will have a potential which will be half that of between x and y.

So, we can write C n is equal to 2 C x y, which is equal to twice pi epsilon divided by log n D by r minus log n H x y by H x x. So, in this way we can calculate the capacitance considering the effect of ground. Now, here what we are finding that, what how this effect of ground is taken into account. If you see this expression and compare it with the expression for the single phase capacitance of a single phase transmission line, then we are saying seeing that, it is this term which is an addition or for taking the effect of earth.

And here, we can see that if the conductors are very much above the ground compared to the distance between them. Then, D x y and D x x will be almost equal, that is this distance and this distance will be almost equal. If the conductors are very much above the ground that is H is very large. And in that case, we find that the effect of ground will be negligible. So, if the conductors are not far off above the ground, as compared to the distance between the phase conductors.

Then, the earth does affect the capacitance and the effect as in increasing the capacitance as compared to when we have not considered the effect of earth, because this total term is now getting reduced.

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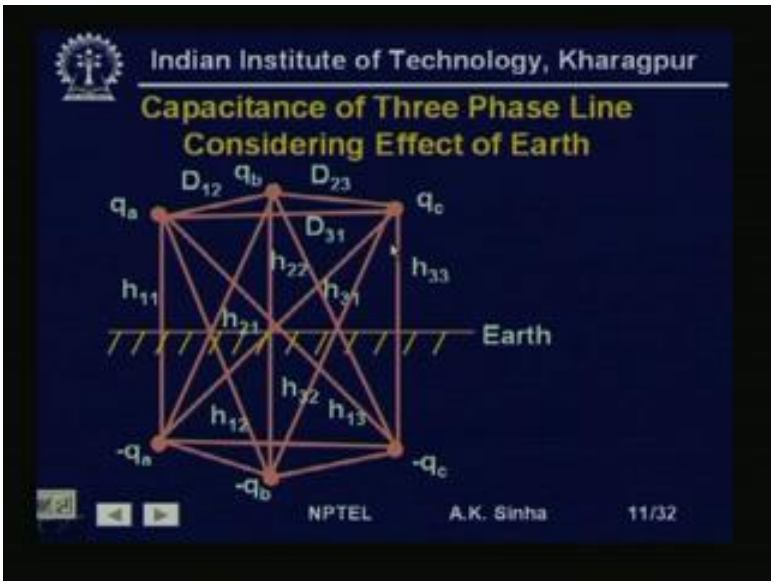

Now, we will talk about the capacitance of 3 phase line considering the effect of earth. Now, here we have 3 conductors a, b and c placed at position 1, 2 and 3. The distance between these conductors are D 1 2, which is the distance between a and b. D 2 3 which is distance between b and c, and D 3 1 which is distance between c and a. The conductors are carrying a charge of q a, the phase a conductor has a charge q a per meter. Phase b conductor has charge q b per meter and phase c conductor has charge q c per meter.

Now, these conductors are placed above ground. And if we have to take into account the effect of ground. Then we have to consider the image conductors. The image conductors will be for the phase a conductor. Here which will be again at a distance, which will be below the ground which will be equal to the height of this conductor above the ground. So, this will be an image conductor here with a charge, which will be negative of that of the conductor here.

Similarly, for phase b conductor, we have a image conductor here with a charge minus q b. And for phase conductor c, we have an image conductor with a charge minus q c. Now, the distance is from the phase conductors to the image conductors are given as from conductor a to it is image a dash it will be h 1 1. That is considering this is position one. Similarly, for phase a conductor and image of b, we will have the distance h 1 2. For the distance from phase b conductor to image of a, it will be h 2 1 and so on. So, we have all these distances which are shown in this figure.

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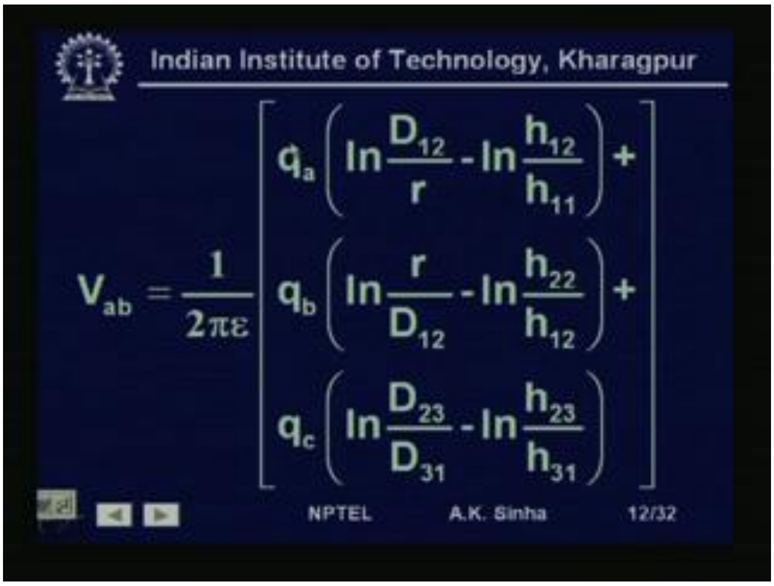

Now, we can calculate the voltage between 2 phase conductors. So, we will calculate that voltage V a b, the voltage between conductor a and b. And this will be given by 1 twice pi epsilon n 2 q 2 charge on conductor a, that is q a. It will be log n D 1 2 by r minus log n h 1 2 by h 1 1, ((Refer Time: 22:02)) that is log n D 1 2 by r. That is from this conductor distance of this from phase b conductor D 1 2.

And distance of this conductor from itself that is D 1 2 and divided by the distance from itself that is D 1 1, which is equal to r. So, we have this first term taking into account that part. Now, because of the image conductor, that is placed here. Again we will have minus q a is the charge on this conductor. And the distance is from this to b, it will be h 2 1 and distance of from this to a will be h 1 1. Therefore, we have this minus log n, because minus q a is the charge, so minus log n h 1 2 by h 1 1.

Similarly, for charge on conductor b, and it is image we will get the term 1 by twice pi epsilon q b log n r by D 1 2 minus log n h 2 2 by h 1 2. Plus due to the charge on conductor c and it is image we will have the term 1 by twice pi epsilon. Q c into log n D 2 3 by D 3 1 minus log n h 2 3 by h 3 1.

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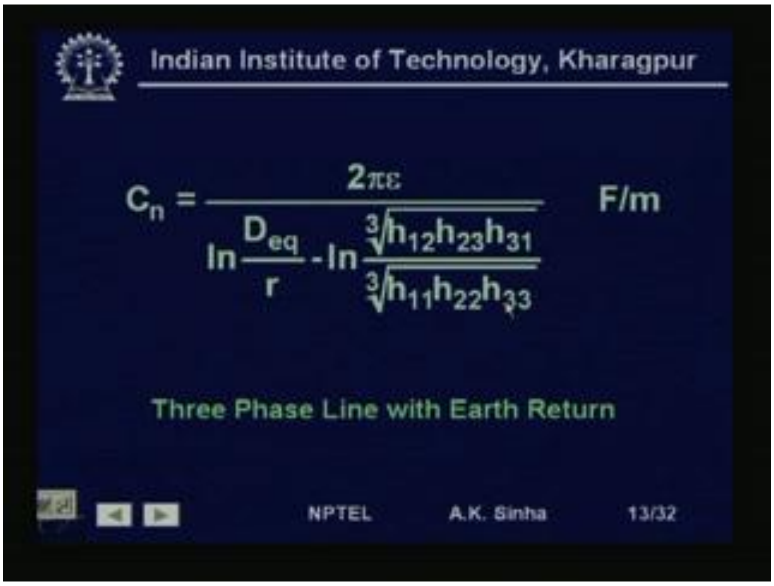

So, just as we have calculated the voltage between the conductor a and b. We can also calculate in the same way the voltage between conductors a and c. So, we will get the voltage V a c in that case, if we add these two voltages V a b plus V a c, we had seen this is equal to 3 V a n. In this way we can calculate the voltage V a n, that is voltage between phase a conductor and the ground or the neutral, and since we know of the charge on conductor a as q a. Therefore, we can calculate the capacitance C n for or C a n for the conductor a. That is the capacitance for phase a conductor to ground will be coming out to be equal to twice pi epsilon divided by log n D e q by r. Minus log n cube root of h 1 2 into h 2 3 into h 3 1 divided by cube root of h 1 1 into h 2 2 into h 3 3. Now, here again what we are seeing is that, the term log n cube root of h 1 2 h 2 3 h 3 1 divided by cube root of h 1 1 h 2 2 h 3 3 is the effect of earth on the capacitance.

Now, this is getting subtracted in the denominator. So, the effect of ground when we consider for calculating the capacitance, the capacitance will be higher than if we neglect the effect of ground. Again here we see if the conductors of the phase conductors a, b, c are vary for above the ground compared to the distance between them. Then h 1 2, h 2 3 and h 3 1 will be very much nearly equal to h 1 1, h 2 2 and h 3 3. And therefore, this term will come out to be 0, that is the effect of ground will be negligible.

However, since these distances or between the phase conductors, and the distance between phase conductor on the ground are of the same magnitude. The effect of ground is basically to increase the capacitance of the transmission line. Now, we will talk about 3 phase line with earth return.

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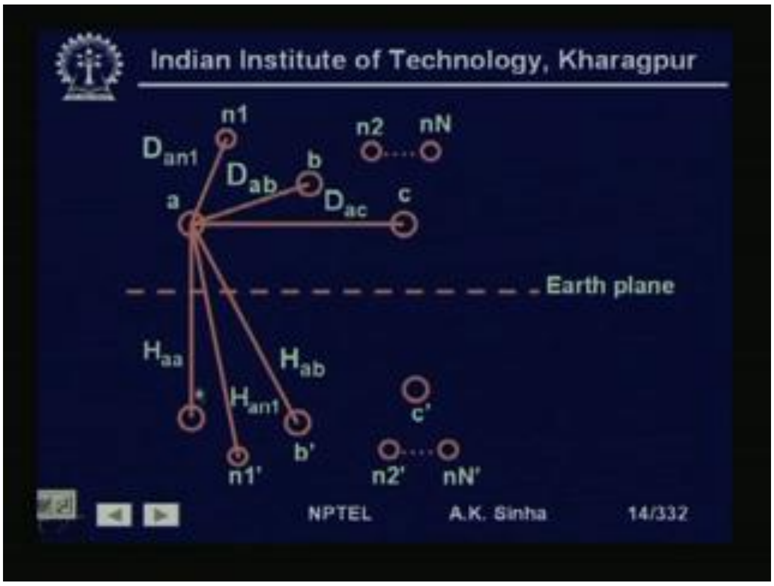

So, again we take into consideration a 3 phase system, with neutral wires of the ground wires on top of the phase conductors. This is the configuration that we have for a 3 phase EHV system. Now, if the phase conductors are fully transposed and are carrying balance current, then there will be no current flowing in the earth conductors or in the ground. However, when there is unbalanced current flowing through the phase conductors. There is going to be some current which will be flowing in the earth conductors or the ground conductors, and also in the ground itself.

As we had seen earlier we can take care of this by means of using the effect of images as we had done for calculating inductance, and calculating the resistance. So, here again since, these conductors are above the ground what we are doing is? We are considering the image conductors below the overhead conductors. Again at a distance which is equal to the distance of the conductor above the ground.

So, we are taking an image conductor and using the method of images. Now, we will have instead of 3 conductors and n neutral conductors. We will have now 6 conductors and 2 n neutral conductors in the system, because we have 3 plus n conductors for the neutral as the image conductors also.

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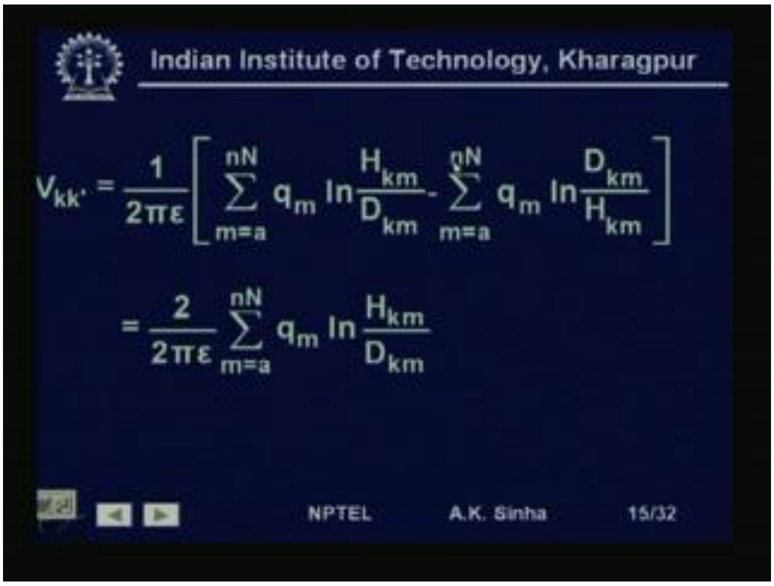

Now, for this system, again we can find out the voltage between any conductor and it is image. That will be given by V k k dash. For any conductor k, we can write the voltage between the conductor k and its image k dash. That will be equal to 1 by twice by epsilon, summation of m is equal to a to n N, where n N is the total number of conductors in the system into q m, the charge on conductor m log n.

The distance from the image conductor k to the m th conductor above the ground, divided by D k m the distance between the k th conductor and the m th conductor. Minus summation m is equal to a to n N, that is to for all the conductors in the system. Q m the charge on m th conductor into log n D k m by H k m. That is again the distance between the image conductor k to the conductor m divided by, distance between the conductor k and conductor m divided by the distance between the k th conductor.

And the image conductor m, that is this part is coming because of the image conductor m. This part is coming because of the overhead conductor m. So, because the image conductor carries a negative charge to that of the overhead conductor above. So, this negative sign is coming here. So, if we add this we will get this as equal to 2 by twice pi epsilon summation m is equal to a to n N q m log n H k m by D k m. That is we can multiplied with by minus 1, then we can inward this. So, this will be plus sigma m is equal to a to n N q m log n H k m by D k m and then we can add them.

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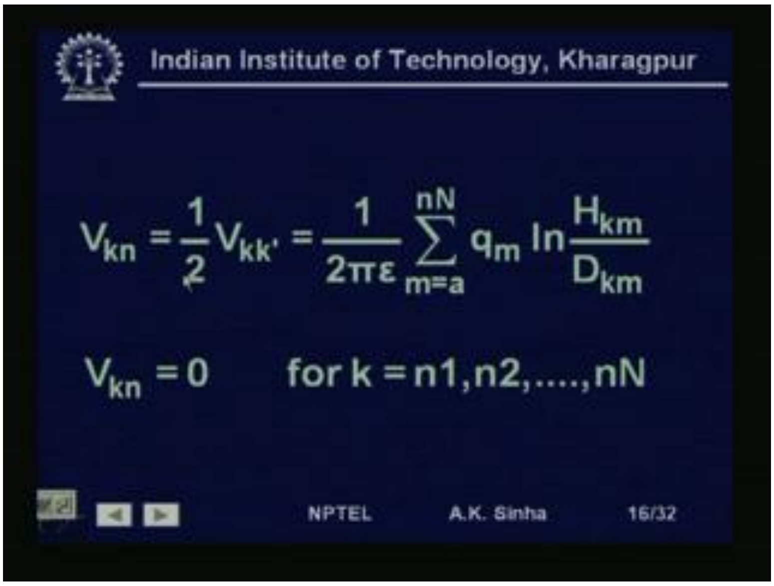

Now, the voltage between the k th conductor and the neutral, or the earth will be equal to half of that between the conductor k and it is image k dash. Therefore, V k n will be equal to half V k k dash which will be equal to 1 by twice pi epsilon. Because, that 2 is cancelled out with this 2 here. So, it is 1 by twice pi epsilon summation m is equal to a to n N of q m log n H k m by D k m.

Now, since the ground conductors which are on top of the phase conductors. Since, they are grounded at regular intervals by means of tower footing. Therefore, the voltage of these conductors with respect to neutral or ground is going to be 0, because these conductors are at ground potential. Therefore, V k n is equal to 0 for k is equal to n plus 1 n plus 2 up to n N. That is expect for the phase conductors, all these ground conductors than ground conductors their voltage is going to be 0

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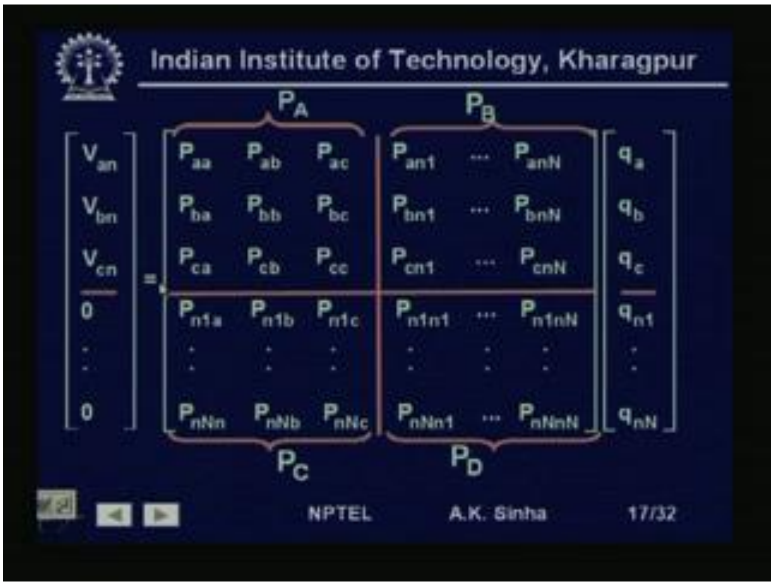

Now, we can put this whole equation into a matrix form as shown here. V a n, V b n, V c n and V n 1, V n 2 and up to V n N, these are 0’s is equal to a matrix of P’s into q a the charge on conductor a. Q b the charge on conductor b, q c the charge on conductor c. Q n 1 up to q n N the charge on neutral, conductors or the ground conductors which are placed above the phase conductors. That is we are talking about the charges on these ((Refer Time: 34:15)) conductors, n 1 n 2 up to n N.

Now, here we see, we can divide this P matrix which will be 3 plus n N matrix, 3 plus n N by 3 plus n N matrix. This matrix we can divide into 4 sub-matrices P A, P B, PC and P D, where P A is a 3 by 3 matrix of which relates the voltage with respect to charge on the phase conductors. P B is going to be are 3 by n matrix, P C is a n rows and 3 column that is n by 3 matrix. And P D is a n rows and n column, that is n by n matrix for all the ground conductors.

And see P A is relating the phase conductors, P B is relating the phase conductors with the charges on the ground conductors. P C is relating the voltage on the neutral conductors, with respect to the charges on the phase conductors. And P D is relating the voltage on the neutral conductors, with respect to the charges on the neutral conductors.

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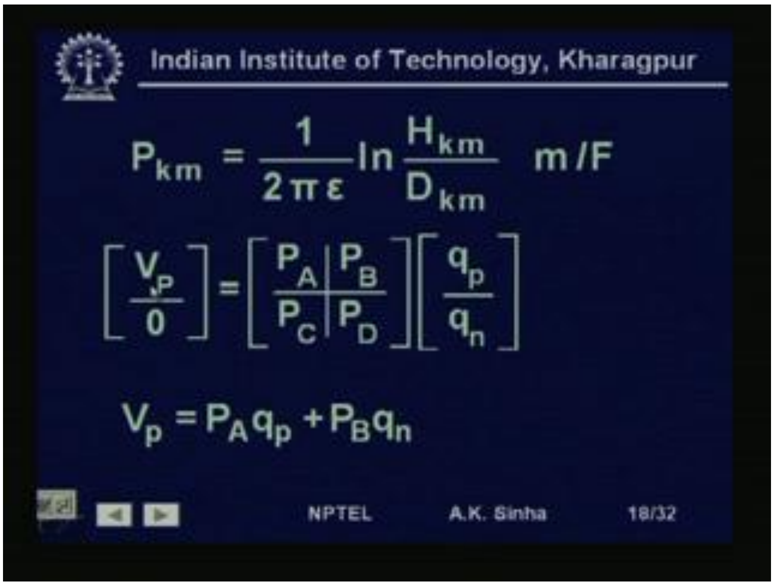

Here P k m, that is any of these terms P k P a b P b b or P n 1 b. Any of these terms, is given by the relationship 1 by twice pi epsilon log n H k m by D k m meters per farad. Now, this matrix which we had this big matrix relationship can be written in a shorter form as V p which is the voltage for the phase conductors. And 0 which is the voltage for all the n ground conductors is equal to P A, P B, P C, P D which we had already defined earlier.

And q p is the charges on the phase conductors. That is q a, q b, q c and q n is the charges on the neutral conductors q n 1, q n 2, up to q n N. Now, from this relationship we can write this as V p is equal to P A into q p plus P B into q n. Similarly, we can write 0 is equal to P C into q p plus P D into q n.

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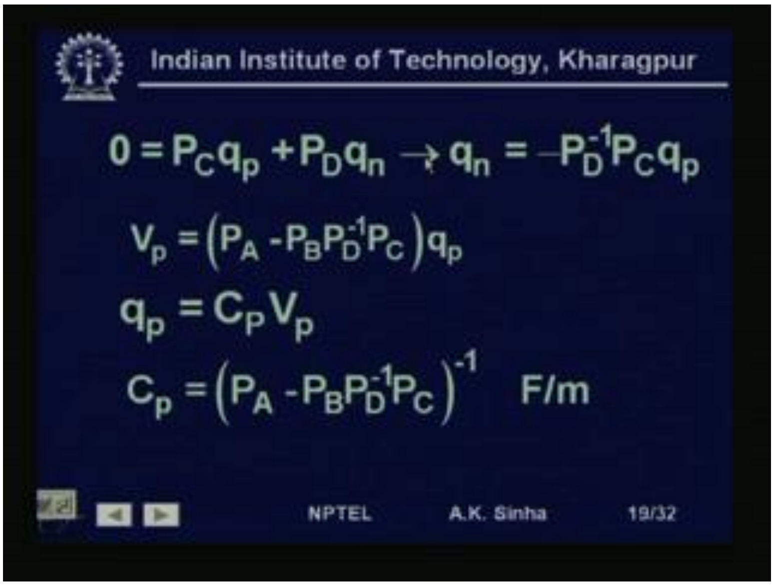

So, 0 is equal to P C into q p plus P D into q n, these results send to q n is equal to that is we can take this part on the other side. So, this becomes minus P C q p is equal to P D q n. And again pre multiplying both sides by PD inverse we will get q n is equal to minus of P D inverse into P C into q p. Now, if we substitute the value of q n into this equation, then we will get V p is equal to P A minus P B into P D inverse P C into q p. We can write this relationship as q p is equal to C p into V p.

We know the charge is product of capacitance and voltage. So, q p will be equal to C p into V p and where C p will be equal to the inverse of this term. That is inverse of PA minus P B, P D inverse P C. Now, this C p will be a 3 by 3 matrix which relates the capacitances between the phases or the 3 phase conductors. Now, here what we have done by doing all this, is we have eliminated the effect of the ground conductors. That is the ground currents which were flowing that effect is included by modifying the phase conductor capacitances.

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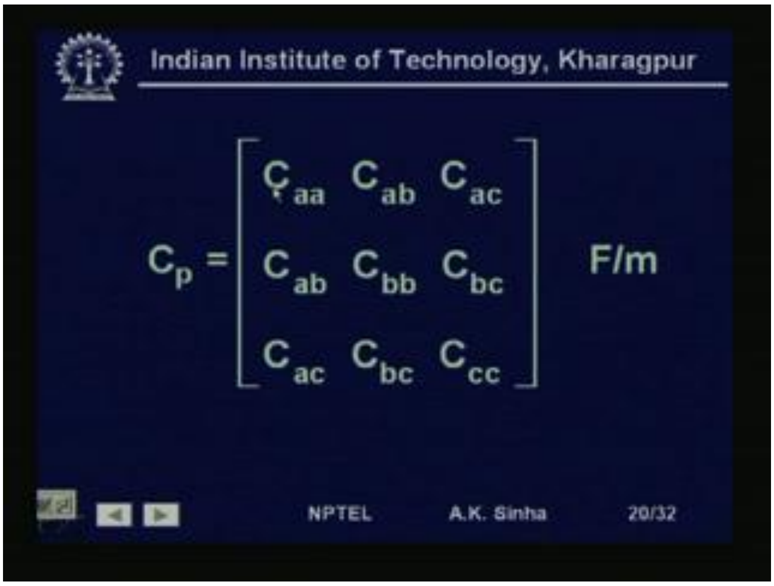

So, C p is a 3 by 3 matrix, C a a the capacitance of a with respect to a C a b between the a and b. C a c between a and c, similarly C a b between a and b, C b b the capacitance between b. And it is image C c c is between C b c is between b and c and so on. So, C p is giving us the capacitance for the 3 phase conductor system. Now, if the line is fully transposed, then we will have the same capacitances for all the 3 phase conductors. As well as the same capacitance between the 2 phase conductors. So, phase to neutral conductor capacitance, as well as the capacitance between 2 phases will be same, for all the 3 conductors.

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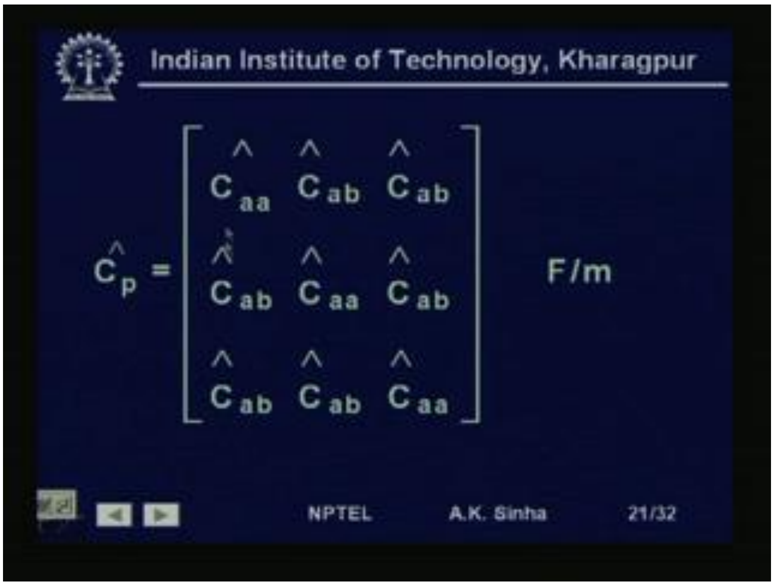

Therefore, C a a hat is equal to C b b hat and will be equal to C c c. So, the three will have the same capacitance to neutral, whereas C a b and C b c will also be same. So, we are for a transpose line system, we are representing them with hat which shows that. This line is a this capacitance is for transpose line, not to confuse with the capacitance that we had calculated earlier.

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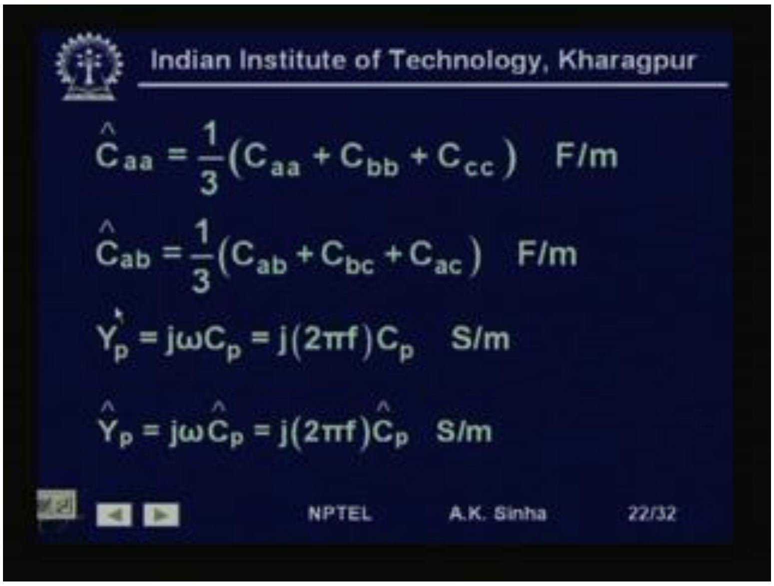

Now, the relationship which governs this capacitance is C a a hat is the average of C a a, C b b and C c c. Because, each phase conductor is occupy the 3 positions for 1 3rd length of the line. Similarly, Cab which will be equal to C b c and C a c, for the transposed line this C a b will be equal to 1 3rd of C a b plus C b c plus C a c, that is the average value of the capacitance between the phases a b, b c and c a. Once we have calculated the capacitance, we can calculate the admittance very easily by just multiplying it by j omega.

So, Y p or the admittance for the 3 phase system with ground wires will be given by this Y p which is a 3 by 3 matrix. Again this will have the terms j omega into C p, which will be j into twice pi f C p, where C p again as we have seen earlier is a 3 by 3 matrix. Same thing will happen for the transposed line. That is Y p hat equal to j omega C p hat plus j into twice pi f C p hat Siemens per meter.

So, in this way we have seen that, we can calculate the capacitance for any general system of 3 phase conductors. That is 3 phase conductors with any number of neutral wires or the ground wires on top of that. Next, we will talk about double circuit line. Now, in double circuit line as we know most of the time when the power demand to an area increases, we would use instead of 1 circuit, 2 circuits. And both these circuits are running parallel to each other mostly on the same tower.

So, since these two circuits are running parallel to each other. And are on the same tower the distance between the conductors of the two circuit, is not large. Because, this distance is not large, the current flowing in them is going to effect the magnetic field of the current flowing in the other circuit. And similarly, also because the voltage of 1 circuit is going to produce electric filed, which is going to effect the electric field produced by the voltages in the other circuit. That means, there is mutual effect which takes place between these two circuits. Because, they are physically not very far off. So, they have effect from one on the other.

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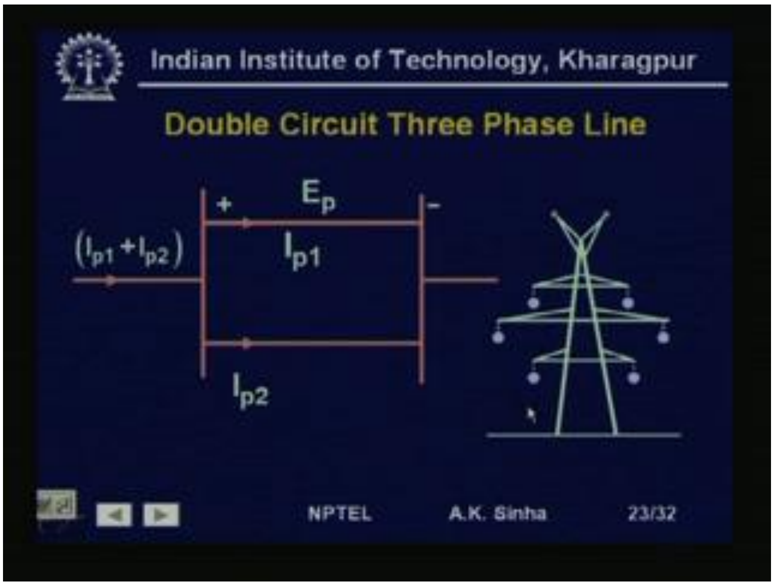

Such a system we are showing here, here we have a three phase line this is one circuit and this is another circuit, which is placed here. So, this is a double circuit system, here we are showing this double circuit line. This is one circuit this is another circuit connecting two bus-bars or two sub-stations. Now, the current flowing in one circuit is I p 1, the current flowing in the other circuit is I p 2. Where I p is basically a three element vector which consists of I a, I b and I c.

So, we have I a 1, I b 1, I c 1 of the circuit 1 and I a 2, I b 2, I c 2 for the circuit 2. Now, this current flowing here from one circuit will be I p 1 plus I p 2 which gets divided into I p 1 I p 2. And maybe it is getting connecting on this side this is this is shown that we are showing. We are talking about the effect of the two currents flowing in these two circuits. How they are going to effect the series impedance of the transmission line. As well as how they are going effect the shunt admittance of the transmission system. So, first we will take up the series impedance.

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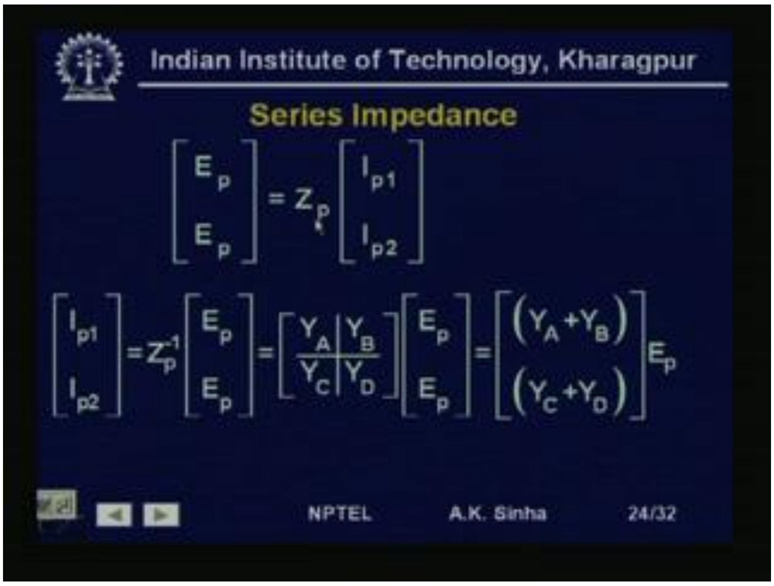

Now, for the two circuits we can write, the relationship E p 1 is equal to Z p 1 into I p 1 and E p 2 is equal to Z p 2 into I p 2. But, since these two circuits are close together there is mutual coupling. So, it will not be right to write separate equations for the two. In fact, what we have here is we are considering a system of 6 conductors, instead of 3 conductors.

Again since we see that, ((Refer Time: 47:25)) these two circuits are connected under two ends. So, the voltage drop between them is going to be same. So, the voltage drop E p 1 is same as E p 2 which is equal to E p. So, we can write E p for circuit 1 and E p for circuit 2 is equal Z p into I p for circuit 1 into I p for circuit 2. And Z p is going to be a 6 by 6 matrix of the series impedance.

Now, from this relationship, we can write I p 1, I p 2 is equal to Z p inverse into E p E p. Because, E p 1, E p 2 are same, so we are writing E p for that. So, we are from here we are calculating this I p 1 and I p 2. So, we are pre multiplying both sides by Z p inverse. So, we get I p 1, I p 2 is equal to now Z p inverse E p E p. Now, Z p inverse will be admittance and this will be again a 6 by 6 matrix which we can divide into 4 sub matrices Y A, Y B, Y C, Y D. Where each of these sub matrices are going to be a 3 by 3 matrix.

So, this is equal to Y A Y B Y C Y D E p E p. And this is equal to Y A into E p plus Y B into E p, so Y A plus Y B into E p and Y C into E p plus Y D into E p, so Y C plus Y D into E p. So, now we can write if we add the two currents I p 1 and I p 2.

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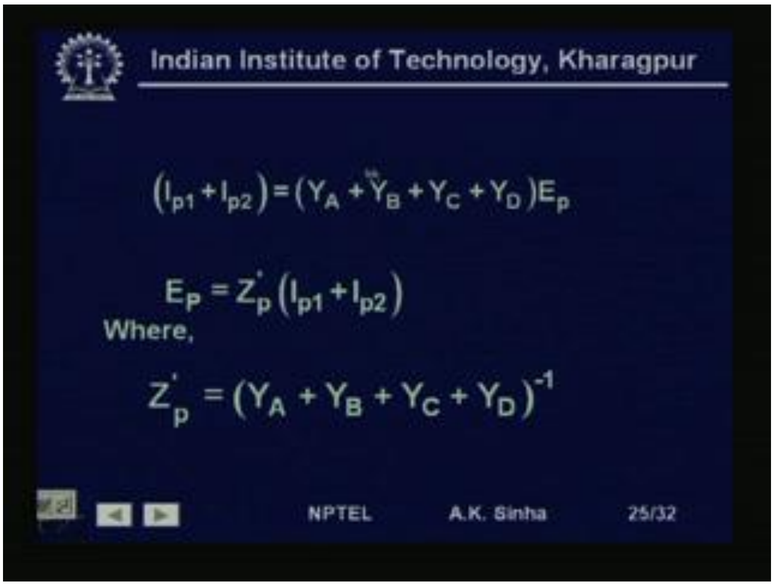

Then, we get I p 1 plus I p 2 is equal to Y A plus Y B plus Y C plus Y D into E p. That is if you see from here, if we have I p 1 is equal to Y A plus Y B into E p and I p 2 is equal to Y C plus Y D into E p. So, if we add them we are going to get this I p 1 plus I p 2 is equal to Y A plus Y B plus Y C plus Y D into E p. And this equation we can again solve for E p. Then, E p will be equal to Z p dash into I p 1 plus I p 2, where Z p dash is nothing but the inverse of this matrix. Now, here if you look at this matrix, this is sum of this 3 by 3 matrix plus this 3 by 3 matrix, solve these matrixes are 3 by 3. So, Z p dash is going to be a 3 by 3 matrix.

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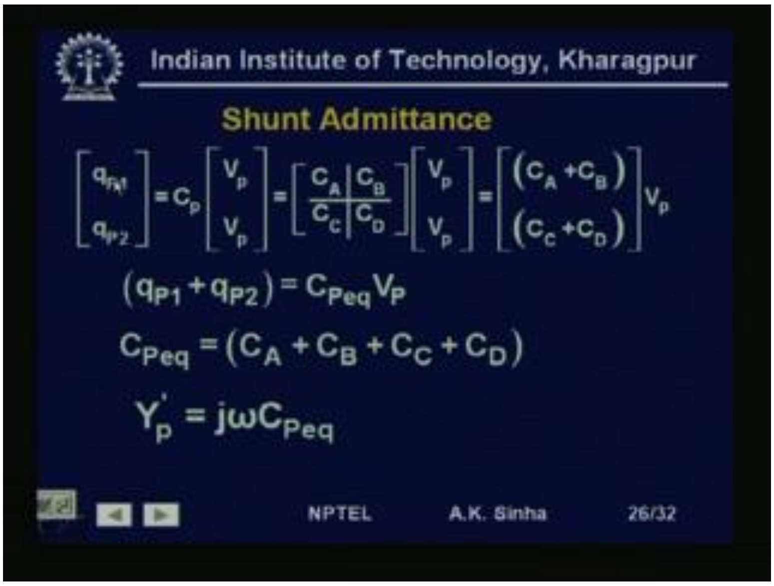

Now, we will talk about the Shunt Admittance for this double circuit line. Again in the same way as we have done for a single circuit line. We can write down the relationship for q p for circuit 1 and q p for circuit 2. Where, q p will be the charges on phase conductors a, b and c. So, q p 1 is q a 1 q b 1 q c 1, q p 2 is q a 2 q b 2 and q c 2. So, this is a vector having 6 rows C p will be a 6 by 6 matrix.

And V p again is the voltage of the phase conductors a, b and c for circuit 1 and circuit 2. Since, these two circuits are in parallel. Therefore, the voltages are going to be same, therefore instead of V p 1 and V p 2 we are writing same as V p and V p. Now, this C p which is a 6 by 6 matrix can be divided into 4 sub-matrices C A, C B, C C, C D. So, we have got C A into V p plus C B into V p, so C A plus C B into V p. C C into V p plus C D into V p, that is C C plus C D into V p is equal to q p 1 q p 2.

From here again we get q p 1 is equal to CA plus C B V p, q p 2 is equal to C C plus C D into V p. Therefore, if we add these two we get q p 1 plus q p 2 is equal to C p equivalent into V p. Now, is this C P is going to be C P equivalent is going to be a 3 by 3 matrix instead of a 6 by 6 matrix C P. So, where C P equivalent is nothing but equal to C A plus C B plus C C plus C D, and this is a 3 by 3 matrix and therefore, we can get the shunt admittance for this double circuit line. In terms of 3 phase system, for at which will gives us a 3 by 3 matrix for the phase a, phase b and phase c, which includes the mutual effect between the two circuits. So, we will get Y P dash is equal to j omega C P e q. So, now that we have seen how to calculate the capacitance taken into account, the effect of earth. And we have also seen how we can calculate the series, or shunt admittance for a double circuit line, taking into the account of mutual effects.

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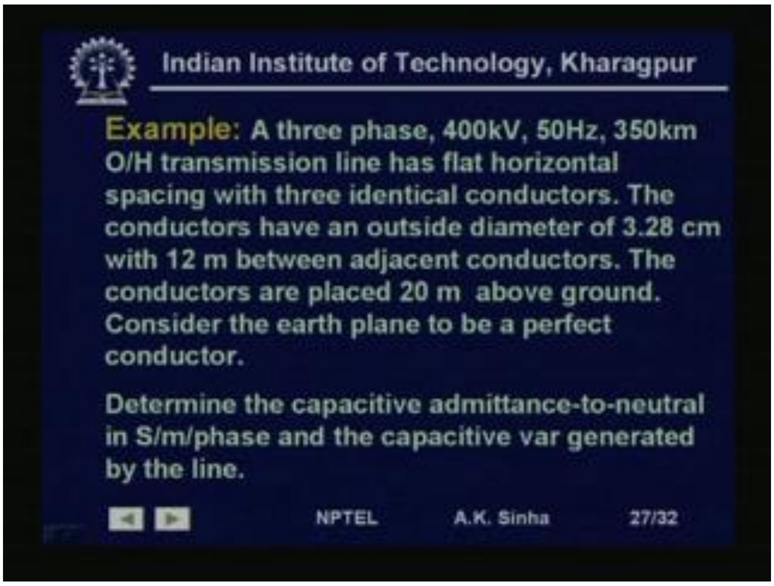

Well, let us take an example to illustrate some of the concepts that we learn today. We consider a 3 phase 400 kV, 50 Hertz, 350 kilometer overhead transmission line with flat horizontal spacing with three identical conductors. The conductors have an outside diameter of 3.28 centimeters with 12 meter between the adjacent conductors. The conductors are placed 20 meter above the ground, we consider the earth plane to be perfect conductor. Determine the capacitive admittance to neutral in Siemens per meter per phase and the capacitive var generated by the line. So, this is the problem that we have.

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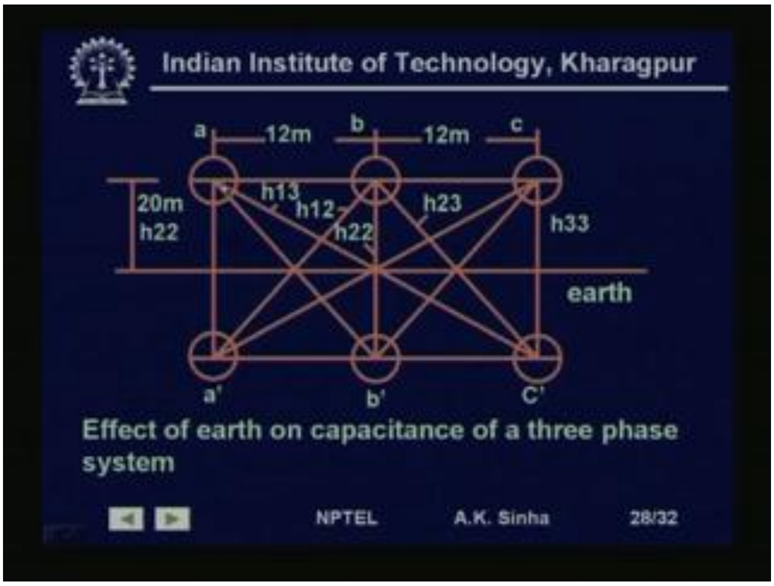

And we can show this configuration graphically as shown here. We have the 3 conductors, a, b and c placed here, we will say that these are positions 1, 2 and 3. There are 12 meters apart from each of the conductors. Since, we are considering the ground to be a perfect conductor, we take the effect of image conductors. So, we have a image conductor of a, as a dash which is again 20 meters below the earth. Similar for b and c and we have the distances h i j which is showing the distance between the conductor I with the image conductor j. So, h 1 3 is the distance between conductor a and the image of conductor c and so on.

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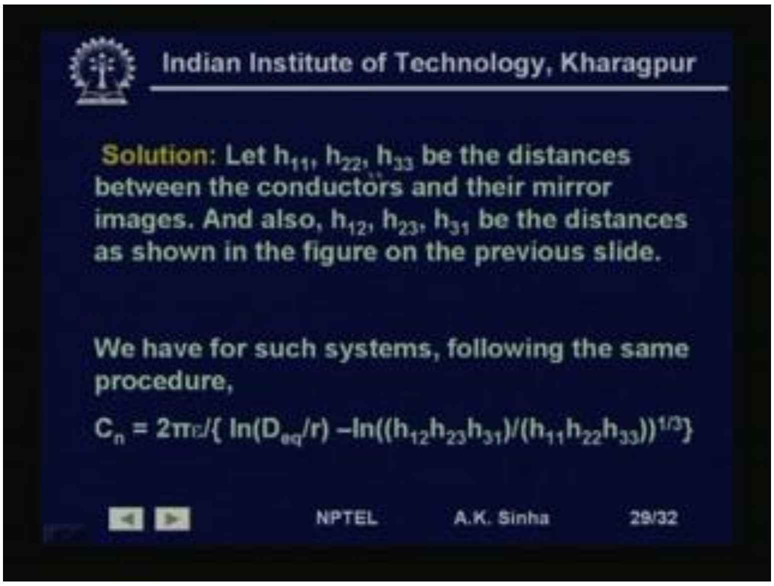

So, we have seen that h 1 1, h 2 2, h 3 3 is the distance between the conductors and their mirror images. That is h 1 1, this should be h 1 1, from this conductor to this a to a dash is the distance between image conductor this will be a 40 meters. Similarly, b b dash will be forty meter and c c dash will be 40 meters. So, and h i j as we have said is the distance shown in the figure.

Now, we have for such a system, following the same procedure as we have shown earlier. That is if we go back ((Refer Time: 56:40)) here we have the capacitance to neutral for 3 phase system with image conductors. This is given by this relationship, we write the same relationship here. So, we have C n is equal to twice pi epsilon divided log n D e q by r minus log n h 1 1 h 2 3 h 3 1 divided h 1 1 h 2 2 h 3 3 a cube root of that.

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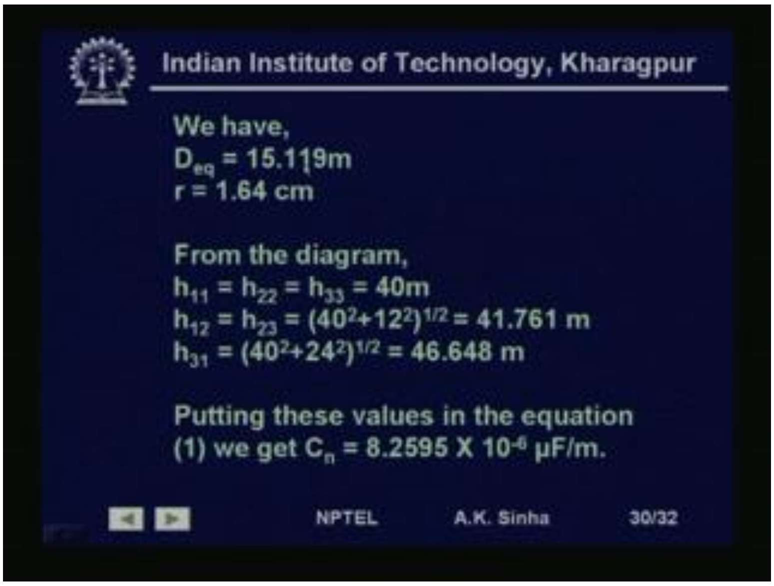

So, now what we do is we substitute all the values, we can calculate D e q as 15.119 meter which is basically the cube root of the distance between the conductors themselves. R is the radius of the conductor which is equal to 1.64, it is 3.28 divided by 2. From the diagram, we have the values by h 1 1 h 2 2 h 3 3 as 40 meters, h 1 2 h 2 3 are shown here is equal to 41.761 meters, h 3 1 is equal to 46.648 meters. Now, putting these values in the equations we get C n is equal to 8.2595 into 10 to power minus 6 microfarad per meter.

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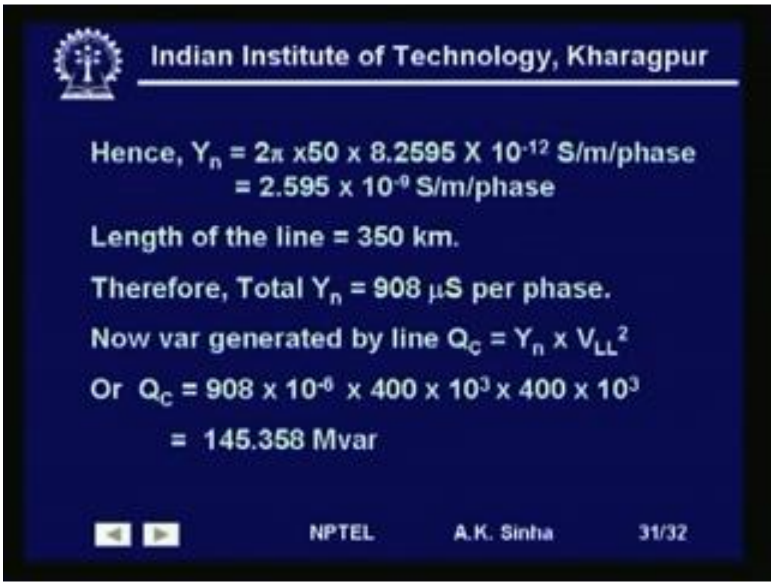

Hence, we can calculate the admittance Y n is equal to twice pi f which is 50 into the C. This is C n that is 8.2595 into 10 to power minus 12 Siemens per meter per phase, this is equal to 2.595 into 10 to power minus 9 Siemens per phase. Now, length of the line is given as three 50 kilometers, therefore total admittance will be simply multiply this by 350, this conserved to be 908 micro Siemens per phase.

Now, the var generated by the line Q c will be equal to Y n into V L L square or Q c is equal to 908 into 10 to the power minus 6 into 400 into 10 to power minus 3 square, that is 400 into 10 to power minus 10 to power 3 into 400 into 10 to power 3, there is a 400 kilo volts. So, this conserved to be 145.358 M v a r. So, that is all discuss about the capacitance calculation. In the next class on lessons 7, we will discuss about modeling of transmission lines.

Once that we have we need we have learnt about how to calculate the parameters of the transmission line. That is the resistance, the inductance and the capacitance for the transmission line. Now, we would like to model the transmission line for analysis. So, that we will do in lesson 7.

Thank you.