Power Network Analysis

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Week-05

Lecture-21

Hello everyone, welcome to the first lecture of week 5 of the course Power Network Analysis. In this particular discussion, we will continue with our fourth main module, which is the evaluation of transmission line parameters, and in the previous week, we continued our discussion on the same topic, where we reached the fact that if we have single strands or single conductor transmission lines, how do we evaluate the inductance and figure out their flux linkages if there are groups of conductors? Based on that, today in this discussion, we will take up our topic of inductance evaluation for actual threephase transmission lines, as I have mentioned. We will take up our discussion based on last week's lecture, where we concluded with how to evaluate the inductance of composite conductors, which was still not complete, but this inductance evaluation is significantly dependent upon the magnetic flux linkages that a conductor might experience due to several groups of conductors carrying respective currents. What we observed is that if we have two composite conductors, composite conductor A and composite conductor B , one of these conductors acts as a return path for the other conductor. So it is analogous to the case of a single-phase two-wire circuit where we had chosen only one conductor per phase or per wire. We are complicating or sort of expanding that single wire to be an ACSR conductor of some form.

There are different types of ACSR conductors with different strands of steel wires or steel strands in between and a different number of strands of aluminum wires coupled or wound around those steel strands. So the number of strands in these ACSR composite conductors could differ. And in composite conductor A , we chose n as the number of strands. Composite conductor B has m strands.

And we have assumed that these conductors or strands are parallel. Their current distribution is uniform. The respective strands have the same current density. Given the fact that at one point in time composite conductor A is carrying current I , which could be AC or DC , and since composite conductor B acts as a return wire or return path for conductor A. So, at the same time, conductor B would carry a current of minus I, and since each of these strands is assumed to have the same quantum of current.

So, basically, each strand in conductor A is carrying current I by n , and each strand in conductor B is carrying current minus I by m. Here, n and m refer to the number of strands present in individual conductors, using the notion of evaluation of magnetic flux linkage of a specific conductor with respect to the currents present in other conductors. So these other conductors could all refer to the remaining n minus 1 strands in conductor A or the m strands carrying current minus i by m , respectively, in conductor B. Because of these different currents, as well as the current that conductor A is also carrying, what was the effective flux linkage of conductor A with respect to a point at infinity? From there, we figured out the inductance value of strand a in composite conductor A, and similarly, we can also evaluate the conductance of strand b and so on until the nth strand for composite conductors A. Similarly, we can also find the inductance of a' strand, b' strand, and so on until m' strand or m in composite conductor B.

And since these strands are all parallel to each other, if we specifically focus on one set of conductors or one composite conductor, then using those individual inductances, we can take the average value, which is indicated by this expression here, $L_{av,A}$ representing the term or notion of average. If we take the sum of individual inductances divided by the number of strands that we have, then essentially we have this sort of expression:

$$L_{av,A} = \frac{L_a + L_b + \cdots + L_n}{n}$$

$$= \frac{\mu_0}{2\pi}\left\{\ln\left(\frac{\{(D_{aa'}D_{ab'} \dots D_{am})(D_{ba'}D_{bb'} \dots D_{bm}) \dots (D_{na'}D_{nb'} \dots D_{nm})\}^{1/m}}{\{(D_{aa}D_{ab} \dots D_{an})(D_{ba}D_{bb} \dots D_{bn}) \dots (D_{na}D_{nb} \dots D_{nn})\}^{1/n}}\right)\right\}$$

and this is where we had stopped in our previous lectures' discussions. Before we proceed further, let me point out certain aspects that would be very useful for today's discussion. If we focus on the numerator, which is the term sitting over here in $L_{av,A}$, how many distances are there, or basically what type of distances are these capital Ds representing? So, if I let us say talk about $D_{aa'}, D_{aa'}$ is nothing but the center-to-center distance, which is let's say the center over here; then similarly, strand a' has a center over here. The distance between these center-to-center strands is aa', and similarly, $D_{ab'}$ is, let's say, if this is my strand b', then from the center of strand a to the center of strand b', the corresponding shortest distance is $D_{ab'}$, and this goes on until we reach the center-to-center distance between strand a and strand m ; that is where the D_{aa} terms come in.

So the numerator essentially consists of distances between one, if I focus on, let's say, one group, this group which is with respect to the center of strand a; then these distances are m in number, and these distances are the distance of the center of strand a with respect to the remaining strands in composite conductor B. Similarly, if I focus on the next group, then this is basically the product of the distances of strand b in conductor A with respect to the center of the strands in composite conductor B , and this goes on until I am evaluating the center-to-center distance between strand n and the other strands in composite conductor B, strand n being in composite conductor A. So essentially, all these groups, if I focus on them, consist of the product of m distances. Similarly, the other group is also a product of m distances, and this goes on until I reach the last group, which is also a product of m distances. And each, and basically how many groups of these products I would have, I would have the same number of groups as the number of strands present in conductor A , which is n .

So essentially, the numerator without the one by mth root is essentially the product of. n, m distances for which the 1 by mth root is being taken, and that is all about the numerator. If we talk about the denominator sitting inside the natural log term, the denominator is nothing but the center-tocenter distance of strands within one conductor, which is conductor A. So, a is nothing but the self-radius for inductance; it is r' or basically r into e to the power of minus μ_r by 4 . So, let me write that for D_{aa} and D_{bb}, assuming these strands are of the same type with the same radius; this is nothing but R times e to the power of minus μ_r by 4 , where μ_r is the relative permeability of each individual strand.

Usually, electrical conductors are poor magnetic materials, so μ_r is close to 1 . So, this is the individual self-distance or self-radius of each strand, and if I focus on one particular group, this strand or distance is basically a product of n distances, and this goes on until the last group. So if I focus on the denominator, essentially I have n , m distances whose products are being taken, and then the corresponding 1 by nth root is appearing. So with that, if this explanation is acceptable, and if this is okay for those who find this discussion complicated or could not figure out how these expressions came about, I request the viewers to please go back and look at the previous lecture we discussed. So from there, things would definitely become clearer.

So, with this, we have figured out the average value of the inductance of all strands in conductor A. Since these strands are all conductors that are assumed to be in parallel because magnetic field distortion is not happen-ing, magnetic flux lines are all constant, concentric, the wires are all straight, and there are no bends, etcetera, etcetera. So, essentially, since these strands are all in parallel, they are of the same nature; their current is essentially the same for individual conductors. So, essentially $L_{av,A}$, which is the average of the inductance of all strands in composite conductor A , could be assumed to have this inductance where it has the same inductance because their properties are more or less the same. So $L_{av,A}$ would essentially indicate this approximate inductance value, which would be common to all strands in composite conductor A.

A similar expression could also be written for a particular strand in composite conductor B, and then its average could be taken. Since these strands are of similar material and similar type, they are If the inductances were to be the same, then $L_{av,B}$ would indicate the corresponding inductance of every strand in composite conductor B. So, assuming that these strands are all parallel, their current distributions are the same, and if we have to find or sort of make our evaluation a little simpler, Then, assuming that this is true, $L_{av,A}$ is the inductance value of each strand in composite conductor A. So, essentially, we would be left with a situation where, from the sending end, let us say, to the receiving end, if I have a transmission line moving from node A to node B, and I am focusing on one conductor, this conductor has n parallel strands running through it. Let's say there are n number of strands, and each of these strands has an inductance of L_{av}.

If I have to find the overall inductance of all these lines combined, then, if you recollect, if there are resistances in parallel and I have to find their equivalent resistance, a similar logic would also be applied to find the average or equivalent inductance if the circuit consists of n parallel inductors. So essentially, the overall inductance, or L effective inductance, of composite conductor A would be nothing but $L_{av,A}$ by n , which comes from the fact that there are n parallel inductances of the same value. So essentially, let's say if I have to find the equivalent inductance, how do I get this expression? Let me explain that you have to find the effective inductance of n parallel inductances. What I would have done is take the inverse of individual inductances and then add these inverses together. Since these inductances average the same for all strands, if I add this up and simplify, I would get this number.

So, since there are n parallel strands each having the inductance L_{av}, the effective inductance, as discussed in the previous slide, would be 1 by n times L_{av}. So, basically, the effective inductance is 1 by n of L_{av}. This 1 by n factor again gets reflected here in the natural log numerator and denominator. And now, if I see if you recollect our previous slide discussion, the numerator is the product of n, n distances, and the denominator is the product of n, n distances. For the numerator, 1 by m, n or m into n root is being taken, and for the denominator, 1 by n into n root is being taken.

So, effectively, if I have n square distances sitting in the denominator, I am taking the 1 by n square root of n square distances, so essentially this becomes one individual or effective denominator distance, and similarly, here I have m comma n distances for which 1 by m comma n root is being taken. So, this also turns out to be an effective distance where the number of distances and the corresponding root effectively cancel out, or the other way around; if I were to say, it appears that not only does it appear, but effectively this distance, or this product sitting in the numerator of the natural log, is nothing but the geometric mean of the geometric means of m and n distances, similar to defining the arithmetic mean, and similarly this term here is the geometric mean of n and n distances. Geometric mean is all about multiplying and then taking the corresponding root. The arithmetic mean is obtained by adding these terms and then dividing by the number of terms that exist. Similarly, I can also find the effective inductance of composite conductor B , which is the overall inductance of conductor B because it has m strands; m strands are in parallel, and in a similar way, $L_{eff,A}$ is evaluated, and on similar lines, $L_{eff,B}$ can be evaluated.

$$\frac{L_{av,A}}{n} = \frac{\mu_0}{2\pi}\left\{\ln\left(\frac{[(D_{aa'}D_{ab'} \dots D_{am})(D_{ba'}D_{bb'} \dots D_{bm}) \dots (D_{na'}D_{nb'} \dots D_{nm})]^{1/mn}}{[(D_{aa}D_{ab} \dots D_{an})(D_{ba}D_{bb} \dots D_{bn}) \dots (D_{na}D_{nb} \dots D_{nn})]^{1/mn}}\right)\right\}$$

Similarly, inductance of conductor $B(H/m)$

$$L_{eff,B} = \frac{\mu_0}{2\pi}\left\{\ln\left(\frac{[(D_{aa'}D_{ba'} \dots D_{na'})(D_{ab'}D_{bb'} \dots D_{nb'}) \dots (D_{ma}D_{mb} \dots D_{mn})]^{1/mn}}{[(D_{a'a'}D_{a'b'} \dots D_{a'm})(D_{b'a'}D_{b'b'} \dots D_{b'm}) \dots (D_{ma'}D_{mb'} \dots D_{mm})]^{1/mn}}\right)\right\}$$

What we see here in these terms is something interesting. The interesting part is that if I compare the numerator of the natural log term of $L_{\text{eff},B}$ with the numerator of the natural log term of $L_{\text{eff},A}$, they are exactly similar terms. The product pairings, wise, are different. But if I, let's say, focus on $D_{aa'}.D_{aa'}$ is present here.

It is also present here. $D_{ba'}$. This is present in this group, but in the other group, $D_{ba'}$ is the first term. Similarly, D_{na} - it appears as the first term in $L_{eff,A}$. Essentially, these two numerator terms are exactly the same. The denominator terms are, however, different.

The denominator, however, in $L_{eff,A}$ is the geometric mean of n square distances, which are the center-to-center distances between the strands. For $L_{eff,B}$, the denominator is the geometric mean of m square distances, where these distances are the center-to-center distances between strands in composite conductor B. So with this, we now have our expressions, or I would say a simplified version of inductance evaluations for conductors A and B . What appears to be boggling is that if the number of strands is greater or if the arrangement is complex, then one probably has to evaluate these distances in order to find these inductances. And if you recollect from the previous lecture, I had given a little clue that there are ways in which these distances need not be evaluated, and still, the evaluation of inductances can be done.

So let us see how it's done. So the previous expression of inductances, the numerators in the natural log terms, as I mentioned, is the geometric mean of the distances. So we call them geometric mean distance, in short, GMD, which is m comma m into the nth root of m comma n distances. And similarly, this GMD is indicating that if I were to represent composite conductor A , consisting of n strands, and composite conductor B , consisting of m strands, as two effective single conductors. So basically, instead of having n strands in conductor A , there is only one conductor in A , and similarly, if there is only one conductor in B , then the center-to-center distance between these two analogous conductors is nothing but the GMD itself, which is essentially what is written here. GMD is the effective distance between the space centers of composite conductors A and B .

If we could figure out analogous conductors that can replace composite conductors A and B respectively, then GMD is the center-to-center distance. Similarly, the denominator in the natural log term is also the self GMD of the conductor, and it is to sort of differentiate it from GMD. It is given the term geometric mean radius (GMR), which is the nth square root of the n squared distances in conductor A and the mth square root of the m squared distances in conductor B. These distances, if you compare them, are the self-radii or the center-to-center distance between strands in a particular conductor. So given that we now understand what GMD is and what GMR is, let's see how these can be further simplified.

So effectively, in terms of GMD and GMR, the effective inductance of A and the effective inductance of B can be written. And since this represents a single-phase two-wire circuit where the space between these two conductors has additive magnetic flux lines, the way the currents are flowing in them, as per the right-hand rule, so effective circuit inductance, the way we did it for a single-phase two-wire circuit, the effective inductance is the addition of the inductances of respective conductors a and b, similar to the single-phase two-wire circuit discussion. The beauty here is that since these conductors are manufactured by some manufacturer, the manufacturer very well knows what type of ACSR conductor this is going to be. And they understand or know how many steel strands are present in the center and how many aluminum connectors are present over the steel strands. What are the individual radii of these strands? What is the spacing between these strands? As manufacturers, they automatically provide these transmission lines when evaluating the inductances for transmission lines.

So the manufacturers provide a data sheet or a table in which the GMR of the conductor is essentially defined or calculated by the manufacturer. So usually GMR does not need to be evaluated. If it is a line provided by a manufacturer. If, for the sake of numerical discussion, one still needs to verify, okay, let me figure out the GMR. Using the data sheet provided by the manufacturer, one can use these expressions again to verify the GMR.

In the last discussion of this particular module, we will also understand how we can numerically verify these GMR values from the specifications given by the manufacturer. And for GMD, if the strands or conductors are spaced apart in the sense that the center-to-center distance between the conductors is very high, then effectively the GMD, which I was talking about here in this particular context, increases as the distance between these conductors increases. Even if we evaluate the GMD as per the actual expression given here, there might be slight inaccuracies in terms of the number of decimals present in the distance that we are going to evaluate. But suppose one doesn't want to evaluate GMD the way it is given here because it's a very complex expression. One has to keep account of the mapping between the strands and the distances that are to be evaluated.

If the distance between connectors is pretty far off, then GMD will essentially be nothing but the space distance center to center, which is the space distance between the geometric centers of these connectors. So essentially, in terms of GMD, if the distance between connectors is pretty far off, GMD is approximately equal to the center to center distance between these two connectors. The center to center distance refers to the effective centers or equivalent centers. So in a nutshell, GMR and GMD are rarely evaluated in practice; they are most commonly available. The GMR part is from the manufacturer, whereas for GMD, one can approximate the GMD evaluation by considering fictitious center to center distances between the conductors themselves.

One who still wants to very precisely evaluate inductance is most welcome to make use of those inductance expressions with GMD being one root of some distances. So coming to our main focus of discussion, which is inductance evaluation for three-phase lines, the concepts that we have learned for inductance calculation in single-phase circuits can still be applied to threephase lines. And for three-phase lines, I mean that at least one composite conductor is assigned or dedicated to one phase of the line. And I'm assuming that these lines are operating in a balanced condition, meaning that these currents are positive sequence currents I_a, I_b, and I_c, and I_a, I_b, and I_c are symmetric vectors. So basically the magnitudes are the same and the phase angles are 180 degrees apart.

For symmetrical spacing of three-phase lines, I mean if I have one composite conductor for phase a , one for phase b , and one for phase c , then for symmetric spacing, it means that these conductors are placed at the same distance from each other, which is, let's say, distance D. And if the distances have to be the same, then essentially it appears that these conductors are placed at the tips of an equilateral triangle whose side is D . Each of the sides is D . That is what is meant by symmetric spacing. So, if I have a symmetrically spaced three-phase balanced line and I have to find the inductance of each phase or each line, then the way we evaluated inductances for composite conductors in the previous discussion, I would just have to know what this GMR is, which is usually provided by the manufacturer.

And since the spacing is symmetric, even if I evaluate the actual GMD, it would more or less be the same as the physical symmetric spacing, which is D . So, once this D is known because of the arrangement of three-phase lines depending on how the towers are constructed or how the towers are positioned, the expression for L can be used here. So far, so good, but every story has a twist. For the inductance of three-phase lines, there again exists a twist: the twist here is that these three lines in a three-phase system need not always be symmetrically spaced. Because our tower constructions are different and our tower designs are different, you would rarely find a tower, or you would have seen very few towers, where this symmetric arrangement is ensured.

For the sake of tower design from the tower safety perspective, if symmetric spacing is not ensured, what would happen? The inductance of phase a , the inductance of phase b , and the inductance of phase c would become unequal. And even if the load is balanced and generation is balanced, the transmission network, which would carry this current from generation to load, would itself be unbalanced because of these unequal inductances. So there would always arise a possibility where, no matter how balanced an operation one wants to have, due to the network structure, the overall operation can become unbalanced. And that is the twist that is there. So what is done to avoid this unbalance entirely? So essentially, flux linkage will be different irrespective of whether the source or the load is balanced or unbalanced.

To avoid this unequal inductance and this unbalance in the circuit, these conductors are placed or their positions are exchanged at a few regular intervals. We call those special towers where this exchange occurs. We call those towers transposition towers. These are specially designed towers placed a few kilometers or miles apart. The frequency of occurrence of transposition towers is uncommon.

These conductors, three-phase conductors, exchange their position with respect to other conductors over a length of equal distance. So let us say there is a line of 800 kilometers. So essentially, the conductors would change their position every 160 to 170 odd kilometers so that in an entire 800kilometer span, every conductor of a particular phase occupies the place that other conductors would have taken up. So effectively, if we were to focus on one section, then yes, the inductance values may be different; if we focus on the next transpose section, the individual inductances may be different, so unbalance may exist. However, if the symmetry is maintained over the entire stretch, then the effective inductances would more or less turn out to be balanced; the values would turn out to be balanced.

So for this arrangement, we call it a transposition arrangement where the conductors exchange their positions at specially designed towers known as transposition towers. So what I have here is an arrangement of a transposed three-phase line. I am associating the phases with small a, small b, and small c. They are not the strands now. So the assumption here is the same that the conductors, phases, or lines in a three-phase line are similar to each other.

Their material is same. So basically, the GMR is the same, and the currents are balanced. So essentially, at any point in time, I_a plus I_b plus I_c is equal to zero because, in a balanced condition, we have seen how these sums turn out to be zero. So at one section of this transposition, which is section number 1 , the other section is section number 2 , transpose the section, and then I have section number 3. If I have to find the inductance of conductor a in section number 1 , which is what I am associating here, a is phase a conductor, and 1 here refers to the transposition section in which the inductance is being evaluated.

This is the phase number of the conductor. And if we recollect our flux linkage expression, which we discussed in the last lecture, then at section a, conductor a is placed over here. Its distance from the other conductors b and c is D_{12} and D_{13}, respectively. The GMR is known to the manufacturer or provided by the manufacturer. So if I have to find the flux linkage of phase a at section number 1 , I have this expression, which is λ_{a1}. Please recollect or revisit the last discussion where we figured out how this magnetic flux linkage expression can be obtained.

$$\lambda_{a1} = \frac{-\mu_0}{2\pi}\{I_a \ln(GMR) + I_b \ln(D_{12}) + I_c \ln(D_{13})\}\text{Wbt/m}$$

If this is the expression of phase a linkage at section 1, then can you guess what the linkage of phase a would be with section 2 or in section 2 ? So in section 2, if you see, phase a has now taken the position of phase b, phase b has taken the position of phase c, and phase c has now taken the position of phase a. So in these distances, a rotation or basically a shifting of positioning has happened. And in this shifting, it is essentially done in a counterclockwise fashion. So a is sitting over here. And now the distance between phase a, phase b, and phase c conductors are D_{23} and D_{12}, unlike D_{12} and D_{13}, respectively.

So λ_{a2} would be $-\frac{\mu_0}{2\pi}\{I_a \ln(GMR) + I_b \ln(D_{23}) + I_c \ln(D_{12})\}\text{Wbt/m}$. Similarly, λ_{a3} can be evaluated along similar lines. So if you evaluate that, then these are the expressions that we would get in different transpose sections.

$$\lambda_{a2} = \frac{-\mu_0}{2\pi}\{I_a \ln(GMR) + I_b \ln(D_{23}) + I_c \ln(D_{12})\}\text{Wbt/m}$$
$$\lambda_{a3} = \frac{-\mu_0}{2\pi}\{I_a \ln(GMR) + I_b \ln(D_{13}) + I_c \ln(D_{23})\}\text{Wbt/m}$$

And the way, since the same conductor is taking up different values of inductance or flux linkage at different sections, one common way is to take the arithmetic mean of these flux linkages. So if the average flux linkage of conductor a is to be obtained After all transposition is done then essentially we have this expression here which gets simplified to this and remember our system is balanced.

$$\lambda_a = \frac{\lambda_{a1} + \lambda_{a2} + \lambda_{a3}}{3}$$
$$= \frac{-\mu_0}{2\pi}\left\{I_a \ln(GMR) + (I_b + I_c)\ln\left(\sqrt[3]{D_{12}D_{23}D_{13}}\right)\right\}$$
$$= \frac{\mu_0}{2\pi} I_a \ln\left(\frac{\sqrt[3]{D_{12}D_{23}D_{13}}}{GMR}\right) \text{Wbt/m}$$

So essentially, I_b plus I_c is equal to $-I_a$, which, if remodified and rewritten, gives us this beautiful expression. So essentially we end up again with an analogous GMD between the different phase lines placed at different sections, with effective GMR remaining the same. So overall, inductance is this. A similar expression could also be written for other phase conductors. So D_{EQ} is effectively the equivalent of GMD, which is the geometric mean of the spacing between transposed conductors in three-phase lines.

Usually, in three-phase lines, there is more than one conductor, which is essentially the reason behind bundling. Composite conductors are those in which one conductor is made up of several strands. Bundling is a phase that consists of several composite conductors. And why is bundling necessary or needed? Bundling effectively helps in the reduction of corona loss. It helps in the reduction of effective line inductance because the effective GMR goes up.

As a result, the line performance is improved, which we will see in the next module. The radio interference and surge impedance also go down. So we will also see about surge impedance in the next module. Please have patience until we arrive at how these numbers, what these numbers are, or what these values are, and how the performance gets improved. So, typically bundled conductors would have two or more composite conductors arranged symmetrically for every phase.

So, how do we evaluate this inductance in such cases also? These composite conductors, in a particular bundled arrangement, are physically spaced apart in a usually symmetric arrangement and are separated at frequent intervals by mechanical devices known as space dampers, which provide or prevent clashing and prevent contact between these conductors. So basically, if I were to typically draw the diagram of a space damper, if you had seen a four-bundle transmission tower, I mean one bundle consisting of four conductors in an overhead transmission line, then if this is my space damper, which is usually an insulated device, the conductors or bundled composite conductors are placed at the tips of this space damper. And this space damper essentially connects or attaches these four composite conductors while also avoiding physical contact with them. And it provides mechanical damping in case of bad weather. It avoids the overall transmission line from swaying away at larger radii.

So it does have its own benefits. So, for the inductance of bundle conductors, what we have understood so far is that in order to find inductance, we essentially have to understand what GMD is and what GMR is. Now, for individual conductors, the manufacturers are providing the GMRs. So for bundle arrangement, if I have an a phase which consists of two composite conductors or two bundles, or in one bundle there are two composite conductors and each conductor has a self radius of R' where R' again is r into e to the power minus μ_r by 4 , then the gmr is nothing but the fourth root of all four distances that can come in. Remember, GMR is the geometric mean of all possible center-to-center distances within one composite arrangement. So, if I have R' as the self-radius and D is the distance between them, then D_{11} is R', D_{12} is D .

So, basically this is one group of distances, and similarly for the other conductor, the self-radius is r', which is the first term, and d_{21}, which is the distance from here to here, is r'd. So effectively, the fourth root results in $\sqrt{R'D}$. For three bundles that are symmetrically spaced apart, I will have nine distances, each distance or each couple or pair having three distances, and I will take the corresponding ninth root. Similarly, for four such bundle conductors, I will have 16 distances, and the corresponding 16th root has to be taken. So, with different bundle conductors that are symmetrically spaced apart, I can evaluate the GMR, obviously using the GMR of the manufacturer; this essentially would be the GMR of the corresponding conductor provided by the manufacturer, which is for one composite conductor.

Remember, each of these bundles or strands is a composite conductor, and the distances that we are talking about are the center-to-center distances between the ACSR conductors. Depending on the GMD of how these bundles are spaced apart, D_{eq} is the equivalent GMD of the center-to-center distance of the respective bundles. With this, we conclude our discussion on the evaluation of inductance. In the next lecture, we will take up the discussion on the evaluation of capacitance. Again, I request my viewers to please revisit these lectures or videos as often as possible to avoid having any doubts. Thank you.