

Power Network Analysis

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Week - 05

Lecture-24

Hello everyone, welcome to lecture four of week five of the course Power Network Analysis. In this discussion, we will continue our discussion on the main module, the fourth main module, which is transmission line parameter evaluation, and this is going to be the last lecture on this particular module, where we will see if there are ways of evaluating line inductance and capacitance specifically without going into the complex evaluations of geometric mean distance and geometric mean radius to the extent possible. So yes, there are ways, thanks to the manufacturers who provide these lines, where they provide certain relevant information about these line parameters in the form of certain tables. And essentially these tables carry all this information; most of the information can be easily used to find the corresponding reactances because eventually line inductance or capacitance would result in some line reactance X . We'll see how those reactances could be obtained, and we'll also conclude this discussion with one numeric example verifying that the actual calculations and the information obtained from the tables match each other. In the previous lecture, we looked at how the capacitance of three-phase lines could be evaluated, specifically how three-phase transposed lines could be evaluated, and we also saw the effect of earth on line capacitance.

The lower the Right of way or the lesser the Right of way of transmission lines. The effect of earth on line capacitance becomes dominant, so overall the line capacitance itself increases, which might lead to a large increase in the charging current even when the line is unloaded, and then there could be other repercussions in terms of the Ferranti effect, where the receiving end voltage tends to become higher than the sending end voltage. More details about Ferranti, how to compensate for or control Ferranti, we'll look at in the next module, which is transmission line parameter performance evaluation. So, as we all know, we have talked in detail about the evaluation of per-phase line inductance and per-phase line capacitance, and we have seen why these inductances and capacitances are important.

Inductances are the result of the magnetic flux lines that are inherent to any current-carrying conductor, and similarly, the capacitance is mostly due to the electric field or flux lines, which again could be associated with charges that reside on or at the surface of the conductor carrying the current. So, because of these natural phenomena, magnetic interaction, and electric interaction of flux lines with the current, the corresponding inductance and capacitance do exist, and we have seen at length how these actual values could be evaluated. But eventually, in power network analysis, or in a more generic way to say for actual power network analysis and performance analysis, often the actual inductance and capacitances are not needed. What is eventually needed is the associated X or the reactance that results from this line's inductance and capacitance, obviously depending on the system frequency. So manufacturers, as I mentioned, the transmission line manufacturers share this information with the transmission line owners or operators, and they provide certain information in the form of tables where mostly the conductors used are of ACSR type, aluminum core steel reinforcement.

So these ACSR conductors, there could be a variety of ACSR conductors, which is the common practice across the globe as well. Mostly, manufacturers of ACSR conductors provide certain information in the form of tables, where they also specify what type of ACSR conductor it is, including how many aluminium and steel strands are present in that ACSR conductor. What is the overall outer diameter of the ACSR conductor, and what is the effective geometric mean radius, both for inductance and capacitance? We'll see those tables in the next few slides. They also provide the actual DC and AC resistance through their own performance testing at different typical operating temperatures, and eventually, the cream or the beauty of these tables is that these manufacturers also provide certain inductive as well as capacitive reactances, which are essential for the steady-state performance in these particular tables for different spacings. So by spacings, I mean these spacings could come in the case of composite conductors; this spacing could also come in terms of bundled conductors.

So, depending on what type of spacing exists between the three-phase lines or per-phase lines, the conductors themselves, at different typical operating frequencies, which could be 50 Hz for India, I mean, across the system, across the globe, except for the US and Canada, or 60 Hz for the US and Canada. The manufacturers they inherently provide these reactances. So basically, if I were to say that a particular inductor has an inductance of L henries, then the corresponding reactance would be ωL , where ω is $2\pi f$ and f is the corresponding operating frequency. So X refers to the actual reactance, where L is the actual inductance of a particular element. And similar lines for capacitors, the corresponding capacitive reactance X is $\frac{1}{\omega C}$. So in terms of the actual reactance value, the inductive reactance is associated with $+jX$, whereas for capacitance, it is associated with $-jX$, depending on whether it is an inductor or a capacitor. So, these X values what I am saying is that these X values are provided by

the manufacturers at different spacings for different composite or bundle conductors at typical 60 Hz or 50 Hz. So these reactances can actually be obtained directly without going into any calculations of figuring out the GMD, GMR, taking the ratio, taking the corresponding natural log term, and plugging those numbers in for the inductive part or the capacitive part. So all that part could actually be avoided. So a lot of complex calculations can just be thrown out of the window.

So starting with the inductance, we have talked about it at length. Generic expression for per phase line inductance. The per-phase line inductance could refer to a single-phase two-wire circuit, a three-phase line, or a transposed line. Composite conductors, bundled conductors, and all those expressions indicate that the generic form of inductance on a per unit length basis is $\frac{\mu_0}{2\pi} \ln \frac{\text{GMD}}{\text{GMR}}$, where the value of μ_0 is $4\pi \times 10^{-7}$ Henry per meter. which, when divided by 2π , results in 2×10^{-7} .

The natural log term doesn't have any units because the argument inside the natural log term is unitless, and the natural log itself is just a numeric value. So from here, if we have to find the corresponding values, basically what are the GMR or GMD, let's talk about it a bit. GMR is the effective radius for a single conductor, and for inductive reactance, this GMR is not equal to the actual radius of the conductor. It has its own skin effect aspect, so $e^{-\mu_r/4}$, where μ_r is the relative permeability of the conductor. Usually, conductors are poor magnetic materials, so μ_r is almost close to 1 for almost all ACSR conductors.

So GMR, in the case of inductance evaluation, it is not exactly R . It is actually R multiplied by $e^{-\mu_r/4}$. This GMR might also change if the conductor is a composite conductor like an ACSR conductor or if there are bundles of conductors present with different spacings; the corresponding GMR has to be accordingly evaluated. Details of this have been seen in the last part of the inductance evaluation. Similarly, the GMD is the effective distance between the space centers of the conductors, which again depends on whether the conductor arrangement is a composite conductor or a bundled conductor on a three-phase basis.

So with this inductance expression, if we have to find the corresponding reactance, I'll probably spend a bit of time before I move to the next slide here. So X_L, L representing the inductive reactance would be equal to ωL where ω , as I mentioned, is $2\pi f$. So if I substitute $2\pi f$ into L , it becomes $2\pi f$ times μ_0 divided by two pi times the natural log of GMD by GMR. Remember that the unit of L is Henry per meter, so the unit of X or reactance is going to be ohms per meter. The unit carries forward, so the same unit is applicable here, which, upon simplification, is written as $\mu_0 f \ln \frac{\text{GMD}}{\text{GMR}}$ ohm per meter.

Now f could be 50 Hz or 60 Hz; μ_0 is $4\pi \times 10^{-7}$ Henry per meter, so with that same logic. If we now look at or see the same number, X_L associative per phase inductive reactance can be written in terms of this expression where f is a steady state frequency. And this

could also be rewritten. I mean, the units can change. Usually, we'd have transmission lines that are a few thousand kilometers or a few hundred or thousand miles apart.

We don't have transmission lines that are a few meters long. So often, the per meter basis for distance measurement for transmission lines becomes a very awkward number. The corresponding reactance tends to be a very small value, in fact. To scale down this overall network inductance perspective from the length perspective, the unit of per kilometer or per mile makes sense because the lines are a few hundred kilometers, thousands of kilometers, and miles, so with per meter getting converted to per kilometer, a factor of a thousand comes in. Then again, from kilometer to mile, when we scale up, we have to keep in mind that one mile is around 1.60934 kilometers.

61 kilometers, so the corresponding factors are accordingly changing. In fact, here 2.202236, the number we are seeing, is actually μ_0 multiplied by 1.6094, which results in this particular factor. f can be 50 or 60 hertz.

Now from here, we can also go a little deeper that, okay, once we know the GMD, once we know the GMR, and once we know the system frequency, we can actually plug in those numbers into this reactance expression and find the corresponding reactance in ohms per mile or per kilometer. But the question here is that the evaluation of GMD and GMR in themselves is a very tedious calculation. So, is there an alternative? So yes, let's see that. So we can always write, remember the important part here is that the natural log of $\frac{GMD}{GMR}$ can also be rewritten as two distinct terms, one term being the natural log of $\frac{1}{GMR}$, the other term being the natural log of GMD. So now, if we substitute this factor for this term here, we can have actual X_L , which is the overall inductive reactance per phase, as two distinct terms.

One term is X_{aL} ; the other term is X_{dL} . Please don't consider X_a and X_d as the arguments here. X_a and X_d have been mentioned here just to indicate that usually the tables provided by the manufacturers make use of this symbol X_a to represent the corresponding portion of reactance, and inductive reactance, while X_d pertains to the corresponding portion of inductive reactance. So that's why X_a and X_d have been written here. They are not the arguments of the functions X_{aL} or X_{dL} , respectively.

So X_{aL} , if we see, then there is some peculiarity about this X_{aL} . For that matter, the same is also true for X_{dL} . In X_{aL} , if we focus on the first term, which is the part that is being underlined, it is common to both terms. In fact, it is common in the actual inductive reactance as well. And this term has nothing to do with the type of the ACSR conductor because 2.

202236, as I mentioned earlier, is coming from μ_0 , which is an absolute, which is a universal constant, absolute permeability. 1.6094 is the conversion ratio between kilometers and miles, and f is the system frequency, which is 50 hertz or 60 hertz in steady state. So the first underlined terms in X_L , X_{aL} , and X_{dL} are the same terms, and they are independent of the type of conductor. Now the portion that is dependent or independent might be, is the term that is a natural log term, which is mentioned here accordingly.

So now, if we look at X_{aL} , the natural log of $\frac{1}{\text{GMR}}$. The natural log of $\frac{1}{\text{GMR}}$ is again a constant, so the natural log is again a function of what the GMR is. So GMR, if we think about what GMR is, is a property of the ACSR conductor. Depending on the arrangement, the number of strands, and the spacing between the strands, GMR is going to change. So essentially, what I'm trying to say is that GMR is dependent on the type of conductor, and hence X_{aL} is a specific number or value given by the manufacturer as per the conductor type.

Whereas X_{dL} , as I mentioned, the first term is independent of the type of conductor, which is the natural log of GMD. GMD, if we recollect, I'll probably go back to the previous slide a bit; GMD, as I mentioned, is the effective distance between the space centers of conductors. It is only dependent on the spacing present between the conductors. GMD is actually independent of the type of conductors. There could be ACSR off-spray conductors; there could be ACSR penguin conductors; etc.

No matter what the specific conductor is, depending on whether the distance is 1 meter spacing or a few centimeters spacing, GMD is only about the distance. It is not dependent on the type of conductor. Basically, depending on the value of X_L that we have seen here, which is the inductive reactance, the same expression is enumerated here where X_L is $\mu_0 f \ln \frac{\text{GMD}}{\text{GMR}}$. The per meter unit could be converted to per kilometer or per mile, where one mile

is approximately 1.609347 kilometers. Usually, the inductive reactances are specified in terms of ohms per mile or ohms per kilometer because the natural distance of transmission lines is a few thousand kilometers or a few hundred miles, depending on that. Per meter would become a very obsolete unit or a very small unit for measuring the distance of the transmission line. That's the reason why Ohm per kilometer or Ohm per mile is often a convenient unit for defining inductive reactance. The same is also true for capacitance when we see it in the next few slides. Now X_L here it can be written or rewritten in terms of two distinct components.

So basically, the natural log of $\frac{\text{GMD}}{\text{GMR}}$, if we were to see, can be rewritten as $\ln \frac{1}{\text{GMR}} + \ln \text{GMD}$. So when we substitute this expression over here, we can get two distinct components. One component is X_{aL} ; the other component is X_{dL} . Please note that X_a and X_d are not the arguments of the functions X_{aL} and X_{dL} . In fact, X_a and X_{aL} refer to the same

quantity.

X_d and X_{dL} refer to the same quantity. The reason I have mentioned X_a and X_d here is that usually the transmission line manufacturers provide these inductive reactances in terms of the notations X_a and X_d . Similarly, for capacitive reactance, the manufacturers' tables that they provide are in terms of X'_a and X'_d . So, just to have a correlation between our discussion and the segregation of inductive reactants and capacitive reactants, I have made use of the term X_{aL} , which is analogous to X_a , and X_{dL} , which is analogous to X_d . Now in X_{aL} and X_{dL} , basically X_L here, the overall inductive reactance is the sum of $X_{aL} + X_{dL}$, according to the distinction or the relationship that we have here. And if we look at X_{aL} or X_{dL} for that matter, the underlying factors are common in all three reactances, and the underlying factor is common to all; in fact, it is independent of the type of conductor because the factor of 2.

02336 into 10^{-3} is coming in because of the term which is coming over here, which is essentially nothing but μ_0 into 1.6094. μ_0 is an absolute constant and a universal constant.

It's the absolute permeability. And 1.6094 is the conversion factor between one mile and one kilometer. So basically, f , and again, the f factor, which is the steady-state frequency of 50 hertz or 60 hertz, is also a system constant; it is not dependent on the type of conductor. So the first terms definitely are not responsible for or dependent on the type of conductor. So the only factor that is present here is the natural log of $\frac{1}{\text{GMR}}$ or the natural log of GMD. Now, the natural log of $\frac{1}{\text{GMR}}$, which is again a constant, means that GMR, if we talk about it, is a factor known as the geometric mean radius.

It depends on the type of conductor, the type of ACSR conductor, how many aluminum strands are present, how many steel strands are present, the spacing between these strands, and whether it is a composite arrangement, a bundled arrangement, etc. So essentially, GMR is dependent on the type of conductor. That means X_{aL} is a quantity that is completely dependent on the type of conductor, whereas X_{dL} is dependent on GMD. As we saw in the previous slide, GMD is dependent on the effective distance between the space centers of conductors. It is independent of what type of conductors they are; it is only how far apart they are, how spaced apart they are, and the center-to-center distances.

That's what it's all about, GMD. It is independent of the type of conductor. So if we talk about X_{dL} , where GMD is the only function or variable, the second term, X_{dL} , becomes independent of the type of conductor. That is a clear observation that we can see. The other observation that we can see is, okay, X_{aL} is dependent on the type of conductor, while X_{dL} is independent of the type of conductor.

Is X_{dL} dependent on anything else? Yes. X_{dL} depends only on the distance or spacing between the conductors, as mentioned in the previous slide. Is the same true for X_{aL} ? In X_{aL} , we have the GMR, which is dependent on the conductor type, and the remaining

number is 1 . It is just 1 , a universal constant. So basically, X_{aL} becomes independent of the distance or spacing between bundled conductors. It does depend on the spacing between composite conductors because that determines the GMR, but it is independent of the spacing between bundled arrangements in a typical three-phase transport line.

So we have two numbers, X_{aL} and X_{dL} , and if we know X_{aL} and X_{dL} , which are often provided by the manufacturers in the form of tables, then we can easily add them up and get our actual reactants without actually evaluating GMD and GMR. So how is it done? We'll just enumerate, explain, or summarize that. X_a , which is this variable or number here, X_{aL} , is the inductive reactance at one foot spacing. One-foot spacing here refers to one-foot spacing or one-foot fictitious spacing between the bundles in the three-phase arrangement when the GMR of the conductor is also in feet. Usually, the radii of conductors are very small, so US standards, European standards, or global Canadian standards use distance units that are mostly in feet, miles, and inches.

So if the GMR is in units of feet, which is the usual case for conductors, and if there were a single conductor, a bundle conductor with one foot spacing, the one foot spacing here is actually a non-existent spacing. It is a fictitious arrangement just to indicate that, okay, $\frac{1}{\text{GMR}}$ becomes a unitless quantity. This is actually a unitless quantity, so if GMR is in meters, the spacing becomes one meter; if GMR is in inches, the spacing becomes one inch. The way these numbers are given is in this table A.3, which we will see in a moment, as we also talked about in the previous slide.

It is independent of the actual spacing between conductors. It is only dependent on the type of conductor, which is what's dictating the GMR. So if we see what table A.

3 is, table A. 3 looks something like this. There are different types of ACSR conductors or coatings present. Where, if we talk about, let's say, a wax wing conductor, then the number of aluminum strands present in the wax wing conductor is two. In fact, there are two layers of aluminum. The number of strands of aluminum is 18, and at the center, there is one steel strand.

That is what AL and ST stand for: the number of strands. And around the steel strand, there are two layers of aluminum, with each layer consisting of 18 strands. The surface area of each overall aluminum portion of the ACSR conductor is also given in CML. The overall diameter of the ACSR conductor is given as 0 .

609 inches. Please don't consider this comma to be a comma. It's actually a dot. I mean, the table is taken as a script from the very famous textbook Power System Analysis by John J. Granger and William D.

Stevenson, Jr., so they usually avoid using dots. They mostly use these commas wherever possible. So, the diameter of the wax wing connector is 0.609 inches. The AC and DC resistances at 20 degrees and 50 degrees. So AC resistance is given for 60 hertz because 60 hertz is the common frequency in the U.S. DC resistance at 20 degrees is also provided. Also, the overall GMR of the aluminum ACSR wax wing connector is given. So this GMR, in terms of inductive reactance, if you have to evaluate, please cross-check. Let's say for the waxwing conductor, if this is the number, 0 .

0198 feet is equal to 0.609 inches by 2; 0.609 is the diameter of the waxwing conductor, so by 2 would be the radius, and this, when multiplied by $e^{-1/4}$, assuming the relative permeability of waxwing ACSR to be close to 1 , these two numbers with one side being inches and the other side being feet should match, and it should happen for all such numbers present in these two columns. Please make sure of that. In A.3, since it is dependent on the type of conductor, it is also providing the corresponding X_a value, which is the inductive reactance at 1 foot spacing when the GMR is also in feet. So the X_a values at 60 Hz are directly given here for different ACSR conductors.

Similar reactance, which we will see in the next few slides, is also given for the capacitive part, which is X'_a . And that's the reason why I have chosen X_a as X_{aL} , and similarly, in the next few slides, we will see X'_a for X'_{ac} . So these numbers are actually given, and one can easily take away from them. So going back to our next table, which is Table A.4, it provides the next inductance value, which is X_d , that is only dependent on the spacing between the connector and is independent of the type of connector.

So if we see or expect something from table A.4, unlike table A.3, which has different ACSR conductors marked here, table A. 4 will not have the type of conductors. Pardon the poor quality, but this is the best that I could get from the corresponding scripts.

And as I mentioned, table A. 4 is independent of the type of connector. It is only dependent on the type of spacing between the composite and the bundle conductors. The spacing has two dimensions. From top to bottom, we would find the spacing in terms of feet, whereas at the top, you would find the spacing in terms of inches. So basically, the inductive reactance spacing factor X_d , which has its own name, is already evaluated by the manufacturer, and the corresponding numbers in ohms per mile per conductor or per phase are evaluated here, actually.

There is an observation here. Again, as I mentioned, let's say I have to find the inductive reactance spacing factor for a spacing of 1 foot and 1 inch, then the X value is 0.009 .

So, 0.0097 ohm per mile. That is essentially what this number is indicating. Please don't confuse these commas with commas. They're actually full stops. And the reason why the inductive reactances for 0 feet and a few spacings or inch spacings are negative numbers is very simple. The natural log of GMD, as long as GMD is more than 1, numerically, the corresponding log of GMD would be a positive number; if GMD is less than 1, then the natural log of GMD would be a negative number.

Again, GMD cannot be a negative number; it has to be more than 0. When GMD is equal to 1, the natural log of GMD is perfectly 0; that is the reason why. At one foot zero inch spacing, the x value is zero because the natural log of GMD is zero, and for spacing less than one foot in terms of inches, the corresponding numbers are negative because the natural log of GMD is negative. So, depending on what type of GMD turns out to be and what type of spacing turns out to be, which is D_{EQ} for three-phase lines or the separation spacing in feet for actual single-phase lines, the corresponding X_d numbers can be easily plugged out. So the question that might come to your mind is, what about the value of X_d for a spacing that is not given here? Let's say for a spacing of one foot and 1.5 inches, what is the corresponding x value to be taken from here? Please have patience; the example that I will discuss will explain clearly how you figure out the value of X_d if the spacing does not fit the numbers I mentioned here, basically.

We would be using the concept of interpolation or, at times, extrapolation if the spacing is way beyond the spacings given here. Typically, the table length refers to the spacing of up to 20, 25, or 30 feet at most. So we'll see that in the examples. Please be patient. So, with X_d and X_a directly obtainable from these tables, if needed, what we have to evaluate actually is, if necessary, depending on bundling, one needs to evaluate GMD or, for that matter, actual GMR, and then plug in or use those tables to find the corresponding X_a and X_d at 60 Hz, add them up, and directly evaluate X_L .

No need to find GMD and GMR in complexity. Similarly, for reactance, if we see the GMR or GMD to be evaluated, please make use of this numeric expression directly, and you will still be able to avoid using tables and obtain those numbers. In terms of capacitance, if the inductance part is clear, the general expression for capacitance per phase is $\frac{2\pi\epsilon_0}{\ln \frac{GMD}{GMR}}$, where

GMR here is exactly the same as the actual radius; there is no effect of skin effect or perspective of skin effect from the capacitance perspective, and it depends on the type of conductor, the type of composite conductor, per phase, etc. The same logic used to find inductive reactants can also be applied to obtain capacitive reactants from C , so here is the expression for X_C in $\Omega \cdot m$ and Ω per kilometer... Why do we have an $\Omega \cdot m$ now? Because the capacitance unit was the farad per meter. $\frac{1}{\text{farad per meter}}$, which is this term here, gets

inverted. And hence, the meter per meter upscales to meters here. And similarly, meters when converted to kilometers will have this 0 .

001 factor, which can again be converted to miles and so on. And here again, we have two distinct terms: X'_a and X'_d . X'_a is dependent on the type of conductor. It is actually independent of the actual spacing.

It is dependent on the conductor. Let me write that. Dependent on the conductor. Independent of the actual spacing between the conductors. If GMR is one foot, one foot is the analogous GMD, which is the fictitious GMD. And vice versa for X'_d ; it is independent of the conductor. It depends only on actual spacing.

The similar way we saw for X_a and X_d in inductive reactants, the same logic applies here. So there we also have different tables. We have, in fact, seen the X'_a value in Table A.3, which was the last column in megaohms per mile. Megaohm into mile, and it is independent of the actual spacing between conductors. Similarly, X'_d is the capacitive reactance spacing factor, which is given in a separate table because the same table A.

4 cannot have two distinct inductive reactances. The expressions are different, the factors are different; whereas for X'_d , the corresponding factors are different. So we have Table A.5, which is only dependent on the spacing, which is the GMD.

It is independent of the type of conductors. So if you see, table A. 5 looks very similar to table A.4, but now we have shunt capacitance reactance, where again, depending on the spacing, the corresponding values can be directly plugged in. So let's say for 7 feet, 11 inches of spacing, the X_{dc} , the capacitive part of the spacing factor, is 0 .

0614 megaohms per mile. That is essentially what this table is indicating. So for an actual conductor, a single conductor, we just have to keep in mind that for capacitance evaluation, the GMR is the same as the actual R . The factor of $e^{-1/4}$ need not be considered. It should only be considered in the inductance calculation. And once we have all these tables in place, we know what the GMR is, if needed, to be evaluated.

Find X'_a and X'_d at 60 hertz, add them up, and you will get the corresponding X_C . So I'll conclude this discussion with an example. This example will only discuss inductance evaluation. The same example could also be verified for capacitance evaluation. So what I have here is a three-phase 60 Hz line where the three phases are arranged in a triangular formation.

So let's say this is phase R, phase Y, and phase B. The triangular arrangement has two distances marked as 25 feet. And the other distance is 42 feet. It doesn't depend on which type of phases these spacings are, but that's the actual arrangement. And the conductors that are there for all three phases are ACSR Osprey conductors.

And we have to find the inductance. We have to use tables A. 3 and A. 4 because we're talking about inductance and verifying that. Our actual table information matches the actual calculation. Since we have a three-phase line where the spacing is different, what do you think would be the evaluation needed? Since it is a three-phase line with different spacings, we actually have to find the GMD for this particular arrangement. Once we know the GMD, we can use that GMD table or value, use Table A.

4, and find the corresponding X_d value. The GMR, however, need not be evaluated because there is no information given about the bundling arrangement, whether there is more than one bundle or not. So if GMR were to be evaluated for bundled, where there is more than one bundle or more than one conductor per phase, then GMR needs to be evaluated. Since the information is not given, we'll directly use the information from table A .

3 to find our GMR value. So let's look into that. So, table A.3, the type of conductor is Osprey. For the Osprey conductor, the GMR is 0.0284 feet. So, 0.0284 feet leads us to this particular number written over here.

For the triangular arrangement, the GMD expression is this one, which is approximately 29.72 feet. Once we know GMD and GMR, we can find the actual inductance. This is 2.24 millihenries per mile. From where 60 hertz is the system frequency, we can also find the actual inductive reactance, which numerically turns out to be 0 .

8437 ohm per mile. Now, does this number also come from the tables? Yes. From table A.3, without worrying about what the GMR is, at 60 hertz for 1 foot spacing, the value of X_d for the Osprey conductor is 0 .

432 ohm per mile. And the same is mentioned here. GMD is 29.716 feet. So if we see Table A.4, I'll have to go back a bit, 29.716 feet, which unfortunately is not part of this table. If you see this reference, you will be able to find the table. So if we look at that table, we have here the first column, which is feet, and 0 .

71706 feet; the remaining factor x has to be interpolated. So if for 29 feet, the X_d value is 0.4086 , which is a term sitting over here, and for 30 feet, it is 0.4127 , which is a term sitting over here, then the difference between these two reactances for one-foot piecing, assuming that linearity holds true, we can use interpolation to segregate or factor out this difference in terms of 0.7176 feet, which is basically what I'm doing via interpolation.

From there, we will find 0.4116 as the X_d value in ohms per mile. We added these two numbers. So from the table, X_L is 0.8436 , which closely matches 0 .

8437, the actual evaluation. The same, as I mentioned, can be verified for capacitance evaluation. Please do that. This will really help you understand better. That is all for this

particular module. In the last lecture of week five, we'll start with our fifth main module, which is transmission line models and their performance evaluation. Thank you.