Power Electronics and Distributed Generation
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Lecture - 13
Distribution system problems and examples

Welcome to class thirteen on topics in power electronics and distributed generation. In this class we will be discussing example problems; for the students in the class it is home work problems; for the students who are watching the video I would strongly recommend that you work out the problems before watching the video.

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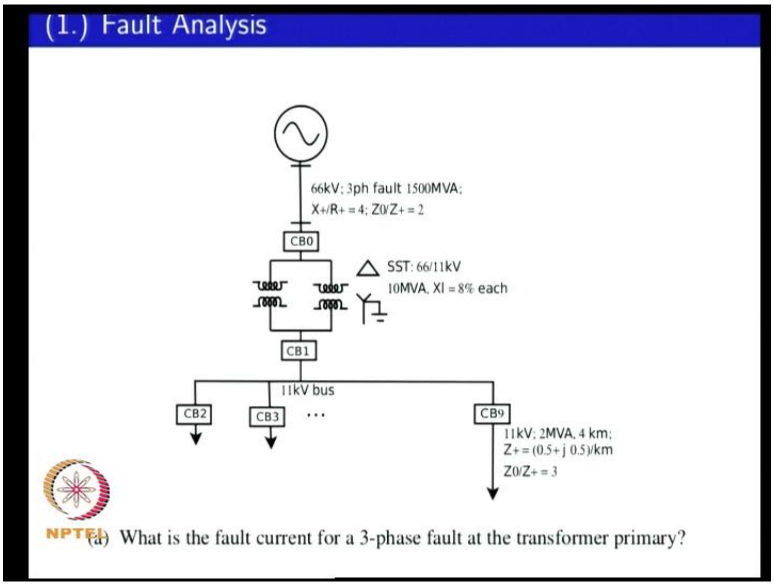

So, we will look at first problem where you have a 66 kv sub-transmission line feeding say a substation consisting of 2 transformers; you are given the fault MVA at the transformer primary 1500 MVA. You are given the X by R ratio for positive sequence, and the ratio of the 0 sequence to positive sequence impedance this is 2. You are given the rating of the transformer; it is 10 MVA, 66 KV slash 11 kv line to line. And your leakage inductance is 8 percent each.

And the output of the transformers combines to form the low voltage bus at the substation; and you have 8 feeders radiating out from the substation; each feeder rated at 2 MVA and 11 kv. So, the first problem is to determine, what is the fault current for a 3 phase fault at the transformer primary. So, say you have a fault somewhere on the primary or somewhere on the bus, primary side bus and you want to evaluate what the fault current is going to be.

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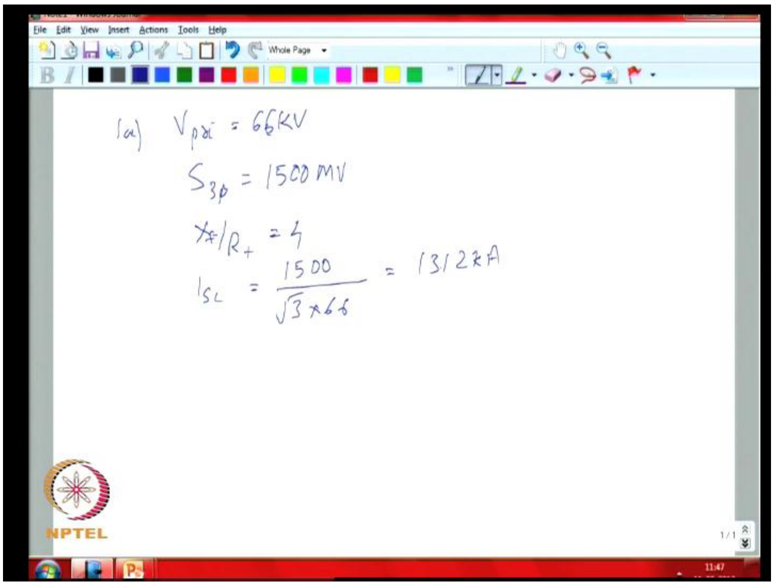

So, you are told that your primary voltage is 66 kv, and your 3 phase fault current level is capacity is 1500 MVA, and your given X by R ratio is 4. So, your short circuit current level is 1500 divided by root 3 into 66 is 13.12 kilo amps.

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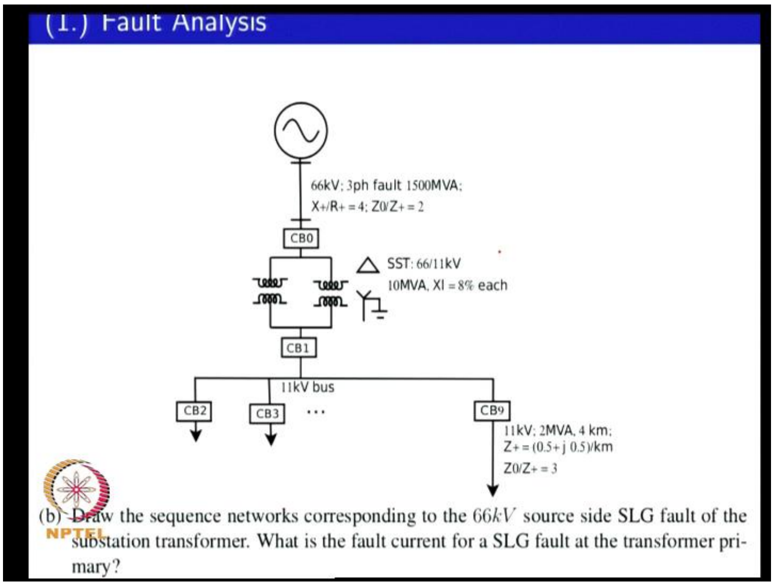

So, in the next problem you are asked to draw the sequence network and find the, what would happen if you had a single line to ground fault on the substation transformer on the primary side. So, to do this first what you have to do is get the value of the impedances X plus, R plus, and the 0 sequence impedance.

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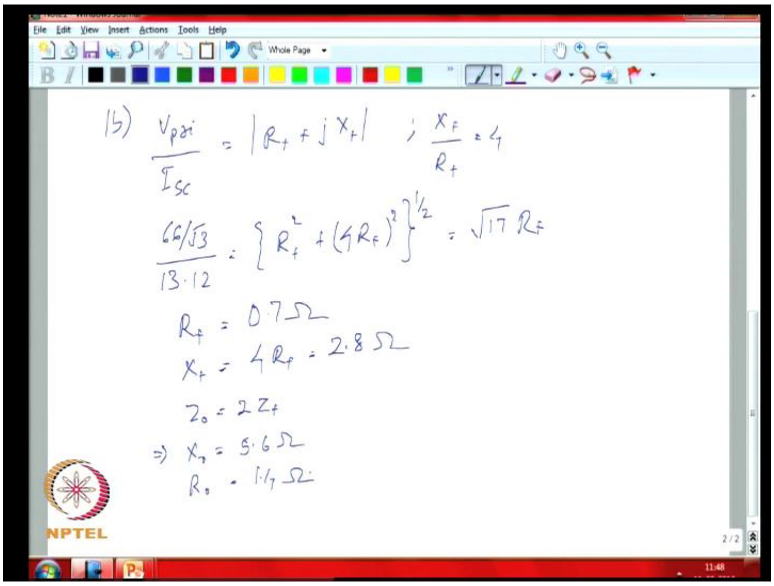

So, you have; and you are given X plus divided by R plus is 4. So, you have, in this particular example because your X by R ratio is 4. So, you can then calculate R plus; R plus is 0.7ohms, X plus is 4 R plus equal to 2.8 ohms, your Z naught is 2 Z plus. So, this means that X naught is 5.6 ohms, and R naught equal to 1.4 ohms. So, now, with this persistence and reactance parameters you could actually calculate what would be your single line to ground fault current level.

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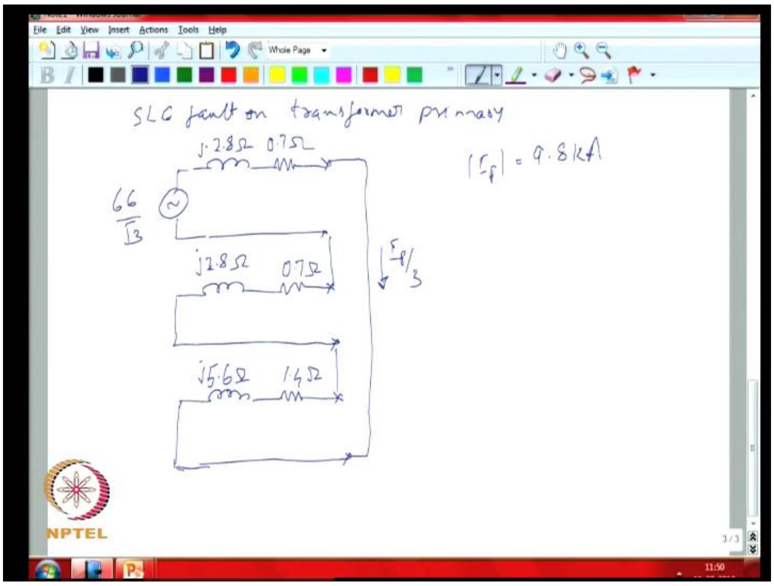

So, you could calculate your fault current level; the fault current level, I f equal to 9.8 kilo amps.

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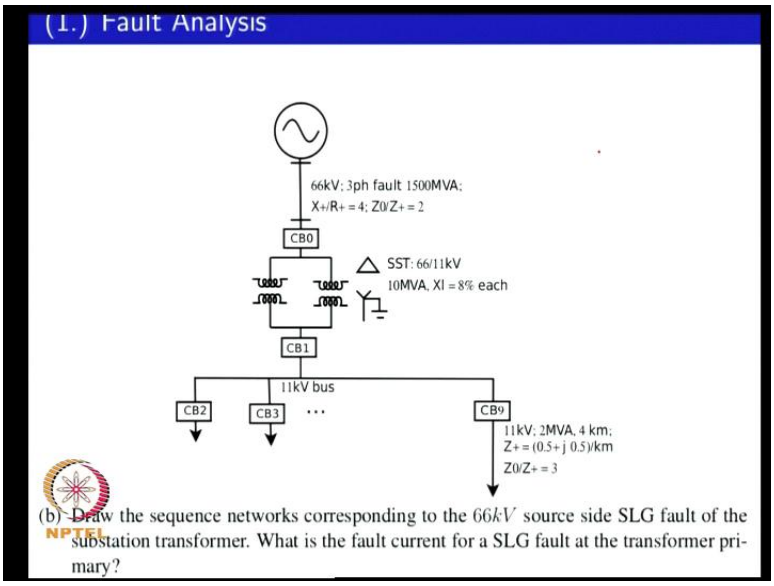

So, the next problem is find to, normalize the system, permutize the system using the 2 MVA base of the feeder.

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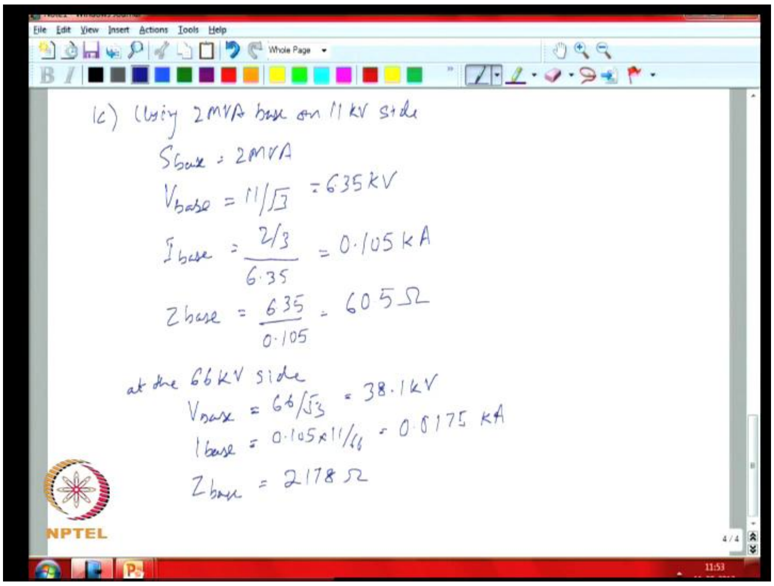

So, you can calculate your S base, V base as we had discussed earlier in class; your current base is 0.105 or 105 amps on the 11 kv side; your Z base on the primary side. If you then want to transfer parameters from your 66 kv side, the base quantities for the 66 kv side would be your V base; of 17.5 amps; and your Z base is 2178 ohms.

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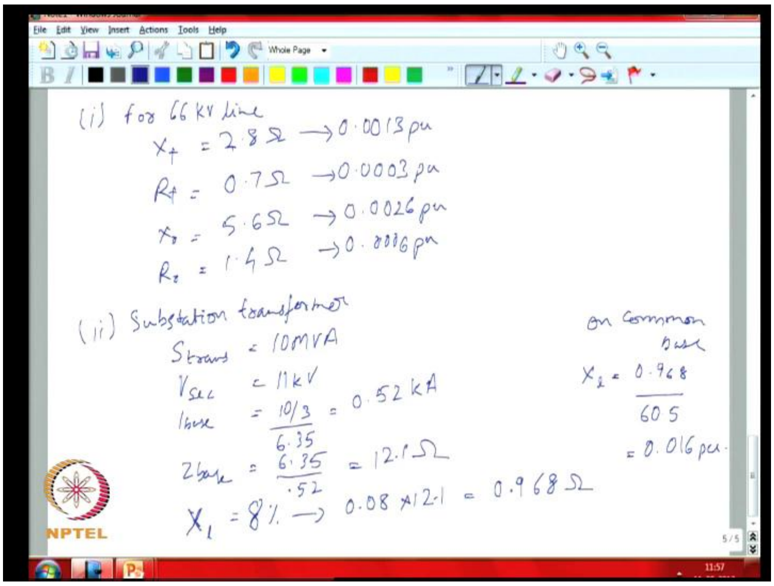

So, now, you see the base quantities depending on which side you are normalizing, you can calculate your normalize parameters. So, one- the first is for the 66 k v line, and 2.8

ohms corresponds to 0.0013 per unit. So, you can see that there is a small quantity of impedance that is being added from the 66 k v side.

Then, the next thing we can look at is the substation transformer, and the parameters are given in the problem. Your transformer rating is 0.52 kilo amps or 520 amps. So, your Z base is 6.35 by 0.52 is 12.1 ohms. So, your leakage inductance of the transformer which is given as 8 percent, this corresponds to 0.08 into 12.1. So, this is equal to 0.968 ohms. So, on that common base; so on the level under 2 MVA base, your X i is 0.968 divided by 60.5 which was our common base. So, this is equal to 0.016 per unit.

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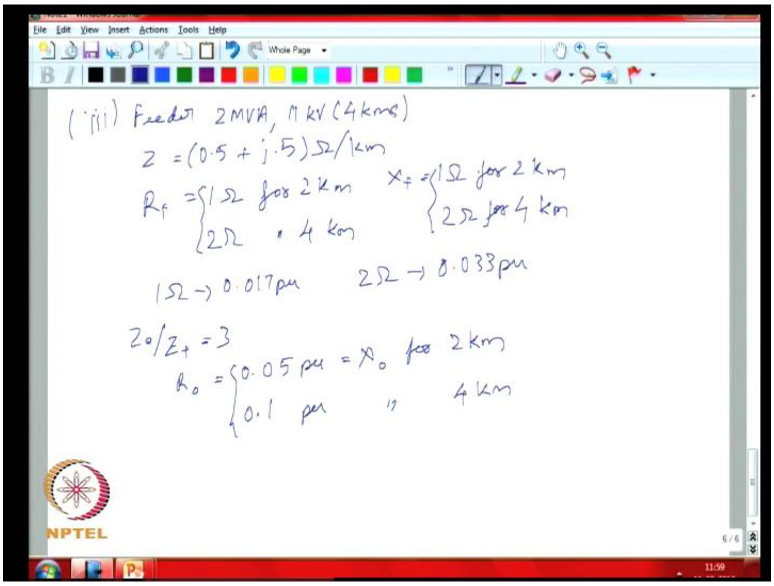

So, the third item to look at is the distribution feeder. And it is 2 MVA, 11 k v, 4 kilometers long; and your given impedance of the line is 0.5 ohms plus j.5 ohms per kilometer. So, your R plus is equal to 1 ohm for 2 kilometers; X plus is 1 ohm for 2 kilometers, and 2 ohms for the 4 kilometer.

So, you have the resistances and reactance of the line of the feeder. And so these numbers turn out to be on the common bases, your R plus 1 ohm corresponds to 0.017 per unit, and 2 ohms corresponds to 0.033 per unit. You are also told that your Z naught divided by Z plus is 3, so you have R naught equal to 0.05 per unit which is also equal to your X naught value for 2 kilometers, and 0.1 per unit for the 4 kilometer.

So, the next thing in the part of the problem is to draw a single hand diagram on the common base. So, now that you have all the parts of your problem on a common base you can do that.

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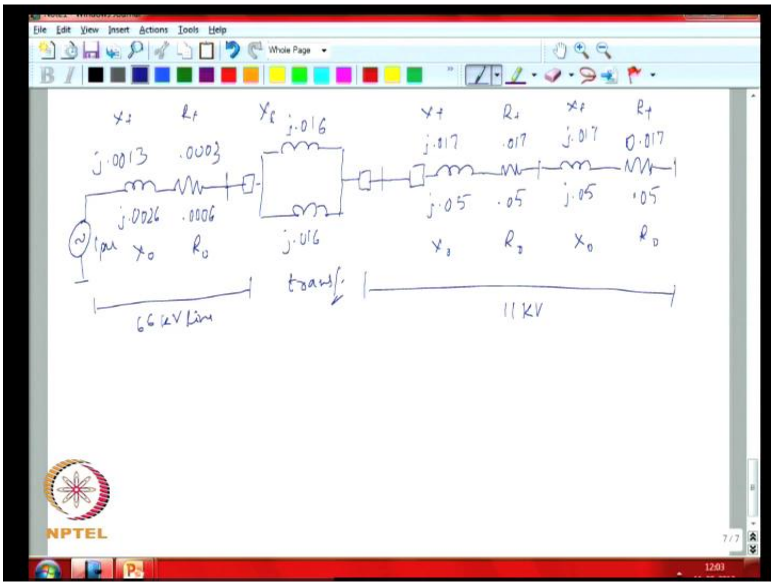

So, you have the source which is 1 per unit. So, you have your transformer primary bus, you have say breaker, you have the leakages of the transformers. So, you have the low voltage bus at the substation; then you have your breakers that protect each feeder; then you have the reactance and the resistance of each section of the line.

So, your X plus is j.0; and you could also write your X naught and R naught. So, the X naught over here is j.0026, R naught is 0.0006. So, from here to here is the 66 k v line, and you have the transformer, and then you have the 11 k v line, and it is split into 2 sections of 2 kilometers each. So, now with this single line diagram you can actually calculate your fault current levels, what happens when you have faults at different points on the line.

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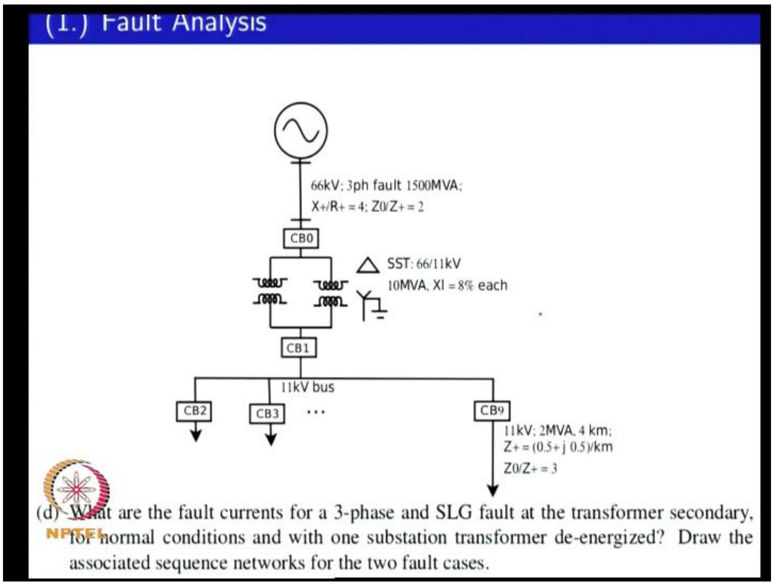

So, the question is what are the fault current levels for a 3-phase and single line to ground fault at the transformer secondary, for normal conditions being when both transformers are available at the substation; and the second case is when one of the, one transformer is de-energized may be for some repairs or maintenance, draw the associated sequence network for these 2 fault cases.

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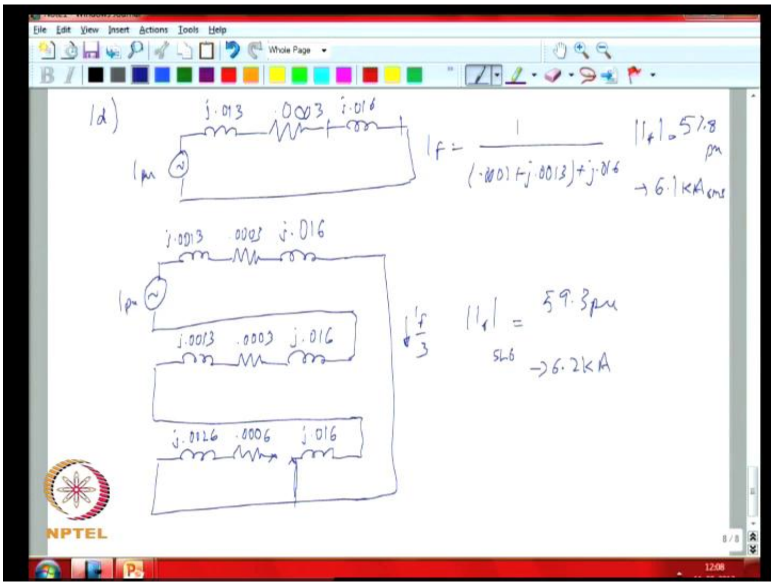

So, we will look at the first case of a fault at transformer secondary when only one transformer is present. So, you have, from what you have the single line diagram that you do, have 1 per unit source; and can calculate your fault current level I f is 1 divided by the total impedance. So, you have magnitude of your fault current is 57.8 per unit, and that corresponds to 6.1 kilo amps r m s; and this is referred to your secondary side, your common base on the secondary side.

So, for your single line to grand fault you have; so when you have a fault on the transformer secondary because your transformer is delta y, your leakage impedance path returns the fault current; it does not include the impedance on your 66 k v side. So, we will see that the resulting situation you will end up with higher residual single line to ground fault current than its 3-phase fault current.

And, you can write an expression for fault current level, I f s l g; this turns out to be 59.3 per unit. So, this corresponds to 6.2 kilo amps on the secondary side, and you can see that the fault current level for the single line to ground fault case is higher than the 3-phase fault case. And essentially the reason is that this impedance is bypass because of your delta y transformer configuration.

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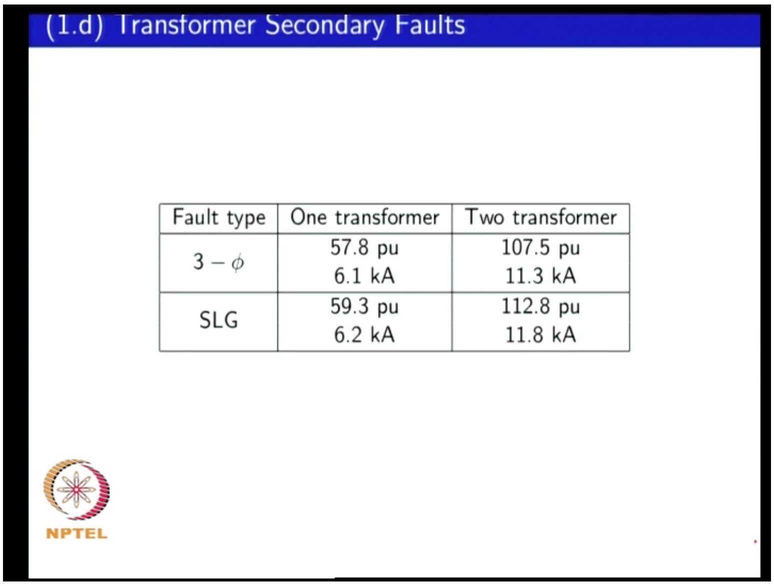

Fault type	One transformer	Two transformer
$3-\phi$	57.8 pu 6.1 kA	107.5 pu 11.3 kA
SLG	59.3 pu 6.2 kA	112.8 pu 11.8 kA

So, you could look at the next case where you have both transformers present; I will just write the result for this particular case and put it in a table, so you can see that this was what we calculated in the example that we did when there was 1 transformer. If you have two transformers you can see that the fault current level is almost doubled. And you can still see that the single line to ground case has higher current. So, if you want to protect say, circuit breakers for say fault occurring on the low voltage bus of the substation, you need to rate your system to be able to handle the highest level of fault current which would happen when both transformers are operating in parallel.

So, the next question is what are the fault current levels for a three phase and single line to ground fault at the transformer secondary, and that is what we calculated, and then what happens for faults at the 2 kilometer and 4 kilometer point on the feeder, and the procedure for doing this is similar to what we did for the transformer secondary fault. Now, you have the additional impedances of the remaining sections that you have to include in your fault current calculation. And you have to repeat it for the case when you have 1 transformer and for the 2 transformer case.

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(1.e) Feeder Faults

Fault location	Fault type	One transformer	Two transformer
Mid feeder	$3-\phi$	26.5 pu 2.8 kA	32.4 pu 3.4 kA
	SLG	19.9 pu 2 kA	21.8 pu 2.3 kA
Feeder end	$3-\phi$	16.6 pu 1.74 kA	18.5 pu 1.95 kA
	SLG	11.2 pu 1.16 kA	11.8 pu 1.24 kA

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So, I have summarized the results over here, in this table. So, you can see that as you go further away from the feeder, the fault current level is lower compared to what it was at the secondary side of the transformer because now you have the added feeder impedance. And you can still see that the fault current level for the 2 transformer case is higher not doubled, but higher than the case when we had just a single transformer.

And, for the faults at the end of the line you have fault current levels which are lower for the single line to ground fault case because now when you are looking at the single line to ground fault you now have the added feeder impedance which is dominating your numbers and reduces the fault current level. So, you can see that there can be a change in value of fault current levels depending on whether they are 2 transformers or 1 transformer at the substation. So, your protection devices should be able to handle the possible range of current levels, not just for your single line to ground fault and the 3 phase fault, but for the situation of may be switching off transformers or switching off lines which can occur on the system.

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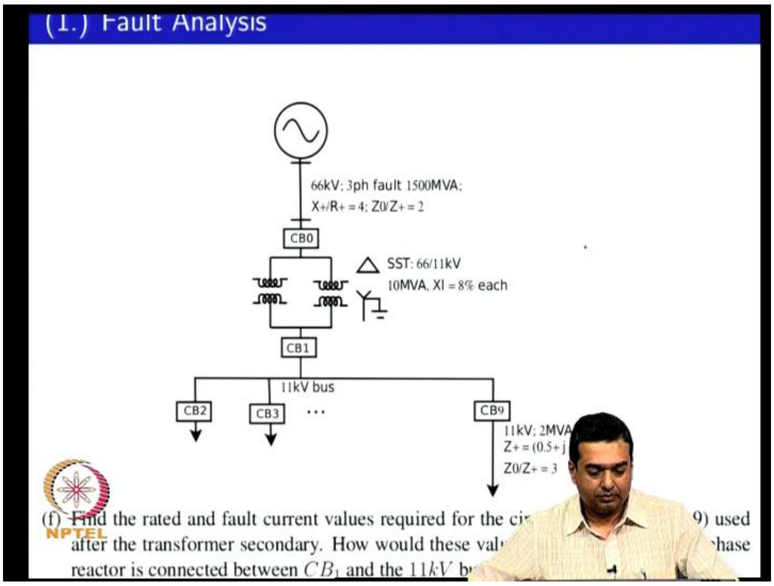

So, the next question is what would be the rated current and the fault current level of this 8 circuit breakers that are protecting the feeder, and the second part of the question is what would happen if you add a impedance in series with circuit breaker 1 on the 11 on the low voltage bus.

So, for the first problem you saw that the transformer secondary fault current level would be the same as fault current level. So, if your fault is occurring somewhere immediately after the circuit breaker the impedance of this particular section may not be that dominant which means that whatever current that we calculated for this particular point would be similar to the fault current level at this particular point, and hence you have to take the worst case.

And, from a previous calculation the worst case corresponds to a single line to ground fault when 2 transformers are present. So, you could use that as your worst case in r m s current level for interrupting your fault on the system, just immediately downstream of the substation. So, you have the rated current of each feeder which is 105 amps. So, that is the 2 m v a power level. So, your breakers have to be rated for continuous current level of 105 amps, and fault current level of 11.8 kilo amps on a r m s basis.

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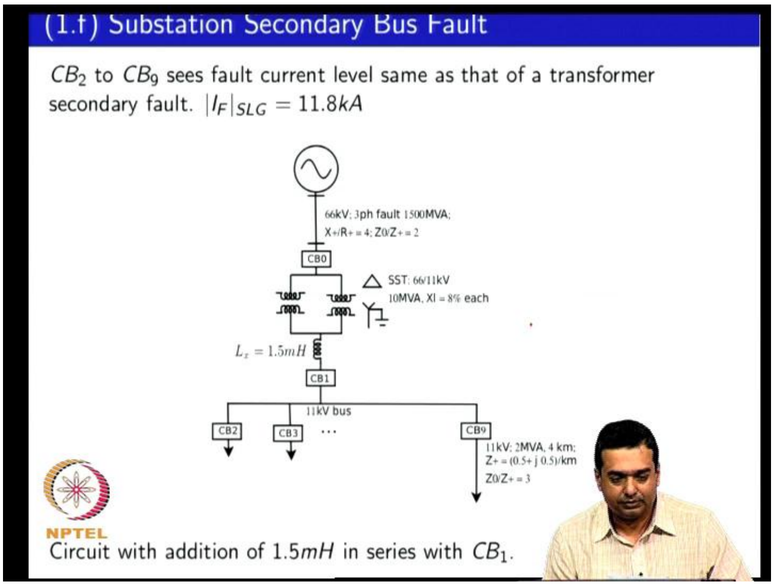

So, then the next part of the problem is what would happen if you now add a reactor of 1.5 milli Henry in series with the low voltage of the, in series with circuit breakers CB 1. So, you can see that essentially adding a reactance over here will now reduce your fault when if you have a fault immediately downstream. So, you could now do the calculations of what would be the fault current level, now which the circuit with this particular reactor.

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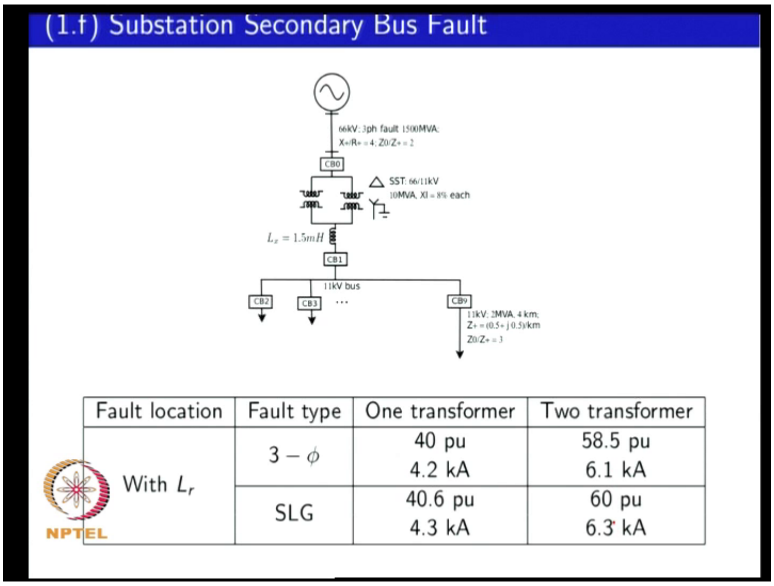

And, you can see that now which the reactor your fault current level with the 2 transformer case it reduces to about 6.3 kilo amps, with 1 transformer it further reduces. But now, compared to the previous case where you had 11.8 kilo amps as the fault current level of circuit breakers to through 9, now you have circuit breakers which need to interrupt 6.3 kilo amps.

So, you can have situations where say for example, by adding a reactor you could reduce your fault rating of a large number of breakers. So, potentially you can, might have a situation where the circuit breaker this cause savings in circuit breaker 2 through 229 might be greater than the cost of the reactor that you are adding. Of course, you will have to look at the voltage regulation by adding that reactor 1.5 milli Henry.

You should also look at the cost of that inductor, and possibly the losses introduced by adding such a component, but if it works out to be economical you could put now impedances in you circuit to ensure that your fault current level does not become excessive. So, the calculations is done for 3 phase and a single line to ground fault case, and you can see again at the low voltage bus the single line to ground fault current level is higher and but the current levels are now reduced quiet significantly.

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(1.f) Feeder Faults

Fault location	Fault type	One transformer		Two transformer	
		no L_x	with L_x	no L_x	with L_x
Mid feeder	$3-\phi$	26.5 pu 2.8 kA	2.3 kA	32.4 pu 3.4 kA	2.8 kA
	SLG	19.9 pu 2 kA	1.8 kA	21.8 pu 2.3 kA	2 kA
Feeder end	$3-\phi$	16.6 pu 1.74 kA	1.6kA	18.5 pu 1.95 kA	1.7 kA
	SLG	11.2 pu 1.16 kA	1.08 kA	11.8 pu 1.24 kA	1.2 kA

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So, the next question is what would be the effect of adding this reactance on the balance of the feeder. And you can see that now if you look at the case where you have no added inductance you have higher fault current level with the reactance, your fault current level is reduced. And one interesting thing that you might note is in the 2 transformer case with the reactor you have 2.8 kilo amps, and with the 1 transformer case with no reactor you have the same 2.8 kilo amps; this is for a mid feeder fault at 3 phase fault.

Similarly, for a single line to ground fault with the reactor when that 2 transformers you have 2 kilo amps, with no reactor with 1 transformer for the single line to ground fault you have similar current level. At the end of the feeder again you can see when the 2 transformers if you have that reactor you have 1.7 kilo amps, without that the reactor in the 1 transformer case you have similar current levels for the 1 transformer and the 2 transformer case.

So, you could now think about a situation where you are potentially adding a reactor, so that irrespective of your transformer configuration your effective impedance seen by your feeder is the same, irrespective of whether you have different switching in the substation.

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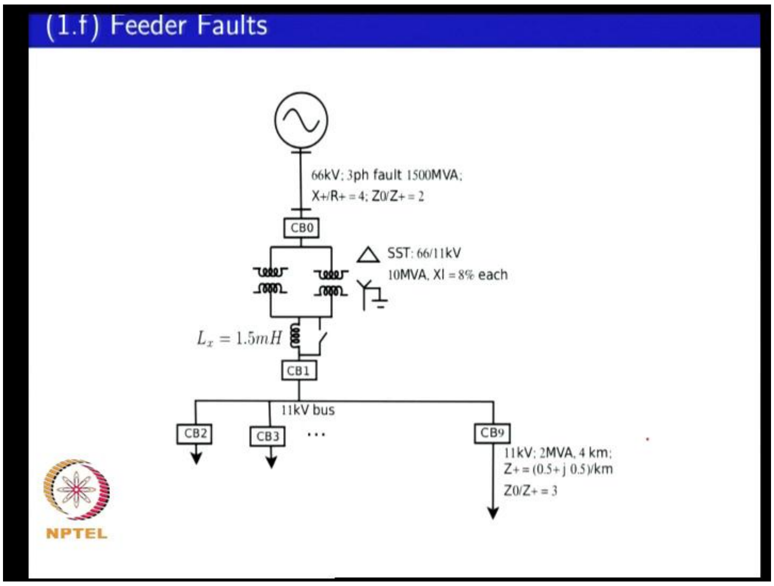

So, you could have a possible case of having keeping your fault current level the same irrespective of your 1 transformer or 2 transformer, what you could do is have the reactor when you are operating with the transformers and bypass the reactor when you are de-ionizing one of the transformer. So, essentially your effective impedance seen of your upstream impedance seen by the feeder stays similar irrespective of switching that can happen at the substation.

So, in addition to keeping the fault current level the same at level of about 66 kilo amps, you are now having the same impedance seen irrespective of whether they are 2 transformers or 1 transformer. So, benefit could be that your protection timings could not change irrespective of what is the configuration of the transformer at the substation.

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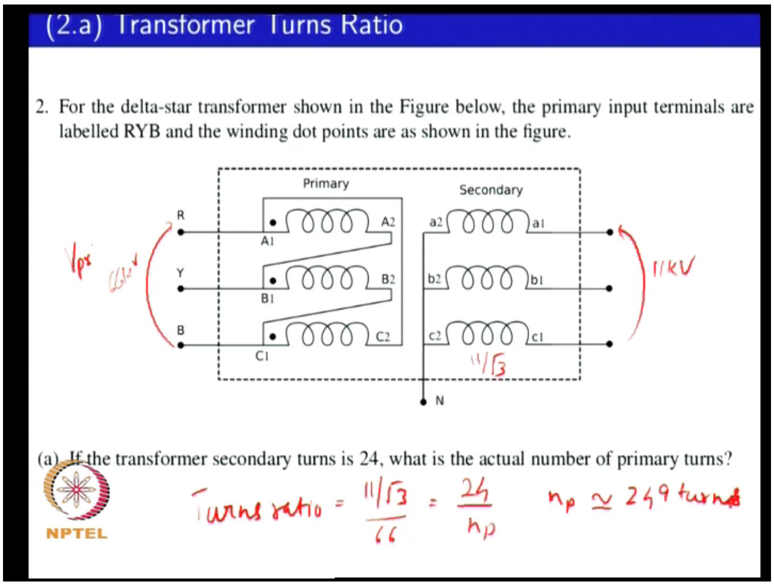

So, next problem is about delta y transformer, and the primary voltage is 66 k v, and your secondary voltage is 11 k v on a line to line basis. So, if you look at your secondary which is Wye your voltage on your winding is 11 divided by root 3. So, you could calculate; so the first question is to calculate what would be your primary turns if your secondary turns is 24. So, you have the turns ratio; your n p is about 249 turns.

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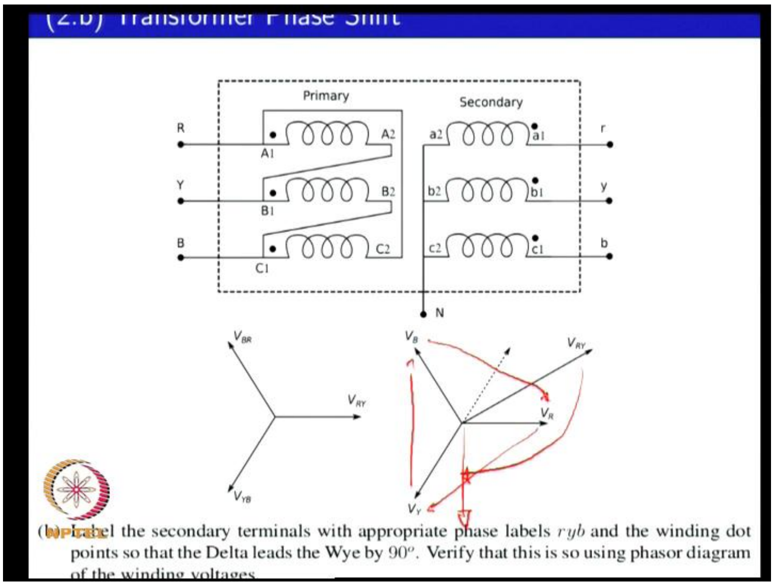

So, the next problem is then to look at the phase relationship, and you would like to label your terminals and arrange your dot points such that your delta leads the Wye by 90 degrees. And you could verify that what you are doing is correct using the phasor diagram. So, first we will just look at the situation where you have the small a 1 and the A 1 to correspond to the dot points of the primary and the secondary in correspondingly.

And, if you label your secondary turns as small r, y, b, you can draw the phases for your line to line voltage on the primary v r y, v y b, and v b r. And from your transformer dot points you know that now your voltage from, a 2 to a 1, is similar to, A 2 to A 1. So, v r y is now in phase with v r. So, you can now draw your v r, v y and v b. And then, if you look at v r y, the line to line voltage, v r y is now 30 degrees leading v r. So, in this particular case your Wye side is leading your delta by 30 degrees.

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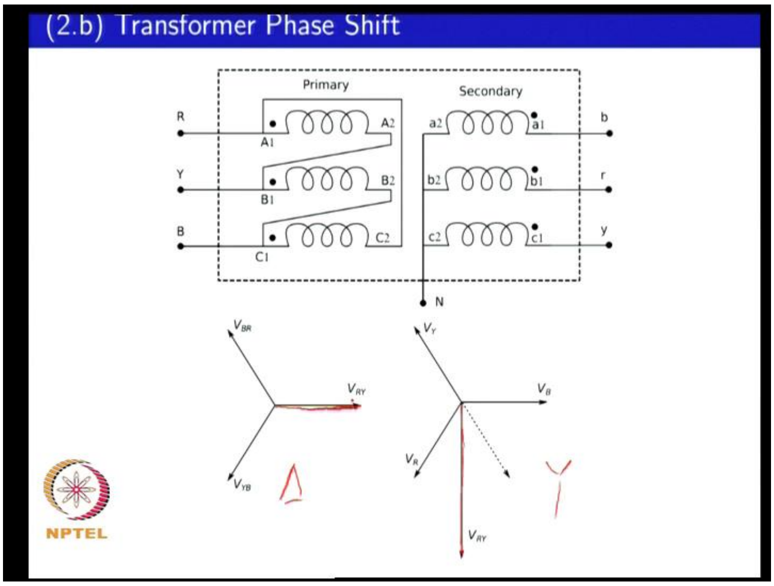

So, what we would like to have is delta leading your Wye by 90 degrees. And for that essentially what you would like to do is you could decide to have essentially your v r y brought to a position which is facing in this particular manner.

And, you could do that if you are say if you shift your v r to this particular location, v y over here and v b to this particular case as what is shown in this figure, so your terminals is now, b r y, then essentially if you then draw your phasor diagram your v r, v y and v b would be of this particular orientation. Than if you look at v r y it would be 90 degrees lagging and essentially in this particular case you will have your delta leading your Wye. So, your delta is leading your Wye by 90 degrees.

So, the next problem is to then relabel, label your secondary terminals and with appropriate dot points so that your Wye lags your delta by 30 degrees, and again verify with appropriate phasor diagram. So, first what will do is we will label our terminals r y b and change the dot points; suppose the dot point was at a 2 rather than a 1, and look at what would be the resulting phase relationship at your winding terminals.

So, essentially if you are looking at the voltage v r y on your primary side on an oscilloscope, and you are looking at your voltage v r b on the secondary side of your oscilloscope, essentially what you are trying to do is see what your phase relationship is going to be. And similar to what we did previously, in this case because now your dot point is exchanged, your v r is now oriented 180 degrees away, similarly v y and v b. So, then if you draw v r y you can see that your Wye side is lagging your delta side by 150 degrees; what you would really like is Wye side lag delta by 30 degrees.

And, to do that essentially what you could do is you want to bring essentially your v r y to this particular location. So, this is where we would like it to be to make this particular condition. And you could to that by shifting your v r, v y and v b by twice 120 degrees. So, if you rotate your terminals by twice 120 degrees you would be able to do that.

And, essentially what is done over here, you re-label your terminals y b and r; and then you will have v r located over here, v y located over here, and v b in this particular direction. And you can see that in this particular case your v r y is now, your Wye side is lagging your delta side by 30 degrees.

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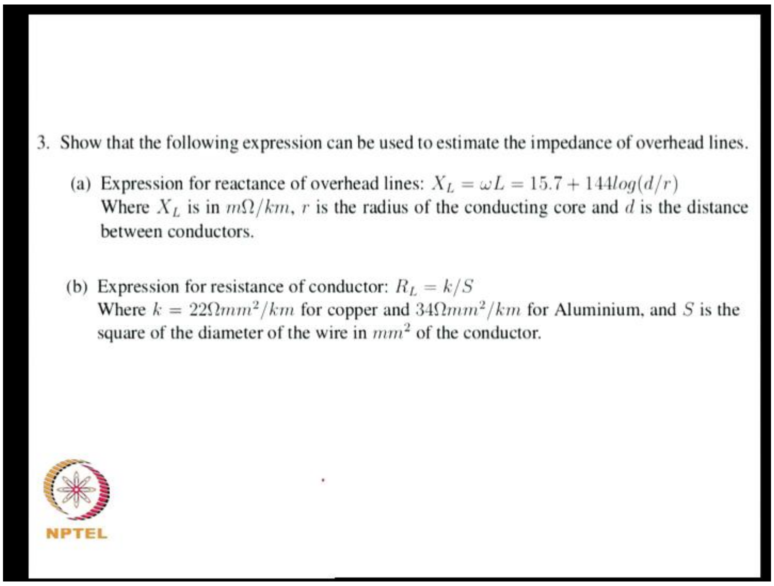

So, in the next problem we are looking at over headlines, and looking at its resistance and its reactance, and you are asked to look at obtain expressions for its reactance and resistance based on its geometric parameters. So, the expression for the reactance of over headline is something that is available from book on, textbook on power system analysis. We will just briefly go through that and write down the expression.

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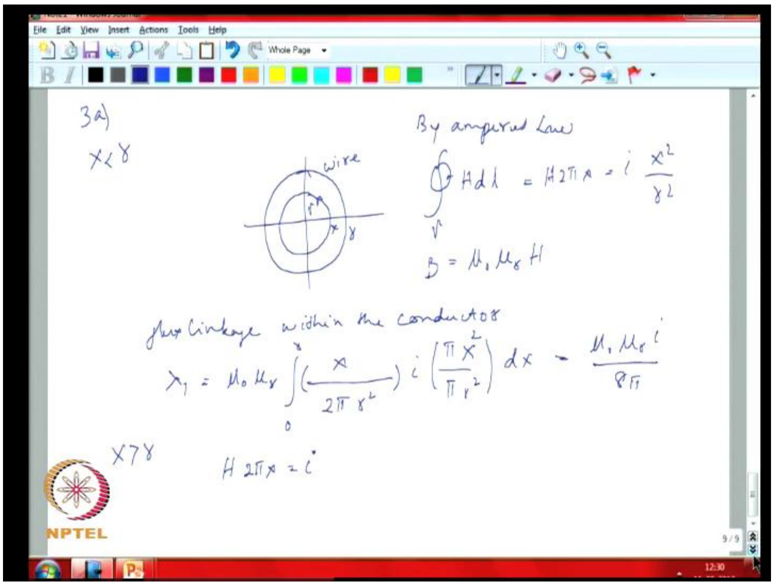

So, to determine the reactance of the line you are looking at the inductance, the flux linkage of the line. So, if you have a round conductor of radius r; and you have look at 2 cases- one is what about the flux linkage within the conductor and the flux linkage outside the conductor. So, when you look at the first case where you are looking radius x less than r. So, you are looking at the flux linkage within the conductor, and say you have a close path gamma and this is the wire on conductor.

And, by Amperes law you have H dot dl is your current enclosed which is, i into x square by r square. So, you can, you know that your b is, mew naught mew r H. So, you can calculate your total flux linkage within the conductor. And for the flux linkage you are looking at the current which is within that particular radius x. So, you have to take the actual current that links with the flux which would be, pi x square by pi r square, where i is the current through the conductor. And you get this as, mew naught mew r i, by 8 pi. Similarly, you write an expression for the case when your x is outside the conductor; you have this Amperes law.

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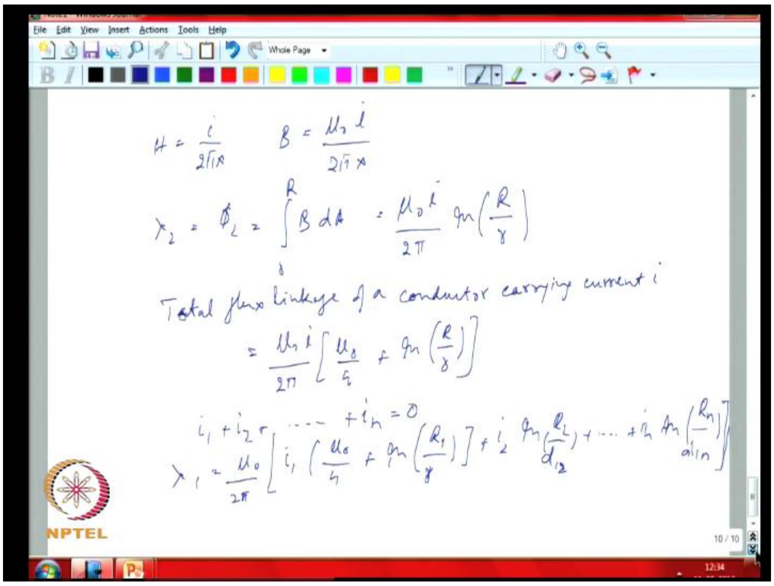

So, you have H; B is mew H; and mew is mew naught for l. So, you can then calculate your flux in cage, lambda 2, where you are considering upto radius r. And then we can look at case where, so you can look at total flux linkage for this would correspond to internal plus external. So, this is;

And, next thing you can look at the case where say you have n conductors where you have i 1 plus, i 2 plus, upto i n, where the current sums to 0; and you can calculate the flux linkage of the conductor, 1 conductor due to the total current that is being carried by all the different conductors. So, you get;

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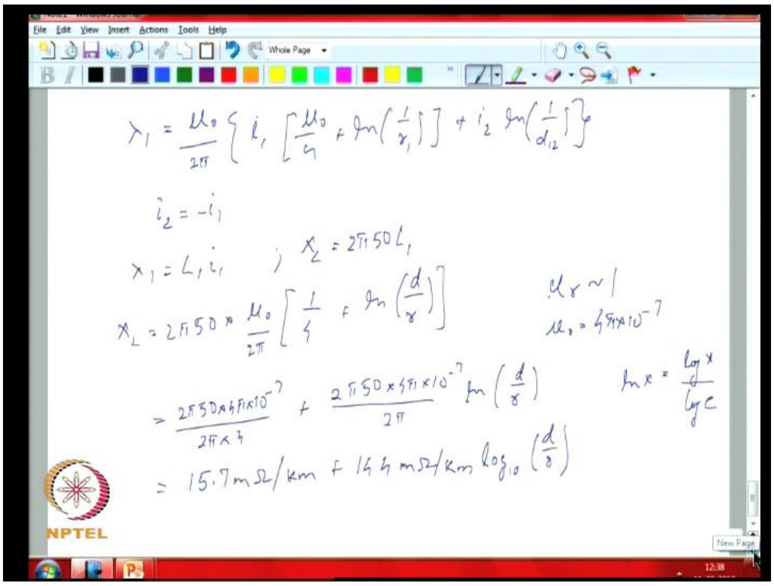

So, then you could simplify the case for 2 conductors where you have one taking the current forward and one returning the current, you can calculate the flux linkage. Again, assuming that you are taking a distance for calculating the flux upto a distance r which is quiet large compared to the distance between the conductors, you get an expression lambda 1 is; and i 2 is minus i 1. So, you can calculate your lambda 1 is, L 1 i 1; and your x l is 2 pi 50 times l. So, you can write an expression for x l.

So, you are taking, mew r to be equal to 1, for the conductor; for aluminum and copper it is close to 1. And you can write an expression for your reactance of the line based on its geometric parameters. And mew naught; so you get the expression x l. So, if you express it in terms of milliohms per kilometer, your milliohms per kilo meter has a 10, is 10 raised to the power of minus 6, so you get something such as 15.7 milliohms per kilometer plus, 144, log is log to base 10 of d by r.

So, essentially your log to, natural logarithm to log to base 10 can written as; so you substitute for that, you get this numbers. So, you can verify; now you have an expression for the reactance of the line in terms of its geometry, its diameter, and its distance between the conductors. So, next expression is to look at the resistance of the line; and here the expression is quite forward; you can look at the resistivity of the conductor.

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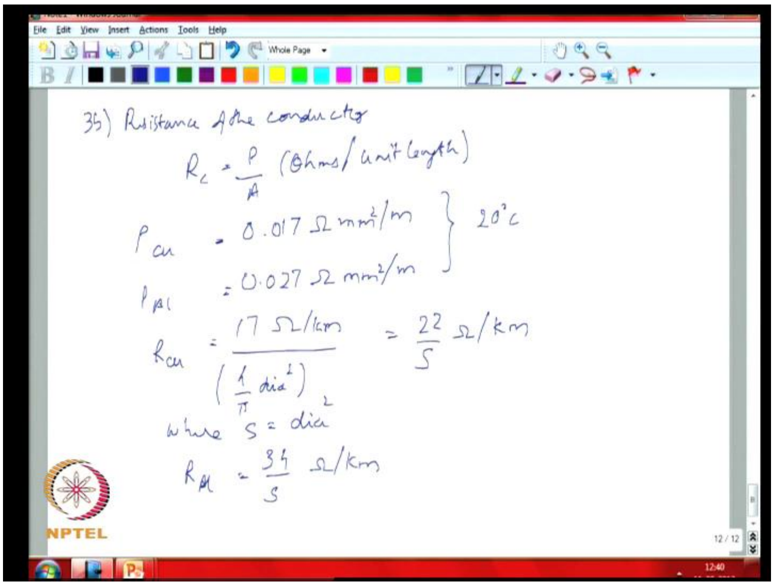

So, the resistance is by row by A, where this is in ohms per unit length. And row for copper is ohms per annum square per meter, and row aluminum; this is at 20 degree centigrade, your resistivity is v of function of temperature. And so you can write your resistance say, of a copper conductor, now in ohms per kilometer, by your area which is 4 by pi into diameter square; where this is diameter square, so that is essentially the occupied area of the wire.

So, even if it is a wrong conductor you put it on a cable tray it will take some, occupy some area. And similarly you can calculate your r for your aluminum conductor is 34 by s ohms per kilometer. So, now, you have your resistance and reactance of the line per on a, per unit distance basis, and you can make use of that to look at what your x by r ratios would be. We will do this and wrap up the example problems in the next class.

Thank you.