Power System Engineering
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Lecture – 11
Cables (Contd.)

So next we will come to the thermal resistances right. So, insulation of first 1 you consider insulation of single core cable right.

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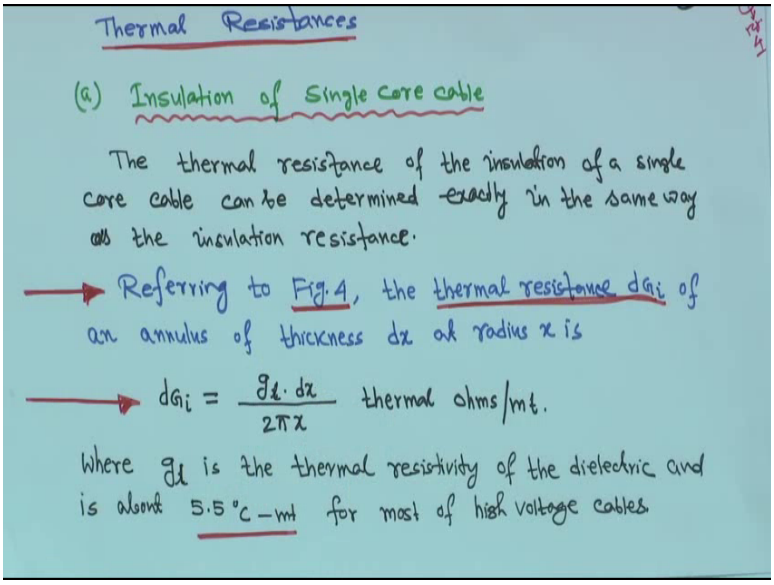

The thermal resistance of the insulation of a single core cable it can be determined exactly in the same way the as the insulation your resistance right. So, referring to figure 4 right just hold on i will show you the figure 4 this 1, referring to your figure 4 the cross section of a single core cable this figure only referring to this figure right. So, that the thermal resistance d G i of annulus annulus of thickness d x at radius x i mean if you consider this.

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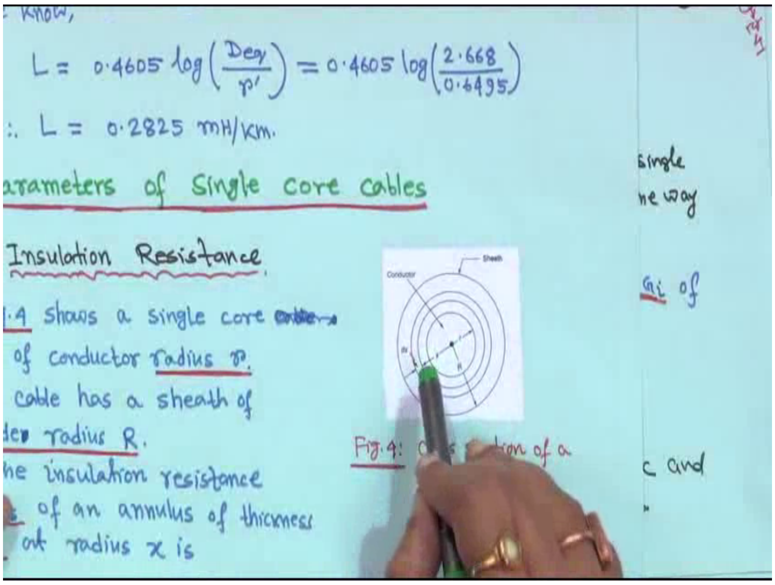

If you consider this the same d x at a distance a x right annulus thickness d x and at a distance a x that is your what you call that that thermal resistance d G i G is the capital 1 can be written as G l into d x upon 2 pi x it is your represented at thermal ohms per meter where G l is the thermal resistivity of the dielectric is about values about 5.5 degree centigrade meter for most of the high voltage cables right.

So, this is your thermal resistance now the thermal resistance this thing d G i.

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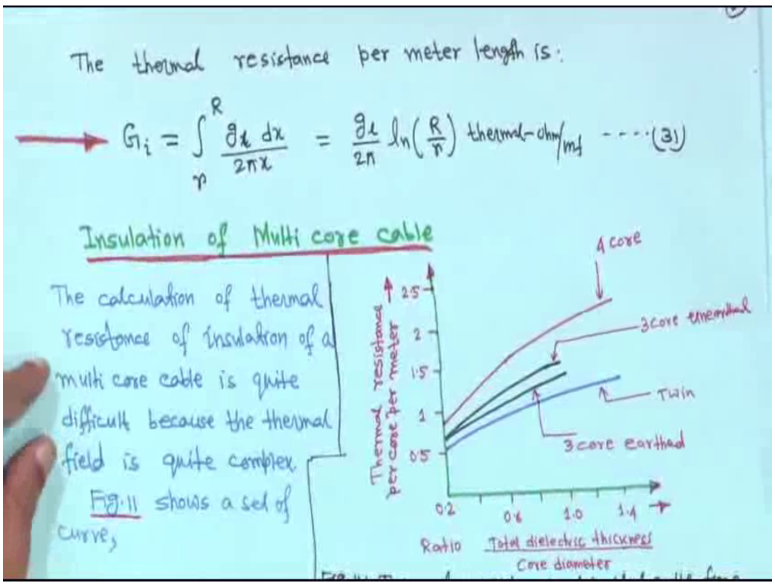

So, thermal resistance per meter length that G i capital G i you integrate this 1 you just integrate you integrate this 1 you integrate this 1 then it will be small r to capital R this figure this figure you think that small r that is the your conductor radiance to the external radius r small r to capital R right it will be r to r G l into d x upon 2 pi x. So, it will be G l upon 2 pi l n capital R upon small r thermal ohm per meter right.

So, this is your G i now next is insulation of your for multi core cable. So, in this case the calculation of thermal resistance of insulation of multi core cable it is very difficult 1 because the thermal field is quite complex right. So, these are this figures I have taken from somewhere right this y x is thermal resistance per meter per core per meter. So, it is 0.5 to 2.5 and this side some ratio is equal to the total dielectric thickness by your upon core diameter, this side is this ratio this this x axis is the ratio is plotted this is total dielectric thickness upon core diameter right.

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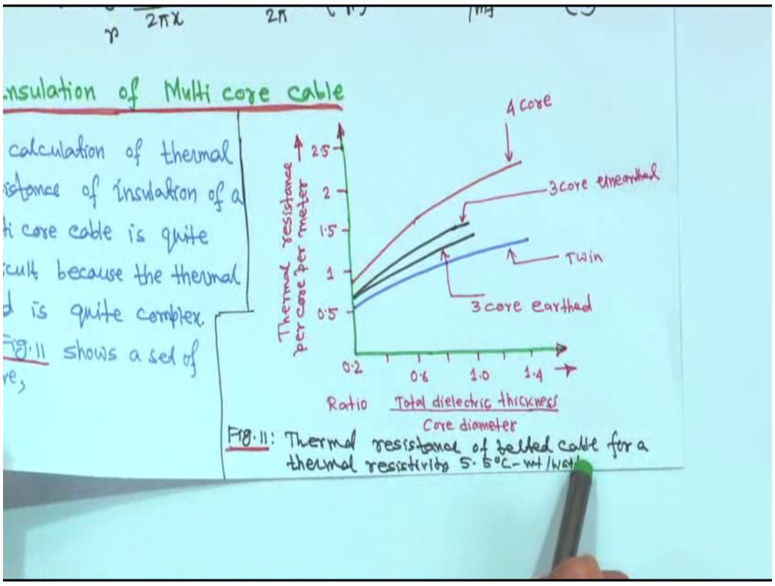

So, thermal resistance of belted cable for a thermal resistivity of 5.5 degree centigrade meter per watt. So, in this case for core cable this is the read 1 for 3 core your 3 core earthed 1 I mean 3 core grounded that earth ed 1 it is the black 1 upper black 1 and 3 core earthed this is this is unearthed sorry this is unearthed this is 3 core unearthed 1 and the bottom 1 is 3 core unearthed and this is twin right. So, double core. So, this is actually from that what you call from that experimental data with these graphs or these figures are taken from somewhere. So, for particularly for the classroom studies or other thing these equations of this graph cannot be given. So, if any numerical anything is there data will be provided. So, this is your figure 11 right so.

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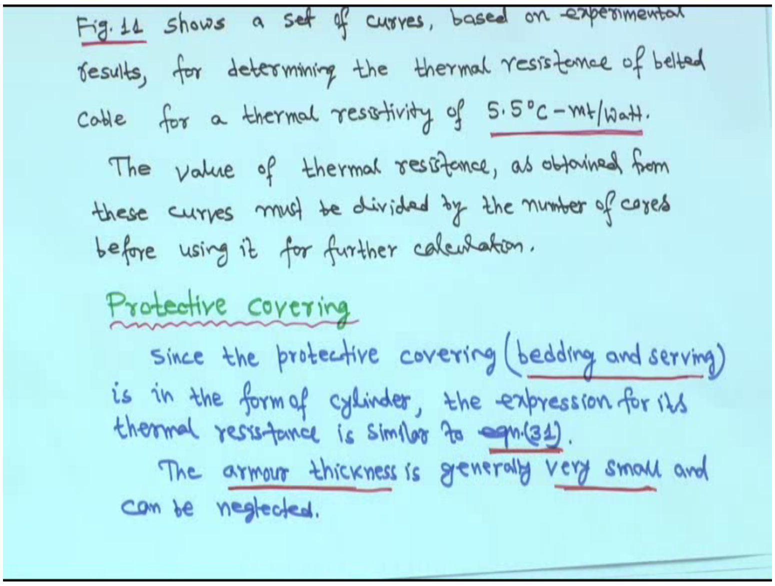

This that is why this figure 11 just another 1 I have written that is shows a set of curve based on a experimental result for determining the thermal resistance of belted cable for thermal resistivity of 5.5 degree centigrade meter per watt right.

So, the value of the thermal resistance as obtained from these curves must be divided by the number of cores before using it for further calculation because the here a this x axis it is actually x axis is the ratio right, this ratio is equal to actually this is actually ratio this is x axis. So, it is total dielectric thickness divided by core diameter. So, direct core for mathematical formula cannot be given, but this curve we can use I mean if you know this x axis this total dielectric thickness by core diameter if you know this 1 you can easily find out the other quantity right which is along the y axis right.

So, now protective covering. Since the protective covering is the bedding and serving of the cable right is in the form of a cylinder. So, the expression for it is thermal resistance similar to equation thirty 1 I mean it is same similar type of expression for this equation 31 right.

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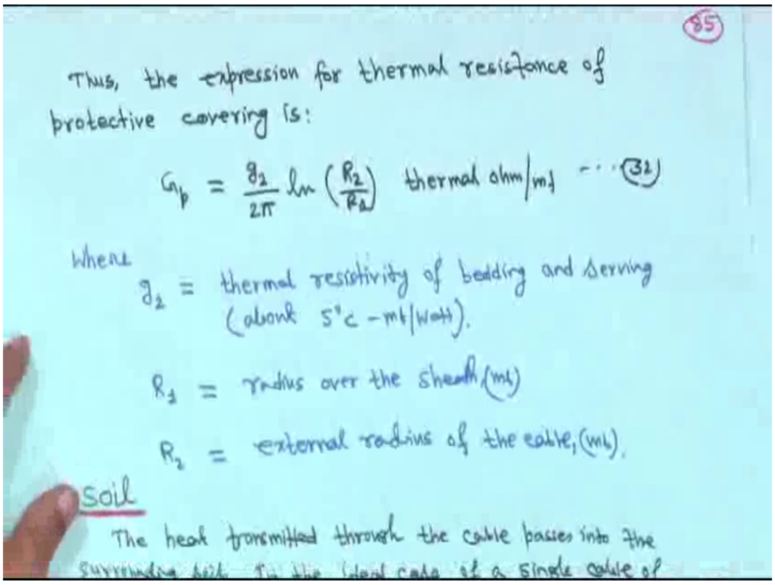

So, in that case the armour thickness is generally very small and can be neglected. So, here neglected the armour of thickness right otherwise it is similar to that therefore, thus the expression for the thermal resistance of protective covering is your G P P stands for protective covering.

So, g 2 upon 2 pi l n R 2 upon R 1 thermal ohm per meter same equation 31 analogues to that only g 2 and R 2 R 1 is different g 2 is the thermal resistivity of bedding and serving about body is 5 degree centigrade meter per watt then R 1 is radius over the sheath that is in meter and capital R 2 is external radius of the cable that is also in meter right next 1 will be the soil.

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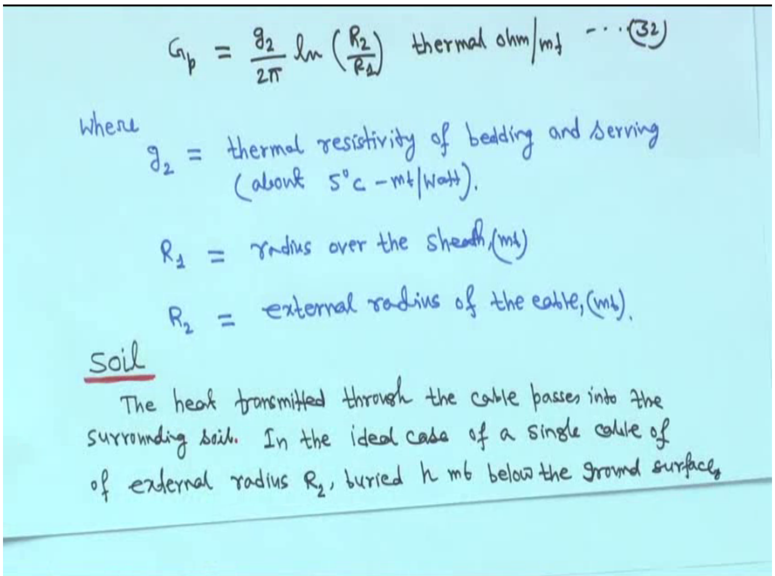

The heat transmitted through the cable passes into the surrounding soil this is understandable right because if cable is buried, in the cable or even this thing and that your what you call that heat transmitted through the cable passed into the surrounding soil in the ideal case of a single cable of external radius R 2 buried 8 meter below the ground surface. Suppose you might have seen the cable laying and the ground right if the external radius R 2 buried h meter below the ground surface in the I mean you assume that cable radius is your what you call R 2 and buried h meter below the ground surface in a soil of constant thermal resistivity say; g 3 the thermal field exactly analogous to the electric field having only dimension is different for various quantities because it is analogous to electric field between a single overhead line conductor and the ground plane right.

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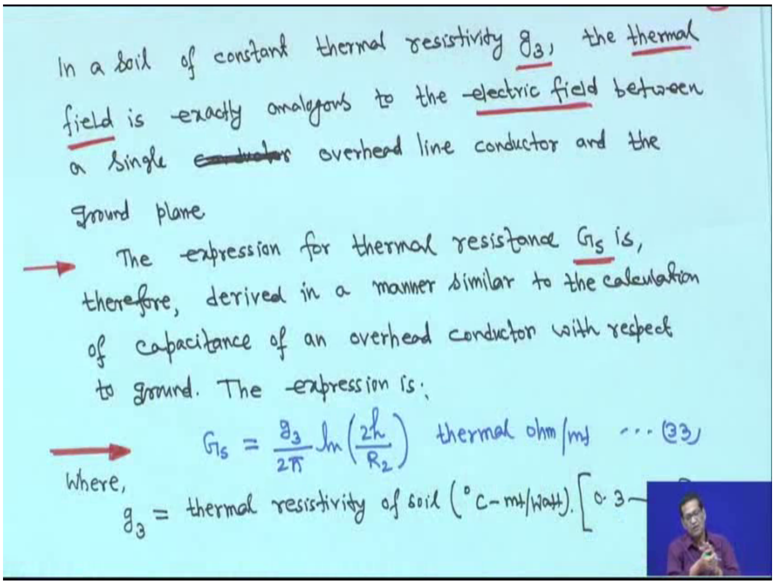

So, the expression for thermal resistance G s that if for soil is therefore, derived in a manner similar to the calculation of capacitance of an overhead conductor with respect to ground, I mean in the in our in the capacitance topic i mean to find out the capacitance of overhead conductor right it will use the same expression right, but analogous to that therefore, directly we can write the expression G s is equal to g 3 upon 2 pi l n 2 h upon R 2 capital R 2 thermal ohms per meter.

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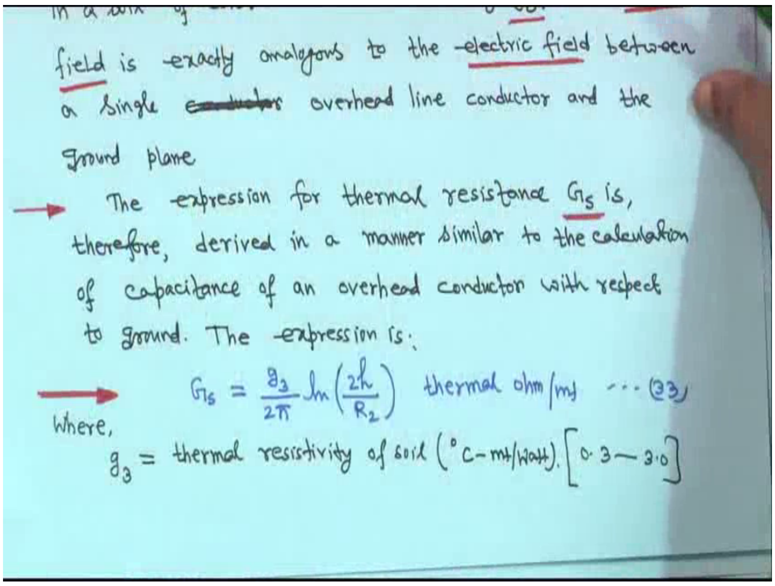

Right where g 3 is equal to thermal resistivity of soil in unit is degree centigrade meter per watt and it is value actually varies in between 0.3 to 3. So, this is equation 33. So, when you are calculating the you know the current rating of a cable you have to consider mane things.

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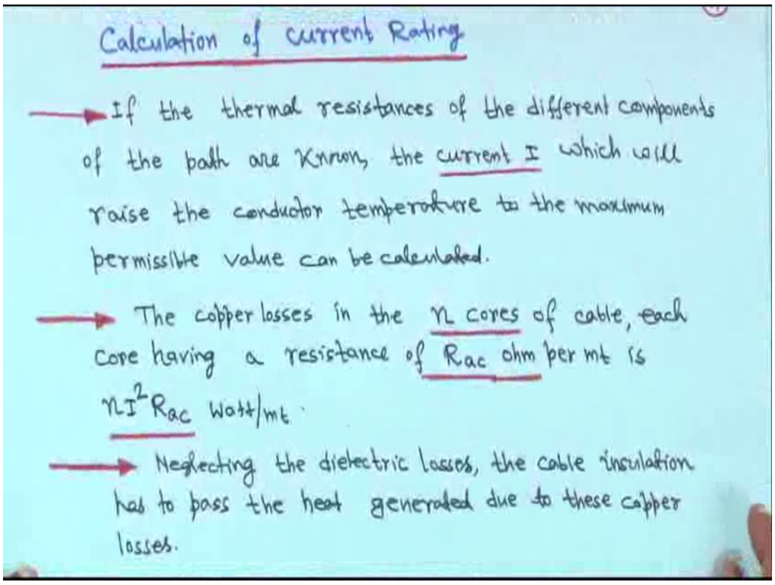

Now, the calculation of current rating you have to little bit you have to understand here and you have to compute many things, if the thermal resistencies of the different components of the path are known the current I which will raise the conductor temperature to the maximum permissible value can be calculated. Now the copper loss in the n, cores of cable suppose you have a n number of cores right each core having a resistance of R a c ohm per meter say that; that means, total loss is i square R a c and you have n number of cores. So, multiply with n. So, it will n into i square into R a c watt per meter right. So, neglected the dielectric for example, you just neglect dielectric loss the cable insulation has to pass the heat generated due to this copper losses so; that means, all these things you have consider for a cable right.

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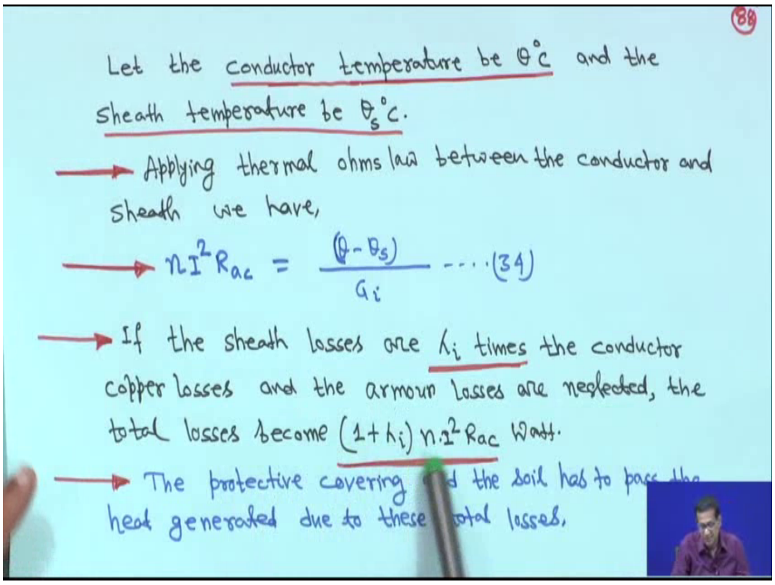

So, if you assume if we have assume that that they will conduct a temperature with theta degree Celsius and the sheath temperature be theta s degree Celsius theta s stands for sheath right. So, applying thermal ohms law between the conductor and the sheath we have n into I square R a c is equal to theta minus theta s divided by capital G suffix i G i right.

So, I mean just between just clear with this thing what you are doing actually that is thermal ohm law between the conductor and the sheath. So, n into i square R a c is equal to theta minus theta s upon G i. So, now, if the sheath laws are lambda i times the conductor right copper losses and the armour losses are neglected the total losses become 1 plus lambda i into n i square R a c, because you are assuming sheath loss is a lambda i times the conductor copper losses that is lambda into this 1 therefore, total losses will be n i square R a c plus lambda times n i square R a c. So, that is why you are writing it is 1 plus lambda i n i square R a c watt right.

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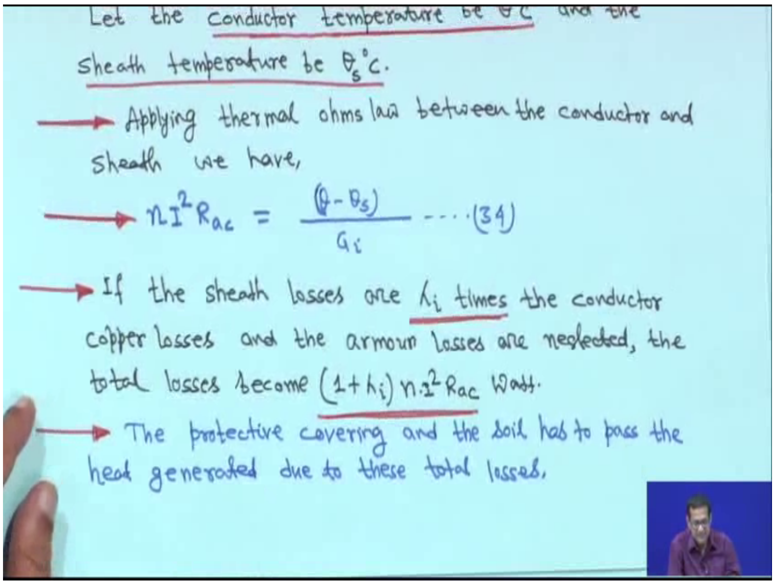

Therefore, the protective covering; protective covering and the soil has to pass the heat generated due to this total losses loss means heat will generated right, when you have all loss means elliptical circuit means heat will generated and the protective covering and the soil has to pass the soil right generated due to this your what you call total losses.

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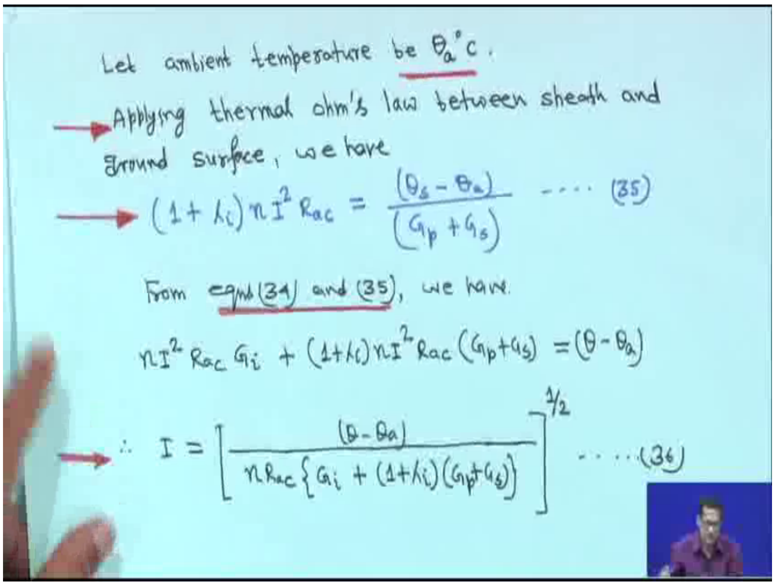

Now, let the ambient temperature be theta a degree Celsius it a stands for ambient right. So, applying thermal ohms law between sheath and the ground surface we have it is between the sheath and the ground surface means both G p and G s both are coming right. So, 1 plus lambda n I square R a c is equal to theta s minus theta a divided G p plus your G s right. So, in the just 1 just 1 minute, this is actually where what you call that we are considering both sheath and the protective covering that is G p plus G s.

So, this is your this way you can write now equation 34 and 35 from equation 34 and 35 you can you can make it like 34 is 34 is this equation this theta 4 is your n I square R a c theta minus theta is G i is equal to 34 and if you will get, I will show you how you are getting n I square R a c G i plus 1 plus lambda I into n I square r a c bracket G p plus G s is equal to theta minus theta actually just to just for your clarification I am writing this 1 that this equation that equation 35 equation 35 you can write like this that your G p plus G s multiply cross multiply then 1 plus lambda i then n I square R a c is equal to theta s minus theta a right this you can write.

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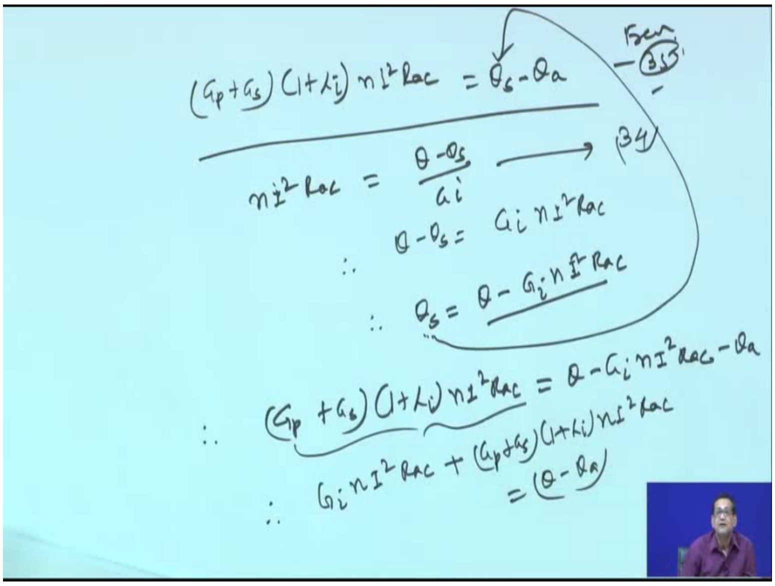

So, now in this equation in this equation 34 it is n I square R a c is equal to theta minus theta s G i; that means, this equation that is your this is your equation 35 we are getting for equation 30, we are getting and from 34 this is from equation 35 from 34 this equation we can write n I square R a c is equal to theta minus theta s divided by G i; that means, theta minus theta s is equal to G i then n I square R a c this equation actually from 34 right.

Therefore in this equation in this equation you look if you look in this equation theta s is not there; that means, you have to eliminate theta; that means, theta s is equal to theta minus G i then n then i square then R a c, this is the thing this theta s this theta s you bring it here this theta s you bring it here. Therefore, G p plus G s then 1 plus lambda i then n I square R a c is equal to theta and we are substituting replacing theta s by this 1 theta minus G i, then n then I square, then R a c minus theta a therefore, this G i n I square R a c bring to the left hand side therefore, G i n then n then I square then R a c plus this all this term G p plus G s 1 plus lambda i then n then I square then R a c is equal to theta minus theta a right.

So, that is why from this equation from these 2 equations just hold on from these equation we are getting from equation 34 and 35 we are getting that this equation that your what you call this n I square R a c G i plus 1 plus lambda i n I squire R a c G p plus it is a minus just now I have shown you.

Therefore from this equation i will be theta minus theta a divided by n R a c n R a c will be common from both in bracket G i plus 1 plus lambda i into G p plus G s it is i square. So, it is to the power half square root. So, this is equation 36 it is the expression of i, but now question is that you have include also the effect of dielectric loss. So, effect of dielectric loss if we include is equation will be modified.

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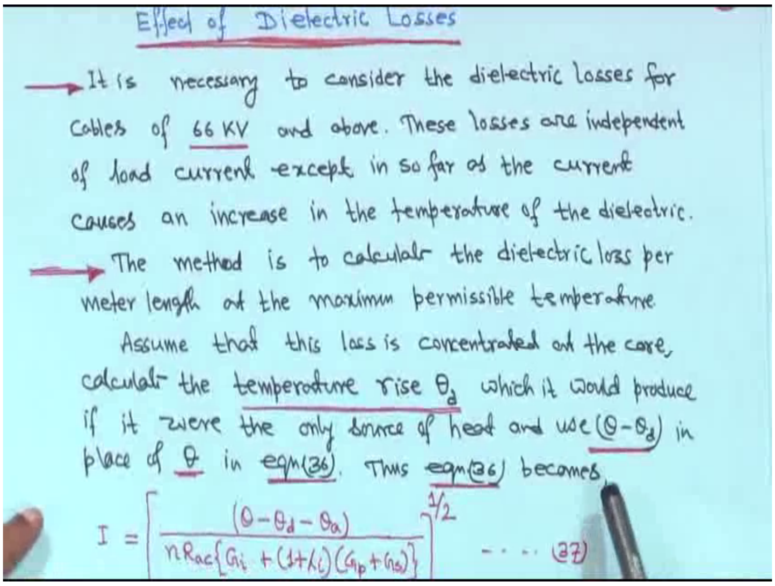

So, because it is necessary to consider that dielectric loss for cables of 66 k v and above these loses are independent of load current except in so far as the current causes an increase in the temperature of the dielectric. So, the method is to calculate the dielectric loss per meter length at the maximum permissible temperature. Now you assume that this loss is concentrated at the core calculate the temperature rise theta d which it would produce if it were the only source of heat and use theta minus theta d in place of theta.

Now, because actually meaning is that dielectric loss will be there right and we are assuming that this dielectric loss actually concentrated at the core of the cable. Therefore, because of this thing if the temperature varies say theta d right then what we can do is in the this this meaning that in this expression we will replace theta by theta minus theta d.

So, that; that means, that in equation 36 becomes now. So, everything will remain same only theta you replace by theta d it will be theta minus theta d minus theta a and numerator denominator as same as it is like equation 36 and to the power half that is square root so 37. So, effect of I mean it is equivalent rise at the temperature due to dielectric loss and that we are considering so; that means, all these things you have to consider for that your what you call for calculation of the current rating of the cable. So, each; that means, in cable different loses are there. So, that will cause the temperature rise. So, there is maximum permissible limit for the what you call for the cable rate temperature; that means, your current rating has to be restricted till it achieves your maximum current rating not more than that right.

Next we will take an example.

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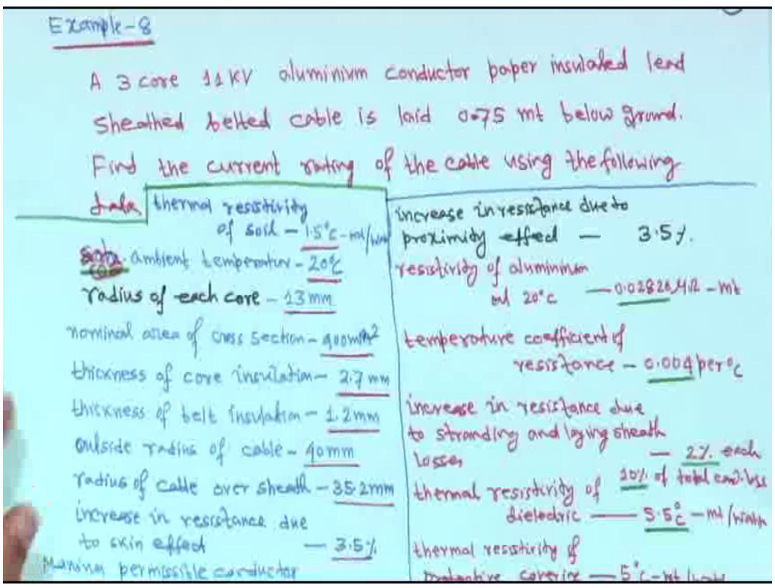

This this example is a too long I have to explain it you all the data law means data that you call that data are given then how things can be solved suppose A 3 core 11 k v aluminium conductor powering your paper insulated lead sheathed belted cable is laids 0.7 5 meter below ground find the current rating of the cable using the following data look. So, many huge data are given, but things are simple for example, thermal I am just uttering all these things 1 after another look thermal resistivity of soil is given 1.5 degree centigrade meter per watt.

Then ambient temperature is 20 degree Celsius radius of each core it is given 13 millimetre; that means, 1.3 centimetre nominal area of cross section is 400 millimetre square this is millimetre square thickness of the core insulation is 2.7 millimetre right. Thickness of belt insulation 1.2 millimetre outside radius of cable is 40 millimetre that is 4 centimetre radius of cable over sheath 35.2 millimetre that is 3.5 2 centimetre in increase in resistance due to skin effect it is 3.5 percent you have to consider this maximum permissible conductor temperature is 65 degree Celsius.

Note that are here increase in resistance due to proximity effect 3.5 percent is taken the skin effect proximity all sort of things you have studied right. So, resistivity of aluminium at 20 degree centigrade it is 0.0 2 8 2 6 micro ohm meter and temperature coefficient of resistance 0.0 0 4 per degree Celsius. The increase in resistance due to stranding and laying sheath losses 2 percent each that also you have to consider and 10 percent of total conductor loss, this is 10 of total conductor loss, then thermal resistivity of dielectric it is given 5.5 degree Celsius meter per watt and one more thing is there thermal resistivity of protective covering that is 5 d 5 degree centigrade meter per watt. So, problem is this much, but data is so 1 2 3 4 5 6. So, 9 10 more than your what you call 15 or 16 parameters are given right, but calculations are straight forward data is not a problem here. So, in this case that dielectric loss is neglected. So, neglect the dielectric loss.

So, conductor resistance right it is Kelvin your this thing resistivity of aluminium is given 0.02826 micro ohm meter this is given and cross section also is given 400 millimetre square

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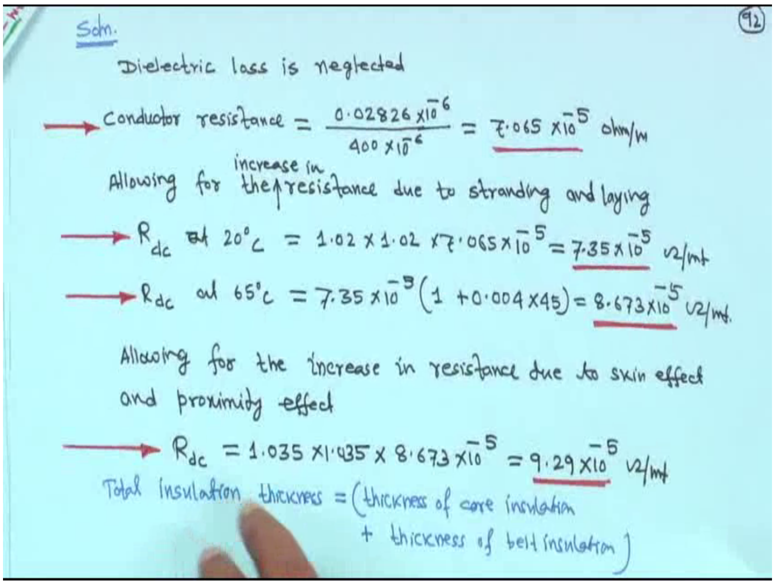

So, thermal conductor resistance we are taking you know that rho l by a, but question is that why a is given a is given l is not there; that means, it will come in terms ohm per meter it will come. So, convert everything with the appropriate your unit particular in terms of meter or meter square right. So, it will it will be 7.0 6 5 into 10 to the power minus 5 ohm per meter right. Now arriving for the increase in resistance due to stranding and laying that is p d c at 20 degree centigrade given 2 percent. So, what 2 2 percent each so stranding for 2 this things is given no here data is here, that is stranding and laying sheath losses right 2 percent each that is why it is multiplied to 1.0 2 into 1.0 2 into 7.0 6 5 into 10 to the power minus 5 it comes about 7.3 5 into 10 to the power minus 5 ohm per meter.

Now, R d c at 65 degree Celsius in this case the temperature coefficient of resistance is given 0.0044 per degree Celsius this is given therefore, R d c at 65 degree Celsius 7.35 into 10 to the power minus 5 in bracket 1 plus 0.004 and temperature difference is your this thing at a ambient temperature 20, 20 degree and permissible conductor temperature rise is 65, this ambient temperature 20 degree Celsius and maximum permissible conductor temperature 65.

So, difference is 65 minus 20 is equal to 45 degree Celsius that is why this 1 is multiplied by 45 right is equal to 8.673 into 10 to the power minus 5 ohm per meter. Now allowing the allowing for the increasing resistance due to skin effect and proximity effect, it is given that your data is given increase in resistance due to skin effect it is 3.5 percent proximity effect also you have to consider that is 3.5 percent right.

So, due to skin effect and proximity effect both you consider right because here it is given proximity effect increase due to proximity of 3.5 percent due to skin effect 3.5 percent; that means, this R d c multiplied twice 1.035 into 1.035 into 8.673 into 10 to the power minus 5 this comes 9.29 into 10 to the power minus 5 ohm per meter.

Now, total insulation thickness is equal to thickness of core insulation plus thickness of belt insulation right, both are given your thickens of core insulation and thickness of belt insulation. So, it is your thickness of core insulation 2.7 millimetre your 7 millimetre and thickness of belt insulation 1.2 millimetre; that means, the total insulation thickness will be 2.7 plus 1.2 is equal to 3.9 millimetre.

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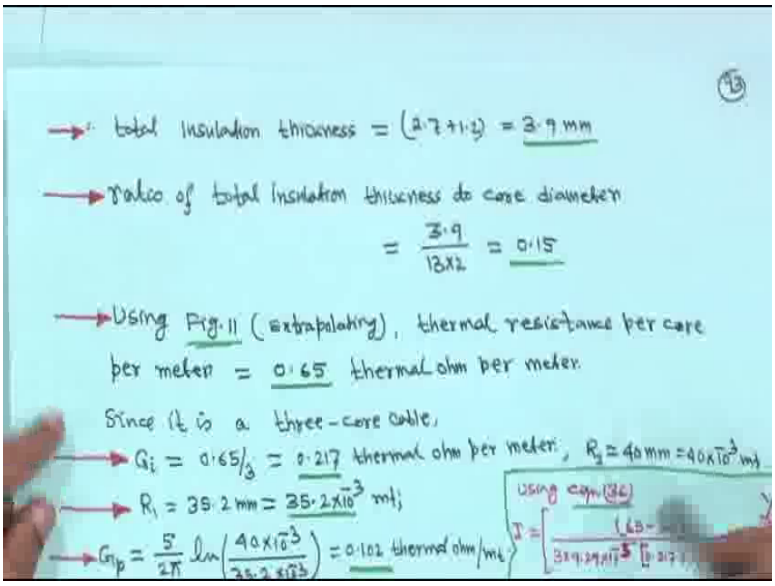

Now ratio of total insulation thickness to the core diameter then 3.9 divided by 13 into 2 is equal to 0.1 5 right to; that means, your this core radius your what you call that your this thing, it is given thickness of core insulation no it is that your what you call core diameter that core outside the radius of the Kelvin actually 40 millimetre right. So, 4 centimetres and here it is your ratio of the total insulation thickness to core diameter right.

So, whatever it comes that is radius of each core is 13 millimetre right. So, diameter will be 26 millimetre right so; that means, 13 into 2 because this is a millimetre this is a millimetre ratio will be dimensionless. So, total insulation thickness is 3.9 millimetre and radius of each core 13 millimetres. So, diameter is 13 into 2. So, it is 0.1 5 right.

Now, that is value if i mean when you solve the numericals we will not provide you any graph, but this ratio corresponding to that that using figure 11 that 4 4 different curves are shown that to get those thermal resistance per core per meter right. So, suppose the ratio will be given and corresponding data will be supplied to you even in assignment also the graphs will not be provided. So, thermal resistance per 4 core meter corresponding to this ratio this value will be given if you get this value correctly then this data will be given right.

So, it is 0.65 your thermal ohm per meter now since it is a 3 core cable. So, G i will be 0.65 by 3 we have to be very careful, we just do not take your whatever has been whatever has been given right. So, it is given your see 0. 65. So, G i it will come 0.2 and 7 thermal ohm per meter and R 2 is 40 millimetre. So, 40 into 10 to the power minus 3 meter R 1 is given 35.2 millimetre. So, 35 point your 2 into 10 to the power minus 3 it is given 40 it is given 45 40 it is given 35.2 it is given every all data are given.

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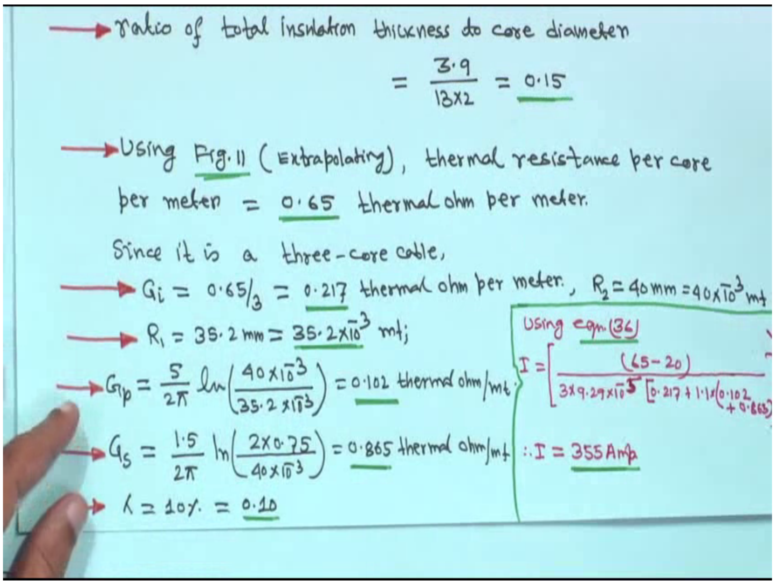

So, from this the thermal resistance you got 0.65, but they have to see the how many cores are there accordingly you please divide. So, this is 0.65 by 3.217 right. So, this formula we know G p is equal to your whatever value whatever data you have here it is given G p the protective covering thermal resistivity of thermal covering 5 degree centigrade meter per watt this is given. So, this is actually G p your this thing is 5 by 2 pi l n your 40 into 10 to the power minus 3 divided by 35.2 into 10 to the power minus 3 this value is given. So, you will get 0.1 0 2 thermal ohm per meter. Similarly it is given 1 point your what you call give by 2 pi. So, this value is also during the data this value is given thermal resistivity of soil this is for soil 1.5 degree centigrade meter per watt this data is given therefore, G s is 1.5 by 2 pi l n 2 into 0.7 5 by 40 into 10 to the power minus 3 same as your before right .

So, it will come 0.8 6 5 thermal ohm per metre and lambda is equal to given 10 percent, because it is given loss is 10 percent of total conductor loss. So, using equation 36 this equation right so it is it is given your theta minus theta s that is that is I think 65 minus 20 and whatever values whatever your this thing data are available I can show you the formula once again right, this one this is general formula dielectric is not here. So, this you should not consider this.

So, n into R a c whatever you got G i lambda i G p G s all you substitute here all you substitute here, whatever you have you have n you know R a c you know equals to 3 core belted cable R a c of computed 9.2 9 into 10 power minus 5 you have computed then lambda is given point ne 10 percent. So, it is 1 plus 0.1 that is why it is 1.1 right into G p plus G s G p and G s we calculated this is G p this is G s that we have calculated to the power half right.

I actually becomes tour 355 ampere right that is your after calculating using equation 36 after calculating this. So, in this problem just the I have taken this problem with whose data such that you have idea actually data; data are not a problem only thing is that this formula right you have to you have to keep it in your mind that this formula I should use right.

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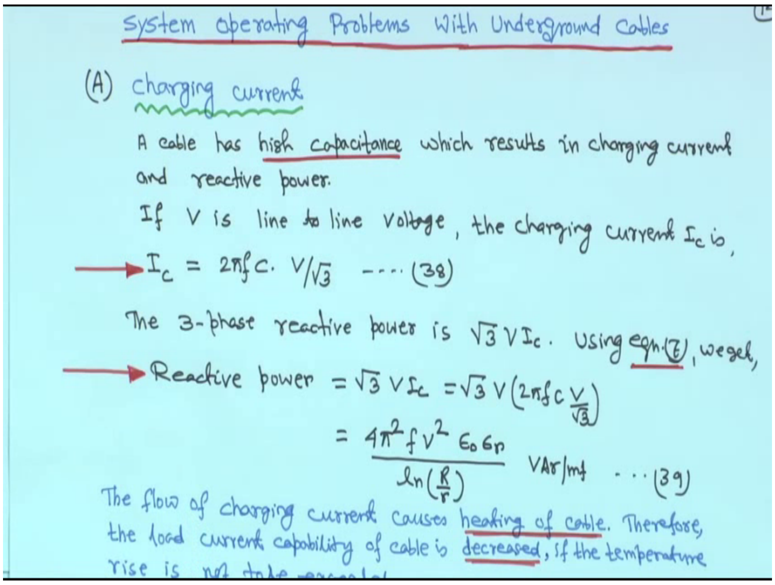

Next is the system operating problems with underground cable you know that phase phase (Refer Time: 28:42) effect. So, just brief we will be discuss like your charging current right. So, system operating problems with underground cables what are the problems the first is the charging current. So, in cable generally for cable you need a high capacitance even for 11 k v k cable you have to consider the capacitance for overhead 11 cable line there is no need to consider the charging capacitance because it is negligible.

So, a cable has a high capacitance which results in charging current and reactive power suppose if v is the lien to line voltage the charging current you know t c is equal to omega c v. So, it is actually 2 omega is 2 pi f c into v upon root 3 right because v is the line to line voltage. So, the charging current i c it can be given as 2 omega c v by root 3. So, this is actually per phase right because v upon root 3 now 3 phase reactive power is root into v into I your I C.

So, if you substitute I C actually root 3 root 3 will be cancelled. So, using equation 7 you will get reactive power is equal to root 3 V I C. So, it will be root 3 v then omega is 2 pi f c v by root 3. So, root 3 root 3 will be cancelled and if you substitute I C value here if you substitute this I C value here itself I C value here itself you will get if your pi square f into v square epsilon 0 epsilon R var per divided by l n R upon R var per meter.

So, this actually that the I mean if you I mean this capacitance thus capacitance expression right this have been substituted here, that is why this has come epsilon 0 epsilon R l n capital R by R has come. So, already you have studied the capacitance your what you call for overhead transmission line same is applicable for cable.

So, this has been substituted. So, we got epsilon 0 that is why epsilon 0 epsilon R has come. So, divided by l n R upon R right, this I am not showing this is this you know this right this I am not showing, but easily you can find out from this expression what is the expression of C right.

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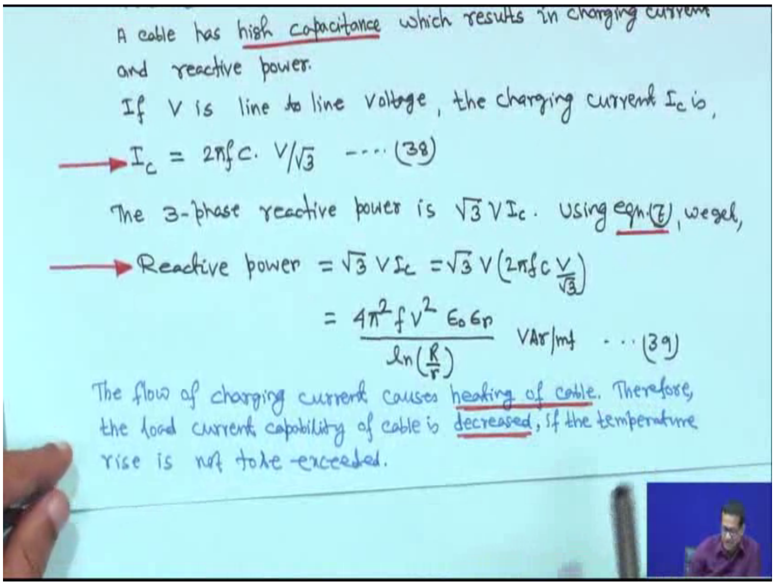

So, the flow of charging current Causes heating of cable this is very simple therefore, the load current capability of cable is decreased if the temperature rises not to be exceeded; that means, if you try to fix the temperature of the cable that is should not exceed for example, I if you do not want that cable temperature should not exceed 70 degree or 75 degree Celsius.

So, in that case your what you call the charging it will therefore, what will happen the load current capability carrying capability of the cable will decrease the right, because if you increase the load current capability the temperature rise will be there in that cable and if you do not want you have to restrict that right.

Thank you we will be back again.