Power System Engineering
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Lecture – 09
Cables (Contd.)

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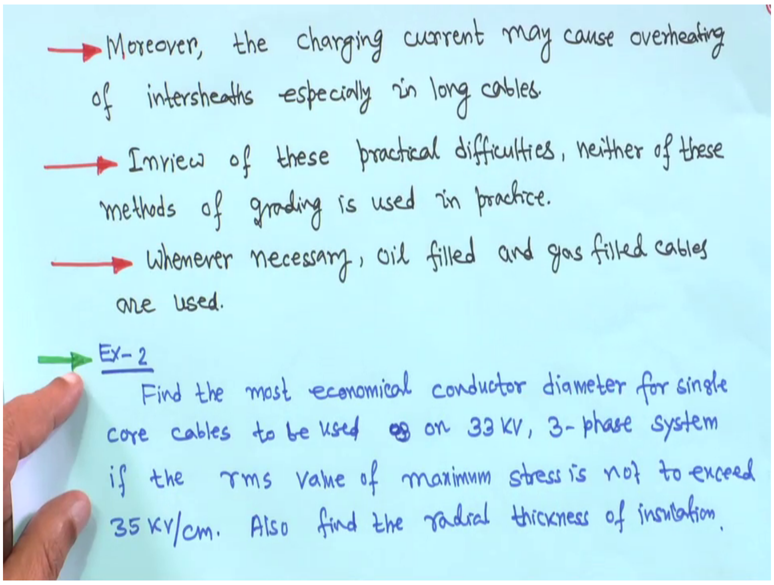

Welcome back again. So, and more over your the charging current may cause overheating of intersheath especially in long cables right. So, this charging current also your will be responsible for your what you call heating of that intersheath right overheating. So, in view of practical difficulties neither of these methods of grading is used in practice. So, in reality these methods are not used. Whenever necessary, oil filled and gas filled cables are used.

So, these are the things for cable. Now further thing we will come later, now come another example 2; it is given that find the most economical conductor diameter for single core cables to be used on 33KV, 3-phase system if the r m s value of maximum stress is not to exceed 35KV per centimeter. Also find the radial thickness of insulation. This is the problem right.

So, you have to find out that most economical conductor diameter for single core cables right and operating voltage is 33KV. It is line to line and 3-phase and maximum stress is

35 kilo volt per centimeter and you have to find out also the radial thickness of insulation. So, it will be how we will solve it.

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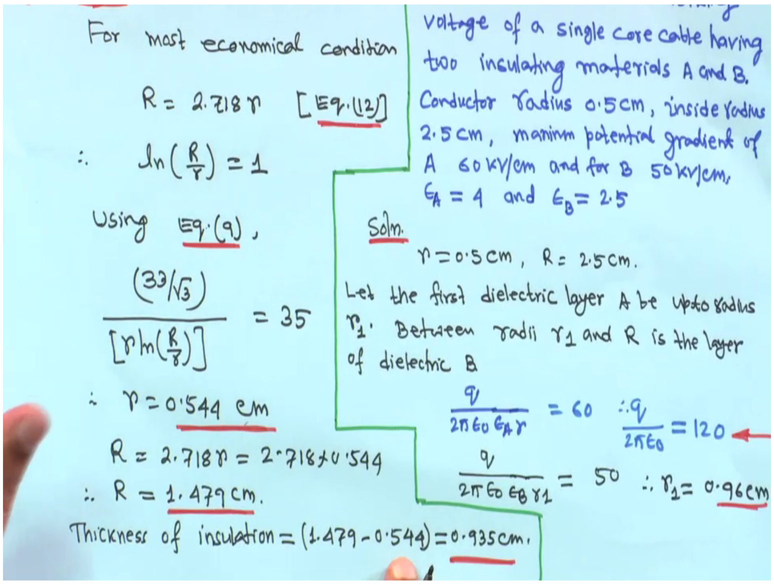

So, look at this one only your this side do not see, this is another problem. No need to see to this side you please see this one, the black one, black ink. For most economical condition we know R is equal to 2.718, capital R is equal to 2.718 small r. This is equation 12.

Actually it is e right that means ln R upon r is equal to and actually it is I am writing here.

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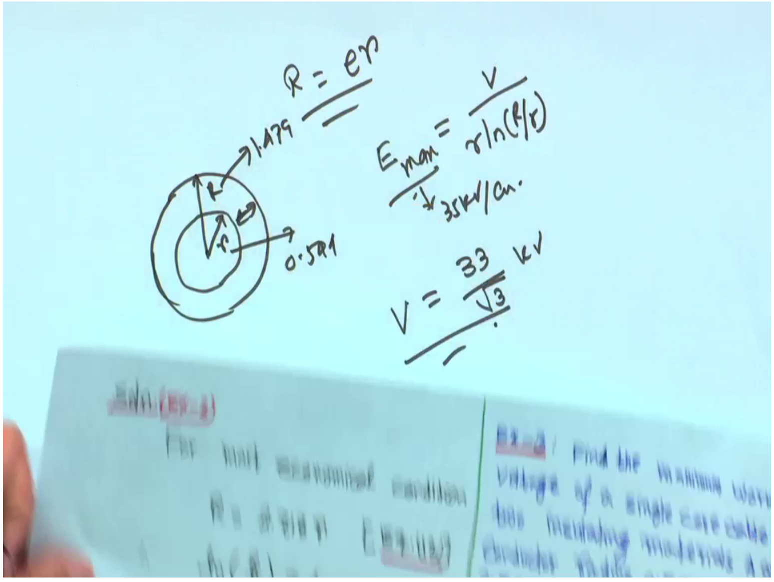

Actually capital R is equal to e into small r right. So, that is why it is ln capital R upon small r is equal to 1. Now using equation 9; equation 9 is your V upon that is the maximum electric stress it is given 35kv by k v per centimeter. So, formula no need to write here, I mean E max is equal to actually E max is equal to it is V that is line to neutral voltage r ln capital R by small r.

And this E max actually given 35kv per centimeter and line to line voltage is given V is equal to line to neutral that is why it is line to line voltage is 33kv, so line to k v is 33 by root 3kv, so this is your V right, therefore, 33 upon root 3 then r into ln R upon r is equal to 35. Now, your if you solve this r your ln R upon r actually 1 this is 1, because when r is equal to it is actually e r I told you I have written e is equal to 2.718 say. So, ln R upon r is 1, so from which you will get r is equal to 0.544 centimeter therefore, R is equal to 2.718 r, so r is 0.544.

So, multiple this one it will be R will be equal to 1.479 centimeter. Therefore, thickness of the insulation will be this is the R right that 1.479 and it is the diameter of the conductor. So, insulation thickness is 1.479 minus 0.544 so 0.935 centimeter I mean it is like this is the conductor right it is radius right this is r and this is your outer radius this is capital R. So, this is the thickness of the insulation this r is .54 and this R is your 1.479. So, thickness is capital R minus small r. So, that is why it is 1.479 minus 0.54, so 0.935 centimeter right this is example to understand level right easy one.

Example 3: In this case you find the maximum working voltage of a single core cable having two insulating material A and B. I mean A is one insulating material and B another insulating materials. Conductor radius is given .5 centimeter, inside radius is 2.5 centimeter maximum potential gradient of insulation A I have just written a of insulation A 60 kilo volt per centimeter.

And for cable B, sorry insulation B rather insulation B 50 kilo volt per centimeter, for insulating material A; it is given epsilon A is equal to 4 and insulating material B epsilon B permittivity that is 2.5 these are the parameter given. You have to find out maximum working voltage, now that r your which given conductor radius 0.5 centimeter and inside radius is 2.5 that is R is equal to 2.5 centimeter right and you have two insulating material A and B. Therefore, let the first dielectric layer A that is for insulating material A be up to radius r1 and between radii r1 and r is the layer of dielectric B. That means it is something this just hold on.

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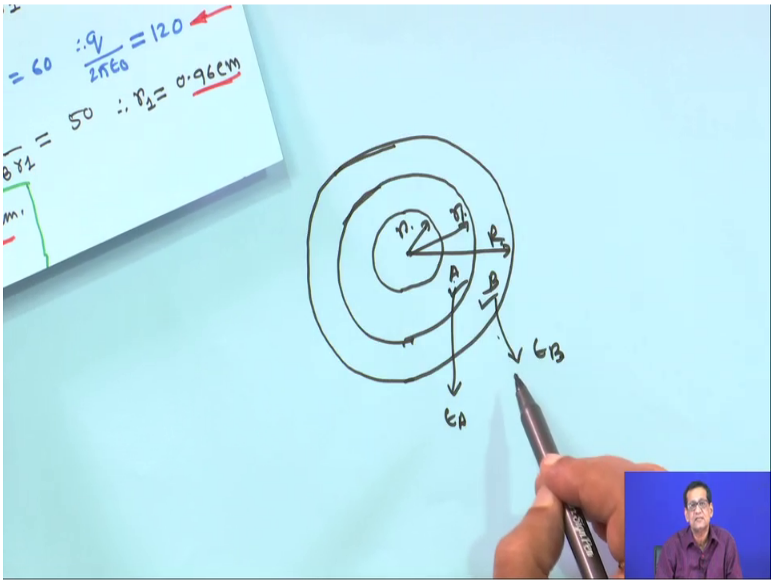

That means you have this is your conductor may not be symmetrical, but this is your insulating material A right and this is insulating material B. So, this radius is given suppose if it is r right and this is your r1 right and this is your what you call? Capital R. So, this is insulating material A, this is insulating material B it is permittivity is epsilon A it is permittivity is epsilon B and this is the conductor radius r this is the diagram so; that means, so let the first dielectric layer A be up to radius r1 so it is a up to radius r1 and that your what you call and between radii r1 and r so r1 and R this is your the layer of dielectric B. Therefore, electric intensity you can write q upon 2 pi epsilon 0 is common everywhere. So, q upon epsilon 0 into epsilon A into r is equal to 60 because it is give maximum potential gradient for insulate A is 60 kilo volt per centimeter square.

Therefore q upon 2 pi epsilon 0 epsilon A r right is equal to your 60 and second one that; that means, q upon 2 pi epsilon 0 right because all parameters are given right r is given directly you can substitute and you calculate you q because epsilon A is given, r is also known if you put it you will get q upon 2 pi epsilon 0 is equal to 120 this will get it I am not showing it here, but you can put and you can check. Similarly for the second one q upon 2 pi epsilon 0 epsilon B r1 is equal to 50, because this is 50 kilo volt per centimeter right and if epsilon B is equal to 2.5 you put epsilon B 2.5 right.

And your what you call and q by 2 pi epsilon 0 is 120 here you substitute q by 2 pi 0 is equal to q by 2 pi epsilon 0 is equal to 120 you substitute here then epsilon B is equal to 2.5 to that you substitute here and then only r1 will be left is equal to 50. Solve for r1 you will get r1 is equal to .96 centimeter right, these are simple thing that is why I did not write the step but I am telling you how to do it, this values substitute here this is 120 actually it will become 120 upon epsilon B epsilon B 2.5. So, it will be basically your what you call that 120 upon 2.5, so roughly it will be 80 upon r1 right.

So, that way then you calculate your what you call that r1 right it is given it is given is equal to this one is equal to 50 right. So, this way your you can get r1 is equal to 0.96 centimeter.

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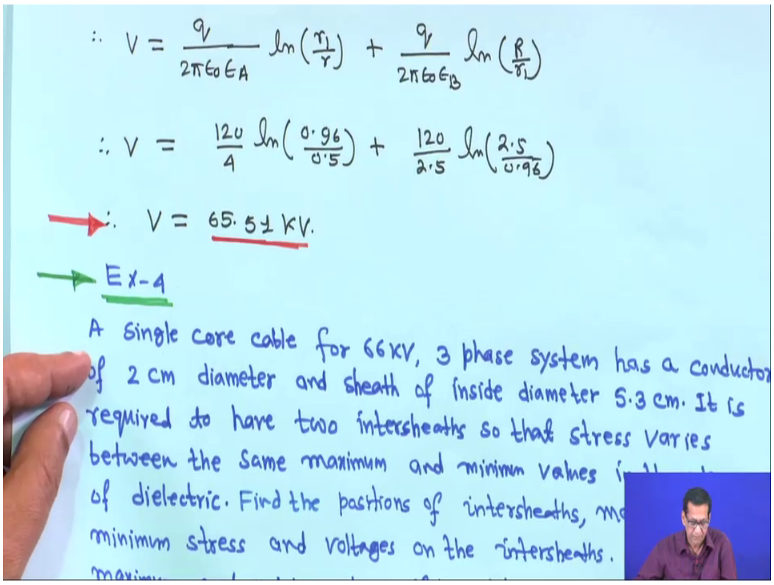

So, similarly your therefore, voltage V is equal to we have seen that previously for general formula. So, V will be q upon 2 pi epsilon 0 epsilon A, ln r1 upon r plus q upon 2 pi epsilon 0 epsilon B ln R by r1 right. So, all these values are known we have got all these value 120 by 4 ln. Then this is 0.96 upon .5 because r1 we have got 0.96 right, r1 we have got 0.96 centimeter right, so then this one your what you call plus q by 2 pi epsilon 0 120 divided by 2.5 because epsilon B 2.5 here also q upon 2 pi epsilon 0 120 epsilon A 4 then ln 2.5 upon 0.96, so V is coming 65.51kv right this is the voltage. Now a small question to again you V is it a line to line voltage or it is a line to neutral voltage? This is a question to you when you will did this you see whether it is a line to line or line to your neutral that is phase voltage or line voltage this is a question to you right now.

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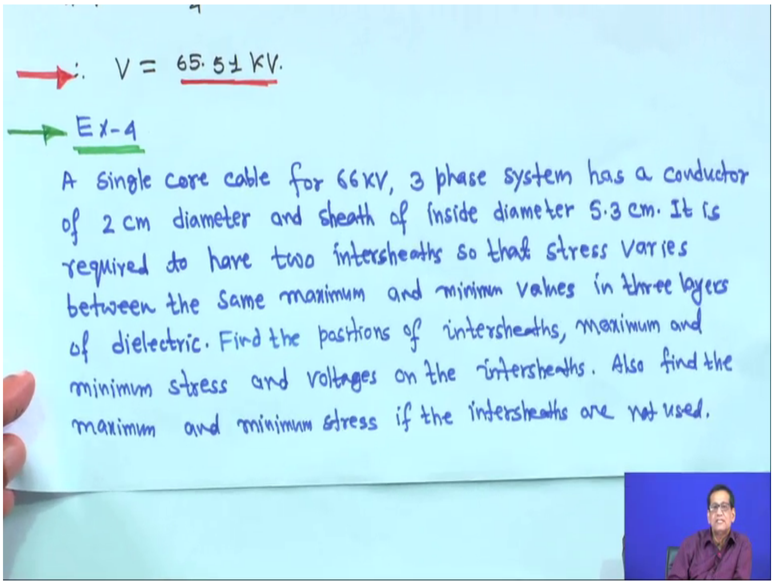

Example four: So a single core cable for 66kv whenever nothing will be mentioned , this is 66 will be this voltage always will be line to line right, 3-phase system has a conductor of 2 centimeter diameter and sheath of inside diameter is 5.3 centimeter it is required to have 2 intersheath. So, that stress varies between the same maximum and minimum values in 3 layers of die dielectrics.

So, find the positions of intersheath maximum and minimum stress and voltages of the intersheath, also find the maximum stress if the intersheath are not used I mean one what will be the voltage distribution with intersheath and another thing is if voltage your what you call if intersheath is not there what will be the maximum stress right and what is the stress with intersheath now this is the problem.

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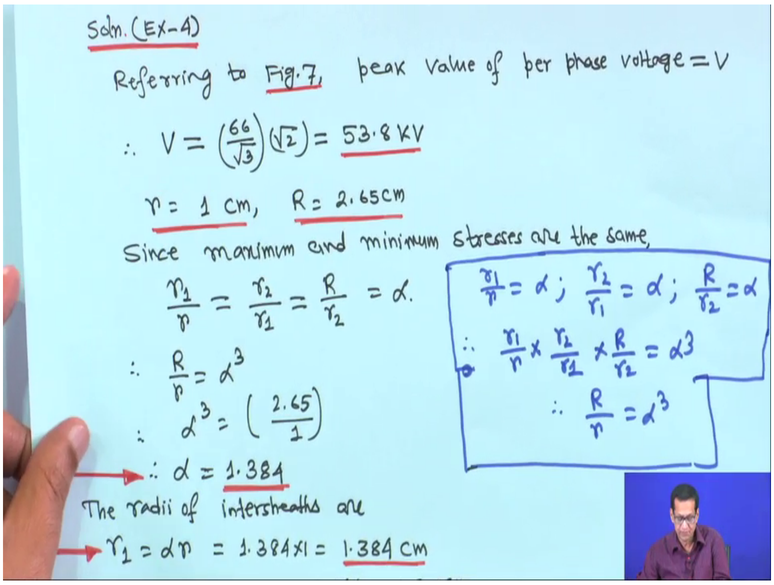

Now, referring to figure 7 peak value of per phase voltage look this is first forget about root 2 first 66 by root 3 is the your whatever you will come line to your neutral that is phase r m s voltage, then multiply by this root 2 it will be peak voltage right that is why v is equal to 66 upon root 3 into root 2 that is 5.83kv, now given that R is equal to r diameter to centimeter so radius 1 centimeter and R is given 2.65 centimeter.

Since maximum and minimum stresses are the same right; that means, all are same that means this condition hold this we have seen therefore, small r1 upon r divided is equal to r2 upon r1 is equal to R upon r2 is equal to alpha. Now then therefore capital R upon small r is equal to alpha cube why? because r1 upon r is equal to alpha, r2 upon r1 is also alpha, r upon r2 is also alpha multiply all; r1 upon r into r2 upon r1 into r upon r equal to alpha cube right; that means, r2 r2 will be cancel, r1 r1 will be cancel then capital then what will be left R upon r this one and this one will be left out.

So, R upon r is equal to alpha cube therefore, R upon r is equal to alpha cube; that means, alpha cube is equal to 2.65 upon 1 hence alpha you will get the ratio 1.384, so this alpha is equal to 1.384. So, radii of intersheath now r1 is equal to from this formula r1 is equal to alpha r so alpha is 1.384 r is 1, so 1.384 into 1 is equal to 1.384 centimeter. Similarly r2 is equal to alpha r1, r2 is equal to here alpha r1 therefore, alpha is equal to 1.384, r1 is also 1.384 so it will be 1.915 centimeter right.

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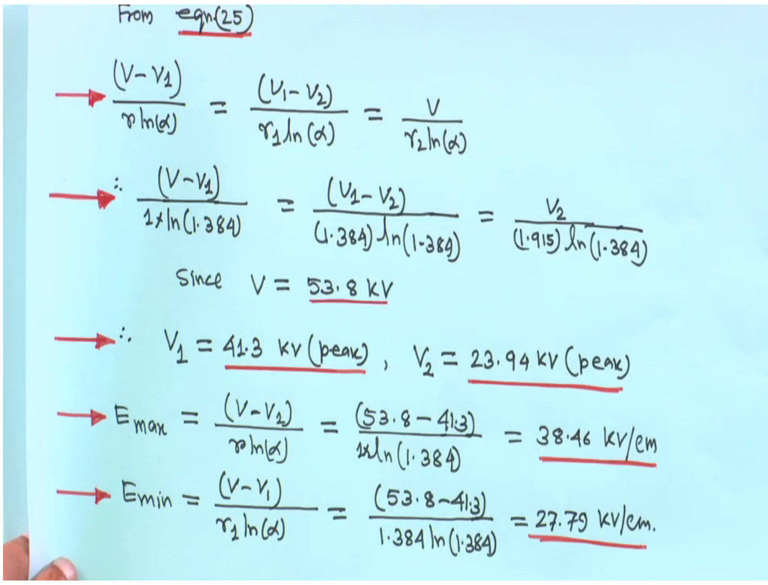

In the calculations if you find any error or any mistake right calculation error anything please your, what you call please let me know this right. So, therefore, from equation 25 this equation V minus V1 upon ln alpha is equal to V1 minus V2 divided by r1 ln alpha is equal to your V upon r2 ln alpha. So, V minus V1 r is 1 into ln alpha we got 1.384 so ln 1.384 is equal to V1 minus V2 that your r1 is 1.384 ln 1.384 is equal to V2 upon r2 is 1.915 we have got ln 1.384 right. Now these equations are given.

So solve this is three equation actually; this one is equal to this one equation, this one is equal to this one another equation and this one is equal to this one another equation. So, from this from this three equations and three unknown if you solve you it you will get this thing I mean V is already given because V actually it is known V is given, V is actually 53.8kv so just two equations, so substitute V and you just solve for V1 and V2 from any two equations right.

That substitute here V is equal to 53.8 then you solve for V1 and V2. So, you will get V1 is equal to 41.3kv this is peak value, because this one we have taken peak value because it has been asked right. Similarly V2 is equal to 23.94kv peak value you have to be little bit cautious about this read the problem carefully and accordingly you have to do. Therefore, E max will be V minus V1 upon r ln alpha, so it will be V is 53.8 and V1 is the 41.3 because it is the it is near the surface of the conductor so it will be 53.8 minus 41.3 divided by r is 1 ln 1.384, so it is coming 38.46 your kilo volt per centimeter.

Similarly e min will be when r is equal to r1. So, it will be V minus V1 upon r1 in alpha, so 53.8 minus 41.3 divided by r1 is 1.384 ln 1.384 that will be your 27.79 kilo volt per centimeter right; that means the maximum stress, so we got E max and e min. So, maximum stress without this is your when intersheath is used 38.46 and 27.79 this is max this is min when intersheath is not use maximum stress is at the surface of the conductor right.

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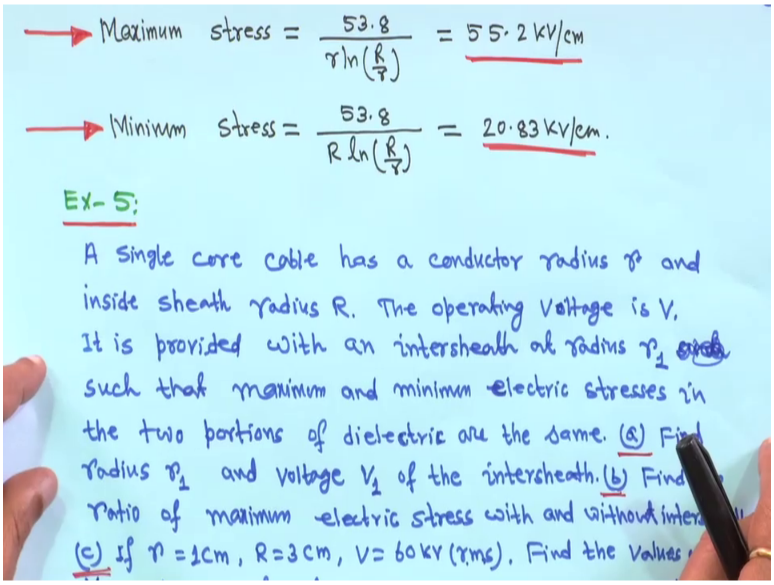

That means it will be 53.8 V is given divided by r ln R upon r you substitute all the values you will get 52.2kv per centimeter. So, with without intersheath max is very higher compared to this one, similarly minimum stress will be at the surface when r is equal to your x is equal to R. So, it is 53.8 R upon ln r up all the data are given, so if you substitute you will get 20.83kilo volt per centimeter whereas, here it is 27.79kilo volt centimeter. So, there is little bit although not, but uniform distribution not possible, but volt this E max e min it be better here right. So this is your, what you call that example 4.

Now, example 5: actually so many different type of examples it giving that sometimes I feel that all the theories whatever we make it should be supported by good examples. So, example 5; A single core cable conductor radius r and inside sheath radius R the operating voltage is V it is provided with an intersheath at that radius r1 such that maximum and minimum electric stresses in the two portions of dielectric are the same.

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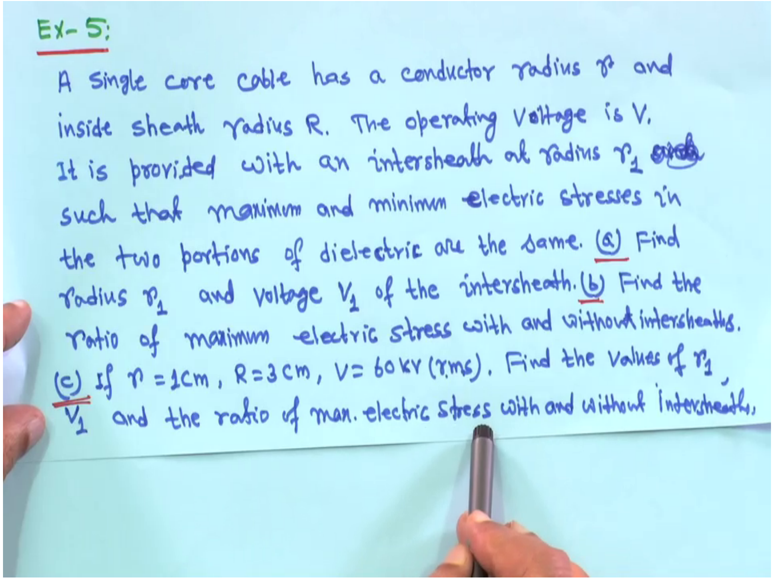

Then a: find radius r1 and voltage V1 of the intersheath. Then b: find the ratio of maximum electric stress with and without intersheath. c: if r is equal to 1 centimeter R is equal to 3 centimeter V is equal to 60kv in bracket it is given r m s value, find the value of r1 V1 and the ratio of maximum electric stress with and without intersheath this is the problem right. So, how will how one can do this same philosophy we will use there it is using I think two intersheath right you provided with an one intersheath and intersheath of radius r1 right.

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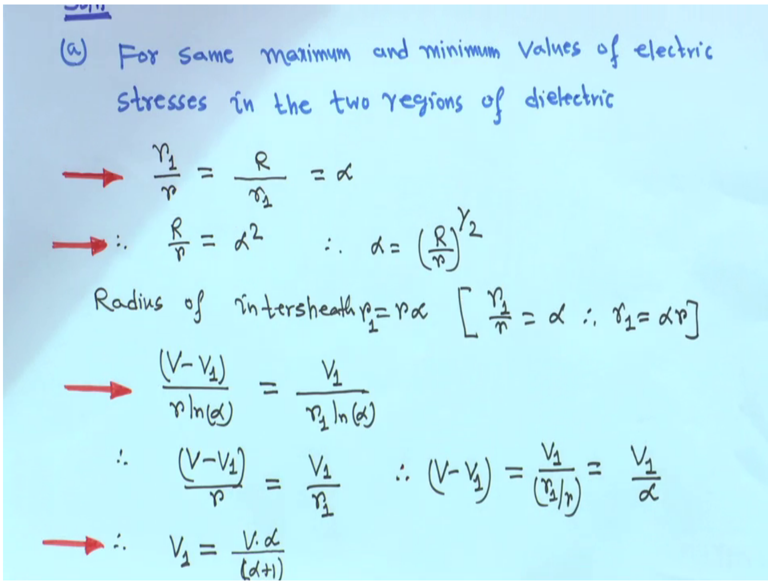

So, question is that solution will be something like this, for the same maximum and minimum value electric stresses in the two layers of dielectric, if it is the same maximum and minimum then same condition we will use r1 upon r is equal to r upon r1 is equal to alpha therefore, R upon r is equal to alpha square because r1 upon r is alpha right and r upon r1 alpha you multiply then you will get r1 r1 cancel R by r alpha square therefore, alpha is equal to R upon r to the power half that is under root right.

So, radius of intersheath r1 is equal to r alpha. Now we know same formula we will use V minus 1 upon r ln alpha here only one intersheath is there that is why is equal to V1 upon r1 ln alpha right therefore, V minus V1 upon r is equal to V1 upon r1 because ln alpha ln alpha both side will be cancel right therefore, V minus V1 upon r is equal to V1 upon r1 therefore, V minus V1 is equal to right V minus V1 is equal to V1 and this r it is going r upon r1, but V1 we are writing divided by r1 upon r and r1 upon r is r1 upon r is alpha. So, we are making in terms of V1 upon alpha right.

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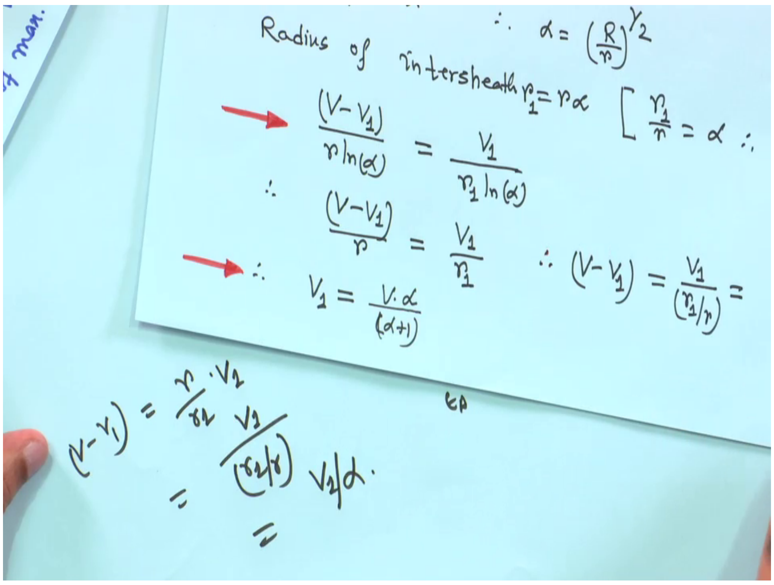

So, actually it is like this just for your this thing it is like this, that your V minus V1 then from this equation from this equation is equal to your r by r1 into V that one you can write V upon r1 by r that one you can write V upon alpha alright. So, that is why your writing sorry V1 it is V1 so it is V1 upon alpha that is why you are writing this one right. Therefore, V1 is equal to your just hold on therefore; V1 V minus V1 is equal to V1 upon alpha from this two only V minus V1 is equal to V1 alpha from that you can write V1 is equal to V into alpha upon alpha plus alpha 1 right this you can first condition you have to derive. So, this is alpha V into alpha upon alpha your alpha plus 1, so this is in terms of alpha.

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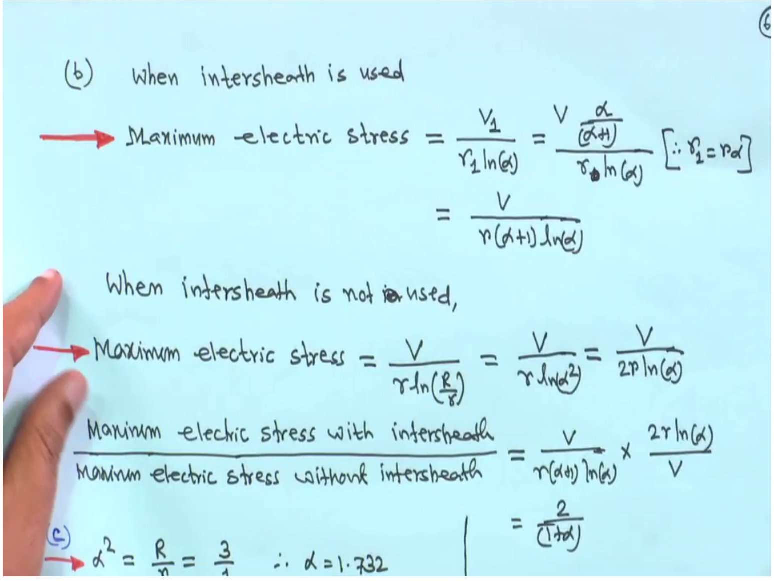

Now, second one is that your when intersheath is used, when intersheath is used maximum electric stress is V1 upon r1 ln alpha is equal to your V1 is equal to this is your maximum electric stress actually V1 upon r1 ln alpha therefore, we have got V1 is equal to V alpha upon alpha plus 1. So, this V1 you substitute here that is V into alpha upon alpha plus 1 then r ln alpha and we know that r1 is equal to r alpha is equal to we can get V upon your what you call r in bracket it is alpha plus 1.

Then ln alpha you simplify r1 is use this condition r1 is equal to r ln pi r and then you will find alpha will be cancel and it will be V upon r into alpha plus 1 ln alpha. Now when intersheath is not used maximum electric stress will be at the surface of the conductor, that is V upon r is the radius of the conductor ln R upon r right, but we have seen r upon r is equal to alpha square r upon r is alpha square.

So, here you substitute r upon r is equal to alpha square therefore, it will be V upon then this 2 will come out V upon 2 r ln alpha. Alright therefore, ratio will be maximum electric stress with intersheath and maximum electric stress without intersheath.

So, maximum electric stress with intersheath is this one V upon r alpha plus 1 ln alpha I mean this one and without inter your intersheath is not used without intersheath it is V upon 2 r ln alpha. So, divide it so if you divide V means your, what you call V will go to the denominator and it will come to the numerator right. So, it will be 2 r ln alpha upon V, V will be cancel ln alpha will be cancel, so finally r will be cancel finally it will be 2 upon 1 plus alpha this is the ratio right.

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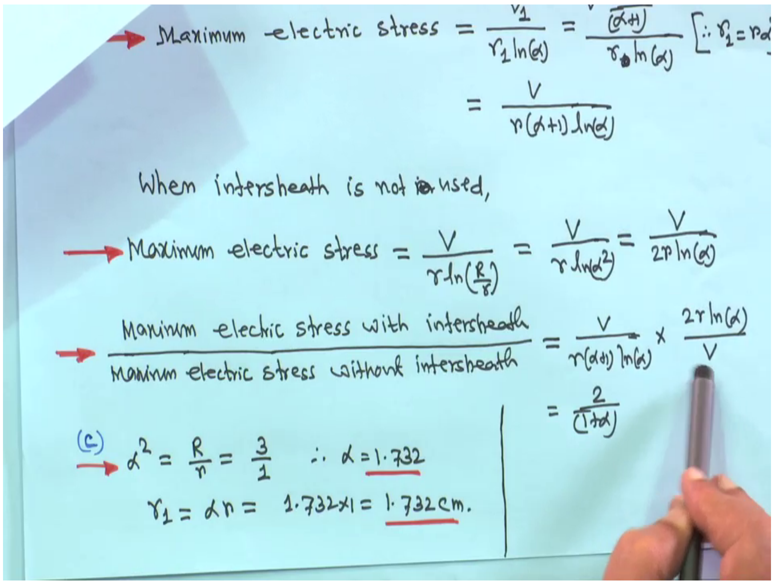

Now, last part see it is given I hope you understood this. Now, if C is given in C r is given capital R is 3 centimeter and small r is 1 centimeter right therefore, alpha square is equal to capital R upon small r is equal to 3 by 1 therefore, alpha is equal to 1.732 therefore, r1 is equal to r alpha this relationship we know from here only, this condition always known r1 upon r is equal to r upon r1 alpha therefore r1 upon r is equal to alpha so; that means, r1 alpha r alpha is 1.732 into r is 1 so 1.732 centimeter that is r1 right.

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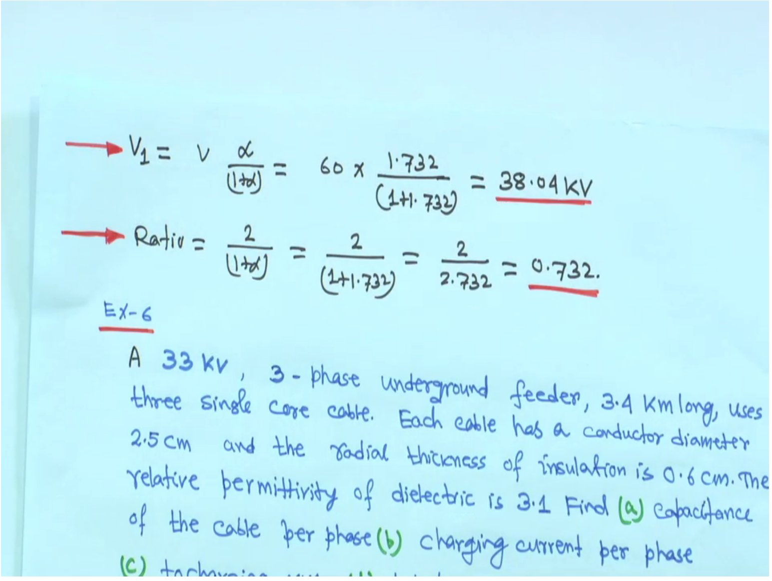

And V or V1 is equal to V1 just hold on V1 is equal to your V into alpha upon 1 plus alpha. So, V is 60 is given right, if it is given r m s value find out in r m s if it is peak value find out in peak value right, your 60 into alpha is 1.732 divided by 1 plus 1.732 it is 38.04kv therefore, ratio is equal to we have seen earlier, ratio is equal to 2 upon 1 plus alpha, so 2 upon 1 plus 1.732 is equal to whatever it comes is equal to 0.732. So, this is the answer right.

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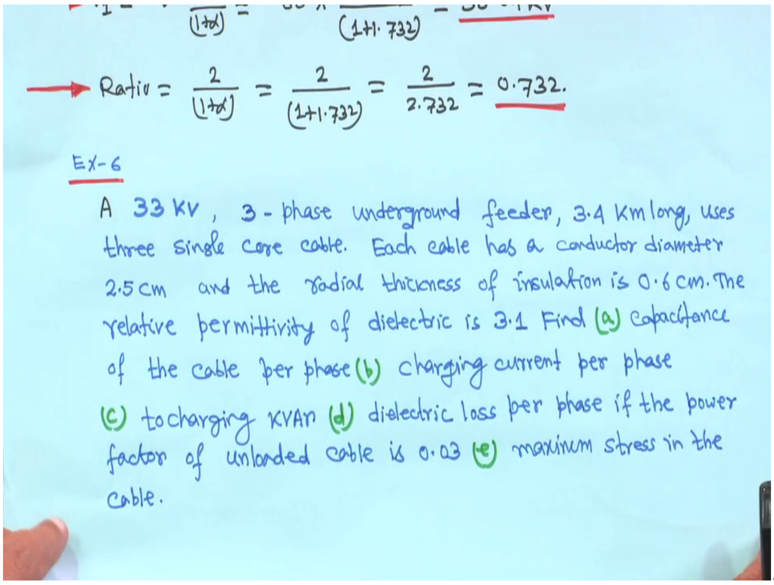

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So, next one is; this another example we will take right, so example 6: Right in this case a 33kv 3-phase underground feeder 3.4 kilo meter long uses 3 single core cable, each cable has a conductor diameter 2.5 centimeter and the radial thickness of insulation is 0.6 centimeter, the relative permittivity of dielectric is given 3.1. Find a: capacitance of the cable per phase, b: charging current per phase, then c: to that your to your charging KVAR right, it is no need to write to it is charging KVAR right you have to find out charging current then kilo VAR, Then d: dielectric loss per phase if the power factor of unloaded cable is 0.03 right. So, that is this thing. And e: maximum stress in the cable. So, these five things you have to determine.

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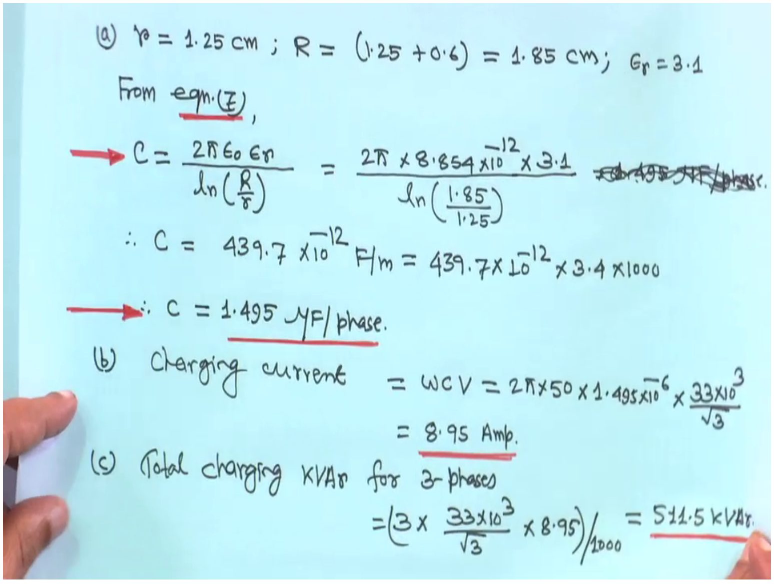

So, how we will do this all the parameters or data whatever is given now question is that, r is your diameter of the conductor is given 2.5 centimeter, so r is 1.25 centimeter. So, R will be thickness this thing is your insulation is there right, your thickness of insulation is .6 centimeter, so radius plus the thickness of insulation will be capital R. So, r is equal to small r plus insulation thickness.

So, small r is 1.25 centimeter and thickness of insulation is .6 so 1.25 plus .6 so that is 1.85 centimeter, and relative permittivity is given 0.1. Now from equation 7; that is C is equal to rewriting equation 2 pi epsilon 0 epsilon r ln capital R upon r the capacitance, this same capacitance chapter for transmission system also we have seen right.

So, but 2 pi epsilon 0 is 8.854 into 10 to the power minus 12 farad per meter you know that, epsilon r is 3.1, capital R is 1.85, small r is 1.25 therefore, C actually is equal to 40 sorry 439.7 into 10 to the power minus 12 farad per meter, but length of the cable is 3.4 kilo meter, so 3.4 into 1000 so this is meter right therefore, C will be this much of farad right. So, 439.7 into 10 to the per minus 12 into 3.4 into 1000 because 3.4 kilo meter length so multiple with thousand it will be meter therefore, C will be 1.495 if you simplify it will be micro farad per phase I have written as micro farad right.

So whatever it is, then charging current is omega C into V, so it is at 50 hertz. So, omega is 2 pi here, then C is 1.495 into 10 to the power of minus 5 that we have computed here. And your, what you call that line to line voltage 33, so line to neutral voltage 33 by root 3. So, and this is in terms of volt, so that is why k v that is why it is may be volt so into 1000 that is 10 to the power 3, so this actually become 8.95 ampere.

So, charging current is 8.95 ampere right, now this total charging KVAR for 3-phases whereas, 3-phases are there so this is 3 is multiplied then we have taken line to neutral voltage phase voltage, so 33 by root 3 per phase we are getting multiplied by 3 because this charging current also given this capacitor is part micro farad per phase, so charging current also 8.95 ampere so 33 by root 3 this is in volt because 33kv into 1000 that is 10 to the power of 3 by root 3 into 8.95. So, it comes about 511.5 kilo VAR that is the total charging your what you call charging VAR quit high right not low, 511 kilo VAR means it is .5 mega VAR right.

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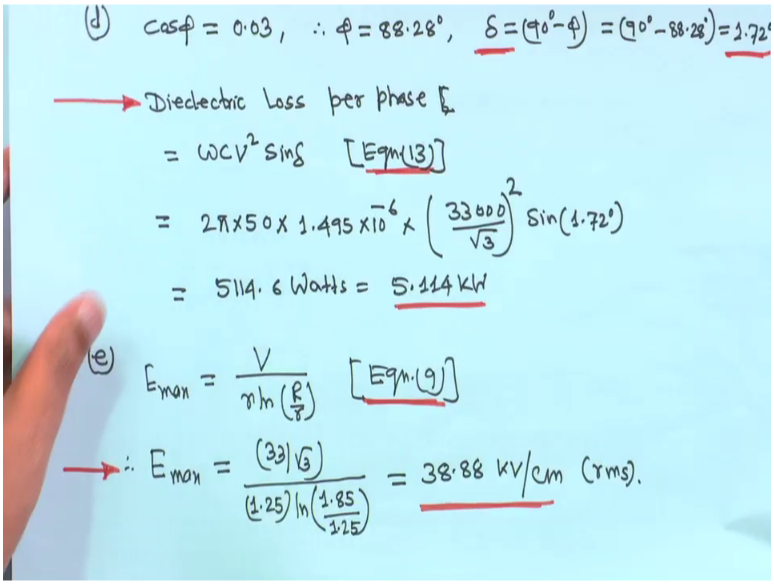

Now, in the part B it is given COS pi is equal to .03 that means, phi will become 88.28 degree. Therefore delta is equal to 90 degree minus phi, so delta will be 90 minus 88.28 because 88.28 1.72 degree so loss angle delta is 1.72 degree. Now dielectric loss per phase in equal from equation 13 only we are writing omega C V square sin delta right that is 2 pi into 50 into 1.495 into 10 to the power minus 6 there is capacitance value you got micro farad per phase right, 2 pi this into this (Refer Time: 30:12) 30 it is kilo volt, so you have made volt it is V square.

So, 33000 by root 3 whole square into sin of 1.72 degree, it comes actually your 5114.6 watts is equal to 5.114 kilo watt right, so this is your what? You call dielectric loss. Now last part e: actually is give that your E max is equal to V upon r ln capital R upon small r this is equation 9. So, V it is 33 upon root 3 line to neutral voltage that is 1.25 that is r ln 1.85 capital R is 1.85 data given divided by 1.2 it come around 38.88kv per centimeter this is r m s value this r m s value right. So, E max will be 38 kilo volt so these are the numerical right. I have considered for this thing only thing is that if any calculation anything is wrong or anything then you please let me know then I can rectify myself.

Thank you will be back again.