Power System Engineering
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Lecture – 08
Cables (Contd.)

So, we have just seen that dry dielectric loss in a cable right. So, just to have discussed this regarding this one.

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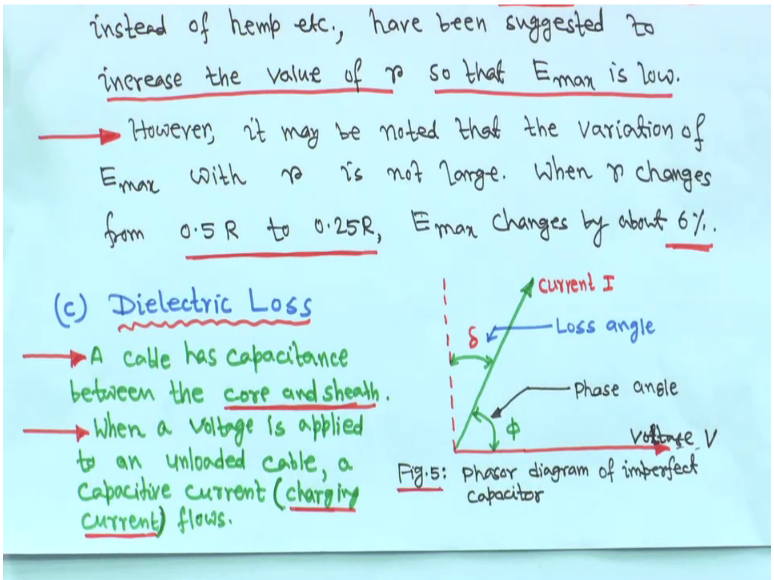

This is the current and this is the voltage and this is your this angle it is called the loss angle and this is your phase angle that is the phase angle between current and voltage right. So, in that case, this we have already discussed.

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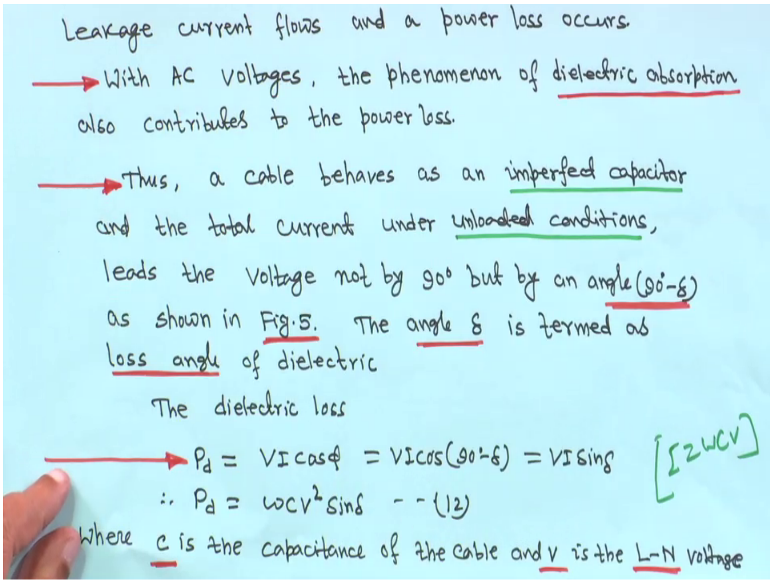

So, this one also we have discussed that dielectric loss in a cable is just to memorize, this VI cos phi and phi is equal to your 90 degree minus delta. So, phi is equal to 90 degree minus delta this phi is equal this is 90 degree. So, here your power loss will be VI sin delta, then VI cos 90 degree minus delta. So, call us will be VI sin delta, but we know I is equal to omega C into V. So, put it here i is equal to omega C into V therefore, dielectric loss will be omega C V square sin delta where C is the capacitance of the cable and V is the line to neutral voltage up to this we have seen.

Next what will come that will come for the grading of the cables.

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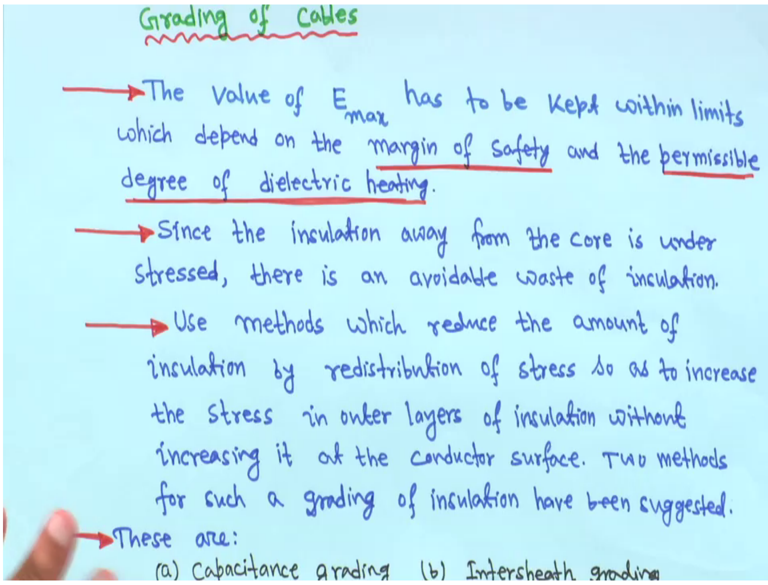

Right because the value of E max has to be kept within limits which depend on the margin of the safety and permeability of dielectric heating. So, E actually see the insulation away from the core is under stressed; that means, when you have I mean if you look at this diagram.

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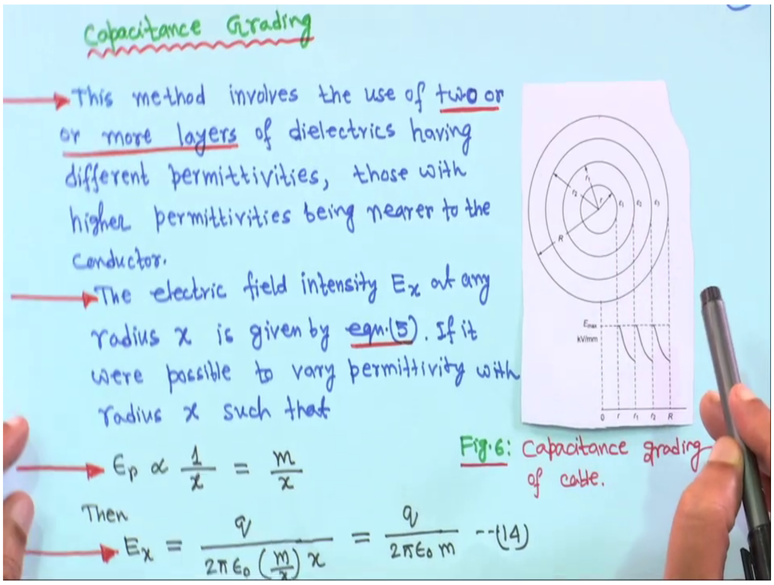

If you just look at this diagram, suppose this is your core and this is your different your epsilon 1, epsilon 2, epsilon 3 different permittivity with different material forgetting that, but the question is that which is away from these away from these core conductor and insulation will be under stress and insulation which is very close to the your core conductor then it will be over stress. So, that is why that insulation away from the core; that means, insulation away from the core which is away from core I am suppose somewhere here see right is under stress.

So, there is an avoidable waste of insulation. So, is the avoidable waste of your, it is insulation, right. So, for this case you have to use methods which reduce the amount of insulation by redistribution of stress. So, as to increase the stress in outer layers of insulation without increasing it at the conductor surface; that means, do not increase it here conductor the (Refer Time: 03:08), your stress you do not insulation stress here that you do not in increasing at the ser near the conductor, but those insulation which are away from the core it is under stress, but try to make it uniform although not possible, but as much as possible you try to increase the stress, but without increasing your at the conductor your sar insulation and at the conductor surface of core conductor right.

So, therefore, by redistribution of stress, as to increase the stress in outer layers of insulation, without increasing it at the conductor surface. So, 2 method generally they use it one is the I mean 2 methods are recommended for this capacitance grading and second one is intersheath grading, this 2 things one has to see. So, although we will we will go for capacitances grading and intersheath grading, but in reality that implementation of these 2 are bit difficult one, but that is why here we use, but we will see that how things can be done.

For example suppose this is actually suppose you have a core co your core conductor this is a; this is the conductor right core. So, 2 or more layers of dielectrics having different permittivity I mean you have here in the diagram this I have taken from a book that in in the diagram that there are 3 insulating materials are there having permittivity epsilon 1 epsilon 2 and epsilon 3 this is their electric field your what you call that characteristic is plot, but 0 to r, then that is that is the conduct radius then r to r 1 t 1 to r 2 r to capital R.

But we will learn will now our interest is here only right. So, with higher permittivities being nearer to the conductor; that means, this epsilon 1 than greater epsilon 2 greater than epsilon 3 this is the ideas because having different permittivities those with high higher permittivities being nearer to the conductor; that means, epsilon 1 greater than equal to epsilon 2 greater than equal to epsilon 3 now the electric field intensity E x at any decision here diagram it is not shown say from the from the centre of the your conductor I will take at any distance x that is E electric will intensity E x right of radius, I take any distance x and its radius is your what you call x therefore, is given by your equation 5 that was that was already that was already given just hold on, if I can bring equation 5 for you, right.

Just let me see where it is just hold on otherwise we rewrite that that is your otherwise directly you will we will make it like this just hold on let me have a look or here it is not that does not matter if possible that electric field intensity E x it is actually q by 2 pi epsilon 0 epsilon r x that is the formula equation 5 right. So, if it were permissible to verify your to vary permittivity with radius x such that your epsilon your inversely proportional to the one upon x; that means, I mean if happen. So, that distance if distance increases this epsilon will decrease this one can be written as your m by x m is constant. So, in general your electric fi your that electric field intensity E x that is equation 5 that is it is something like this.

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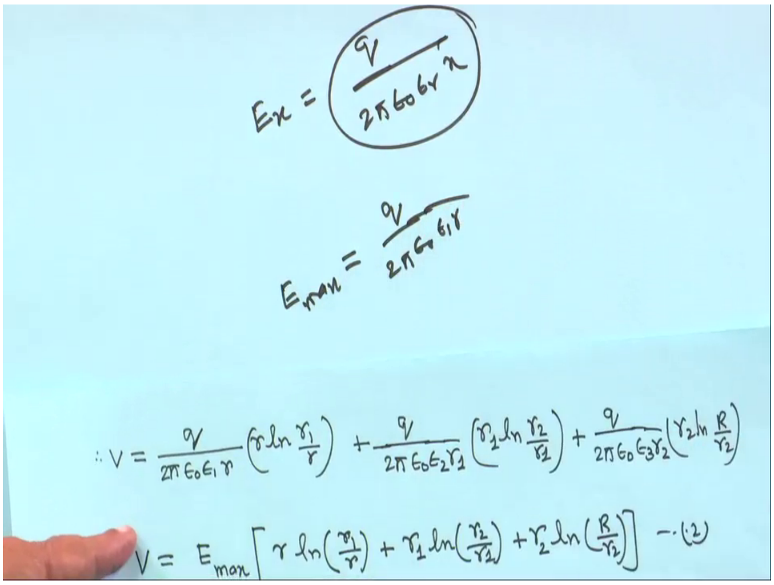

E x is equal to your q divided by 2 pi epsilon 0 epsilon r into x this is the equation right that that is actually equation 5.

So, now if epsilon r is equal to m by x, then in that equation in that equation you substituted your epsilon r is equal to m by x this equation 5 actually if you do. So, it will be E x is equal to it will be q upon 2 pi epsilon 0 then m by x into x. So, x; x will be cancel. So, it will become actually q upon 2 pi 0 your 2 pi epsilon 0 into m. So, m is a constant epsilon 0 is constant pi also constant and q is also constant; that means, this E x will be a constant value this is equation 14 right.

So, that means, that E x actually then; that means, if you if it follows if this if this property is followed then E x will constant at your every higher everywhere E x will remain same, but it reality it is not because epsilon were epsilon r cannot be made proper inversely proportional to one upon x, but inversely proportional to x. So, question is that your, but based on that only we will produced, therefore, from this formula only from this formula only. So, I told you that this remains constant.

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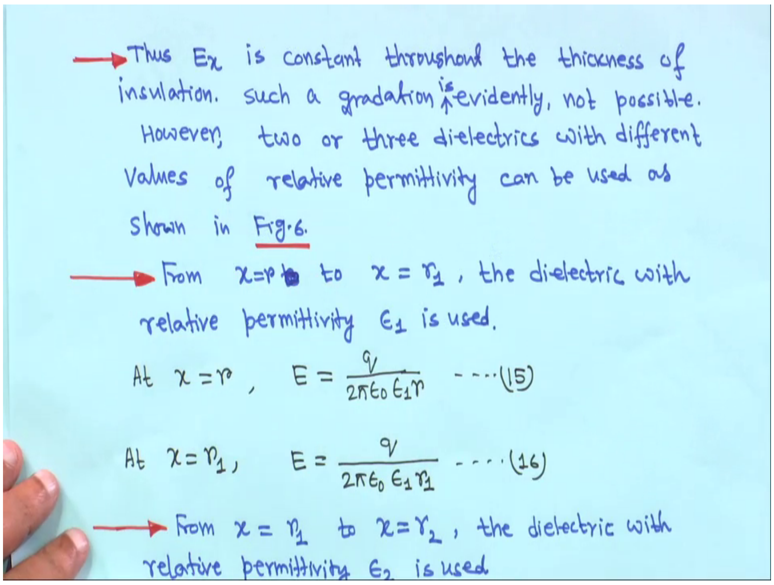

So, E x is constant throughout the thickness of the insulation. So, everywhere your everywhere that wherever it is that electric field intensity x remain constant if assumption is epsilon inverse inversely proportional to x epsilon r is equal to m by x right.

Therefore such a such a gradation is evidently not possible right it is not possible; however, 2 or 3 dielectrics with different values of relative permittivity can be used as shown in figure six that, but that is continuous thing is not possible because epsilon are inversely proportional to x continuous that such thing is not available, but we can use 2 or 3 layers of dielectrics with different permittivity this is epsilon 1 epsilon 2 here in the figure there are 3; your insulating material with different permittivity and I told you epsilon 1 greater than epsilon 2 greater than epsilon 3.

So, with differ that that I showed in the figure six right now from x is equal to r to x is equal to r 1, I mean your this is conductor radius r and from center to the first that is your insulation sheath first insulation it is r 1 right; that means, at x is equal; that means, from x is equal to r to x is equal to r 1 that dielectric with relative permittivity epsilon 1 because its relative permittivity epsilon 1 right. So, that at x is equal to r E can be written as q upon 2 pi epsilon 0 epsilon r into r because general formula is that states. It is q upon 2 pi epsilon 0 epsilon r into x right, but x is equal to your r and x is equal to r 1 you have to see when x is equal to one you can write that E is equal to q upon 2 pi epsilon 0 epsilon 1 into r this is equation 15.

Now at x is equal to r 1 that is at x is equal to r 1 right at this this one this is for your insulation insulating material whose permittivity epsilon 1. So, x is equal to r 1 in first one you are considering it is E is equal to q upon 2 pi epsilon 0 epsilon 1 into r 1 because it is here to here r 1, right, this is equation 16 similarly from x is equal to r 1 to x is equal to r 2 that is x is equal to r 1 to r 2 right that second layer r 1 to r 2 permittivity is epsilon 2 that one from x is equal to r 1 to x is equal to r 2 the dielectric with relative permittivity epsilon 2 because here permittivity is epsilon 2; that means, that means your; just hold on.

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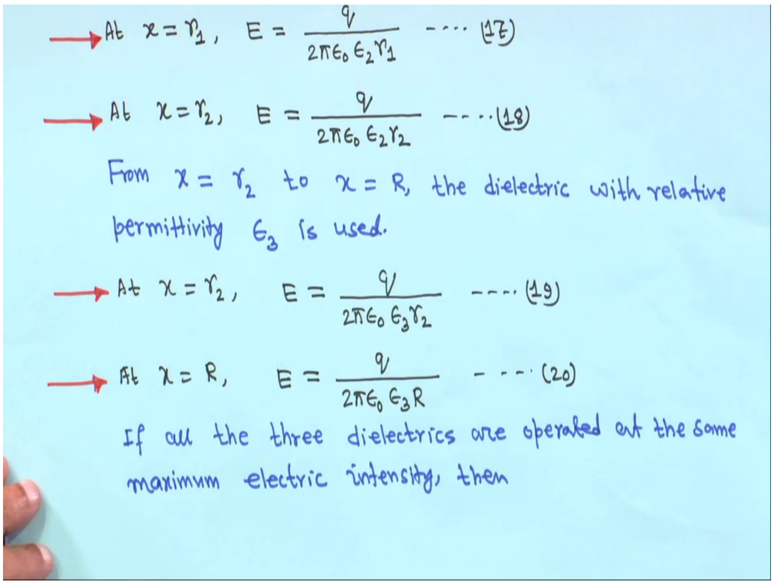

That means at x is equal to r 1 right E is equal to q by 2 pi epsilon 0 epsilon 2 r 1 you listen (Refer Time: 11:32) that.

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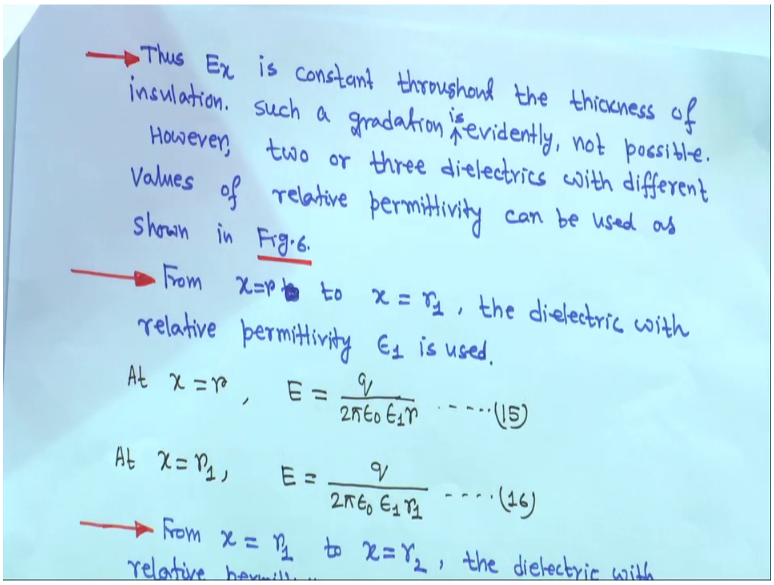

This when x is equal to r 1 that for permittivity or what you call (Refer Time: 11:37) epsilon 1 it was q upon 2 pi epsilon 0 epsilon 1 r 1, but when it is this when it is going to the next insulating material epsilon 2 r 1 to r 2, but it is epsilon 2 that why again that x is equal to r 1 E upon E is equal to q upon 2 pi epsilon 0 epsilon 2 r 1, right.

So, but note here epsilon 1 because for second (Refer Time: 12:04) starting from r 1 to your r 2. So, it is epsilon 0 epsilon, 2 r 1, this is equation 17. Similarly at x is equal to r 2 E is equal to q upon 2 pi epsilon 0 epsilon 2 into r 2 this is equation 18, right. So, from x is equal to r 2. Now similarly from x is equal to r 2 to x is equal to r that is the third one that is x is equal to r 2 to r right the dielectric with relative permittivity here epsilon 3 that relative permittivity epsilon 3.

Therefore, x at x is equal to r 2; it will be E is equal to q upon 2 pi epsilon 0 epsilon 3 r 2 here, this is for (Refer Time: 12:47) one because this when it actually that r 2 is the beginning of the your what you call it is a ending of this second this thing insulating material and when it is going to epsilon 3 then r 2 is the beginning of this and capital R is the ending that is why at x is equal to r 2 capital E is equal to q upon 2 pi epsilon 0 epsilon 3 r 2 here also x is equal to r 2 that 2 pi epsilon this is for your insulating material

2 epsilon two, but again for epsilon 3 that is starting from r two. So, E is equal to q upon 2 pi epsilon 0 epsilon 3 r 2. So, not 2 ha it is epsilon 3. So, this equation 19.

Similarly, at x is equal to r that is the boundary one last this one surface one right that E is equal to q upon 2 pi epsilon 0 epsilon 3 r. So, this is your equation 20, right, I hope you have understood this. Now, therefore, just hold on.

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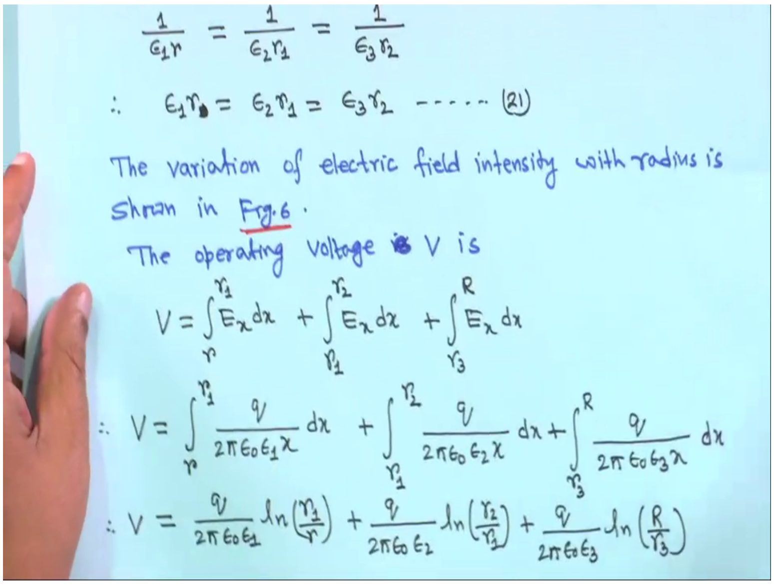

Therefore using this equation because if you look at all these all these equations right this E x is equal to is given, then your; at different values that everywhere that we want to make that E is same right. So, all these equations whatever it is there you just equate to them q 2 pi epsilon 0 all will be cancel just equate to them please do yourself just equate to them all the all the Es are same right if it. So, I mean happens.

So, it happens that all E at every point that is same and if they are equal, we want equal electric field distribution (Refer Time: 14:38) stress right. So, if all are equal then it q upon 2 pi epsilon 0 will be cancel and finally, the equation will be one upon epsilon 1 r right; that means, your this thing your; what you call that one upon epsilon 1 r is equal to 1 upon epsilon 2 r 1 is equal to 1 upon epsilon 3 r 2 right just hold on here.

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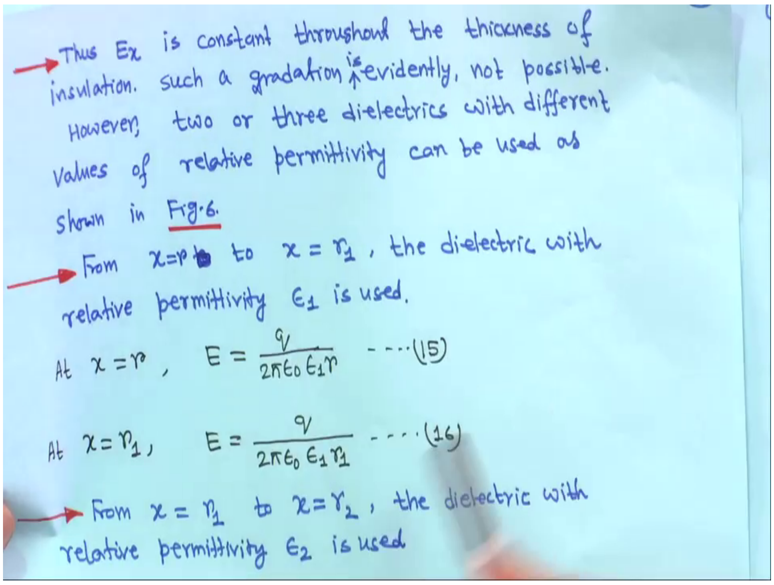

That it will be if you equate this one q upon 2 pi epsilon 0 epsilon upon epsilon 1 r 1 right and this is epsilon 1 r all are equal actually therefore, we can write one upon epsilon 1 r equate to this with epsilon to this one epsilon with this equate this one upon epsilon 2 r 1 that equate with this one; 1 upon epsilon 3 r 2 right that mean q upon 2 pi epsilon 0 all will be cancelled and finally, it is one upon epsilon 1 r equal to one upon epsilon 2 r r 1 is equal to 1 upon epsilon 3 r 2; that means, 1 r is equal epsilon 2 r 1 is equal to epsilon 3 r 2; this is equation 21, right.

So, the variation of electric field intensity with radius is shown in figure 6; that means, this figure I showed you the electric field intensity variation this one this one this the electric field intensity variation from r to r 1, r 1 to r 2, r 2 to capital R right, therefore, the operating voltage V is therefore, you integrate no need to show the figure here look r to r 1 E x d x plus r 1 to r 2 E x d x plus r 3 to capital R E x d x right therefore, V is equal to r to r 1 q upon 2 pi epsilon 0 epsilon 1 x d x plus r 1 to r 2 q upon 2 pi epsilon 0 epsilon 2 x d x plus r 3 to r q upon 2 pi epsilon 0 epsilon 3 x d x; that means, this is for the first insulating materials with permittivity epsilon 1 this is for the second insulating material permittivity epsilon 2 and this is for the third insulating material with permittivity epsilon 3, right.

Now, if you integrate; it is you will get q upon 2 pi epsilon 0 epsilon 1 it will be l n r 1 upon r it will be q upon 2 pi epsilon 0 epsilon 2 l n r 2 by t 1 and this one will be plus q upon 2 pi epsilon 0 epsilon 3 l n capital R upon r 3 right. So, this is expression or the your; what you call your voltage V operating voltage this is the expression now what you do this all these equation; all these equation this is l n r 1 upon r. So, what you do numerator and denominator multiple by r here also it is r 2 by r 1 numerator and denominator you multiply by r 1 and here also numerator and denominator you multiply by r 3 if you do.

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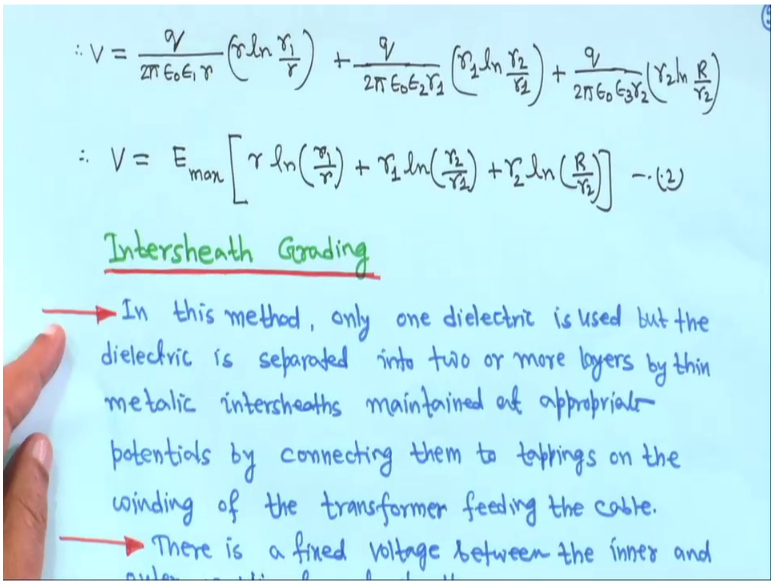

So, if you do. So, then it will be q; q upon 2 pi epsilon 0 epsilon 1 r r l n r 1 upon r the numerator and denominator multiplied by r similarly here also multiplied by r 1 numerator and denominator. So, q upon 2 pi epsilon 0 epsilon 2 epsilon 1 r 1 l n r 2 upon r 1 plus here q upon 2 pi epsilon 0 epsilon r 2 into r 2 l n r by r two; that means, this is actually q upon 2 pi epsilon 0 epsilon 1 r this is actually E max because conductor radius is r.

So, at the surface of the conductor that that E or electric field intensity will be maximum; that means, it will be E max actually E max this is at the service of conductor it will be q upon 2 pi epsilon 0 epsilon 1 r right because earlier also I have told you that surface at a surface of the conductor that electric field intensity maximum.

So, it will be q upon 2 pi epsilon 0 epsilon one. So, this is E max actually E max is equal to q upon 2 pi epsilon 0 epsilon r then r l n r 1 by r plus r 1 l n r 2 upon r 1 plus r 2 l n capital R upon r 2. So, this your volt your what you call the operating voltage expression when you use in this case, we have used 3 or 3 dielectric right with different parmittivities. Now that was your that is one thing second thing is that your intersheath grading right in this case, in case that what they do that only one dielectric used only one dielectric will used, but the dielectric is separated into 2 or more layers by thin metallic intersheath maintained at appropriate potential right I mean.

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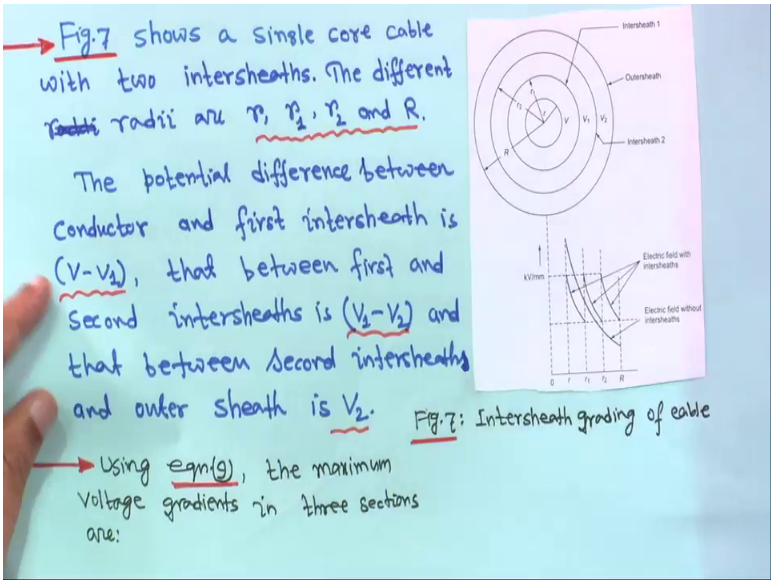

Here this is another diagram; this is the conductor.

But you have that you have the insulating material having same dielectric right, but you are you are putting in between intersheath; this is one intersheath 1, another is intersheath 2 and this is and this intersheath if you can maintain that potential I mean by some mechanism, right. So, maintain appropriate potential by connecting them to tapings on the winding of the transformer feeding the cable this is not easy procedure right, but in any way so, but if possible connecting it to tappings on the winding of the transformer feeding the cable.

So, there is a fixed voltage between the inner and outer radii of each sheath. So, there will be fixed voltage then between inner and outer radius of the your what you call that intersheath. So, in this diagram 2 inter sheaths are show and this is actually some your characteristics is shown this is your electric field intensity it is given in kilo volt per millimeter this is electric field with intersheath when you put intersheath electric will look this thing more or less they are following the same characteristic, but electric field without intersheath this is showing the this one that long curve, right.

So, in this case there is a fixed voltage between the inner and outer radii of each sheath right; that means. So, this is the figure this is the figure seven and this is actually in this is actually this one this one this one this is the intersheath outer sheath this is intersheath 2 intersheath 1 and here voltage is V, here it is V 1 here it is V 2 now. So, figure seven shows this figure only this figure only single core cable with 2 intersheaths; the different radii are r r 1 r 2 and capital R, right.

The potential difference between conductor and first intersheath is V minus V 1. So, the port this is this is at the surface it is V then V 1 then V 2. So, potential difference between the your what you call between the conductor and the first intersheath will be V minus V 1 this is understandable that is between the first and the second intersheath is actually V 1 minus V 2 here it is V 1 here it is V 2. So, it will be V 1 minus V 2 and the between the second intersheath and outer sheath between the second and outer sheath it is actually V 2; my question is here it will only V 2 right because outer sheath is V 2.

So, between your; what you call that the first in between the second intersheath and outer sheath between the second intersheath and outer sheath; it is taken V 2, my question is it (Refer Time: 22:51) why we have taken V 2 right; here we have not (Refer Time: 22:53) outer sheath we have not assume anything V; V 1 V 2 is a question to you that when you read this you mail me it is a simplest answer actually, but leaving up to you. So, and if you if you answer; this I will to reply to your mail when you read this right, but here we have taken only V 2 and this is the outer sheath this is outer sheath right. So, using equation 9 the maximum voltage gradient in 3 sections are so.

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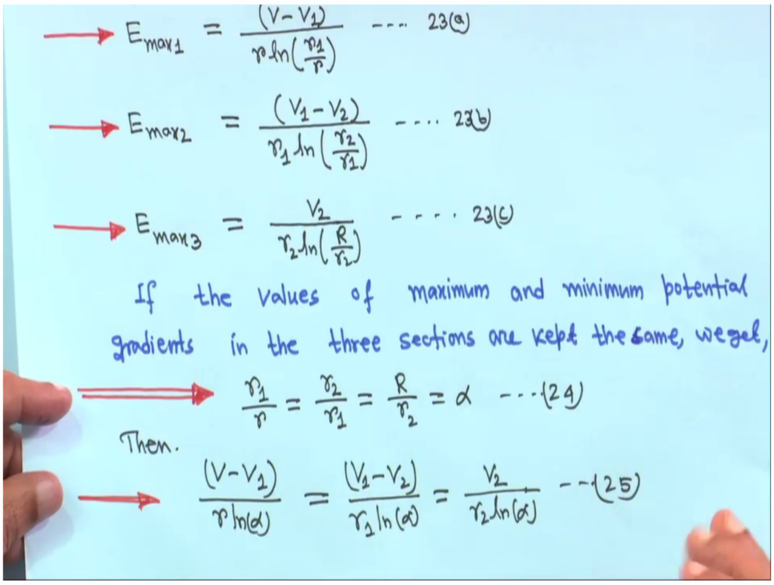

So, first one is first one between the conductor and the first sheath it is V minus V 1, therefore E max 1 will be instead of V actually it will be V minus V 1 r l n r 1 (Refer Time: 23:37) r this is actually coming from equation 9; this is coming from equation 9, right; therefore, that E max one will be V minus V 1 upon r l n r 1 upon r this is I making equation 23a. Similarly E max 2 will be that is between first and second intersheath the voltage difference is V 1 minus V 2 therefore, it will be V 1 minus V 2 that r 1 l n r 2 upon r 1 this is equation 23 b right.

And then this E max E max 3 will be V 2 upon r 2 l n capital R upon r 2 this is 23 C this is straight forward you can write right. So, in that in in this case if the values of maximum and minimum potential gradient in the 3 sections are kept the same if you assume that they are they all are same that is your what you call maximum and minimum potential gradients in the 3 sections are kept the same then you will get r 1 upon r is equal to r 2 upon r 1 is equal to capital R upon r 2 is equal to alpha. So, in that case if you if you try to make that they all are same, right.

If you want to if you want to make this one, this one, this one, all are same that in that case what will happen that r 1 upon r is equal to r 2 upon r 1 is equal to capital R upon r 2 is equal to alpha; that means, all this ratio all this ratio it will be your what you call they have to be same in general formula is V upon r l n your what you call l n capital R by small r right. So, if you assume that all the things will be same then this is the condition that is; that means, if it is.

So; that means, the your what you call the V minus V 1 if r 1 upon r is equal to r 2 upon r 1 is equal to capital R upon r 2 is equal to alpha right then this equation this equation can be written as all are equal. So, V minus V 1 upon r small r into l n alpha then is equal to V 1 minus V 2 upon r 1 l n alpha is equal to V 2 upon V 2 upon r 2 l n alpha this is equation 25, right, if you want to make it this ratio you have to make same right.

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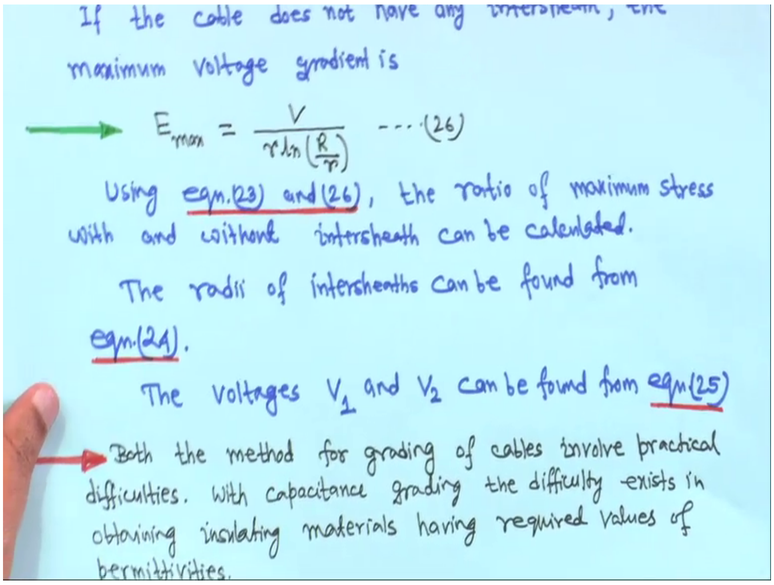

That means if the cable does not have any intersheath suppose it dosent have an intersheath in that case the maximum voltage gradient is E max will be V upon r small r l n capital R by small r, this is 26, if there is no intersheath then this is that E max because that is at the surface of the your conductor. So, using equation 23 and 26 the ratio of maximum stress with and without intersheath can be calculated because this is without any intersheath and other equation 23; 23 means 23 a 23 b and 23 c, right calculated the radii of intersheath can be found from equation 24; that means, from this equation that radii radius of intersheath, you can find out from equation 24, right.

So, when voltage V 1 and V 2 can be found from your from equation 25, I mean there are here there are 3 equations actually this one is equal to this one; one equation this one is equal to this one; one equation and this is one is equal to this one another equation right. So, from that you can compute if data are known you can solve this if data given and you can find out V 1, V 2, V 3, etcetera, right. So, both the methods for grading of cables involve practical difficulties there is there are practical difficulties of implementing this method with capacitance grading the difficulty exist in obtaining insulating materials having required values of permittivities.

I mean you have a you have to put insulating materials of suppose you are make a designing some cable that different if you want that I want this much of electric field (Refer Time: 27:59), then different permittivity of insulating material it is difficult to get right. So, this is one disadvantage. So, it is almost not possible although; although just hold on.

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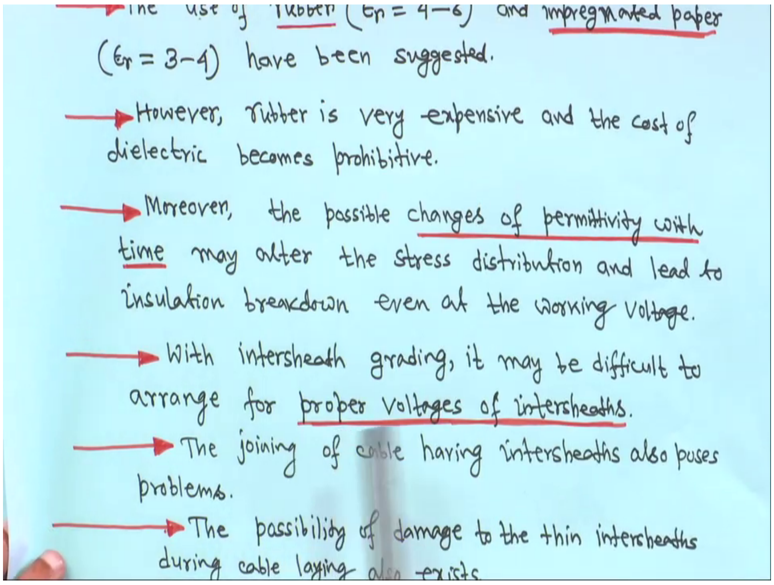

Although, use of rubber, it has permittivity value in between 4 to 6 and impregnated paper that permittivity have to 3 to 4 have been suggested I mean you can if you can use rubber, paper, etcetera, any one thing, but rubber is very expensive and the cost of dielectric become prohibitive rubber is expensive more over possible changes of permittivity with time may alter the stress distribution and lead to insulation breakdown even at the working voltage.

Then with the time, there is a possibility the permittivity your with the time this permittivity your value may alter in that case there is a possibility of breakdown even at the working voltage also another thing with inters heath grading it grading; it may be difficult to arrange the proper voltage of inters heath because you have to connect it to some transformer winding tapping. So, these are very difficult task.

So, that is very difficult to get the proper volt this thing proper voltage and the joining of cable having inters heath also poses problems suppose we have cut the cable and 2 cable you are going for jointing and if inters heath is there then it will be difficult to because inters heath will be spoiled, but the possibility of damage to the thin inters heath during cable laying also exist because when was joining right damage to when you are laying the cable also because inters heath will be very thin and there is a possibility that your what you call that this inters heath may damage right.

So, these are the your; these are the disadvantages of capacitance grading and you are inters heath right.

Thank you, we will come again.