Power System Engineering
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Lecture - 03
Overhead Line Insulators (Contd.)

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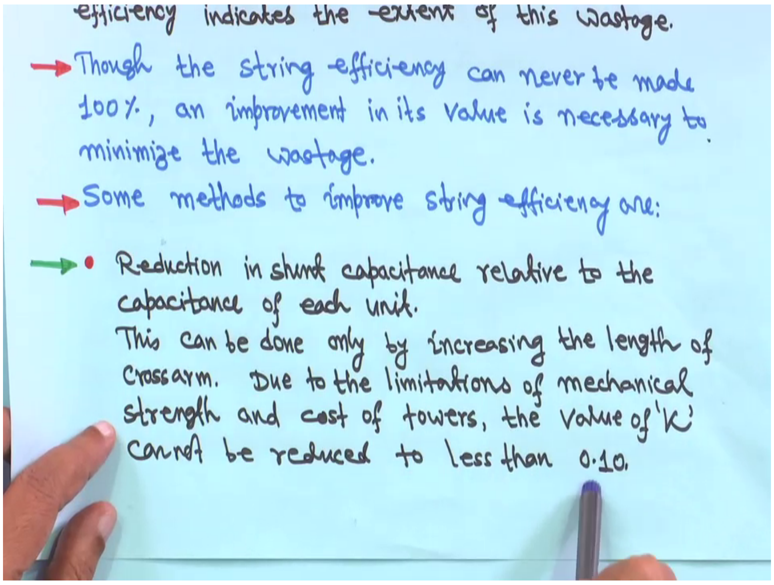

So, reduction in some capacitance relative to the capacitance of each unit this is one end. This can be done only by increasing the length of the cross arm, but you cannot increase the length of the cross arm, because cost is a mirror factor, but due to the limits and limitation of mechanical strength and cost of towers right, the value of K cannot be reduce to less than 0.1.

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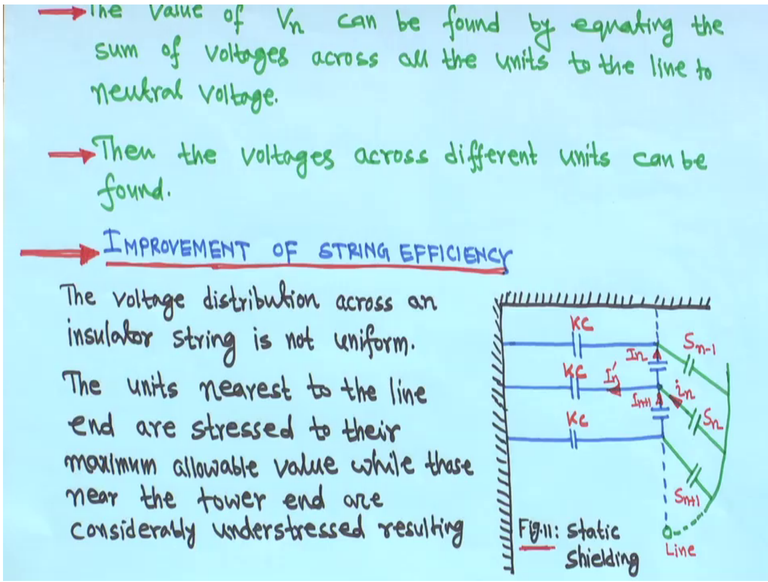

So, you cannot make it that k value; that means, this value 0 to 1 sorry less than 0.1.

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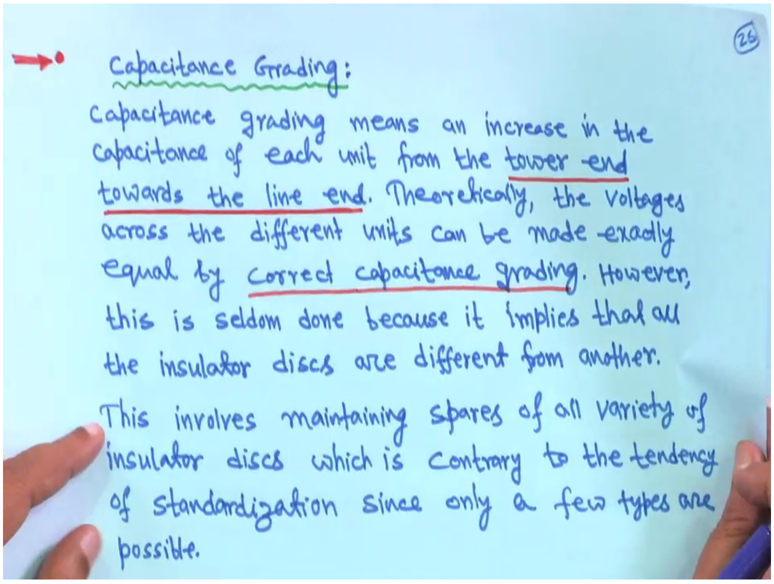

Now, that is why one method is there that is called capacitance grading. So, this way insulator efficiency can be string efficiency can be increased. Capacitance grading means an increase in the capacitance of each unit from the tower end towards the line end. So, you increase the capacitor from the tower end towards the line end, so that is called capacitance grading. Theoretically, the voltages across the different units can be made exactly equal by correct capacitance grading. If you can go for a correct capacitance grading then voltage across each unit there are so many units in each string it can be made equal, but this is seldom done because it implies that all the insulator discs are of different from another. I mean if you try to make it then you will find insulator different disc will be of different types I mean one will be different from another. So, in this case this involve maintaining spares of all variety of insulator disc I mean all type of insulator disc are required right which is contrary to the tendency of standardization since only a few types are possible.

So, only few types of insulator discs are possible. So, in reality it is not possible to make all the voltage I mean that voltage across a different units can be made exactly equal. So, voltage across each string, it is not possible to maintain exactly the same voltage. So, if you try to make it then that different units will be of different sizes and may not be available all different units I mean different sizes except some standardized size is there. Therefore, the value of V n can be found by e or what you call this one sorry therefore, one method is there therefore, one sorry therefore, one method is there that is called static shielding.

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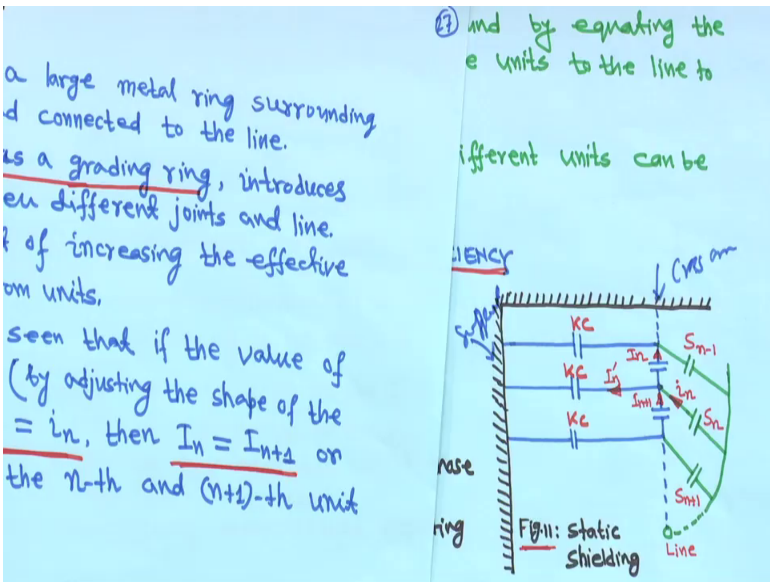

This figure 1 actually, now look at this figure, figure 1 is static shielding. So, here it is this is your cross arm, this is actually your cross arm, and this is your support that is the tower, this is your support. So, what is that this is called static shielding.

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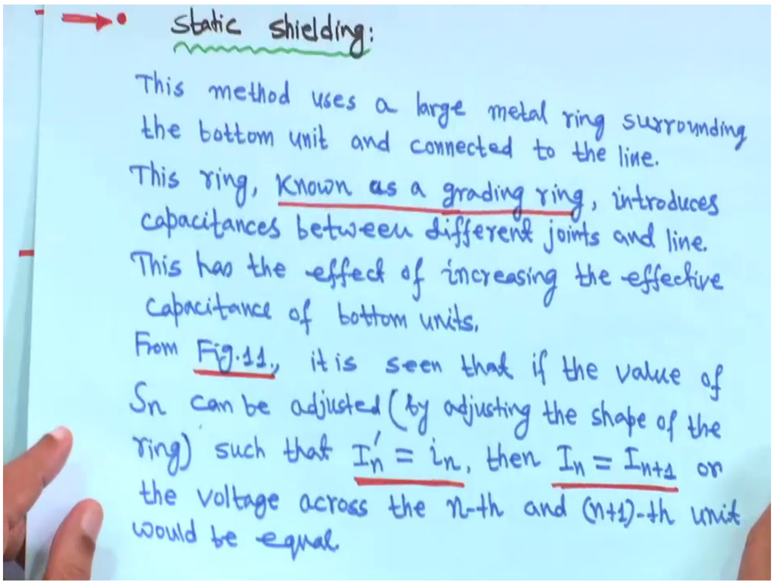

What is done actually, this method uses a large metal rings surrounding the bottom unit here it is the bottom unit here, a large metal ring surrounding what you call bottom unit and connected to the line. If you look at the transmission tower in many places this thing also you will observe, this is capacitance grading, this thing also you will observe. This that means, this method uses a large metal rings surrounding the bottom unit connected to the line. So, this ring known as a grading ring; and it introduces capacitances between different joints and line. This has the effect of increasing the effective capacitance of bottom units. So, this has effect that it will increase the capacitance of the bottom units.

So, this figure 11, it is seen that, look at that it is seen that if the value of S n can be adjusted that mean this value, if this S n value this, a capacitance value I have put S n, if S n can be adjusted by adjusting the shape of the ring. That means, the ring you have to adjust that this ring you have to adjust the shape of the ring. Such that if you can make that your I n dash is equal to i n, if you make I n dash is equal to i n then all this string your all this unit you will find this same I current is flowing. But in reality it is not possible then voltage will be equal. If you can adjust this S n value such that your i n will be I n dash I mean equal current then if you apply Kirchhoff's first law here, then it will it will find I n plus 1 is equal to I n that may be every unit you will find the same current, but which is not possible. So, it is seen that if the value of the S n can be adjusted then this one or the voltage across the n-th unit would be equal n-th and n-th n plus 1 unit would be equal then be a n and n-th plus 1 unit voltage will be equal which is not possible actually. But this capacitance grading is there if you look at any transmission tower, you will find this is there.

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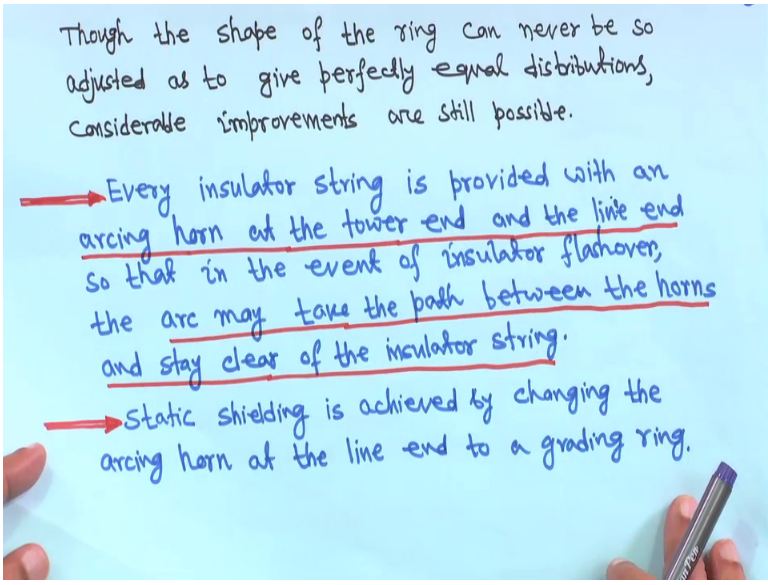

Though the shape of the ring can never be adjusted, it is not possible actually, though the shape of the ring can be never be so adjusted as to give perfectly equal your distributions considerable improvements are still possible. Although, you cannot make I n is equal to I n dash, but by adjusting this you can try to improve that your voltage distribution. So, every insulator string is provided with an arcing horn at the lower end and at the line end. If you observe the insulator, you will find on the top and bottom of the top and bottom right is provided with an arcing horn at the tower end on the tower side and the line end, so that the event of insulator flashover, the arc may take the path between the horns and stay clear of the insulator string. So, on the top and the bottom, you will find some arc horn in there; if flashover take place it will be through that to only and somehow it will bypass what you call that insulator string.

So, static shielding is achieved static shielding is achieved by changing the arcing horn at the line end to a grading ring. So, static shielding can be possible by changing the arcing horn at the line end to a grading ring. So, this is your line end, that means, this way it is your what you call it is possible. So, this is later the we are we are not deriving this is your what you call this much formula or anything for that, but when we will take the numerical on this at that time we will try to solve the numerical, but these are one method and commonly used also that your static shielding.

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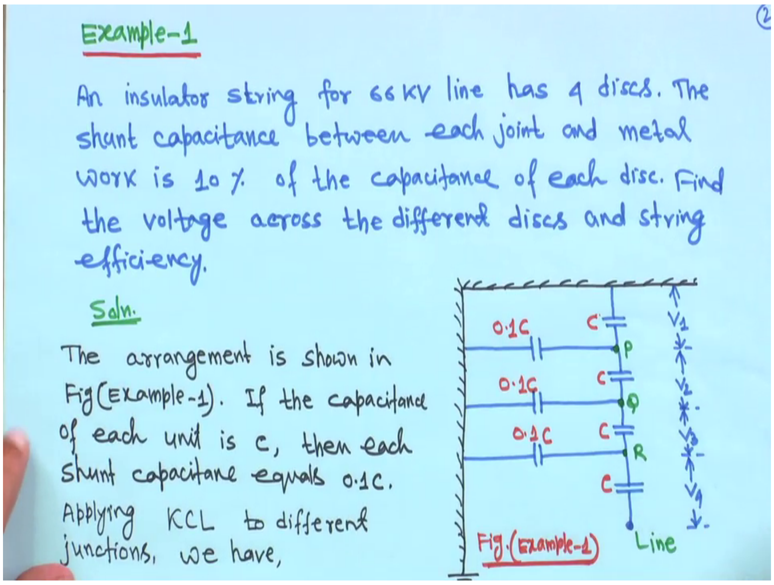

So, next come to the example that capacitance grading other thing if possible we will take the problem. Now, question is that example one you come. And actually insulator topic is a quite easy for you compared to many other difficult topics. So, just you have to little bit concentrate and that is all. So, an insulator string the problem is 66 KV line has 4 discs; that means, 4 units are there. The shunt capacitance between each joint and metalwork is 10 percent of the capacitance of each disc. Find the voltage across the different disc and string efficiency. So, it says that 4 disc are there. So, 4 capacitance - 1, 2, 3, 4 C, C, C and may under shunt capacitance between each joint and metal work is 10 percent, so that means, your this is your 0.1 C that is k is equal to 0.1 actually 0.1 C, 0.1 C, and 0.1 C. If you have a 4 disc means three such shunt capacitance will come, this from one, this is from one, this is from one and nothing will be there because it is a line actually line is connected here conductor is connected here. So, if you have n number of units in the string that you will have n minus 1 number of this shunt capacitance. So, the arrangement is shown in figure, this is figure example 1. If the capacitance of each unit is C, then each shunt capacitance equal to 0.1 C applying KCL to different junction we have you apply you have to apply KCL equations.

So, this is P; this is Q; and this is R, these three points are taken. So, look at this, this thing at junction P. You can write your omega, this is your at P point that omega C your the way it has been made it is voltage this is V 1, this is V 2, this is V 3, and this is V 4. Total is V 1 plus V 2 plus V 3 plus V 4; up to this is V 1 plus V 2 plus V 3 plus V 4. So, at junction P, if you write at junction P, this equation it will be this is coming from that same equation omega C V 2.

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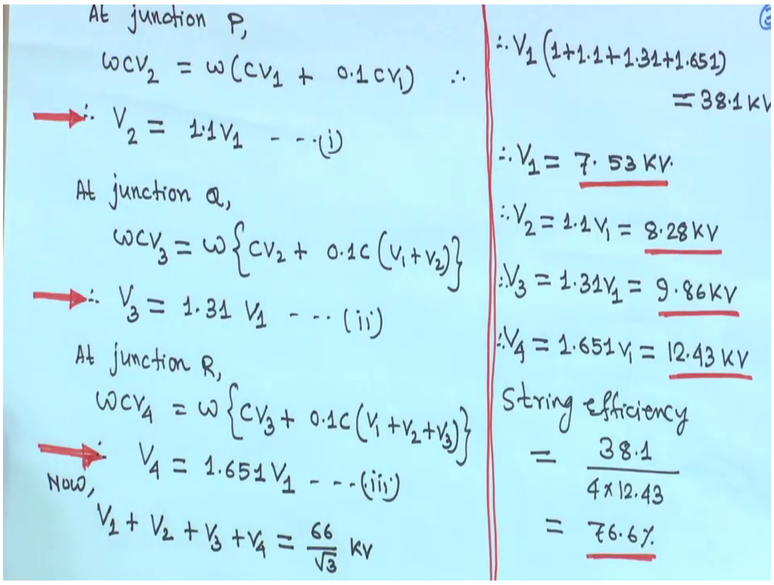

That means your this current this current is this Q to P this current is omega C V 2 is equal to the current here current in this branch omega C V 1 omega, omega is taken common out, so in bracket omega C V 1 plus omega into K C V 1.

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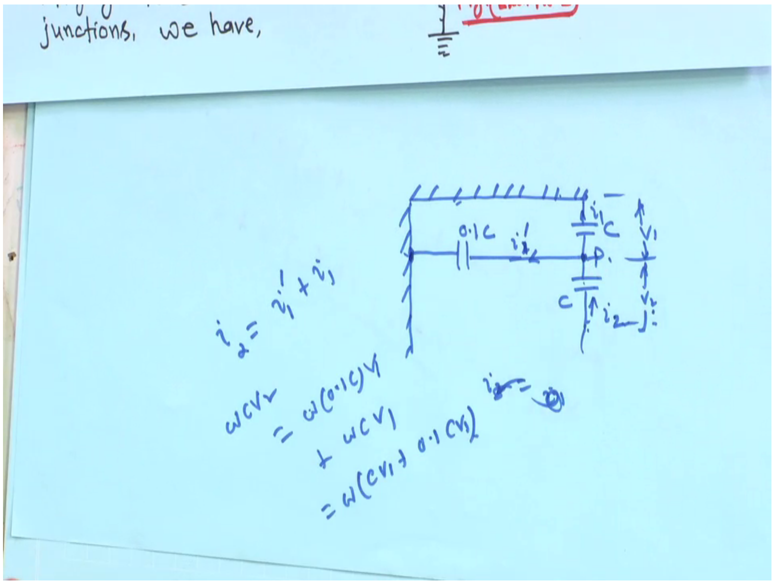

I mean if you have any understanding problem that I am just drawing one for you. Take the first one. This is your this is that your cross arm this is cross arm and this is your supporting tower, this is your first one I am making for you, this one, this one and this is your 0.1 C and this is C and this is C. This point is P, this point is P. Suppose current here for example, say it is say your i 2, current here you say it here i 1 dash and this current is your what you call i 1. Therefore, i 2 is equal to your i 1, i 2 here I am writing that your i 2 is equal to i 1 dash plus i 1. Now, voltage across this is V 1 and here it is V 2. Similarly, another capacitors is here, but I am making only for this one. So, i 2 is equal to what we are writing i 2 is equal to omega C into V 2 because voltage across this is V 2. So, is equal to i 1 dash; i 1 dash is g omega in to 0.1 C into your V 1 because this point, this point same, this is cross arm this tower. So, it is voltage is V 1. So, this is V 1 plus this is the voltage across this first unit is V 1. So, it is omega C V 1. If V is equal to that that means, is equal to if you take omega common it will be your this one I am writing first C V 1 was 0.1 your C V 1.

So, just you apply your KCL at every point P, Q, R. So, if you do, so you will get at junction P, you will get at junction P that omega C V 2 is equal to omega common this one. So, V 2 is equal to 1.1 V 1 this is equation 1. Similarly, if you apply at Q and R and so on, please do yourself I have done it here right then your you can write at junction Q omega C V 3 will be omega C V 2 plus 0.1 C V 1 plus V 2. Because as soon as you will apply for Q, so this volt across this voltage will be this one V 1 plus V 2 V 1 plus V 2 that is why we are writing in straight forward writing omega C V 3 is equal to omega C V 2 plus 0.1 C in bracket V 1 plus V 2. That means, simplifying V 3 will be one point three one V 1 right this will be your equation 2.

Now question is that that V 3 we are writing V 1 means this expression of V 2 you substitute here then only we will get 1.31 V 1 directly I have I have written here. So, please substitute V 2 is equal to 1.1 V 1 here itself and then you simplify you will get V 3 is equal to in terms of V 1 1.3 V 1. Similarly, at junction R, if you apply then omega C V 4 will be that omega C V 4 will be at R, omega C V 4 will be your this one omega C V 3 plus this voltage and this voltage that means, this voltage of V 1 plus V 2 plus V 3. So, it will be your omega C V 4 is equal to omega and bracket C V 3 plus 0.1 C plus V 1 plus V 2 plus V 3.

Again here if expression of V 3 as well as V 2 both you substitute here, V 2 is equal to 1.1 V 1 and V 3 is equal to 1.31 V 1, you substitute here. If you substitute you will get V 4 is equal to 1.651 V 1, this is equation 3. Therefore, total voltage is given that line-to-line voltage actually if nothing is mention means it is line to line voltage you know that. Total voltage is 66 k v; that means, V 1 plus V 2 plus V 3 plus V 4 is equal to 66 by your what you call root 3 because you have to make per phase. So, V 1 plus V 2 plus V 3 plus V 4 is equal to 66 by root 3 KV.

Now, what you do in this expression you substitute V 2 is equal to 1. V 1 you substitute V 3 is equal to 1.3 V 1 and you substitute V 4 is equal to 1.651 V 1 all you substitute and simplify it, you will get V 1 into 1 plus 1.1 plus 1.131 plus 1.651 is equal to 38.1 KV, 66 by root 3 is equal to 38.1 KV. Therefore, V 1 is equal to 7.53 KV, V 2 is equal to 1.828 KV, V 3 is equal to 9.86 KV, and V 4 is 12.43 KV; that means, I told you that your unit, which is nearer to the line have higher voltage stress. Suppose you have this four units 1, 2, 3, 4 you can see the V 4 is the maximum 12.43, and V 1 is 7.53, it is a lowest one. Although same insulator same metal is used. So, this is on a higher state, you lower unit which is close to the conductor, and this has a lower voltage which is close to a tower right. So, it has lower voltage and this has the higher voltage. And string efficiency it is the total voltage is 38.1 KV - this voltage, and total number of disc is 4. So, it is n is four into the 12.43. So, it is 76.6 percent string efficiency. So, this is how one can calculate I hope you have understand this, understood this numerical.

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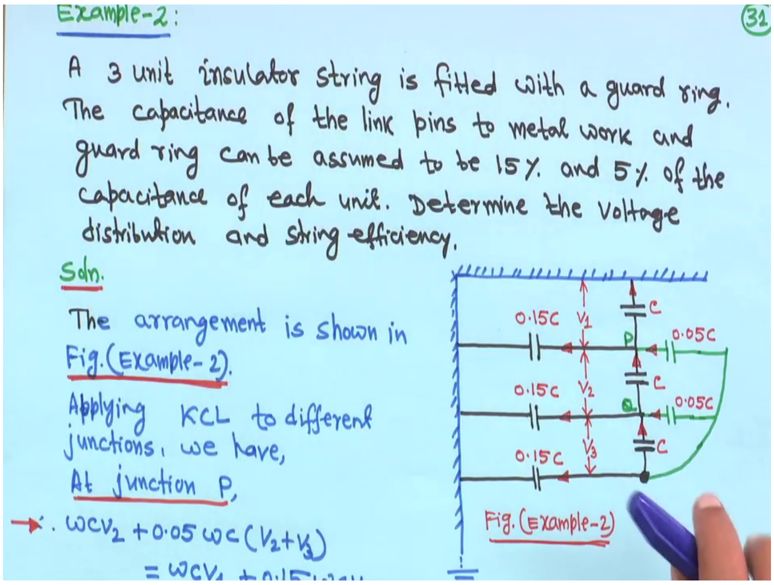

Now, second one just hold on, example 2. In this case, I have taken three unit. A three unit insulator string is fitted with a guard ring that is yours that capacitance grading thing right this guard ring. The capacitance of the link pins to metalwork and guard ring can be assumed to 15 percent and 5 percent of the capacitance of each unit. So, this is 15 percent of this one - this shunt capacitance, and this one is taken 5 percent, so 0.05 C, 0.05 C, and this is 0.15, 0.15, 0.15 C, this figure for example. You have to find out the voltage distribution and string efficiency.

This example rather than mathematical derivation directly I have taken this example. This arrangement is shown in figure example 2. So, applying KCL to different junction we have at junction P, you apply your what you call that your KCL at junction P at this point you apply KCL. If you do so, you will get omega C V 2 because voltage across this one is V 1 voltage across this one is V 2 and voltage across this one is V 3 shown here, V 1, V 2, V 3 this shown here.

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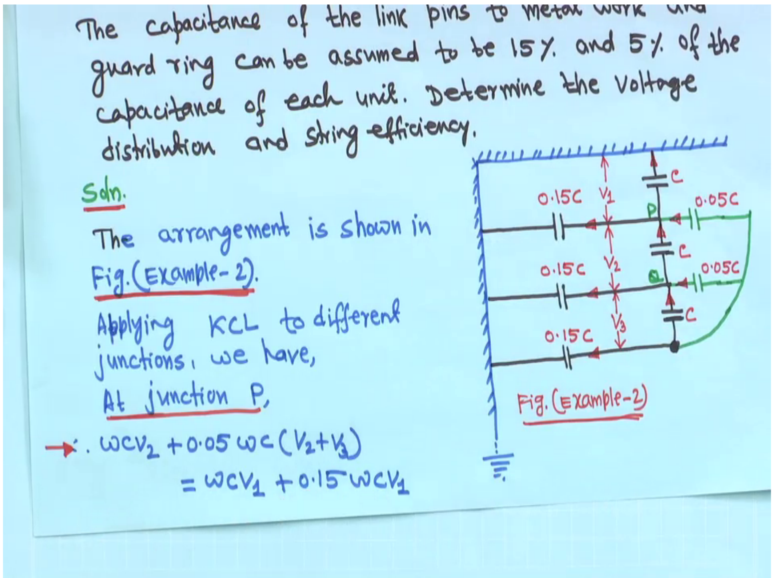

So, at junction P omega C V 2 that mean this is your omega C V 2 is equal to 0.05, omega C V 2 plus V 3, because this voltage across this one, this is actually V 2 plus V 3. Because this point and this point across this, this point and this point means this point and this point, that mean V 2 plus V 3 that is V 2 plus V 3 voltage right. It is equal to your we can write sorry this one omega C V 2 plus this voltage is equal to (Refer Time: 18:16) only is equal to omega C V 1 that is you're here omega C V 1 plus 0.15 omega C V 1 because voltage across this is V 1 voltage at this same point. So, voltage across this V 1, so 0.15 omega C V 1.

I repeat once again you apply your KCL at point P, so if you do, so at this junction P, if you do, so this current is omega C V 2 this current is entering at this point plus this current is also entering in the point. So, 0.5 omega C into V 2 plus V 3 from this point to this point, this capacitance grading actually from this point to this point, the voltage actually V 2 plus V 3. So, V 2 plus V is equal to this two current, one is here, another is here that is omega C V 1 that is current here, this arrow direction is given omega C V 1 plus 0.15 this one omega C V 1. So, this is at junction P.

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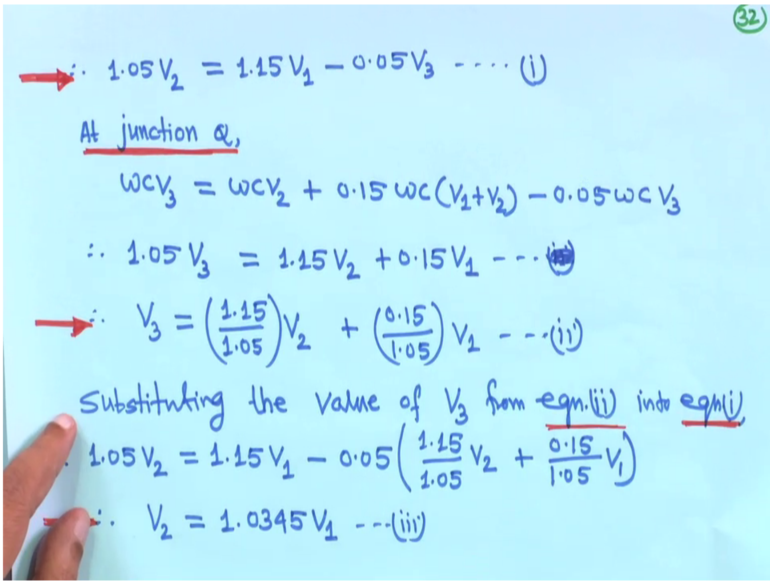

If you simplify if you please simplify this one, if you simplify you will get 1.05 V 2 is equal to one 0.15 V 1 minus 0.05 V 3 this is say equation one this is equation one. Similarly, you at junction Q, you please apply again KCL at junction Q you please apply KCL. If you do so, it will be omega C directly I am writing that omega C your V 3 right and if this current is going omega C V 3, this is omega C V 3. And this one I have written minus means if you bring to this - this one, this current is entering it will be omega C V 3 plus 0.05 your C or your omega V 3 that this actually directly taken to this side. So, please apply this, this current summation is equal to this current is entering this two and this two are leaving.

So, just please do it and simplify. So, you will get omega C V 3 is equal to omega C V 2 plus 0.15 omega C V 1 plus V 2 minus 0.05 omega C V. If you bring to the left hand side it will be omega C V 3 plus this one left hand side, but directly I am writing here. So, I think it is understandable to you. So, if you simplify, it will become 1.05 V 3 is equal to 1.15 V 2 plus 0.15 V 1. Then the V 3 is equal to 1.15 upon 1.05 V 2 plus 0.15 upon 1.05, this is equation 2. So, substituting the values of V 3 from equation two into equation one you substitute here the value of V 3. So, you will get after substitution you please make this then you will get V 2 is equal to 1.0345 V 1, this is equation 3, because you have to solve for V 1, V 2, V 3 just like solving like a linear equations.

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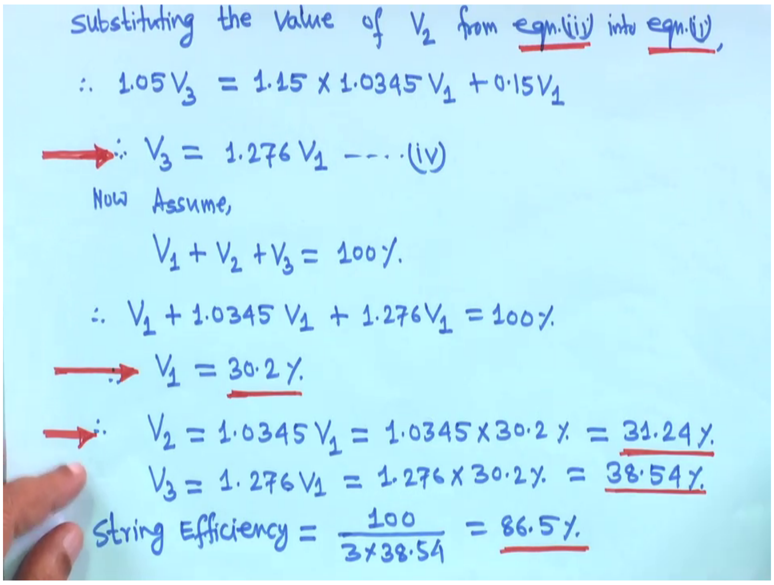

Now, again substituting this value of V 2 from equation 3 from this equation in equation two then you substitute in equation two then you will get 1.05 V 3 is equal to 1.15 into 1.0345 V 1 plus 0.15 V 1 therefore, V 3 is equal to 1.276 V 1, this is 4. So, now, we know that that you assume because in this problem in this problem actually voltage is not mentioned whether it is 66 or 132 or 220 KV nothing is mentioned in this problem. So, what will do we will assume that we in terms of percentage of voltage we will find out. We assume that V 1 plus V 2 plus V 3 is equal to 100 percent that will assume that means, now V 2 and V 3 in terms of V 1, you substitute here then V 3 will got this one in terms of V 1. And V 2 also we have got this one, V 2 also we have got in terms of this one. So, substitute here. If you substitute it will V 1 plus 1.0345 V 1 plus 1.276 V 1 is equal to we make 100 percent that mean V 1 will be 30.2 percent.

Similarly, V 2 will be 31.24 percent, and V 3 will be 38.54 percent. Therefore, string efficiency it will be voltage you taken in terms of percentage, it will be 100 percent divided by 3 because 3 disc are there in, n is equal to 3, 3 disc are there into the highest voltage is 30 lower bottom unit voltage across the bottom unit is 38.54 percent. So, 38.5 percent 86.5 percent string efficiency has improved. Look one thing because of this capacitance grading right look at the voltage percent is 30.2 percent, this 31.24 percent and 38.54, they are not equal, but V 1 and V 2 are very close. And this is this thing, but efficiency has increase.

Now, there will be an exercise for you that this is I have got 86.5 percent. Same problem you will solve without considering this capacitance grading, this part you will not consider, only you consider this disc capacitance and this shunt capacitance, and try to find out efficiency and compare that one with 86.5. You will get definitely you will get less than 86.5 such that because of this grading efficiency, this is an exercise for you, please you ignore that and only solve this one, and try to see yourself. I have not done it I have not done it for you, but you do it. And when you will do this course when you solve it you can mail to me and forum is also there, there you can put. So, this is your example 2.

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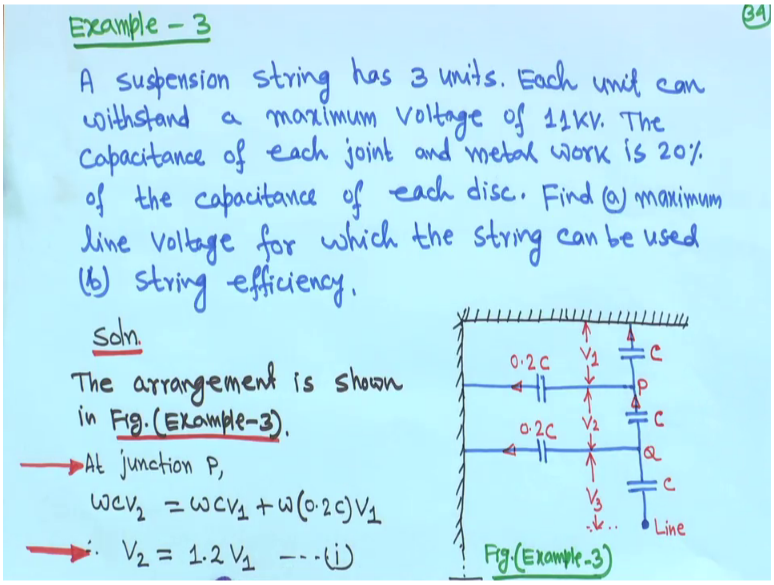

Next one, so example 3, here that is suspension string has three units right. So, each unit can withstand a maximum voltage of 11 KV. The capacitance of each joint and metal work is 20 percent of the capacitance of each disc. Find, a - maximum line voltage for which the string can be used; b - string efficiency this two you have to calculate. Now, this one now this one that this diagram is shown for example, three diagram is shown. So, similarly you apply your junction P that omega C V 2 is equal to omega C V 1 plus omega into 0.2 C V 1 same as before. So, you will get V 2 is equal to 1.2 V 1. So, this is equation one.

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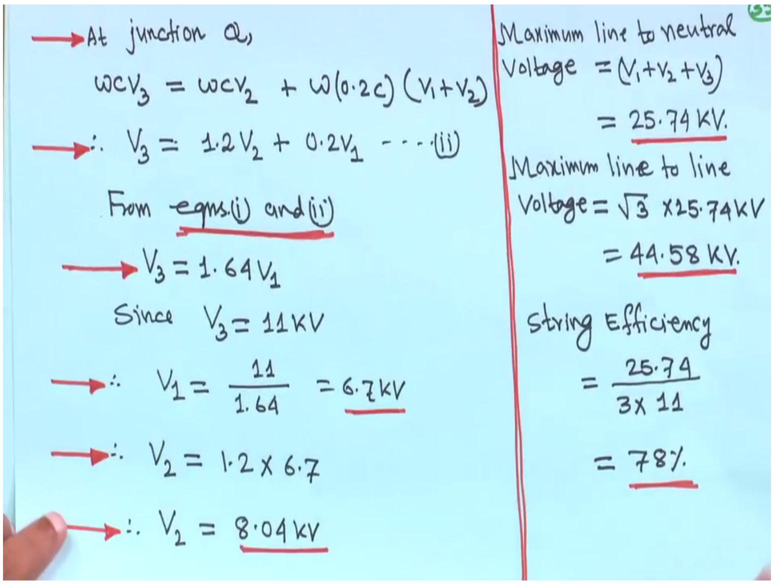

Similarly, at junction Q that omega C V 3 that mean this one at junction Q omega C this one V 3 is equal to look at this diagram, it is omega C V 2 plus omega into 0.2 C bracket V 1 plus multiplied by V 1 plus V 2. So, you will get V 3 is equal to 1.2 V 2 plus 0.2 V 1. So, this is equation two. So, from equation 1 and equation 2, you will get V 3 is equal to your 1.64 V 1 because here V 2 is given 1.2 V 1, this V 2 you please substitute here this V 2 you substitute here. So, you will get V 3 in terms of V 1, 1.64 V 1; and V 3 is equal to given 11 KV. So, V 1 will be eleven by 1.64, so 6.7 KV. V 2 is equal to 1.2 into 6.7, so 8.04 KV. And your V 3 your V 1 plus maximum line to neutral voltage V 1 plus V 2 plus V 3, so it will become 25.74 KV.

So, V 1 you have got 6.71, and V 2 you got 8.04; and V 3 I have not calculated here you they have V 3 is given sorry 11 KV it is given. So, V 1 plus V 2 plus V 3 because in the problem it is given, problem it is given that maximum line voltage for which the string can be used, and we have to find string efficiency and this is given that each unit can withstand a maximum voltage of 11 KV. So, V 3 is taken your maximum because the lowest unit lower unit near the line will take the maximum voltage it has that is why V 3 actually taken as 11 KV. So, total is 25.74 KV. Therefore, maximum line-to-line voltage will be root 3 into 25.74, so it is 44.5 KV. Therefore string efficiency 25.74 number of disc is three. So, 3 into 11 that maximum allowable limit 11 KV that is a lower unit voltage that is that your V 3 is 11 KV, it is taken, so it will be 78 percent. So, string efficiency will be 78 percent.

Thank you, again we will be back.