Power System Engineering
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Lecture – 02
Overhead Line Insulators (Contd.)

So, next is the strain or tension insulator.

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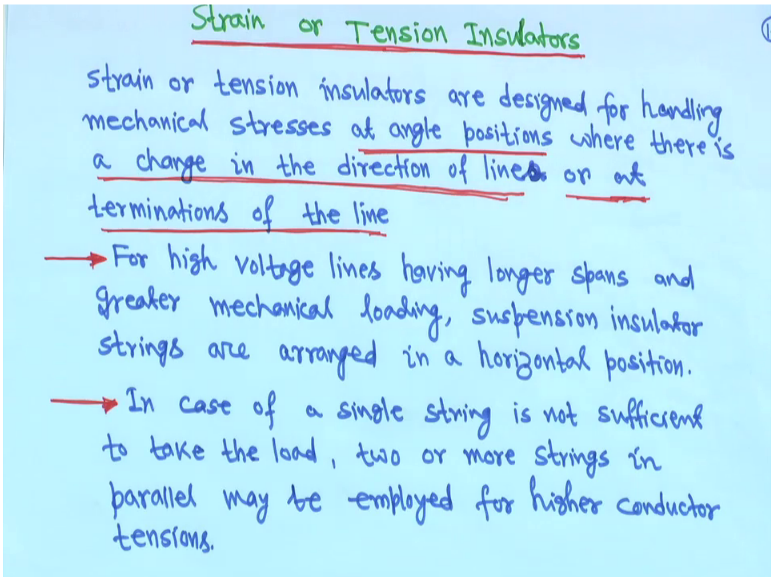

So, strain or tension insulator a design for handling mechanical stresses at angle position, where there is a change in the direction of line or at the termination of the line. You might have seen I am roughly sketching it is something like this; you can observe that suppose this is the line.

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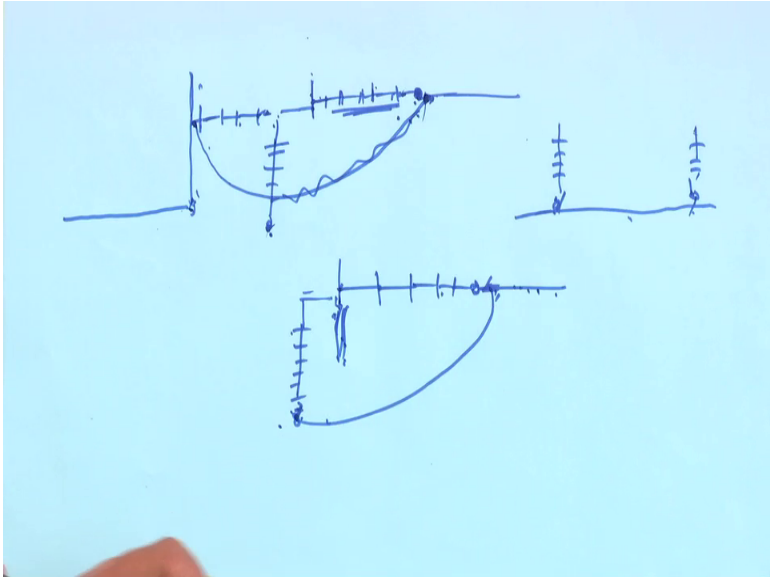

So, this is insulator string, it is insulator string only and it is coming like this. So, this is the cross arm, it is connected and suppose a conductor is connected here, you can see these are all the insulated pieces.

So, conductor is coming from somewhere, you will see the horizontal it is placed tension string and when it is line is going out either I mean when line coming from suppose a line is coming like this direction and when it is taking this direction something like this or angle any angle direction, then you will find at that it will be your stay your tension type, it in horizontal position, it is kept and either another thing is that for another side suppose, if you have you want to take the same horizontal thing then another tide are also may be insulator pieces are there like this, it is there and this side conductor is there.

So, this is conductor this is also conductor but you have to connect this, you will observe that this is connected like this by the same conductor, if you observe on the high tension tower you can see that. So, that means a strain type so and sometimes it is coming in a horizontal position from some a suppose conductor is coming like this and going like this.

So, somewhere it will be tension type if you it will make it horizontal positions and that conductor will be tension and from there again you can find out another 1 maybe, the same horizontal position or maybe depend on the design or maybe you will find it is coming on the your what you call the horizontal position and that may be vertical position.

But it will be connected to your what you call it will be connected to that your this thing by this same conductor, you can observe it that when insulator is going connected somewhere in the tower and when it is suspension type that it is like this, it is like the another tower is here say it is like this. So, conductor is connected so it is going like this right.

But question is that when it is coming from somewhere, and supposes taking another direction. So, either it should be either side you can see a horizontal type or sometimes you can see it is coming like this and after that some other cross arm maybe that string insulator is coming, and from there I mean it will be something like this. If it is not like that it will be something like this, from another cross arm it is I can make it like this. So, many strings are there, so conductor will go like this.

So, in that case this and have to connect because this is conductor end, this is also conductor is this thing. So, if you joint this conductor, suppose this is not there this is for this one I draw a separate thing. Suppose you have this insulator string that is horizontal position, this conductor is connect coming from somewhere, this is your conductor. So, another cross arm from the same tower maybe it is a string insulator, vertical position this is another 1 right. When it is coming and taking changing the direction; that means, that is you are coming from 1 direction that conductor taking and not necessarily be 90 degree.

But taking in another direction may be p, then this portion should be connected like this conductor right. Otherwise how the continuity will be maintained because this is insulator this insulator and there it is connected, this is your tower right, so this way thing takes place. So, if you observe the your high tension transmission line anywhere in front of your house or college or whatever it is, if you see this then you will see that this is the different way it is connected you can say v shape also v connection.

So, that is why this strain or tension insulators your are designed for handling mechanical stresses at an angle position, where there is a change in the direction of line or a termination of the line. At termination of the line also not only for high tensile line even low tension line also at the termination point, you will see the insulators are connected horizontally, it is to keep intention right.

Sometimes in the railway tracks and if you look also you will see the same thing any railway station you just try to look at that although that operator 25 kv, but design is little different, but you can have a look on that right. So, for high voltage lines having larger spans and greater mechanical loading, suspense and insulated strings are arranged in a horizontal position. Suppose that that is why I told you that rather than vertical position you arrange it horizontal position right.

So, in case of a single string is not sufficient to take the load 2 or more string in a parallel may be employed for higher conductor tension right; that means, suppose it is something like this, suppose from the say cross arm you have once insulator suppose it tension.

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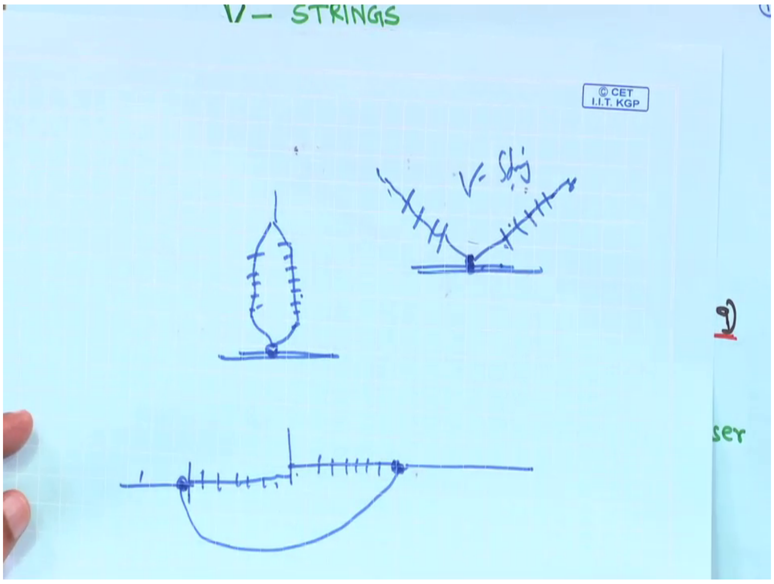

I mean line loading is very high another cross arm you have this right. So, 2 string of insulator a concept conductor is connected here, you can observe that thing also.

Whenever you are traveling by train or anywhere you know high tension line looking that, you can see different type of insulators are there, it depends on the your voltage level and it is double conductor or 3 conductors in each phase, several things you can observe. Even 4 conductors in a phase, you can see that I usually I went somewhere I found in each phase there are 4 conductors right.

So, question is that there is a change, this thing for high voltage lines having longer span because for high voltage line, that span will be longer and greater mechanical loading because, conductor size is more that mean cross sectional area of the conductor is more. So, suspension insulator strings are arranged in a horizontal position. So, as to keep them in a tension, that is how it must be in horizontal position and in case of a single string is not sufficient your this thing to it the load 2 or more string in a parallel may be employed by higher conductor tension, like this 2 or more you will be there; you can observe it is connected like this you can observe that is they are in parallel right. And if it is I told you that for high tension line I told you that sometimes it is connected like this, that suppose this is the tower cross arm for example. So, these are insulator string I told you suppose conductor line is coming from somewhere connected here and from another side that just schematically I am showing that this is you are insulating. So, conductor has this is your conductor.

But these 2 has to be connected right, it if you look into that it has to be in this thing connected right. So, in case of a single string is not sufficient to take the load 2 or more string, I will just show you that how it should be connected. That is only connection of those insulators right. Now another thing is that is v connection V strings.

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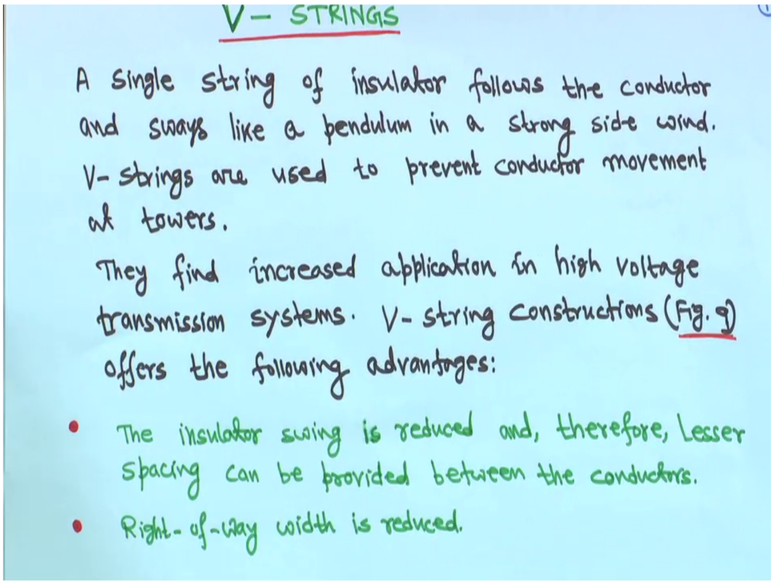

So, this is also just see if I have any diagram for V strings, I can show you I think I have missed somewhere.

So, a single V-strings means it will be connected like this, another side insulator will be like this these are all the pieces right, string these are all the pieces and this is the conductor point. So, conductor will be connected here this is actually V-strings it will like connected like this, so this is actually V string.

So, advantage of this one is that a single string of insulator follows the conductor and shows like a pendulum in a strong side wind. So, V-strings are used to prevent conductor movement at towers right. So, if it is connected like this either 1 it is this one another is this one. So, though these will both the side insulators are there so it will balance that one. So, conductor swing will be very less minimum that is why V-strings connection, also you can observe I have seen it many places right.

So, these your what you call V-strings are used to prevent conductor movement at towers, but they find increased application in high voltage transmission system; because high voltage transmission system conductor itself is a across sectional area is a very this thing high and V-strings constructs and offers the following advantages right, if I use such sort of figure it is marked as figure 9. If I get the figure where I have kept it I will show you just 1 minute.

If I have I can show you otherwise I but anyway I showed you that how it is connected, but as it is mentioned figure 9 I will see if it is there or not it is here I got it right.

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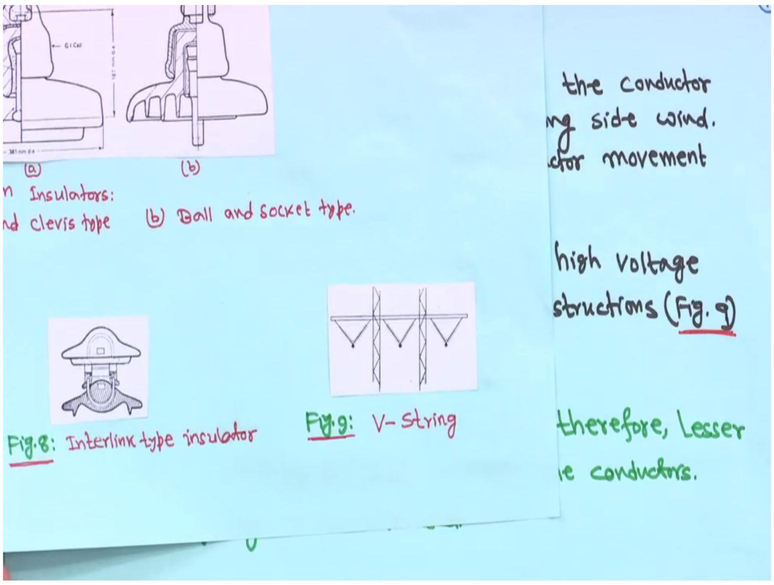

This is actually V-strings that how it is connected right, there is 1 conductor here 1 is here and for 3 phase line this is the tower, that how that insulators are connected whatever I showed that such that if there will be no swing of this 1, this is actually figure 9 this is v string.

So, to find increase of V-strings conductors offers the following advantage it has some advantages, the insulator swing is reduced naturally and therefore lesser spacing can be provided between the conductors; that means, as if it is connected like but look at that 2 insulator strings are used, so their insulator cost will be higher that is also another aspect right.

Because the 2 insulators are used, but as the conductor swing our conductor movement will be very less. So, distance between the conductor this is our phase 1 phase, this is another phase. So, distance between the conductor it can be kept a minimum right, but it will be expensive because you are using at this side 1 in each tower. So, it will be expensive right. So, right of way width is reduced that is true because, it will not takes much space and your then reduction.

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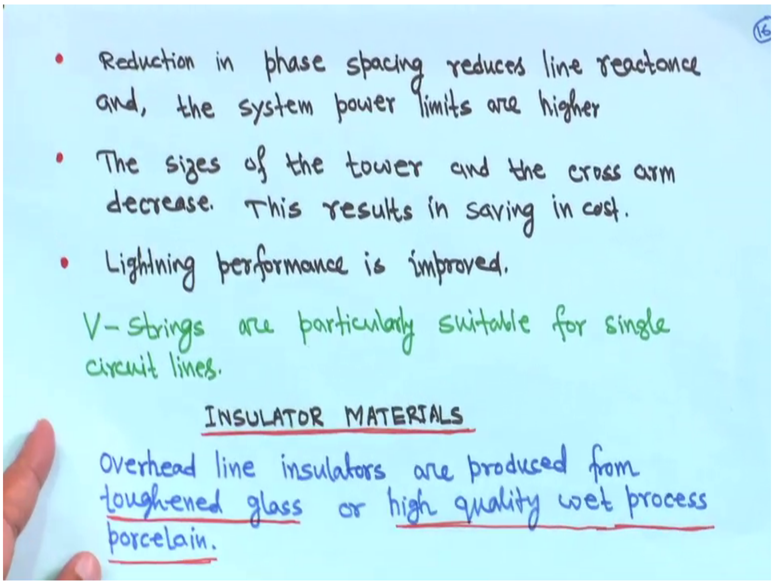

In phase spacing reduces the reactance you have studied transmission line inductance calculations.

So, there you have we have seen it, those who have taken the power system analysis course there we have seen it so and or we have read it in any book. So, reduction in phase spacing reduces the reactance and the system power limits are higher. So, you can raise the power limits, the sizes of the tower and the cross arm decrease naturally, it will decrease this result in saving in cost and lightning power your lightning performance is improved. V-strings are particularly it is suitable for single circuit lines because if 2 circuit comes then number of string will be doubled right.

So, generally it will be expensive. So, these things are particularly suitable for your circuit this thing was single circuit line. So, high voltage line it is better single circuit means in each phase there will be only 1 conductor right, 1 circuit insulator materials. So, overhead your overhead line insulators are to your produce from toughened glass or high quality weight processed porcelain is very common. There is the toughened glass also used for high voltage, but for your porcelain is very common the materials little bit idea you have to have for insulating materials.

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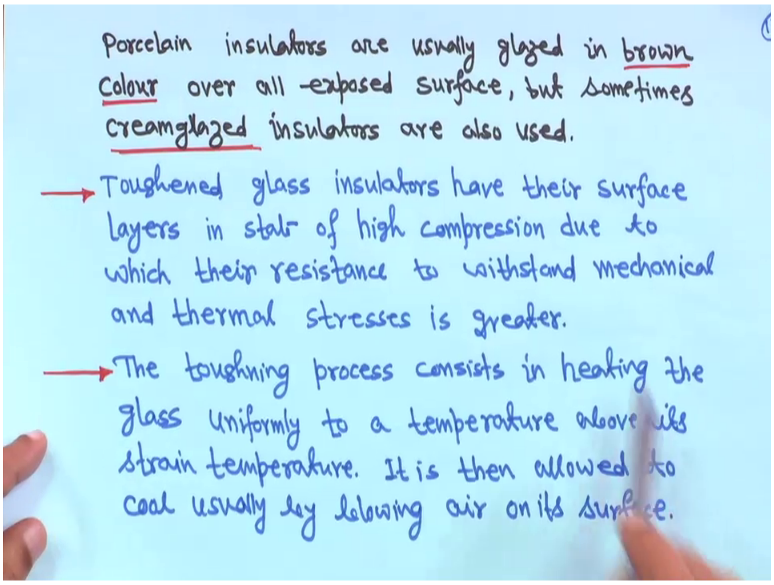

Porcelain insulators are usually glazed in brown color that also you have seen right, over all exposed surface that you have seen, but sometimes cream glazed insulators are also used right. So, toughened glass insulators have their surface layers in state of high compression due to which their resistance to withstand mechanical and thermal stress is greater, but the same time expensive also right. And the toughening process consists of a heating the glass uniformly to a temperature above is strain temperature and then it is then allowed to cool you are usually by a blowing air on it is surface right.

So, this way mechanical strength of this glass is increased toughened glass rather. So, some of the your what you call this is some general idea.

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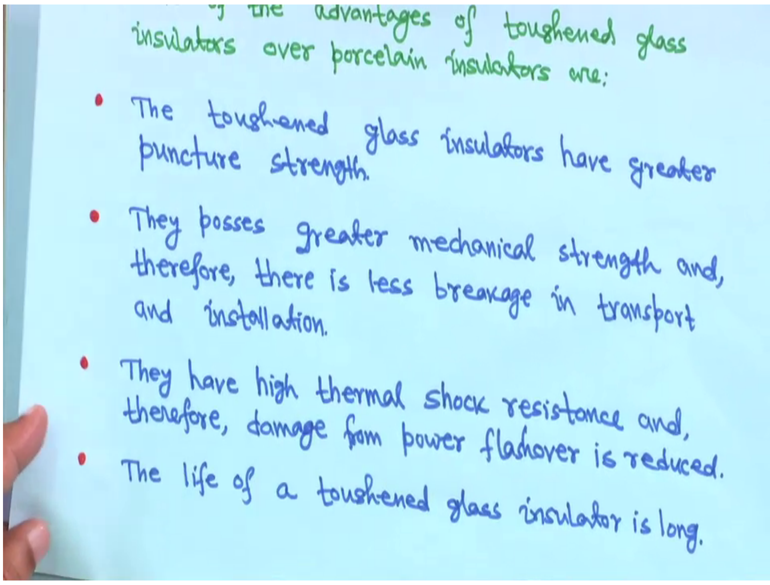

You have to have at least from general knowledge of view. So, some of the advantages of toughened glass insulators over porcelain in today insulators are right. The toughened glass insulators have greater puncture strength this is true. The process they possess greater mechanical strength and therefore there is less breakage in transport and installation this is also true, they have high thermal shock resistance and therefore damage from power flash over is very much reduced.

The life of a toughened glass insulator is long, these are the your what you call the advantages right just 1 minute.

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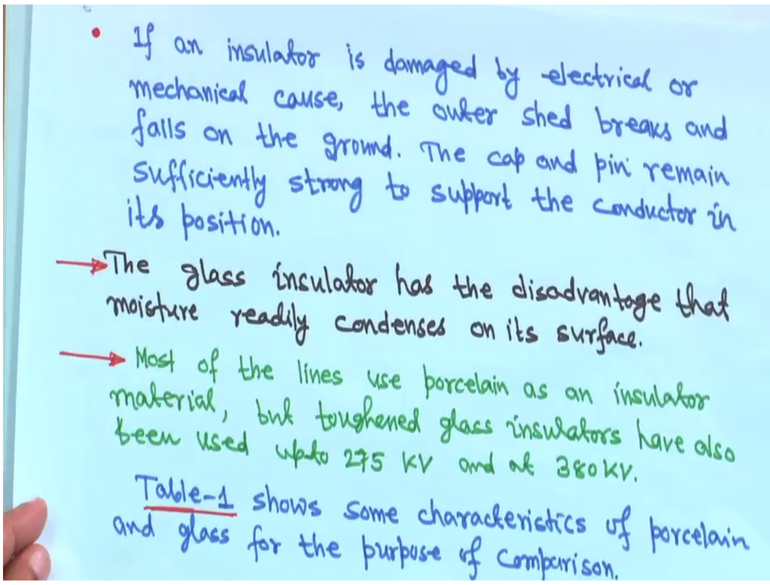

Next if an insulator is damaged by electrical or mechanical cause, the outer shed breaks and falls on the ground, the cap and pin remain sufficiently strong to support the conductor in it is position. The glass insulator has the disadvantage that moisture readily condenses on it is surface, these are disadvantage.

Most of the lines use porcelain as an insulating material, but toughened glass insulators have also been used up to 275 kv and at 380 kv, I mean in general about 220 kv line the toughened glass insulators are used right so, but in general rest of the thing you will find that these are mostly they are porcelain. Now whatever I have seen here and there they are mainly more mostly porcelain type of this thing porcelain made insulators.

So, now table 1 shows the some characteristic of porcelain and glass for the purpose of comparison.

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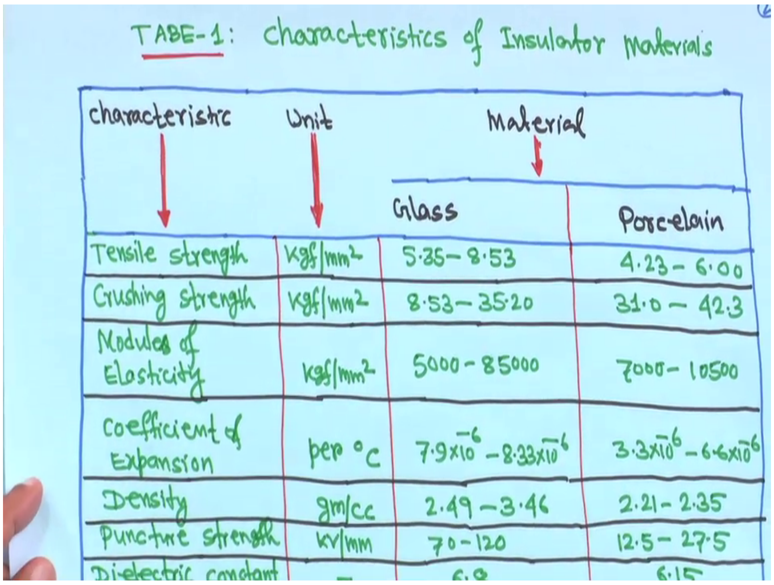

TABE-1: Characteristics of Insulator Materials

Characteristic	Unit	Material: Glass	Material: Porcelain
Tensile strength	kgf/mm^2	5.35 – 8.53	4.23 – 6.00
Crushing strength	kgf/mm^2	8.53 – 35.20	31.0 – 42.3
Modules of Elasticity	kgf/mm^2	5000 – 85000	7000 – 10500
Coefficient of Expansion	per °C	$7.9 \times 10^{-6} - 8.33 \times 10^{-6}$	$3.3 \times 10^{-6} - 6.6 \times 10^{-6}$
Density	gm/cc	2.49 – 3.46	2.21 – 2.35
Puncture strength	kV/mm	70 – 120	12.5 – 27.5
Dielectric constant	–	6.8	6.15

So some table is here this is the characteristic of insulating materials right, this one is your characteristic tensile strength this is kg force per millimeter square, in the case of glass it is 5.35 to 8.53, whereas, in the case of porcelain it is 4.23 to 6; that means this strength is your tensile strength where glass is higher.

Then crushing strength; in this case it is an kg per millimeter square it is 8.5 to 35.20 and whereas it is 31 to 42.3 this crushing strength or porcelain is more than your glass. Then modulus of least says your elasticity right. So, this is kgf per millimeter square here it is 5000 to 8500 and here, it is 7000 to 10500 so porcelain case is high.

Coefficient of expansion in this case it is 7.9 10 to the power of minus 6 to 8.33 10 to the power minus 6, but in the case of porcelain it is 3.33 to 10 to the power minus 6 to 6.6 into 10 to the power minus 6.

Now, density in this gram per cc it is 2.49 to 3.46 and it is 2.21 to 2.35. So, it will be heavier because if density is higher compared to porcelain. So, toughened glass will be heavier right, then puncture strength kilovolt per millimeter here in this case 70 to 120 and here it is 12.5 to 27.5. So, puncture strength is much higher for the toughened glass compared to porcelain and dielectric constant this is 6.8 it is much higher.

Then I will not say much higher, but higher than porcelain where it is 6.15. So, these are the difference between that glass toughened glass or porcelain and they are your what you call a different characteristic 1, 2, 3, 4, 5, 6, 7; characteristics, these are the differences. So, with this just I say before going to mathematics part, with this we would like to tell that insulators are of a pin type or suspensors or what you call this suspension type are mostly used particularly in the high tensile line and anywhere you can see that your suspension type insulators are there.

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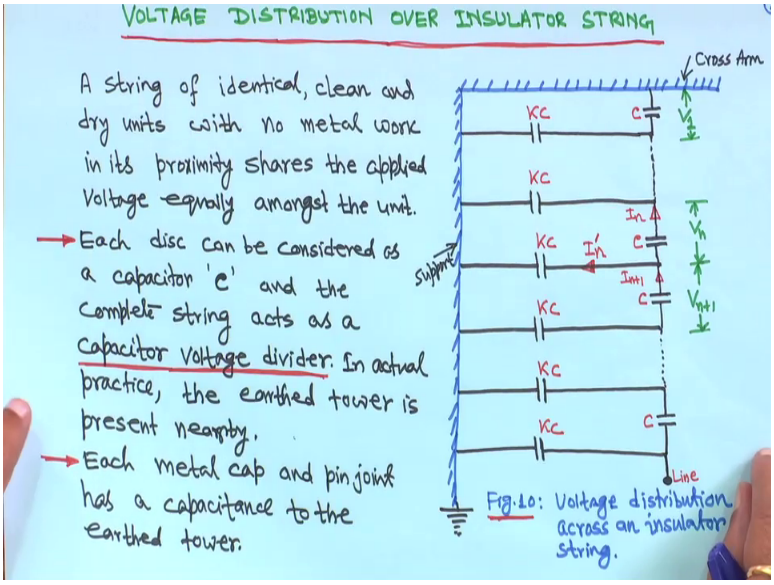

So, in each insulator or each string this thing a string there will be several pieces. So, ach one we will assume that it is a formation of something like a representation like the sun capacitor and whenever it is that is between and same thing that there will be a cross arm and supporting tower. So, capacitance will happen between that your tower and that your what you call that insulator pieces. So, that thing has to be considered.

So, now how the voltage distribution of insulators string right, over insulator string how things will happen. Suppose this is your cross arm because insulator are hang hung from the; your cross arm and this is your support the tower. So, you have suppose you have n number of strings, for example so many strings are there sorry n number of your pieces are there in a 1 string, each one we are asked this thing each one having equal capacitance.

So, ach one represented by equal shunt capacitance. So, c and voltage across this one say ach one is V 1 then next one is V 2, then V 3 like that and for n th a piece for n th piece, it is your V n for n plus 1 piece it is V n plus 1 right and from your in from each piece to that support you have a sun ray this thing you have also a capacitor capacitance. So, it will be c then it is multiplied by k c, k is a fraction greater than 0 less than 1. So, everywhere we are assuming these are all kc because all are equal distribution right and voltage is V 1, V 2, V n like this up to V n plus 1 and at the bottom the line is connected at the bottom that the conductor is connected.

So, this is general figure so voltage distribution across an insulator string. So, now it is what I have said a string of identical clean and dry units with no metal work in it is proximity shares the applied voltage equally among the unit. So, all those there are so many units in each string right and each disc can be considered as a capacitor c; that means, you have so many disc I showed you that in your suspension type insulator. So, each disc can be considered as a capacitor c and the complete string act as a capacitor voltage divider the whole string it acts as a capacitor voltage divider right.

In actual practice the earthed tower is present nearby right. So, each metal cap and pin joint has a capacitance to the earthed tower. So, each metal cap and pin joint right, so everywhere this one this k c has a capacitance to the earthed tower. So, this is actually support so these are these stray capacitance have an important effect.

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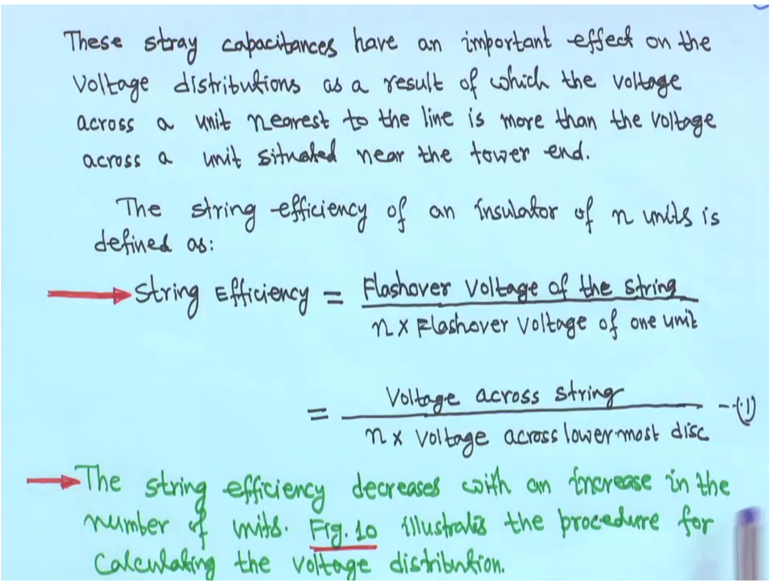

On the voltage distribution as a result of who is the voltage across a unit nearest to the line is more; that means here because of these stray capacitance voltage near the nearest to the line this and this is the your what you call that unit it is, there are 7 several unity it is string right. So, it will be higher so that is this effect on this is that voltage distribution, result of which the voltage across the unit nearest to the line is more than the voltage across a unit situated near the tower end.

So, this is actually this is the tower end and this is your near to the line. So, voltage will be more here than this 1. So, the string efficiency of an insulator of n units suppose in this string you have n number of units, say then string efficiency with flash over voltage of the string divided by n into flash over voltage of 1 unit, other way you can write voltage across the string divided by n into voltage across the lowermost disc, that if this voltage across the lowermost disc is that this is that lowermost disc right and you have total n number of in this case.

I will tell you it is n into flashover voltage of 1 unit and flashover voltage of the string. So, total plus 1 is equal to voltage across the string, whatever voltage will come across the string total voltage divided by n into voltage across the lowermost disc. So, in this diagram this is the n th 1 this is n plus 1 some more is shown right, ideas is there should not be any confusion from this diagram actually right. You have the idea if the voltage across the string you will find out total voltage, then n into voltage across the lowermost unit.

Suppose in this case if this is the n th unit say forget about these thing, suppose this is the n th unit then n into voltage across the lowermost unit is because this unit this voltage is higher than the this one right. So, that is why your thus the string efficiency decreases with an increase in the number of units naturally, if your if n is more than naturally this will be less. So, then figure 10 illustrates the procedure for calculating the voltage distribution.

So, this is a your figure 10 in this case you can see suppose this is the current your this kappa in an n plus 1 capacitor this thing unit right and we can say n plus 1 capacitance in this case current is I n plus 1 and part of the current is going to that this is say I n dash and here it is n th decrease the I n. So, if you apply at this Kirchhoff's first law, then your I n plus 1 will be is equal to I n plus I n dash right; that means, the capacitance of each unit to the earthed tower can be assumed to be kc.

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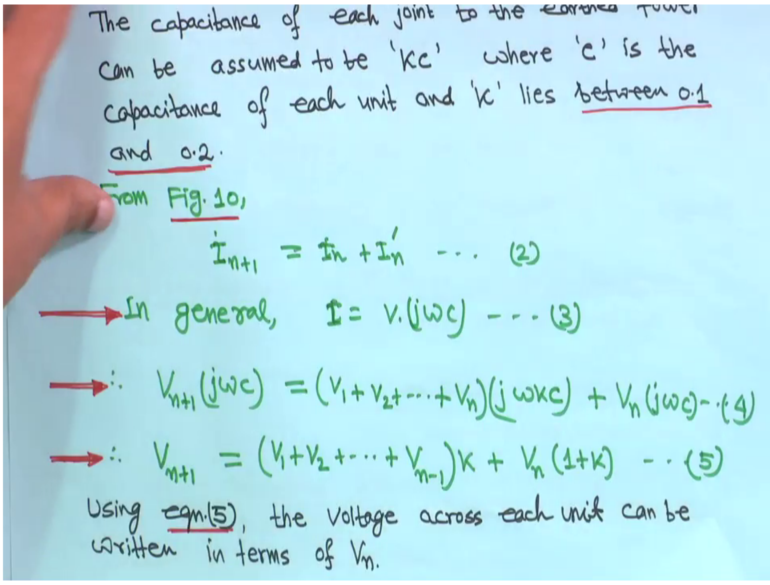

So, all these all these thing has been taken k into c, k lying between 0 and 1 right; where c is the capacitance of each unit and k lies between here it is given k lies between 0.1 and 0.2 mathematically it is greater than 0 less than 1, but is value generally it happens in reality it will be it will be between 0.1 to 0.2 right.

So, from figure 10 I mean from this figure you can write I n plus 1 is equal to I n plus I n dash. So, I n plus 1 is equal to in plus I n dash right; next in general we know I is equal to you know I is equal to in general formulas, formulae I is equal to I into v and y is the admittance. So, I is equal to I v, so y actually is equal to j omega c. So, in general this formula I is equal to v into j omega c, so this is equation 3.

Now, for n plus 1 this in plus 1 case you can write V n plus 1 into j omega c because, this is the capacitor of your each unit c. So, it will be V n plus 1 into I n plus 1 j omega j omega c and this one this in dash first I am writing the I n dash that with this first I am writing in dash here, if you look I n dash for n th 1 then what will happen when I am writing V 1 plus V 2 plus V n j into omega k c because, that your this I n dash; that means, this one first I am writing this 1.

Suppose this is the in dash the n th 1 no. So, this voltage all the voltage if you take this one is a common terminal like this and this one is a common point; that means, voltage impress act over this will be V 1 plus V 2 up to vn, that is why you are writing V 1 plus V 2 plus up to V n into that j omega kc right. Because this is required basically it is a support and tower. So, whole voltage actually across this, whatever is the voltage across this means it is basically voltage across because these 2.this tower is common right.

So, that is why we were writing j omega kc and then I am writing I n, this I n I n is equal to V n j omega c this is equation 4; now that means, j omega c j omega c both sides cancel, then you are writing V n plus 1 is equal to V n V 1 plus V 2 up to V n minus 1 right; that means, n th term is added here n th term that v your V n into k term is added here, actually it is like this just hold on actually this equation if you write it will be yours.

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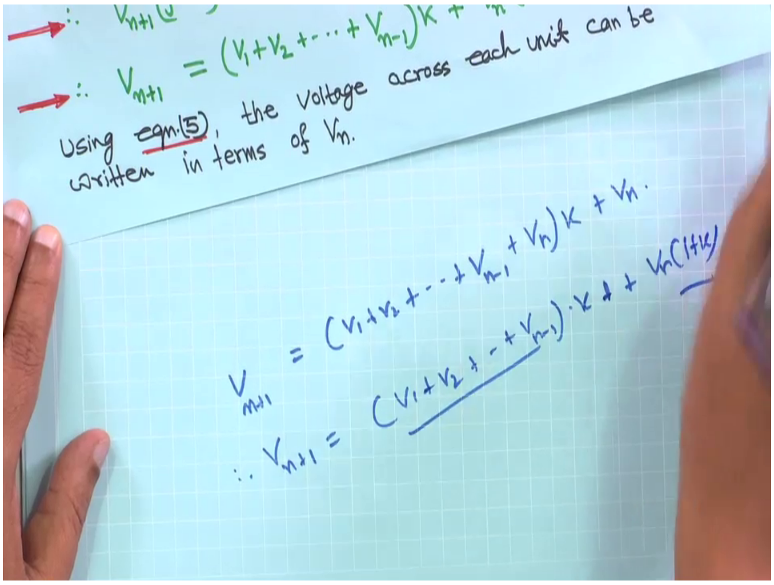

V n plus 1 is equal to V 1 plus V 2 plus say this way you write V n minus 1 the previous term for this one plus V n right into k plus V n right j omega c this is both side cancel; that means, V n plus 1 is equal to V 1 plus V 2 plus up to V n minus 1 term into k and k into V n is added here with this Vn. So, it will be V n then 1 plus k right, that is why we are writing V n plus 1 is equal to V 1 plus V 2 up to V n minus 1 into k plus V n into 1 plus k this is equation 5. So, in the equation 5 the voltage across each unit can be written in terms of V n right. So, that can be written. So, now that means, the value of v can be found by equating the sum of voltages that are across the unit n.

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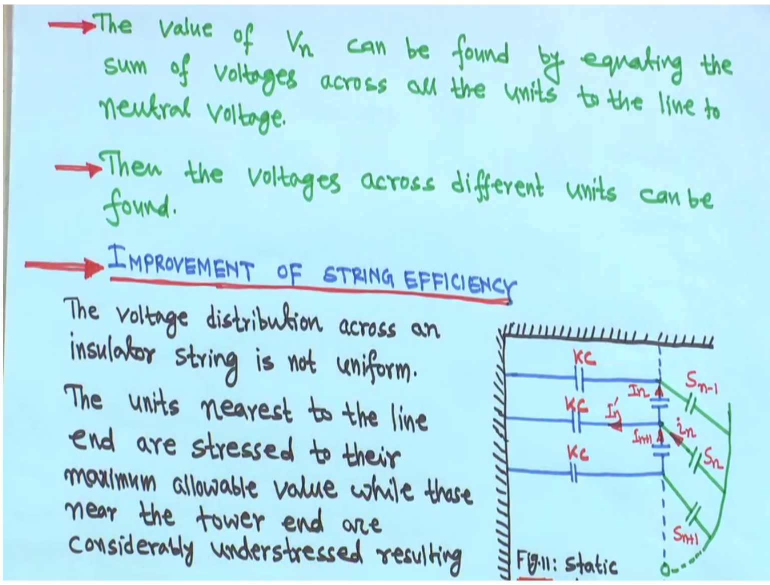

So, using that equation the values of your this thing that values of V n can be obtained, this value can be obtained using this equation right; equating the sum of voltages across by all the units to the line to neutral voltage. So, we will take some numerical so you will see.

Then the voltage across different units can also be found right. So, another this is that simple mathematical derivation. Now another thing in improvement of string efficiency look it is not possible to make the string efficiency 100 percent this is not possible. So, voltage distribution across an insulated string is not uniform. So, this is true it is because of this your discussed capacitance rights, the units near to the line end are stressed to their maximum allowable value.

Here which was that a unit near to the this thing line, it will be test your what you call the maximum allowable value while those near to the tower, I mean here near to the tower are considerably under stress right, resulting in a worst of insulating material that what does it mean that this unit this unit is not under your this thing, but at your at lower voltage and units which is near to the line it has the higher voltage all though we are using the identical insulating material.

So, it will be lower stress and it will be at higher stress, that is why you are trying to mean that wastage of insulating materials. So, idea should be to try to make as much as possible, equal voltage across the each unit that is the idea.

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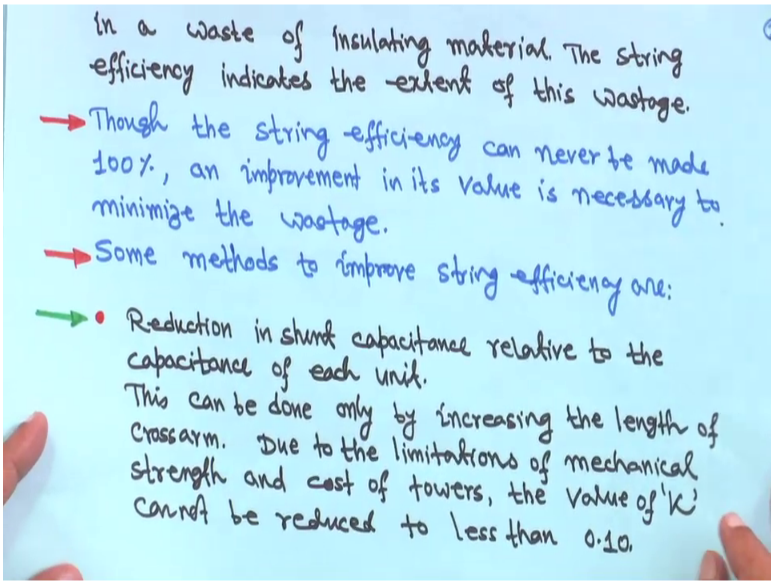

So, in the string efficiency indicates the extent to this wastage. So, this is an understanding that that maximum allowable value, while those near the tower it are considerably under stress resulting in a waste of insulating material.

Therefore the string efficiency indicates the extent of this wastage, this is an indication. Although a 100 percent is not possible, but it is your; to some extent that you can in try to improve the stir your string efficiency. So, there are some methods for string efficiency is there; such that if you can reduce the shunt capacitance, then there is a possibility to increase the; your string efficiency.

Thank you we will be back.