Power System Engineering
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Lecture - 05
Insulators & Cables

Welcome back again. So, before going to the example 6, just from the book I would like to show you that V-string.

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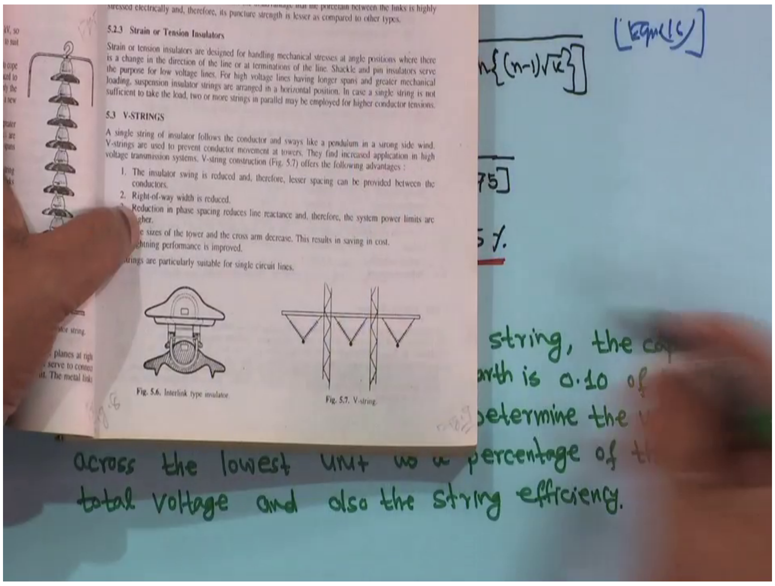

This is your what you call this is your V connection of the insulator. Look this side one string, this is another string and conductor is connected here. When we will study corona, I will show you that corona how things are happening, at that time also due to I will take from a book the photograph they have taken at that time I will show you. So, this is your V-string. And that your grading ring right whatever numerical we have done for grading ring also I am showing, just hold, on before proceeding to the next example just hold on that different type of grading rings are there.

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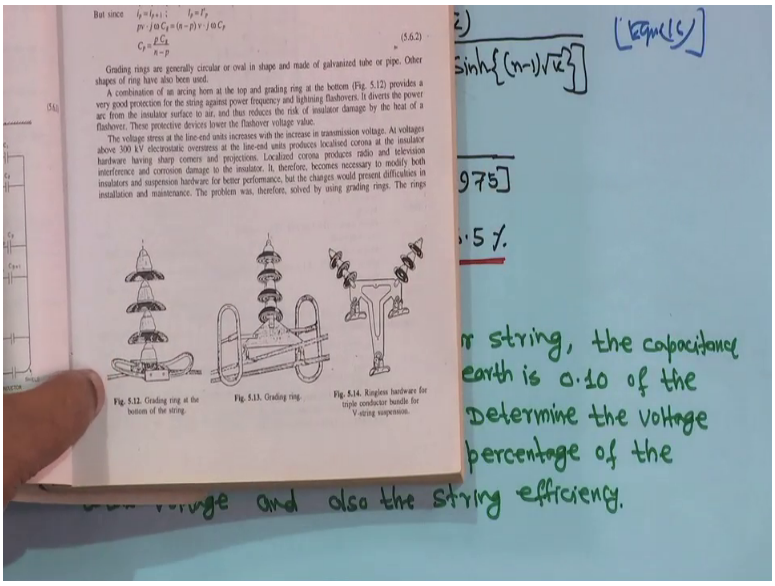

Look, this is not photograph, but it is drawing actually look the grading ring at the bottom of the string, look this grading ring is there.

Here also look different type this is also grading ring is there. So, this is how if you look at what you call at that your transmission tower you will find these things are there. This is just to show you that how things are.

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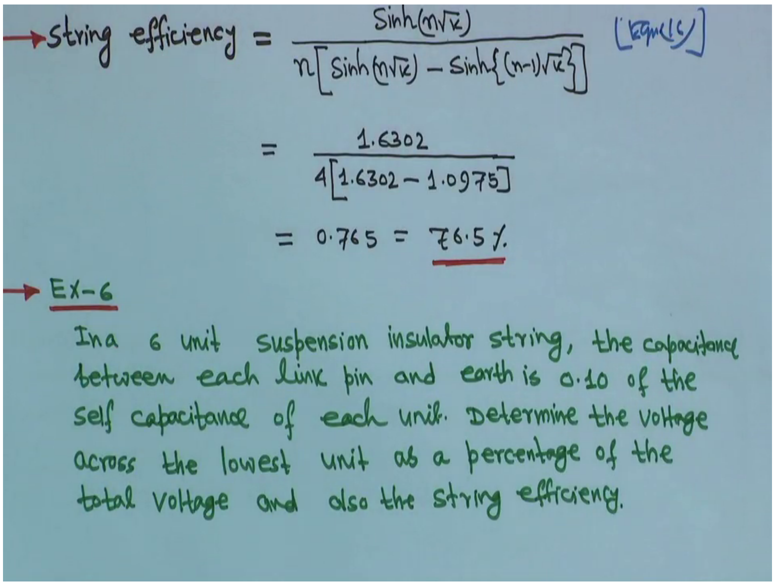

So, next we will come to the example 6. So, in a 6 unit suspension insulator string, the capacitance between each link pin and earth is 0.10 of the self capacitance of each unit. You have to determine the voltage across the lowest unit as a percentage of the total voltage and also the string efficiency. So, that is your problem.

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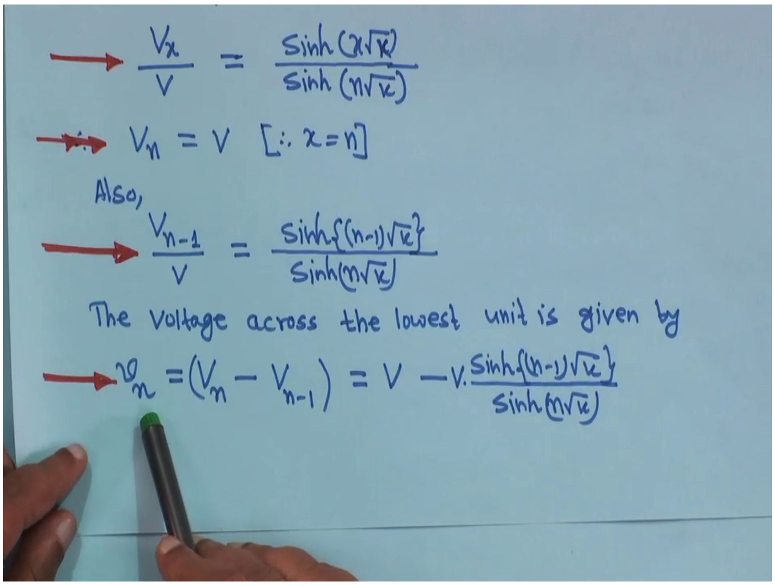

Now, we have already derived that we know that, your V x upon V is equal to sine hyperbolic x root k divided by sine hyperbolic n root k. Now, for x is equal to n, V n is equal to V. Therefore, we can write V n minus 1 upon V is equal to sine hyperbolic n minus 1 root k divided by sine hyperbolic n root k. Now, voltage across the lowest unit is given by small v n is equal to capital V n minus capital V n minus 1. So, you substitute V n is equal to V and V n minus 1 is equal V into sine hyperbolic n minus 1 root k divided by sine hyperbolic n root k. Now, only have to recall these formulas.

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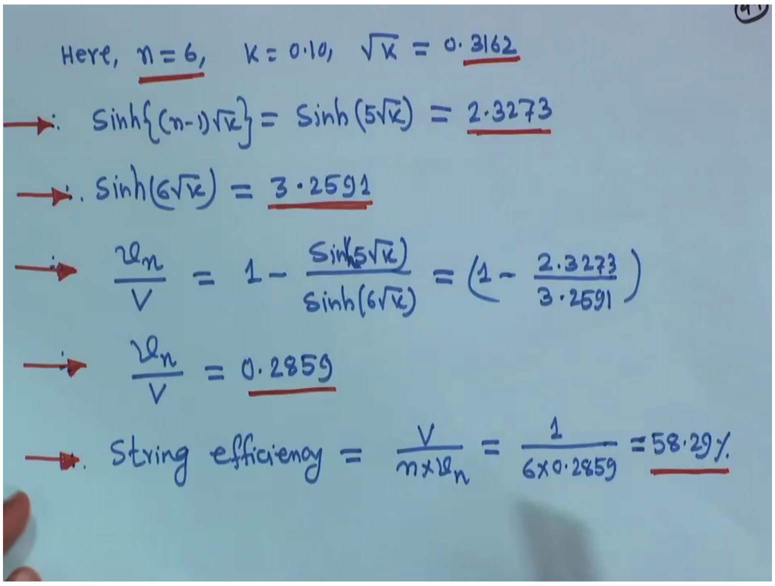

Now, it is given that n is equal to 6, k is equal to 0.1. So, root of k is 0.3162. Therefore, sine hyperbolic n minus 1 into root k is equal to sine hyperbolic 5 root k. So, root k is equal to 0.3162, you multiply 5 into this one and then take sine hyperbolic of this, it will become 2.3273 and sine hyperbolic 6 root k, when n is equal to 6, it will become 3.2591. Therefore, small v n by capital V is equal to 1 minus sine hyperbolic 5 root k upon sine hyperbolic 6 root k. Substitute all this values, you will get v n upon V, that is, 0.2859. n means that n is insulator that is the last one, last piece which is near to the conductor. So, that is small v n. So, it is 0.2859.

Therefore, string efficiency will be capital V divided by n into small v n, but V n by V is equal to 0.2859. So, therefore, it is 1 upon 6 into 0.285 because if you take the reciprocal of V it will be 1 upon n into v n upon capital V; v n upon capital V small v n upon capital V is this one, therefore, it is coming roughly around 58.29 percent. That is the string efficiency.

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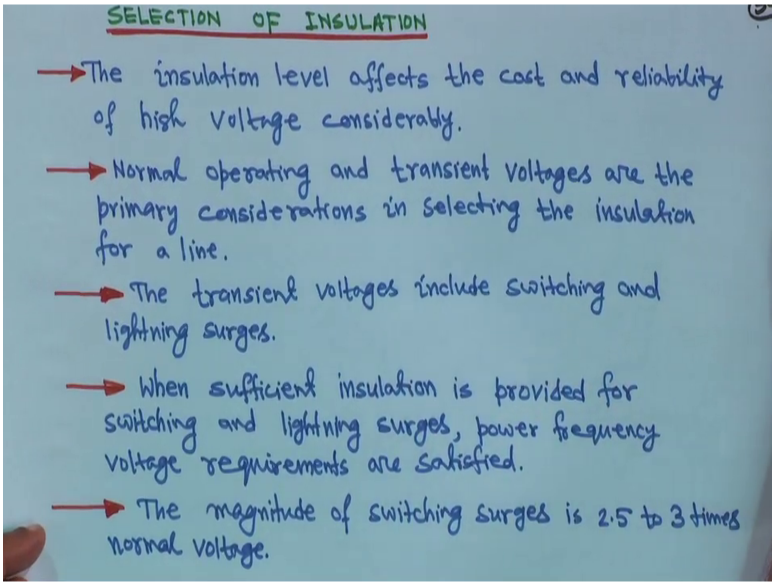

So, next you will come to the selection of insulation. Basically, the insulation level it affect the cost and reliability of high voltage considerably. So, normal operating and transient voltage is as a primary consideration in selecting the insulation for a line. Operating as well as transient voltages are the primary consideration both you have look in selecting the insulation for a line. So, that is transient over voltage. We will see those things later. The transient voltages include switching and lighting surges. So, when sufficient insulation is provided for switching and lighting surges, power frequency voltage requirements are satisfied. So, sufficient insulation will be provided by switching lightning surges. Particularly, when you are designing everything you have to take into account and accurate calculation is required.

Next is the magnitude of switching surges is 2.5 to 3 times to normal voltage. So, that means, the insulation should sustain that kind of high voltage, so that is 2.5 to 3 times the normal voltage. That way you have to design.

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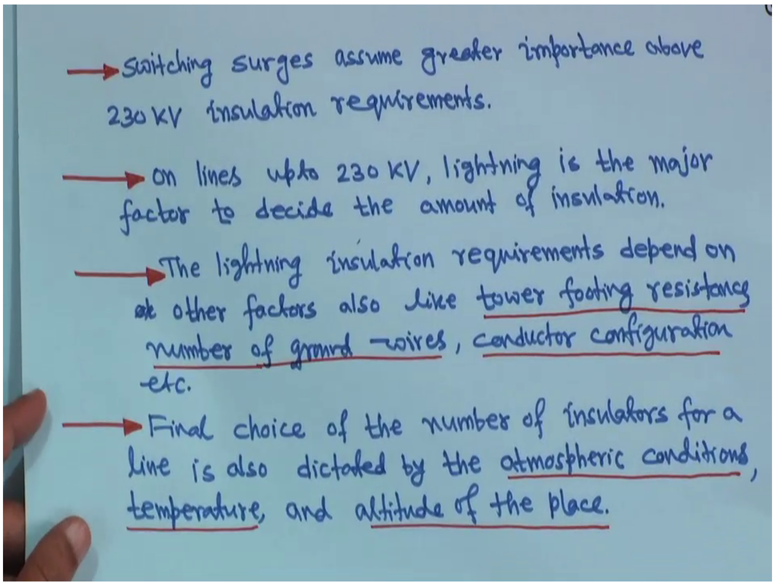

Next, is that your switching surges assume greater importance above 230 kV insulation requirements; in our country 220 kV or above 220 when 400 kV line, so, 230 kV installation requirements. Now, on the lines up to 230 kV lightning is the major factor to decide the amount of insulation, because lightning stroke is very common phenomena in our country, everywhere all over the world and you have to protect all these things on the lightning is the major factor to decide the amount of insulation.

If lightning stroke is there on the top of a tower there you do not know how far how much it can affect to the your equipments or operators at the substations. So, lot of protection is required. You have lightning arrester and other things, but anyway. So, lightning is the major factor to decide the amount of insulation for everything. Then, lightning insulation requirements depend on other factor also like tower footing resistances, then number of your ground wires and conduct a configuration etcetera.

So, tower footing resistance the number of ground wires all these things are required because grounding is another important factor. So, this lightening surge is very important phenomena in power system. Final choice of the number of insulators for a line is also dictated by the atmospheric conditions, then temperature and altitude of the place. So, many factors are associated that you are what you call for number insulators for a line. So, all these are your like something like your general knowledge that we need all sort of things to know before making that your choice choosing the correct insulator for a particular voltage level.

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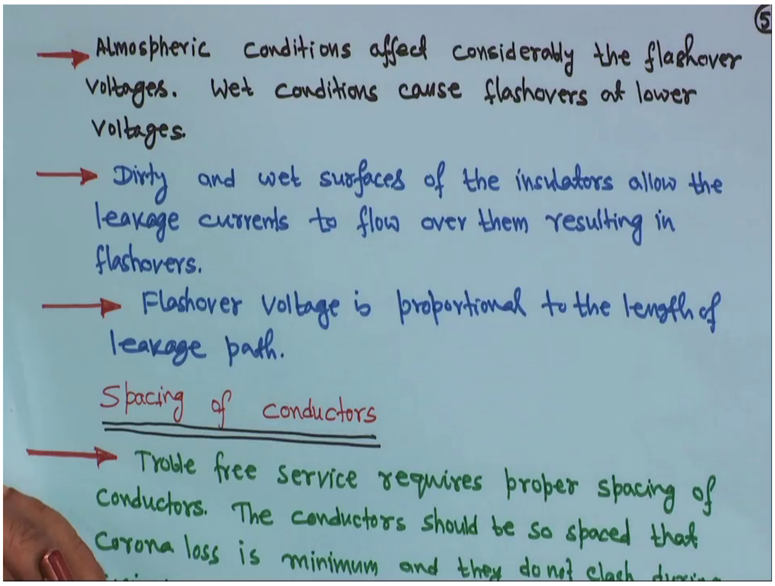

Next, is that atmospheric; these atmospheric conditions affect considerably the flashover voltages. It is very important particularly for insulators. Wet conditions cause flashovers at lower voltages also. Particularly, during rainy season right this can create problem. So, this flashover I mean I do not know whether you have observed or not, many times I have observed that flashover is happening particular in rainy reason. Even in the railway taxi line any railway platform or sometimes you can observe that some flashover is going on. So, these I have seen somewhere that it is happening.

So, dirty and wet surfaces of the insulator allow the leakage currents to flow over them resulting in flashover. Naturally, dirty and wet surfaces are there, so the insulator it will allow leakage currents because it gets a conducting path, therefore, possibility of flashover is there. But, it does not generally does not spoil the insulator. The insulator can withstand such kind of flashover. So, flashover voltage is proportional to the length of the leakage path, it is directly proportional to the length of the leakage path.

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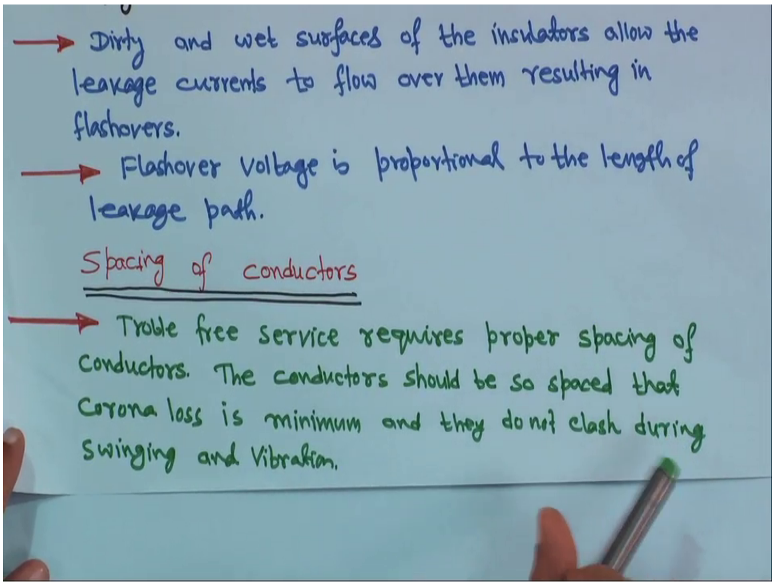

Next one, is that spacing of conductors; you have seen for transmission line 33 kV, 66 kV, 132 kV or 220 kV or above you have seen different type of conductor spacing are there, also in each space you can see 2 conductors or 4 conductors are there in each space. Recently, I went somewhere, I found that 4 conductors are there in each space and you know why we use that 2 conductors or 4 conductors or even more for high tension transmission line that if I use that; so spacing of conductors.

So, trouble free service requires proper spacing of conductors. The conductors should be so spaced that corona loss is minimum; this corona loss, we will see later. After this next we will cover cables, after cables we will go to what you call that transient overvoltage and insulation coordination after that we will come to corona. So, that corona loss is minimum and they do not clash your during swinging and vibration; that means, conductor spacing should be such that that even during storm or wind this should not clash with each other. So, it should be you have to see that this spacing of the conductor. So, you have to design accordingly and those conductors will connect tower to tower through your insulation you have to see the vibration will be less.

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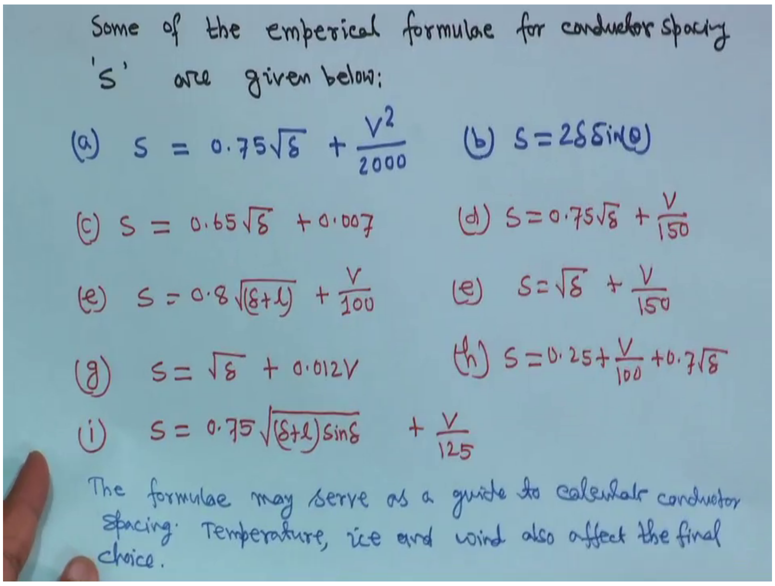

So, there are many direct formula is there for conductor spacing, there is no direct formula, but some empirical formulas for conductor spacing S are given by. They look so many, I have whatever I have got I have got with here one is the spacing should be maybe 0.75 root over delta plus V square by your this thing 2000. So, this actually will give some kind of ideas. So, that another is S is equal to 2 delta then sine theta then, what you call another is S is equal to 0.65 root delta plus 0.007. Another S is equal to 0.75 root delta plus V upon 150 this way. So, many empirical formulas are there.

So, when you design they have to choose the proper spacing. This formula may serve as a guide to your calculate conductor spacing. Temperature, ice and wind also affect the final choice. That ice, wind we will see sag and tension. During that sag and tension calculation we will see that temperature, this ice and wind calculation. So, your consideration or this also affects the final choice. So many different logic is there, different empirical formulas are available, but no direct formula are proved, that is, I have not got it anywhere. So, whatever I have got these are the certain things.

Now, here 1 question to you that what is delta V you know and what is l? So, this is a question to you, I did not write for you, but and also 2 delta sine theta everything has been taught, but before that, this is an exercise for you. So, you should find out.

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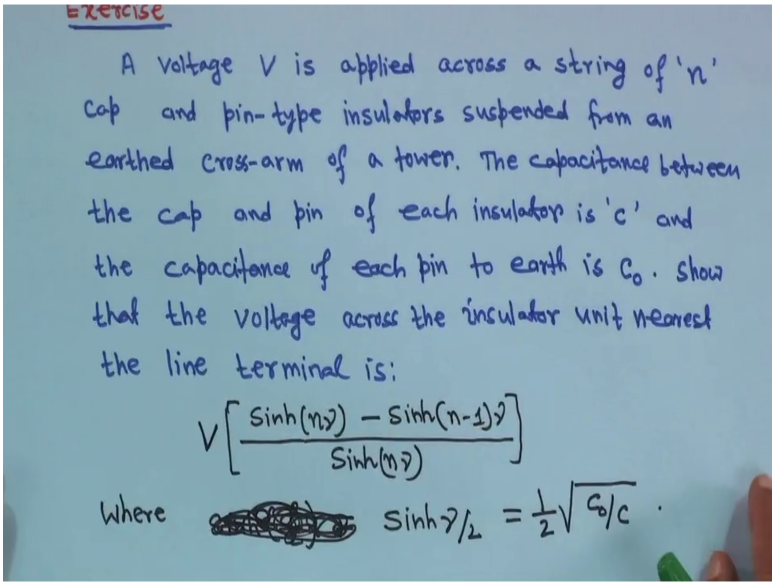

Next is, this is an exercise for you. I have not solved this problem, but I am giving it to you while we will go through this video lecture and that I will do it. For example, a voltage V is applied across a string of n cap and pin-type insulator suspended from an earthed cross-arm of a tower. The capacitance between the cap and pin of each insulator is capital C and the capacitance of each pin to earth is capital C 0, suffix 0. Show that the voltage across the insulator unit nearest to the line terminal is this; that means, v n; you have to find out small v, suffix n is equal to V into sine hyperbolic n gamma minus, sine hyperbolic n minus 1 into gamma, divided by sine hyperbolic n gamma, where you have given something that sine hyperbolic gamma by 2 is equal to half root over capital C 0 by C, this is given.

So, based on that, you have to solve. You have to prove this that small v n is equal to this one. So, with this that I believe nothing is left for cable chapters, sorry, insulator chapters. So, there are I mean whatever was there varieties of insulators and other thing we have tried to cover, but whenever you have any questions or anything you please put it into the forum or you can send mail to me. So, all these questions other things will be clarified and just this is a mathematics is less in this chapter, theory is more, you have to learn different type of insulators and other thing, but this is insulators cables these are the main part of the I mean main components of the power systems.

So, in this course we will see next the cable. So, next let us come to cables. So, cable is a underground cable is a very big chapter. Somehow, I have tried to condense it as much as possible particularly the number of diagrams and other thing because I found in the literature that underground cables is a not a small topic, it is a very big topic.

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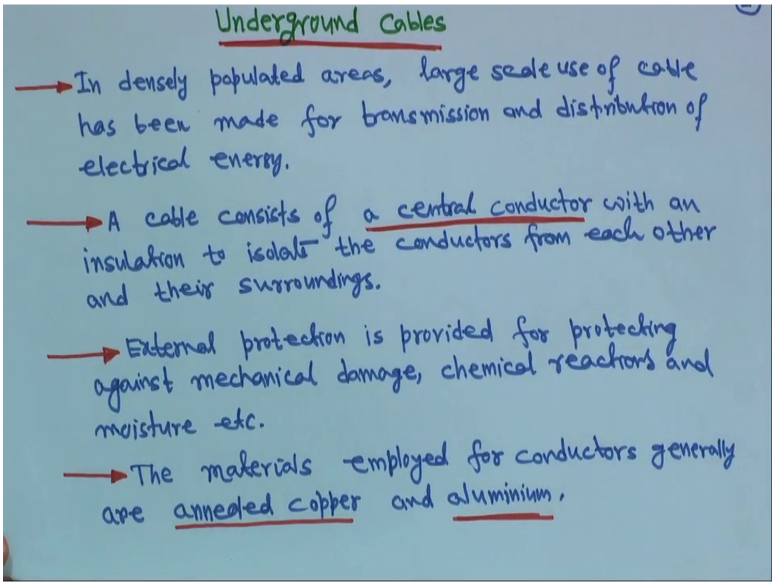

So, somehow I have to restrict it compared to because we have to cover many other things. So, first is introduction regarding underground cables. First thing is you know that general knowledge is that underground cable is much more expensive than your overhead conductor, at least 2.5 to 3 times more than that your overhead conductor.

So, naturally cable are very expensive, but many places to use cables particular densely populated area or sometime rural areas and many places in hilly areas I have seen also cables are not like buried in the ground, but it is on the I know it is to from pole to pole it is cable had been taken. So, anyway, different types of cables are there. So, we will come for first little interaction first 1 hour, I think it will be theory only for underground cables. Some of the diagrams I will show, but all is not possible in this video lecture class and some of I have to condense this thing.

So, first thing is in density populated areas large scale use of cable has been made for transmission and distribution of electrical energy, this is a first thing. So, every cable consists of a central conductor, later I will show you diagram and other thing, central conductors with an insulation to isolate the conductors from each other and their surroundings, this is the thing. Cable have to have its conductor then insulation sheet, so many things armor, so many things will be there.

So, external protection is provided for protecting against mechanical damage, chemical reactions and moisture etcetera, because cables in most of the cases it will be buried in the ground. Therefore, you have to see there should not be in mechanical damage and there should not be chemical reactions and moisture etcetera. So, it should not, external protection is required for the cable. The materials employed for conductor generally annealed copper or aluminum; either copper or aluminum conductor is used for the cables. So, diagram other thing I will show later, but all this things cannot be put it here, I have to condense.

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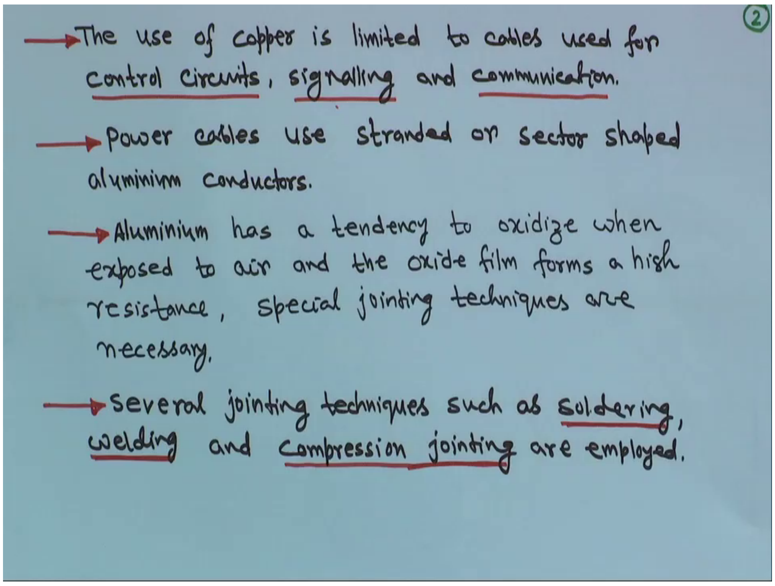

So, the use of copper; that use of copper is limited to cables used for control circuit, signaling and communication. So, as you know that your copper will be expensive than the aluminum. Power cables use stranded or sector shaped aluminum conductors I will show you the diagram later. Either it will be used stranded conductors the way we have seen know the stranded conductor like your 1 conductor around that 6 conductor, then 12, then 18 those the stranded conductor or sometimes this sector shaped aluminum conductors are used. I will show you the diagram later. So, aluminum has a tendency to oxidize when exposed to air. So, naturally we have seen also aluminum has a tendency to oxidize and because of these that the oxide film forms a very high resistance.

So, special jointing techniques are necessary for this thing for cable jointing. Suppose, 2 cables are there where you joint it some special technique is required. So, some several jointing techniques such as soldering, welding and compression jointing are employed. So, this is the thing, but for cables you have to have insulations.

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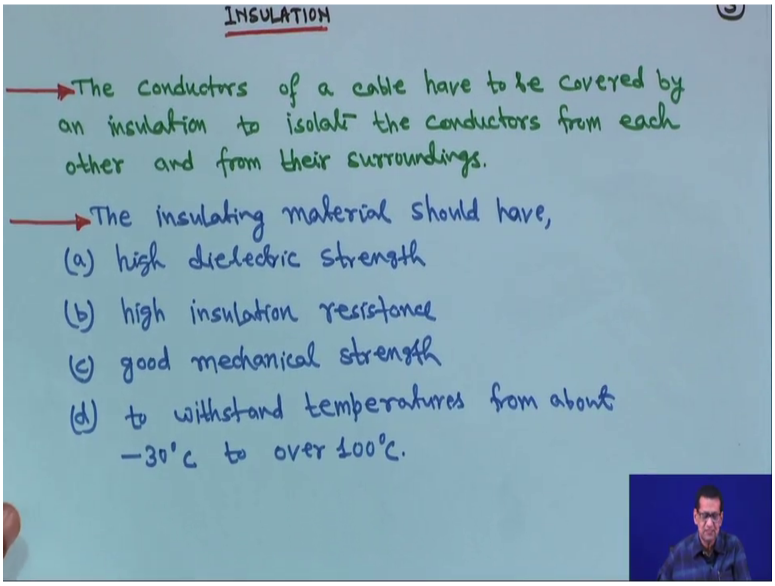

Therefore, when we come to the insulation the conductors of a cable have to be covered by an insulation to isolate the conductors from each other and from their surroundings; suppose, if you have a 3 phase line and 3 core cables then each 1 has to be insulated from each other, otherwise there will be short circuit. Therefore, insulation is more important.

So, insulating material should have; it should have high di-electric strength, high insulation resistance, good mechanical strength and fourth one is to withstand temperatures from about minus 30 degree to over 100 degree Celsius. So, these properties are required and from the testing only, you have to see that whether this property holds or not for the insulator. So, some properties of cable some I mean these are the properties require main properties.

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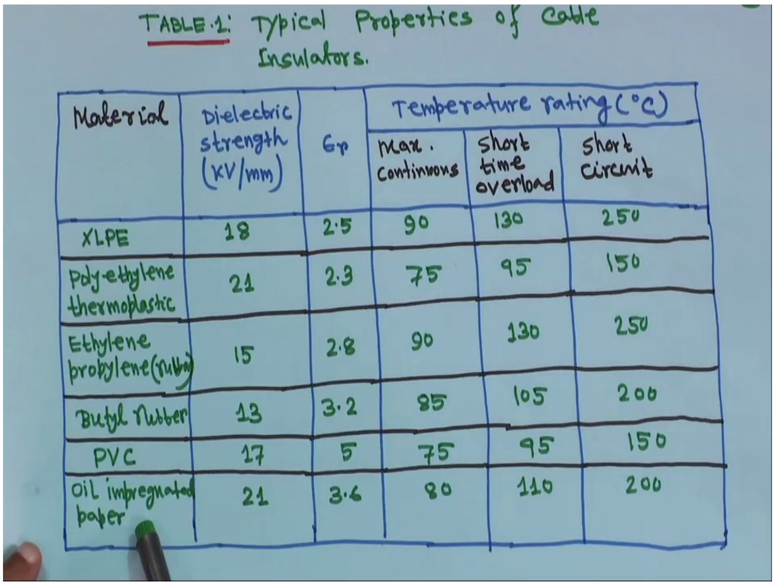

TABLE 1: Typical Properties of Cable Insulators.

Material	Dielectric strength (kV/mm)	ϵ_r	Temperature rating (°C)		
			Max. continuous	Short time overload	Short circuit
XLPE	18	2.5	90	130	250
Poly-ethylene thermoplastic	21	2.3	75	95	150
Ethylene probylene (rubber)	15	2.8	90	130	250
Butyl rubber	13	3.2	85	105	200
PVC	17	5	75	95	150
Oil impregnated paper	21	3.6	80	110	200

So, typical some properties of cables are look this material is one is XLPE cable then I we will come to that most of the cables later then polyethylene your thermoplastic, then ethylene propylene that is rubber, then butyl rubber then, PVC, then oil impregnated paper. So, different type of insulation their typical properties of cable. So, di-electric strength for this one kilovolt per millimeter is given. So, XLPE is 18 many places XLPE is used mostly, then 21 then 15, 13, 17 and 21.

So, di-electric strength among all these, maximum is that polyethylene thermoplastic one. Therefore, your permittivity 2.5, 2.3, XLPE is 2.5, then ethylene propylene 2.8 and butyl rubber 3.2 and oil impregnated paper highest is 3., No, PVC is the highest p 5, oil impregnated paper is 3.6. Now, temperature rating one is maximum continuous, one is short time overload another is short circuit. So, I mean 90, if you look at that 90 here, then 75, 90, 85, 75, 80. More or less, except polyethylene thermoplastic and PVC more or less all are 80, 90, the maximum continuous temperature.

That means that is your what you call temperature rating. Maximum continuous means at normal operating condition it can withstand this continuous temperature. Now, short time overload if there is no overload, for say for a very short time then XLPE is 130 and next your ethylene propylene the rubber, 130, then others are there 110, that oil impregnated paper then PVC, 95 and so on all these things. Then short circuit it is 250 and this ethylene propylene is 250 others are 200 or 150. There is a during short circuit the temperature rating, short circuit last your what you not for longer duration. So, this is your typical properties of cable insulator. So, different type of insulators are there.

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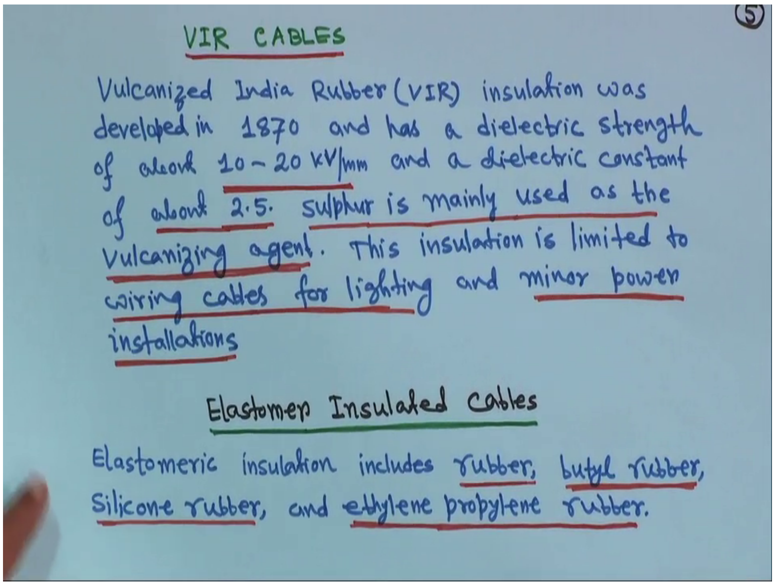

Next one is that VIR cable, which is Vulcanized India Rubber we call. It was developed in 1870, that is, more than the 147 years ago, but at that time anyway those days there was no electricity in those days, it came later. But anyway, but this is vulcanized rubber was used I mean developed in 1870 and has a di-electric strength of about 10 to 20 kilovolt per millimeter, when I am putting this thing because 1870, just putting a question to you when the first of course, not high voltage cannot say high voltage, but first transmission system or power transmission system when in which year it was started and which place, this is a quiz to you.

So, this is a quiz to you. You should find out and as a di-electric strength of about 10 to 20 kilovolt per millimeter and a di-electric constant is about 2.5. In this case it is a vulcanized rubber, sulphur actually mainly used as the vulcanizing agent. So, this insulation is limited to wiring cables for lighting and minor power installation that mean a low voltage level. This type of cable can be used because this for lighting and minor power installation.

Next one is that elastomer insulated cables. So, these are all coming from polymers. So, elastomeric insulation includes rubber, butyl rubber, silicone rubber and ethylene propylene rubber.

So, different type of if you see those cables I mean in your then you will see different type of insulations are used. So, of course, it difference from your different properties as well as cost is an important aspect.

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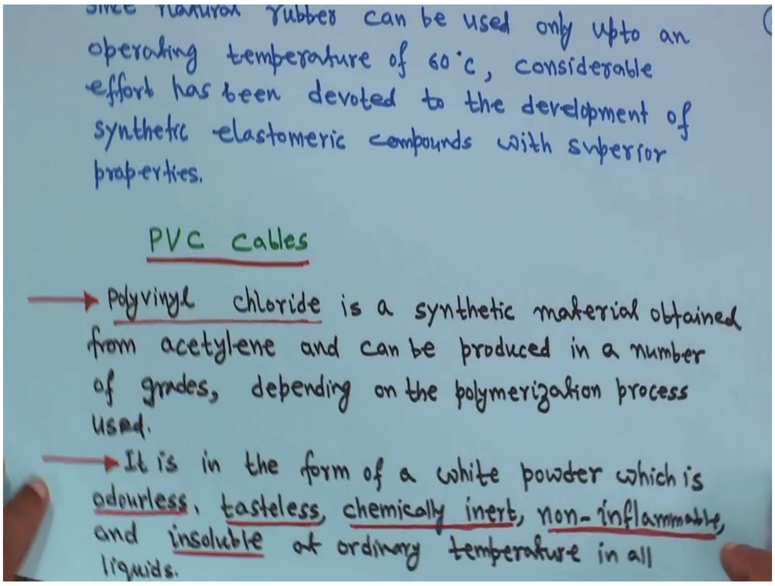

Natural rubber can be used only up to an operating temperature of 60 degree Celsius. So, considerably effort has been devoted to the development of synthetic elastomeric compounds with superior properties such that its operating temperature can be increased. So, details will just condensate these are all this thing different insulation. For example, polyvinyl chloride cables that PVC cables they call polyvinyl chloride is a synthetic material obtained from acetylene and can be produced in a number of grades depending on the polymerization process used PVC cables also used.

So, it is in the form of a white powder, the advantages is, which is odorless, tasteless, chemically inert, non-inflammable and insoluble at ordinary temperature in all liquids. This is the major advantage is that it is chemically inert, non inflammable and insoluble at ordinary temperature in all liquid. This is actually this is the main advantage of this one. So, this is what you call that PVC cable; diagram other thing construction I will come later.

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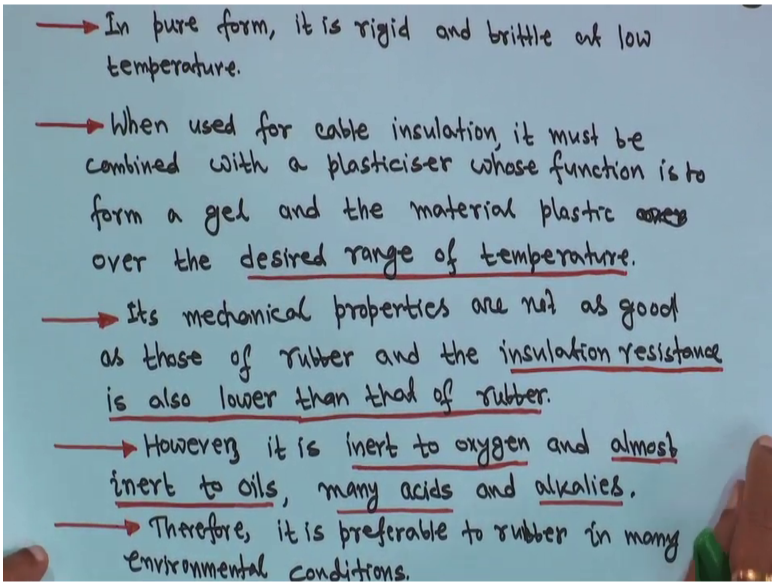

Then, is in pure form it is rigid and brittle at low temperature. In pure form it is rigid and brittle at low temperature. I have seen some where the cables low tension cables that the cable was for nearly if I recall correctly the people told me nearly 25 to 30 years supplying power cable is without any fault or anything when they were trying to replace it and I saw it in my eyes that when they are trying to replace those cable it was not in its original conditions. So, it became very brittle and everything is very loose, but as long as it was is your under the ground where these that there was no problem at all. So, anyway people I mean those they have told I have seen this one.

So, when used for cable insulation, it must be combined with a plasticizer whose function is to form a gel and the material plastic over the desired range of temperature. Its mechanical properties are not as good as those of rubber and the insulation resistance is also lower than that of rubber. Insulation resistance is a great matter for cables. So, however, it is inert to oxygen and almost inert to oils. Then there will be no reaction and many acids and alkalis also. So, this is the advantage. Therefore, it is preferable to rubber in many environmental conditions. So, you have to consider many things which environment you are using the cables and accordingly you have to choose.

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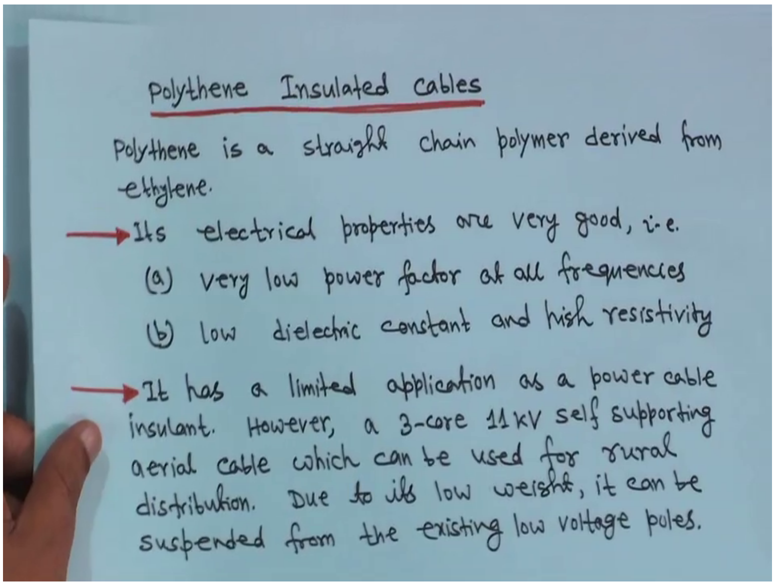

Then next one is the polythene insulated cables. So, polythene is a straight chain polymer derived from ethylene. So, its electrical properties are very good; number one is, very low power factor at all frequencies, low di-electric constant and high resistivity; this is your polythene insulated cables. It has a limited application as a power cable in your power cable insulant. However, a 3-core 11 kV self supporting aerial cable which can be used for rural distribution; aerial cable means not buried in the ground, you can take it to the tower or some kind of arrangement.

Due to it is low weight it can be suspended from the existing low voltage poles; that is why low voltage pole also you can make it I have seen somewhere I mean I do not know, nowadays it may not be there, but in hilly areas I have seen this aerial cable. Even I saw that it is going through your trees instead of pole because many trees are there. So, it was I have seen it in the past.

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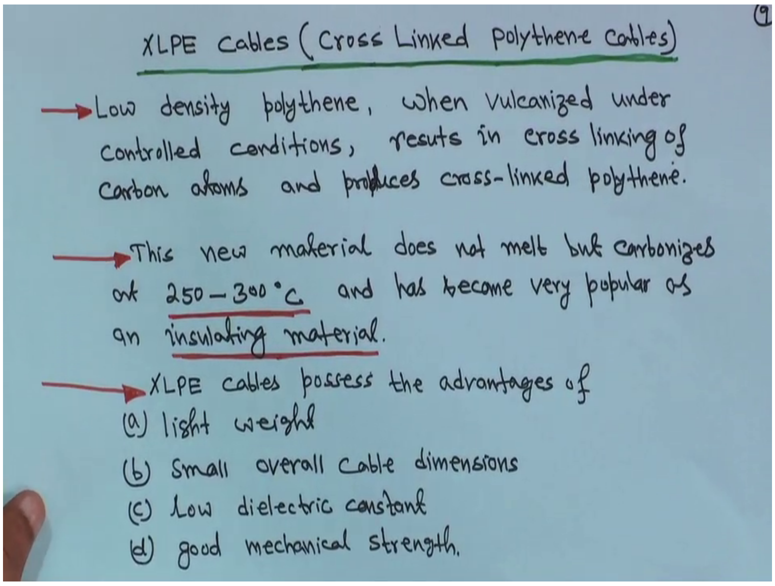

So, next one is that XLPE cables, that is, Cross Linked Polythene Cables. So, it has low density polythene, when vulcanized under controlled conditions results in cross linking of carbon atoms and produces cross linked polythene. This is mostly that chemistry portion. So, we will not cover that, but some general ideas. This new material does not melt, but carbonizes at 250 to 300 degree Celsius and has become very popular as insulating material. So, XLPE cables possess the advantages of light weight, then small overall cable dimensions, low di-electric constant and good mechanical strength.

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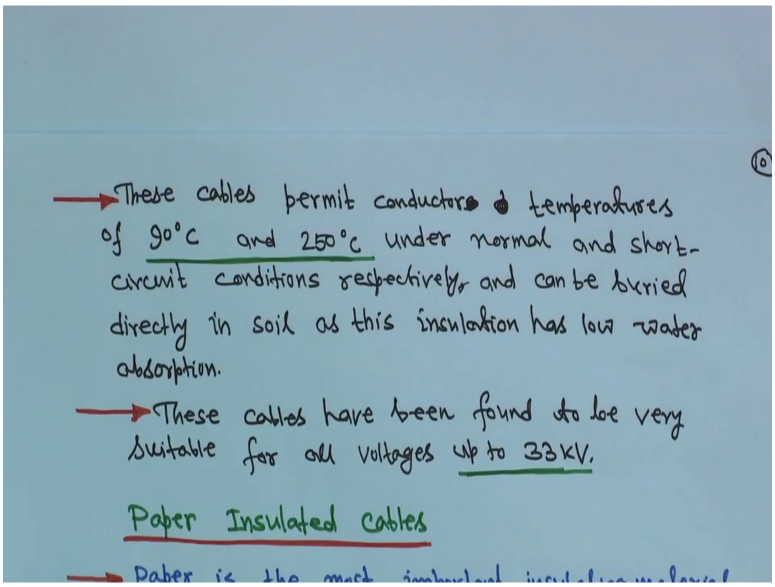

So, it has some properties that your what you call which it can be preferable to compared to other cables. So, that means, this cables permit conductor temperatures of 90 degree Celsius and 250 degree Celsius under normal and short circuit conditions respectively. So, 90 degree normal is quite high and short circuit 250 also it is ok and can be buried directly in soil as this insulation has low water absorption. So, that means, without anything you just can directly lay in the soil. You might have seen the cable lying, how they are doing it. So, these cables have been found to be very suitable for all voltages up to 33 kV.

Thank you very much. Again, we will be back.