Power System Engineering
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Lecture – 18
Transient over voltage and Insulation coordination (Contd.)

Welcome back actually this is your figure 13.

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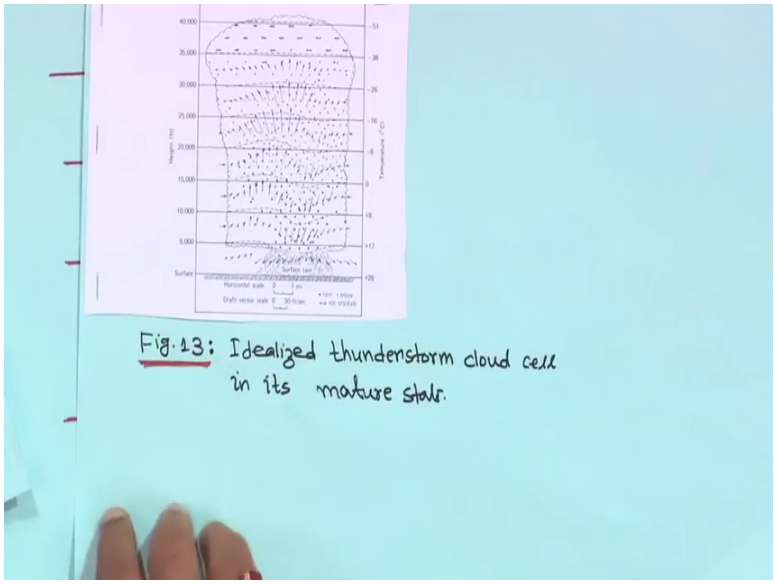

I have showed you; this is figure 13.

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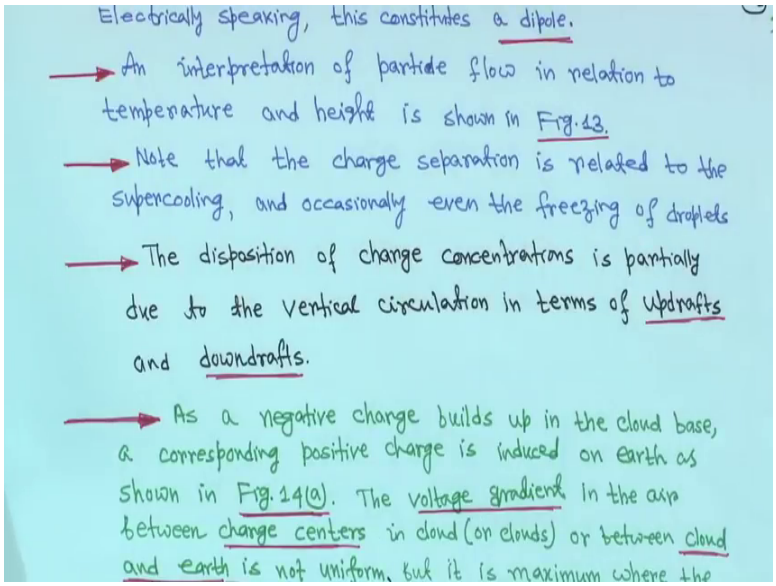

Now next is the figure 14.

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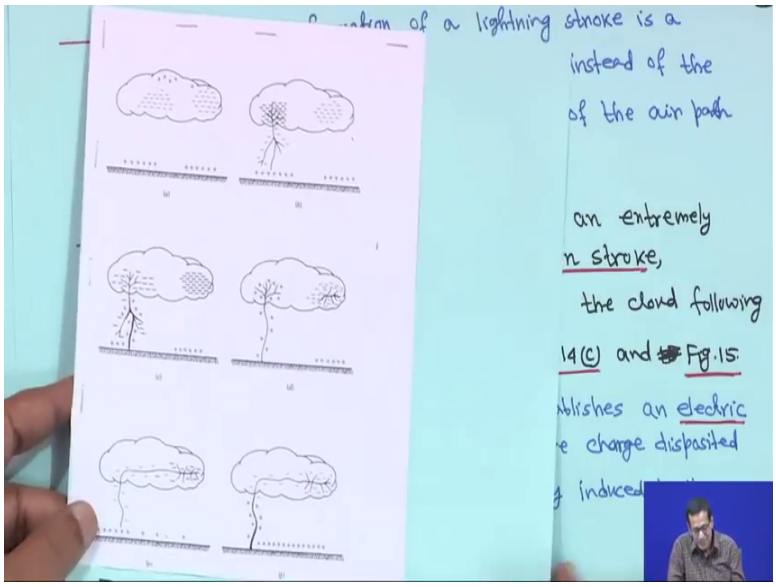

This is figure 14; so, before telling anything; so, just we will look at the figure; this is actually cloud. So, upper portion is the positive charge concentration and lower is the negative charge so on the ground, there will be a positive charge. So, this is actually its figure a.

So, what happen? Actually this lightning stroke whatever you see it does not happen instantaneously, it jumps actually. So, what happens? That as a negative charge builds up

in the cloud base a corresponding positive charge is induced on the earth as shown in figure 14 a. So, they are tickly on the cloud base it is negative charge; so, positive charge will be you have to build up on the earth surface; this is earth surface or ground.

So, the voltage graded in the air between charge centers in cloud or between cloud and earth is not uniform; that means, that voltage gradient; suppose either two clouds either between, the clouds or between the cloud and earth that voltage gradient is not uniform it is not at all uniform, but it is maximum where the charge concentration is greatest.

So, in that case; that means, here in the diagram it is showing only one cloud, but wherever charge concentration is high the voltage gradient there it will be very high. Now what happened actually? When the voltage gradient become; 5 to 10 kilo volt per centimeter either between the clouds or between the cloud and the earth.

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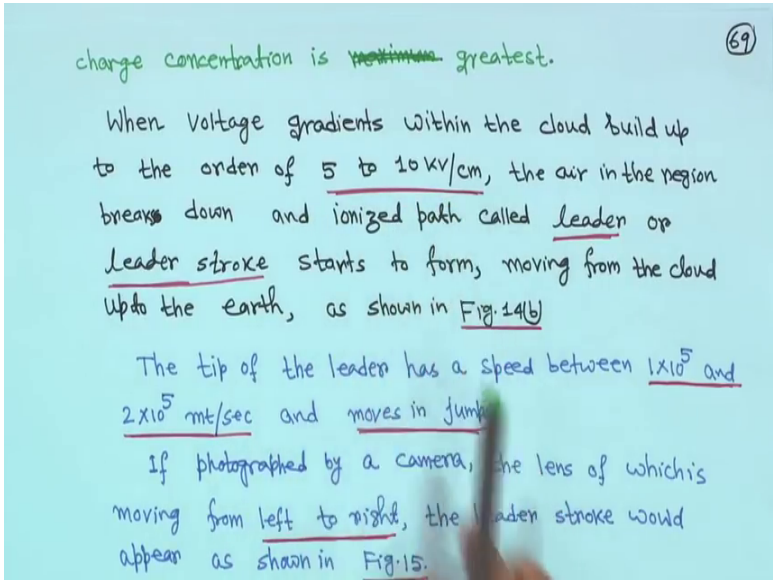

So, voltage can within the cloud build up at the order of if 5 to 10 kilo volt per centimeter the air in the region breaks down; an ionized path called leader, a leader stroke starts to form, moving from the cloud up to that as shown in figure 14 b that mean what happen? That if the voltage gradient it becomes at 5 to 10 kilo watt per centimeter; surrounding earth you will be ionized and at the time what will happen?

That here will be ionized and breakdown, so what will happen? A leader strokes start to form, you can see that when lightning is happening such kind of several lightning your

leader; you have seen like a like a root. So, here also this kind of your leader; this is called leader this kind of thing will happen. So, what will happen? That it will try to move from the cloud to the earth, ultimately it will come to the earth. And that is actually moving from the cloud up to the earth as shown in figure 14 b; this one, it is moving up to the earth.

So, what happens? That tip this speed of this lightning it is not the speed of the light, but its speed will be 1 into 10 to the power 5 meter per second to 2 into 10 to the power 5 meter per second general. So, that is why; its speed will be 1 into 10 to the power of 5 to 2 into 10 to power 5 meter per second. And moves in jumps, it is not a continuous because it moves in jumps. So; that means, because that your air breakdown that is your or gradient; it is not uniform, it moves in a jump.

So, if you photograph by camera; if you try to take the lens of which is moving, I will show you from left to the leaders stroke would appear as shown in figure 15. I mean if you take the photograph like that from left to by camera, this leader stroke it is moving like this and finally, it is coming to this one; ground.

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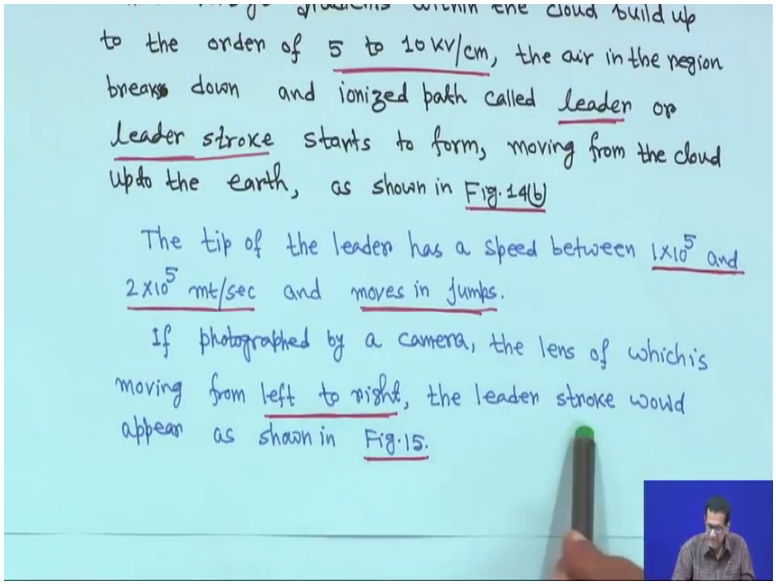

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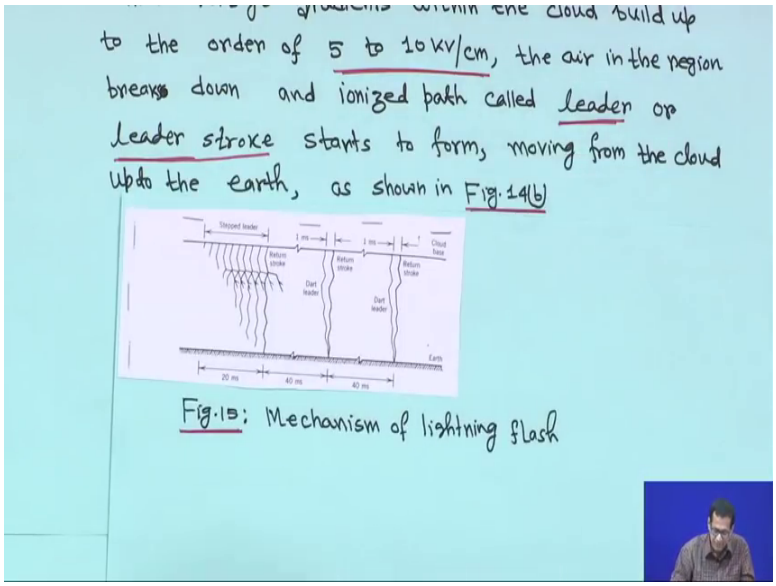

So, basically it moves in a jump; it is not a continuous that directly it is not coming from the cloud to the earth, it is not reaching near the earth; it moves in a jump because of that are un-uniform distribution of the voltage gradient.

So, that is figure 15 next is; so, active; that means, what happen? It is a progressive breakdown of the arc path.

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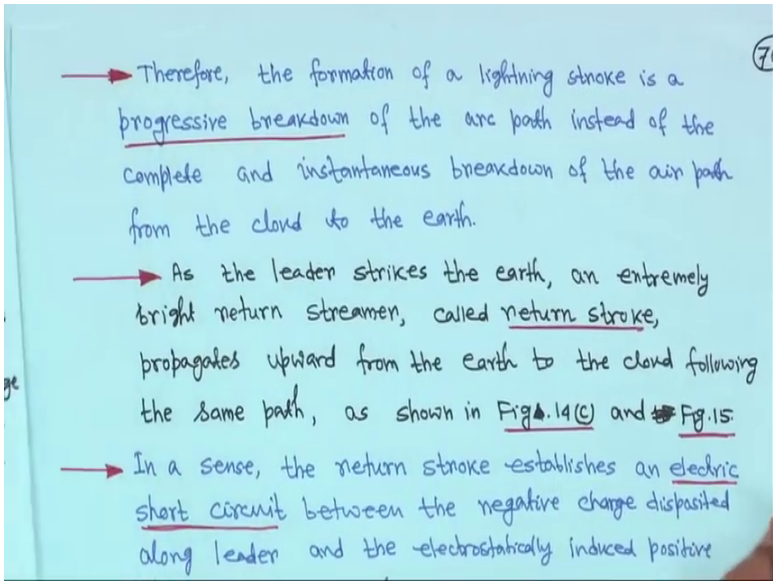

So; that means, the formation of a lightning stroke is basically a progressive break down of the arc path, instead of the complete and instantaneous breakdown of the air path from

the cloud to the earth. So, it does not come instantaneously, but it is; what you call it is a progressive breakdown of the arc path.

So, that is why that your what you call leader stoke moves. So, as the leader strikes the earth; an extremely bright return steamer called returns stroke, propagates upward from the earth to the cloud following the same path as shown in figure c.

As soon as this leader stokes come to the earth, immediately from the earth actually what will happen? That a leaders; return stroke will be going from this your earth to the your what you call to that cloud. So, that is why as the leader strikes the earth; an extremely bright return streamer, we call steamer called return stroke propagates upward from the earth to the cloud following the same path as shown in figure c; they following it to follow the same path.

And figure 15 also, this is your figure 15 that return stroke; here also you look return stroke, return stroke, return stroke; it follows the dart leader will come later; so, return stroke.

So, in that case in a sense the return stroke establishes an electric short circuit between the negative charge disposition along the leader and the electrostatically induced positive charge in the ground. So, return stoke actually; whenever it connects it makes an electric short circuit. So, when lightning happen you have seen; suppose on a tree though, so what happen?

That there will be heavy accumulation or a positive charge on the trees and then, when there is a return stroke, when it moves; following the same path of the leader stroke; that means, from the top of that tree is moved to the cloud and it makes an electrical short circuit; that is why you see that tree is completely burned actually.

So, sometimes it may happen that suppose you are working; on street; plane street maybe lightning stroke happens on the plane road also. And you can find that as if it has happened in front of you, but it is not; then person will never survive. So, one day one of my students told me, Sir, I have survived today because of lightning; so, what happened? Sir, in front of me that there is heavy flash on the road and a light flash and there was a lightning stroke on the road, I said it never happen in front of you; at least 500 to 1 kilometer away.

So, that is why that light is so bright actually; that it will happen as it is happening in front of you. I also experienced once or twice in this thing that when the video recording; I do not like to tell that and only what incident is very funny that I was coming by car. So, my driver was driving all of a sudden on the long road; all of a sudden, there was lightning stroke on the side of the road; my driver actually; brake the car. So, car stopped I said we both are alive; that means, it has happened at least 1 kilometer away from us.

So, seeing that he actually brake the car; well after moving 6 to 700 meter, we found the right of the road, there is a big hole and there was a lightning stroke on the road itself. So, it is not like that it will be on the top of the tower or building or this thing; lightning can happen, lightening stroke can happen even in the plane place also; so, this I have observed this one.

Another one from (Refer Time: 08:17) somewhere I saw there was a lightning stroke; I think on the coconut trees and the tree totally burnt actually from distance.

So, anyway so; that means, then this happens because of your return stroke because it makes the electrical short circuit. So, this is actually induced positive in; this I have told you therefore, the charge energy from cloud is released; it is a heavy energy is lighting current is very high actually.

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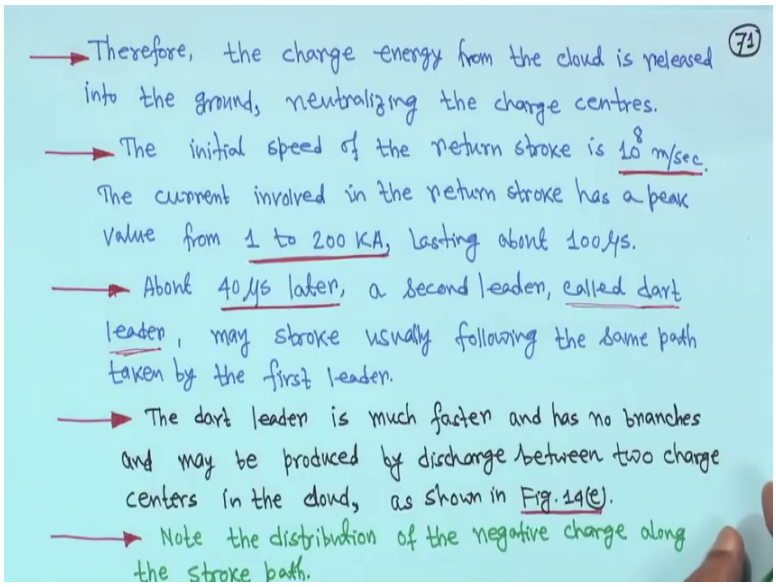

So, the charge energy from the cloud is released into the ground. So, neutralizing the charge center so; that means, that because all the energy will be released from the cloud. So, the initial speed of the return stroke is 10 to the power 8 meter per second approximately; that not equal to the speed of the light. Light is 3 into 10 to the power 8 meter per second approximately; it is 10 to the power 8 meter per second, that this initial speed of the return stroke; that means, this one. Occasionally, you can observe also it is moving as if from the ground or from the trees to this one.

So, and the value of this current is 1 to 200 kilo ampere; that means, 100 kilo ampere; which is 1000 ampere to 2 lakhs ampere. So imagine its strength, your intensity and it last about hardly 100 microsecond; very fast phenomena, but about 40 micro second later; a second leader called dart leader, means stroke usually following the same path taken by the first leader.

I mean will not this happen; there is a possibility that there will be repeated return stroke, you have to follow the same path. For example, there is one diagram at this 15; this is the dart leader, I mean main stroke already main lighting stroke already has happened and after that there may be many; with a smaller strength of course, dart leader also you can see it.

As many as maximum, as many as 40 you can see, but if you see carefully you will see at least after the mean; your thing there may be few your return stroke also they are called dart leader. But intensity will be less than the main one; so, then gap between the mean and dart will be about 40 micro second; very small time.

A second leader called dart leader may also stroke usually following the same path taken by the first leader; almost the same path, but here in the diagram we cannot show the same path; then you cannot see anything that is why little bit this thing, but pattern if you see that both are following the same path. So, that is the same way it will move; little bit zigzag way.

So, the dart leader is much faster has no branches and may be produced by discharge between two charge centers in the cloud. So, as shown in figure 14 e; so, this is your figure 14 e. So, it may be; this may happen; this is this one then your 14 d also, that your dart leader and here also dart leader and this one also.

So, note that distribution of the negative charge along the stroke path; if you see the distribution; here it is positive, negative, energy negative charge. Now here it is dart leader look positive; positive; it is negative here; that means, here it is positive, here it will negative. So, this path will follow; so this will follow.

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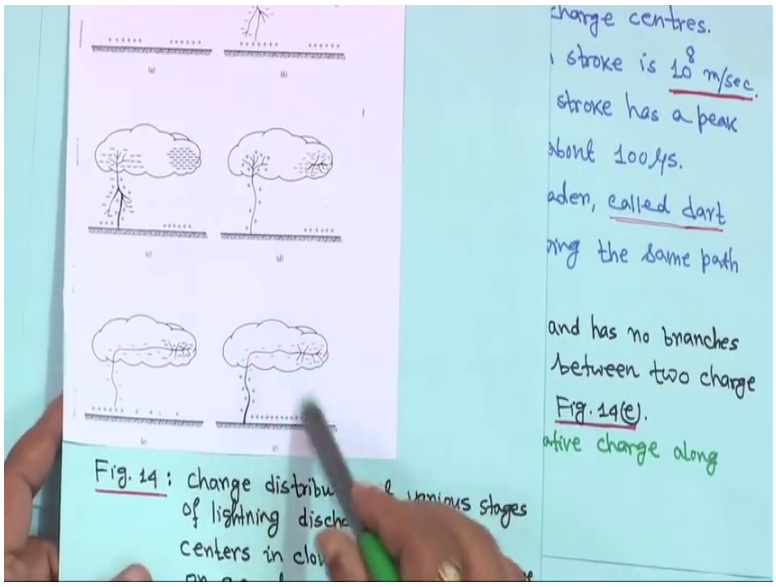

This is ground positive, this is negative here also it is negative. So, this is similar phenomena; here it is positive, positive, here it is; the cloud is negative.

So, note that distribution negatives are along the stroke path; so all the plus, minus signs are shown in this diagram.

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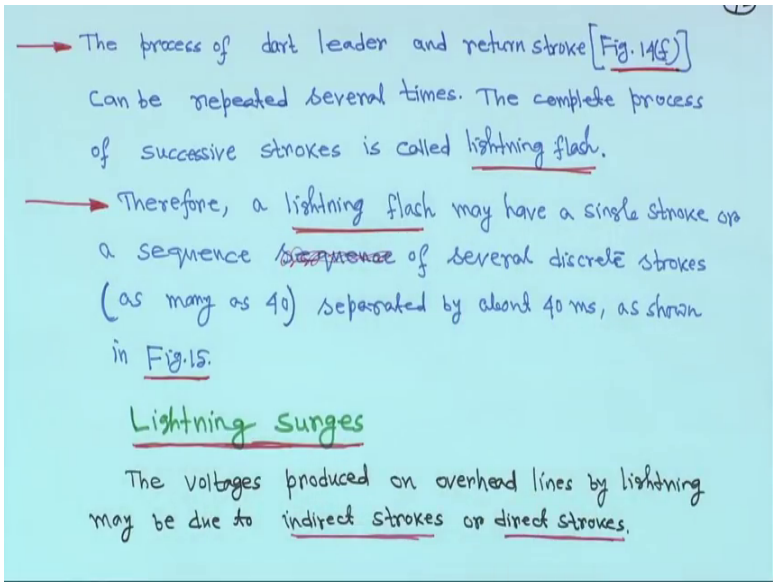

So this process of dart leader and return stroke that is figure 14 a; this is also shown here also; 14 a, the process of dart leader and return stroke can be repeated several times. I told you, if you observe during thunderstorm you can see. The complete process of successive stroke is called lighting flash.

So, when lightning happen you have observed that and that noise comes due to the air break down. Therefore, a lightning flash may have a single stroke or a sequence of several discrete stroke; as many as 40 it can happen, separated by about 40 millisecond as shown in figure 15; so this is actually figure 15; so dart leader, return stroke; everything is shown. So, therefore I mean this actually this as many as 40; when it is taking 40 means; it will be a heavy lightning stroke.

So, separated by about 40 millisecond as shown in figure 15; I showed you, so this is how the phenomena of your lightning stroke. So, this is only we have talked about general lightning stroke, but we have not talked about; when it is lightning struck happen on the overhead transmission line or in direct or indirect stroke.

So, next we will come to the lightning surges; so, the voltage produce and overhead lines by lightning may be due to indirect stroke or direct stroke. Because our objective here is still; if lightning happens on a directly on the shielding wire; that is that ground wire or the overhead transmission line, you might have seen or directly to your conductor or directly on the top of the tower; these are direct stroke.

And indirect stroke means may be nearby trees or nearby ground that lightning stroke has happened. And due to this some charge will be accumulated on the ground wire or on the conductor; those are indirect stroke; due to indirect stroke.

So, first we will see the indirect stroke.

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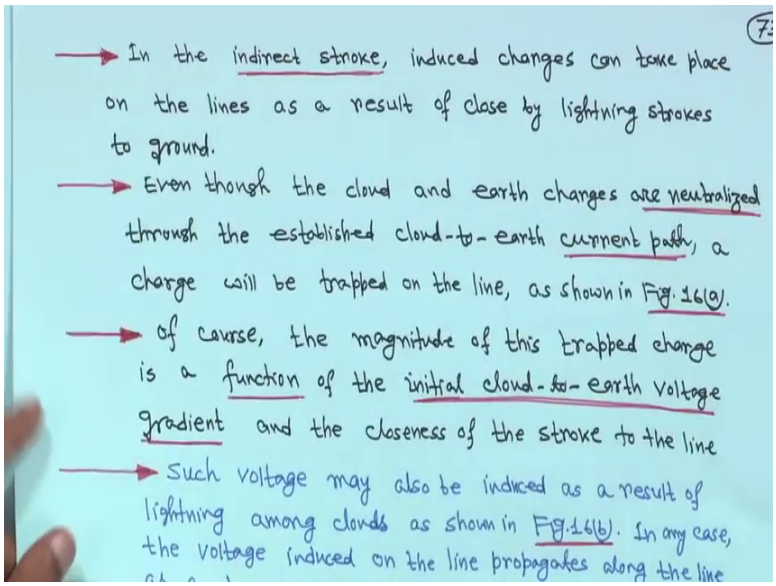

In the indirect stroke, induced voltage can take place on the lines as a result of close by lightning stroke to ground. It may be very close that lightning stroke has happened or maybe your nearby tree also; because of that some charge will be accumulated on the either ground wire or on the conductor or on the top of the tower.

Even though the cloud and earth charges are neutralized because when like this lightning stores has happened; that charge through the cloud and earth will be neutralized; totally neutralized. And when the cloud to earth; current path also established, lightning stroke has happened; a charge will be trapped on the line.

So, there is a possibility that some charge will trapped on the line; as shown in figure 16 a; so, this is figure 16.

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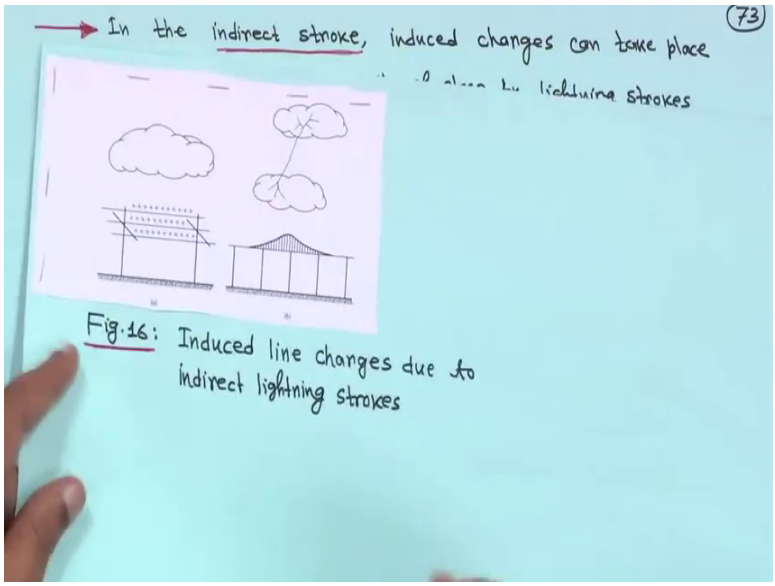

This is say some overhead line; so, lightning stroke has happened somewhere, but some charge may be accumulated on the line conductor or tower or ground wire or shield wire. So, in this case; a charge, this thing the magnitude of this trapped charge is a function of initial cloud to earth voltage gradient and the closeness to the stroke to the line.

I mean how close that lightning stroke has happened and of course, that cloud to earth voltage gradient.

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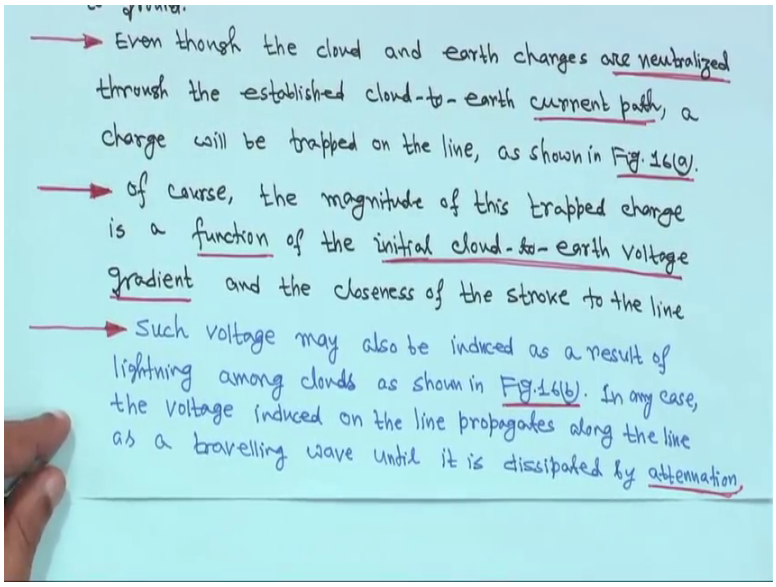

Such voltage may also be induced as a result of lightning among clouds, as shown in figure 16. I mean this kind of thing also can happen, if there is a lightning stroke between two clouds or in that case also; this charge can be accumulated on the line.

So, in any case the voltage induced on the line propagates along the line as a traveling wave. So, until it is dissipated by attenuation; I mean whatever it is, if any voltage induced on the line, it will propagate along the line; we call traveling wave, as a traveling wave until it is dissipated by attenuation.

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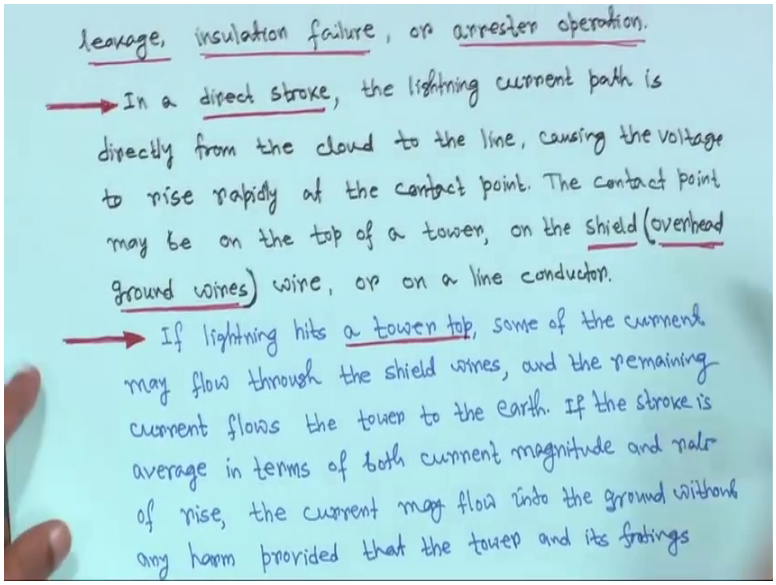

So, then due to leakage insulation failure or lightning arrester operation; arrestor operation is there, but somehow I have to make it little bit (Refer Time: 17:09). So, only little bit arrestor, different type of arrest another thing we will not study in this course. But the arrestor every substation you will find arresters are there everywhere, later it is found little bit function what exactly it is; we will come to that.

So, and in the direct stroke the lightning current path is directly from the cloud to the line; that means, there is a direct lightning stroke on the transmission line. The direct lightning stroke may be happen in the middle of the line, may be on the top of the tower or may be on the ground wire or shield wire; here it is or on a line conductor. If it happens, if lightning hits at tower top; suppose it lightning; this is a very common phenomena, if lightning hits a tower top.

So, transmission tower is there if lightning hit there. So, some of the current may flow through the shield wire because shield wire of down there will connected on the; if you look through on the top of the covered conductor reviewer. And on the top also ground or shield wire will be there. So, some of the current will be flowing through the shield wire and the remaining current flows; tower to the earth; that means, rest it will go from the tower to the earth.

So, in that case that if the stroke is average in terms of both current magnitude and rate of rise; stroke is average means intensity is less. The current may flow into the ground without any harm provided at the tower and it's; footing have low resistance value, if it is a low resistance value, it will get an easy path. So, what you call the damage and other thing will be very very; less I mean almost no damage; otherwise what will happen?

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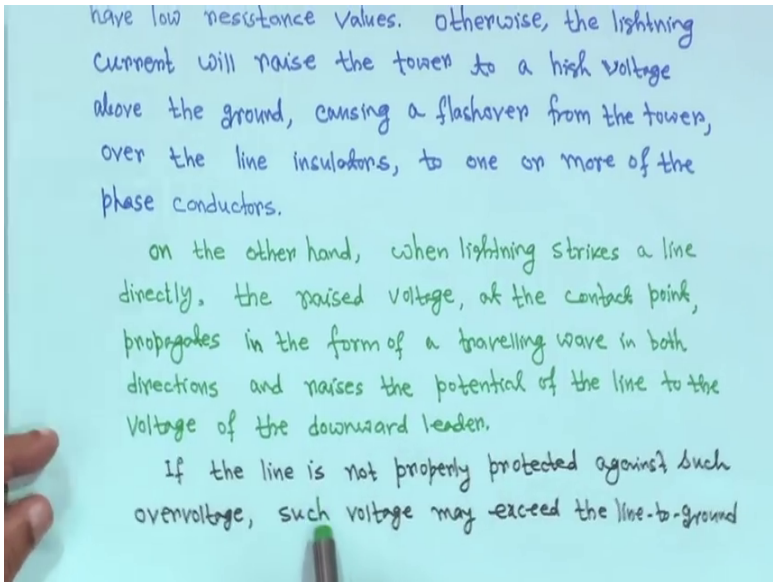

That lightning current will raise the tower to a high voltage above the ground. Because you have grounding resistance, if the resistance path is high; then there will be what it does actually, it will raise the tower to a very high voltage above the ground; causing a press over from the your tower over the line insulator. I mean if it happens that from the tower and their line insulators also connected, there will be press over between the tower and the insulator to one or more of the phase conductors.

So, in that case there is a possibility of the line outage also and in insulator also will be damaged. So, on the other end when lightning strike the line directly; the raised voltage

at the contact point propagate. Suppose a transmission a line is there and where that lightning should happen; suppose in middle of a line. So, both side that what you call; this voltage will propagate at the contact point propagates in the form of travelling wave; when both side it will move, in both direction and raises the potential to the line to the voltage of the downward leader. That means, the potential will be whatever is the voltage of the downward leader that is that coming from the cloud through the conductor; it will race to that potential.

So, imagine that how; although it is for microsecond or so, but how; it is a numerical value, it is very high actually. If the line is not properly protected against such over voltage, such voltage makes it the line to ground fault withstand voltage.

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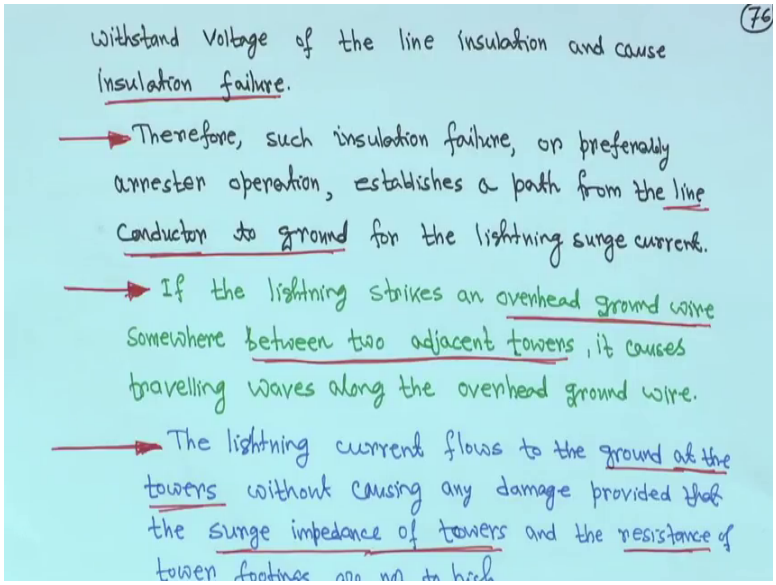

So, in that case of the line insulation and cause insulation failure; this will happen. So, proper protection is there; therefore such insulation failure or preferably arrestor operation establishes a path from the line conductor to ground for the lightning such current.

So, that is why that whenever your lightning arrestors are there in substation; if you go, you can see that if it is a design in such a fashion such that it encounter a minimum amount of current for which it protects the other equipment in the substation. But even when they design these, they consider all the facts and accordingly that engineers; they design your minimum rating of the lightning arrestors.

So, even with that what will be the maximum lightning currents or maximum intensity of the lightning stroke that they calculate. But even practically, I have seen in some substation in my young age that even at the substation that lightning arrester failure; it got burned. I mean maybe that maximum intensity of the stroke was very high, could not your encounter this far I mean; so, that is why; there it will mainly damage first the transformer and the substation.

So, that is why such insulation failure or preferably arrestor operation, establish is a path from the line conductor to ground for the lightning surge current. If the lightning strikes an overhead ground wire, somewhere between; I mean if it is not exactly the conductor, but top you can see the ground wire is there, it causes a traveling waves along the overhead ground wire.

It will be the same phenomena that overhead that there will be traveling wave.

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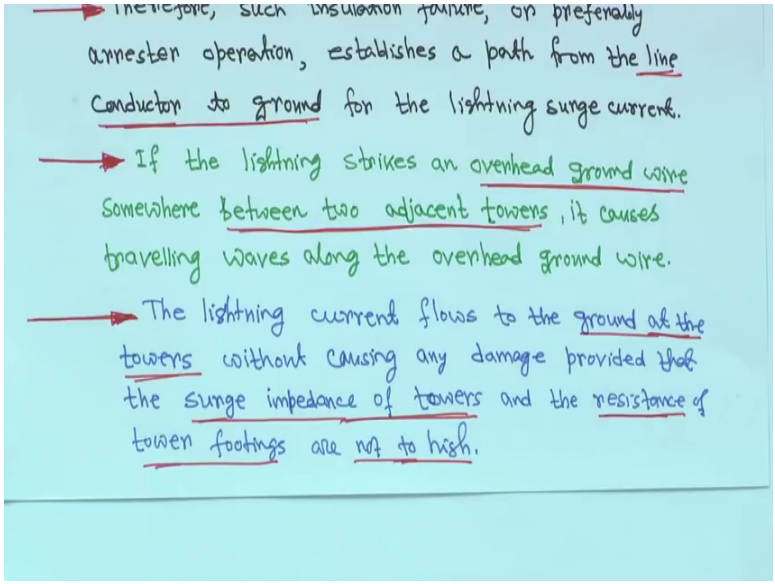

So, lightning current flows to the ground at the towers without causing any damage provided that the surge impedance of towers and the resistance of the tower footing are not high. So, if tower footing resistance is low and that surge impedance of the tower then what will happen? That it does not cause much damage, but otherwise what will happen?

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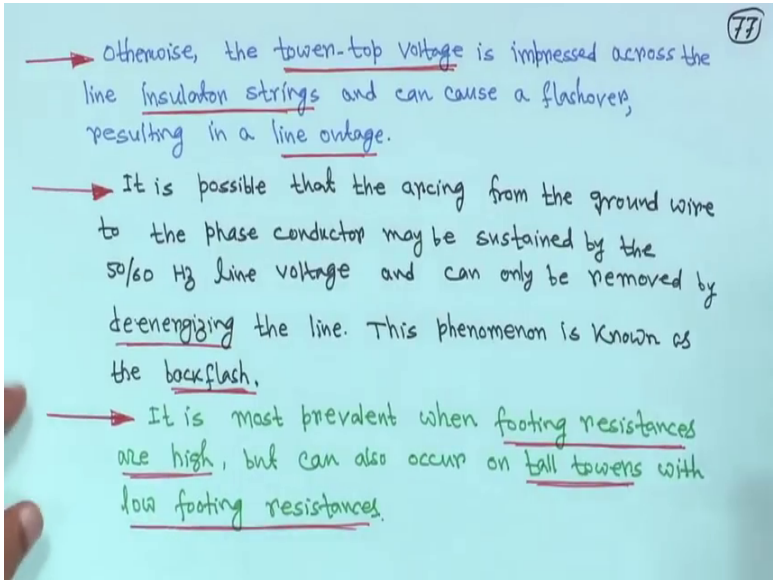

That if surge impedance is high, then on the top of the; tower top voltage will be impressed across the line insulator string also and can cause a flashover resulting, in a line outage.

So; that means, when the design just when you look into that transmission tower and putting resistance; all these things they design it in different way. So, from distance we can sees many these things, but actually many engineering concepts are there; for your reacting towers and the insulators, as well as your footing resistance their engineering concepts are there; just not like transporting the; erecting the tower and the design of the tower also, we can see different kind of designs are there.

Although we will not study tower design here, but different type of designs are there insulators are there. So lot of engineering concept are there in there; so, it is possibly that the arcing from the; sometimes what happen that arcing from the ground wire to the phase conductor may be sustained. That means, if that the top of the tower if you see the shield wire has gone the ground wire and the conductor.

Some time that arcing thing, it may sustained at that time you have to; for 50 hertz or 60 line voltage. And it can only be removed by de-energizing the line; this phenomena is known as backlash. Sometimes actually; nowadays several techniques are there for example, suppose it is just general phenomena suppose first you take a line, conductor suppose it was carrying current or power say high tensor line.

For example, says 220 KV line; now suppose load is disconnected, line is switched off. So, according to that; so line there will be no current flowing, because the load is switched off, but line is charged. The reason is that line; over it conductor to the ground there will be uniformly distributed, capacitance will be there. Although line is not carrying power or current, but line will remain charged.

So, if suppose with that; without any caution for example, I mean just giving an example any human being say if you take a conducting rod and if you try to touch the line that person will die actually. Because this discharging will take place through the body of the of the person. So, what they do actually; both side of the line, you have to ground it such that that line to charging capacitance first will be discharge and after that you can work.

Nowadays, you can see on line they are working even with a lot of protection, but this is the phenomena that if this line is still remain charged, then you have to first discharge it. And in this case that sometimes it happened at the 50 or 60 line voltage; there will be arc formation between the ground wire and the conductor. So, in that case you have to de-energize the line fast and this phenomena sometime they call as a backlash.

So, it is most prevalent when footings resistances are high, but can also occur on tall towers with low putting resistance. If tower is tall, it can also happen that, but otherwise when footing resistances are high this may happen; so, this is lightning stroke and on the conductor.

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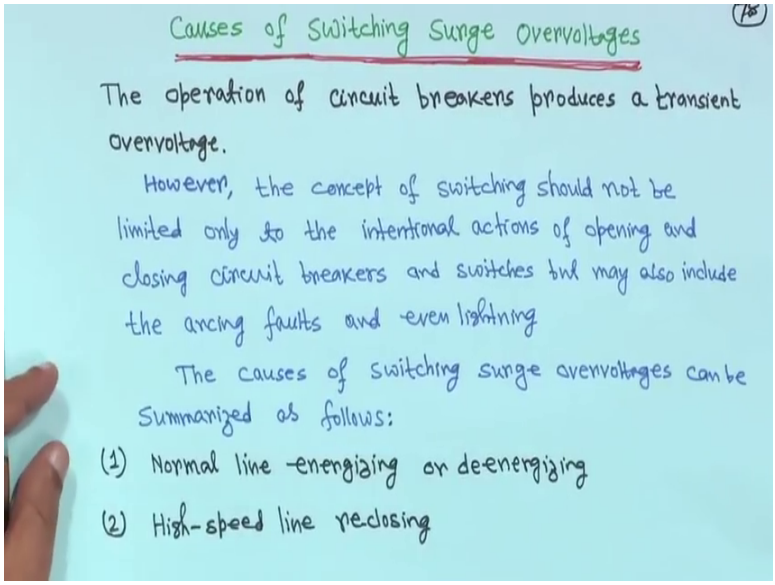

So, these are general ideas; so all if I miss anything, so some things I have brought for all of you. So, now causes of switching surge over voltages. Whatever we see that switching surge that is one thing we saw; that due to lightning that over voltage is there, but question is that operation of circuit breakers produces transient over voltage.

However, the concept of switching should not be limited to the intentional actions of opening and closing of circuit breaker and switches. But may also include the arcing faults and even lightning; all these things can happen. The causes of switching surge, over voltages can be summarized as follows.

So, it may happen normal line energizing or de-energizing; this is what happen and high speed; different type of switchings are there. I have decided I should not cover here because it will take long time. So, normal line energizing or de-energizing, high speed line reclosing; so many things are there.

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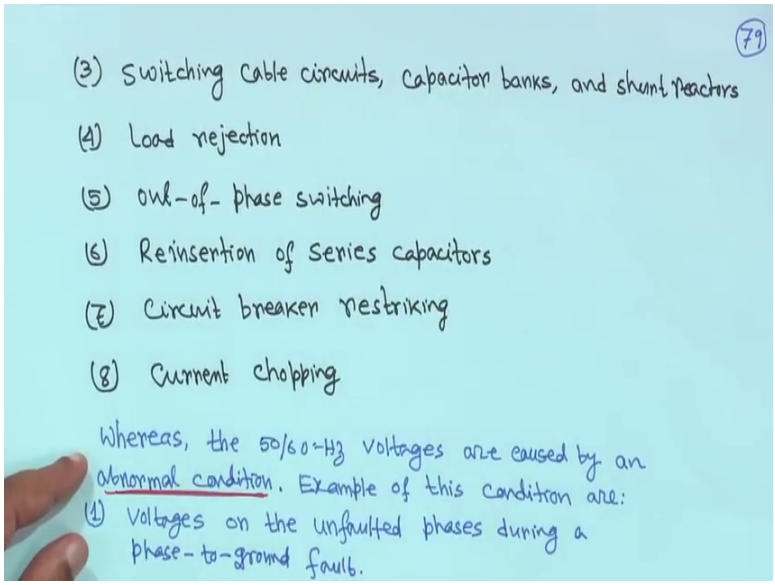

Next is then switching cable circuit, capacitor banks and shunt reactors, then load rejection; this is a question to you; very simple thing. What is load rejection? From common sense, you have to tell; just this question I am putting, what is load rejection? I am not answer that; this is for you that what is load rejection?

Then out of phase switching; then reinsertion of series capacitor many high tensile line sometimes 132 KB or above; they use series capacitors of course, they are resonance is a

problem that this thing; that thing you have to consider. Not only at fundamental frequencies some third harmonic, fifth harmonic all these things you have to taste for resonance.

But high tensor line for increasing the maximum power carrying capability; series capacitors are also there. So, this thing then circuit breaker restriking and current chopping; these are the (Refer Time: 28:59) thing that you have to consider for switching surges; over voltages, whereas the 50 or 60 hertz voltages are caused. 50 hertz, 60 hertz means in many countries; 60 hertz means there; our country it is 50 hertz.

Example of these conditions are; voltages on the unfaulted phases during a phase to ground fault; that you have studied in your power system analysis. So, suppose a phase to ground fault has happened then what are the voltages or your un-faulted phases.

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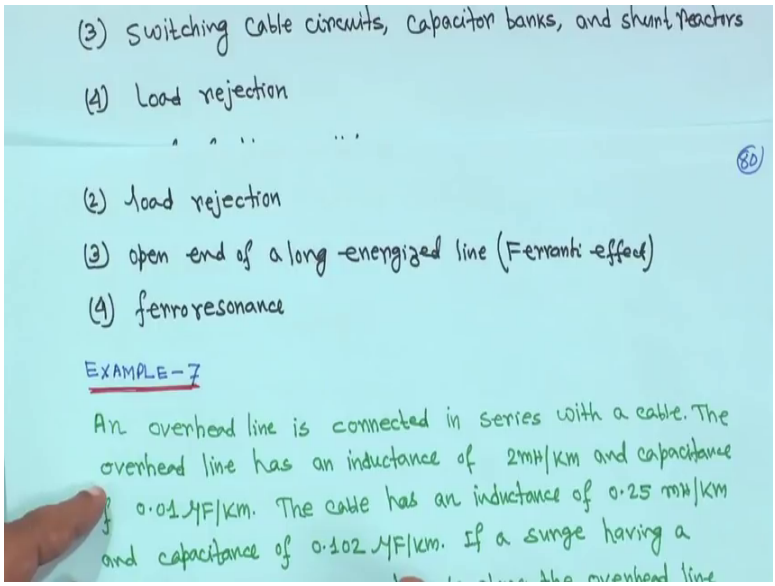

Then load rejection again here also coming and another thing is; open end up a long energized line that is Ferranti effect. You know in the Ferranti effect; receiving in voltage will be more than sending in; that we have seen. And another thing is ferro resonance. So, all these things happen that this is causes of switching such over voltages; as well as at the normal your 50, 60 Hertz voltages.

Thank you very much, we will be back again.