Power System Engineering
Prof. Debapriya Das
Department of Electrical Engineering
Indian Institute of Technology, Kharagpur

Lecture – 17
Transient over voltages and Insulation coordination (Contd.)

Welcome back now. So, this is Lattice Diagram now.

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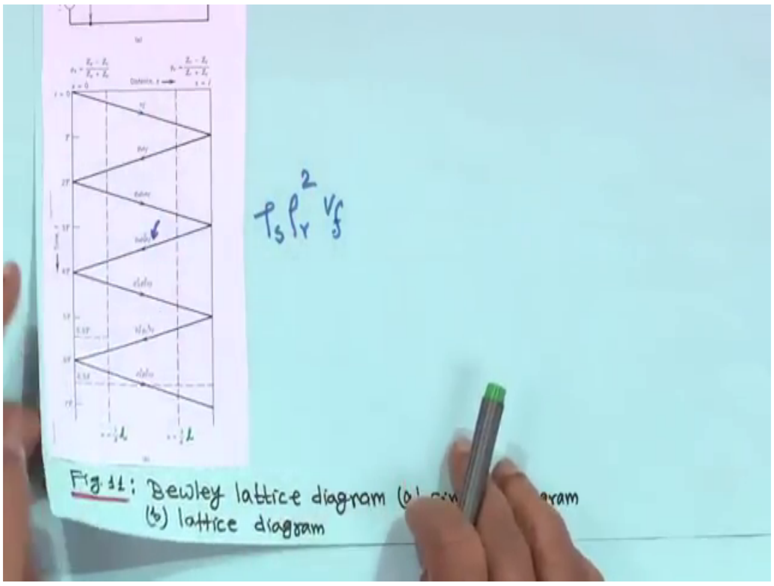

If it is asked for example the voltage at a given point in time and distance is found by adding all terms that are directly above that point. For example, suppose if it is that voltage at t is equal to 5.5 T and x is equal to l by 4. Suppose you have to find out when time t is equal to 5.5 T and x is equal to l by 4. Now look at this diagram.

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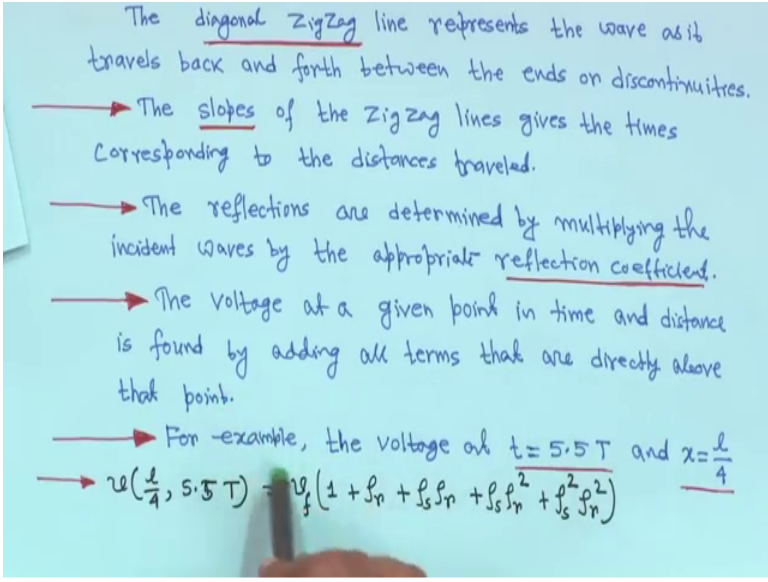

Time is 5.5 T then when x is equal to your l your l by 4 this is one-fourth length and this is this is one fourth this is line total length is x is equal to l. So, it is one-fourth means this is 1 by 4 l and this is 3 by 4 l like total length is l. So, in this case now time is given that t is equal to 5.5 T. So, this is 5 T, this is 6 T. So, you take 5.5 T. Now if it is 5.5 T, from that you go above that right and you add all the voltages.

So, in x is equal to l by 4 and time is T is 5 point is 1 2 3 4 5. So, look if you take this one and this one these are all below 5.5 you should not consider. You should consider only from that time whatever 5 pointed above this because this is the time this is T is equal to 0. So, t is equal to 5.5 T. So, all this term you will be added. So, if you add you will get your that is why I am writing v bracket is function of length l by 4 and T is actually the v x t x is l by 4 and small T is equal to 5.5 is equal to is equal to what you can do is I am just showing you that before showing this one suppose look at this look at this diagram. So, we will come 5.5 T means this one, this one, this one, this one and this one. So, here it this, this line is showing actually zigzag line this one is v f.

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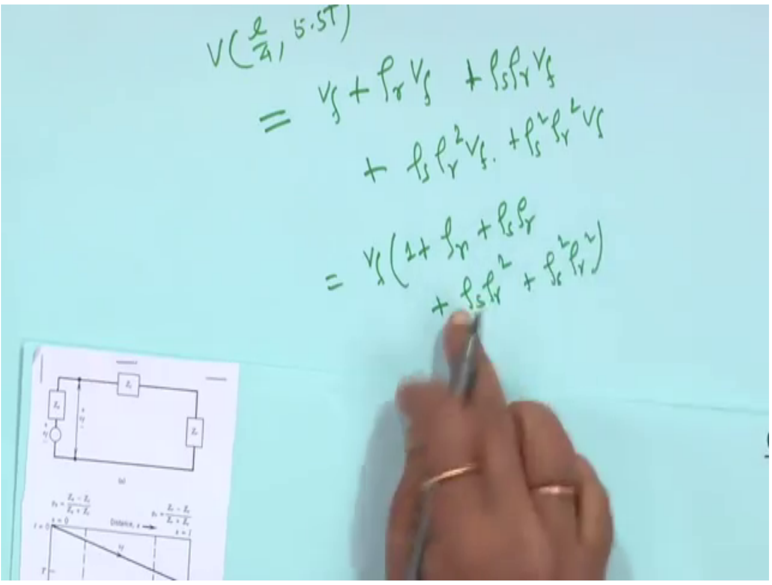

So, you that is your x is equal to l by 4 and t is equal 5.5 T is equal to right. Now you this one is there. So, you add here plus this one also is there because have a 5 point for, rho r v f right. Then this one you come it will be rho s rho r v f right. Then come to this one it will be rho s then here it is it is here only rho s rho r square into v f. Then one more it will be rho s square rho r square v f plus rho s square rho r square v f because up to 5.5 T, above that if you come below that it is more than 5.5 T. If you take v f common it will be one plus rho r plus rho s rho r plus rho s rho r square plus rho s square rho r square right.

So, this is the evaluation that how you evaluate from the lattice diagram right. So, that is why this expression whatever I showed you where this is the same thing I have written you take v f common it will be one plus rho r plus rho s plus rho r plus rho s rho r square plus rho s square rho r square whatever you have got 5 terms right, whatever you have got. So, this is actually the voltage at t is equal to 5.5 T and x is equal to l by 4 this is from the lattice diagram.

Another one I have made it, but your job will be to this one answer I am not telling here what you will do it right, you will do this. Just hold on.

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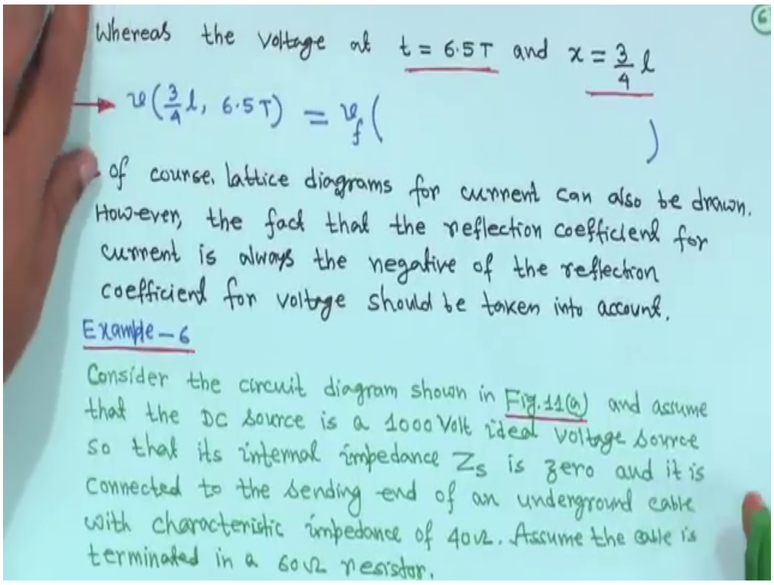

It very easy right if why whereas, this voltage it is, I am not writing the answer here you will find out at t is equal to 6.5 T and x is equal to 3 by 4 l. So, x is equal to v x t. So, x is equal to 3 by 4 l comma 6 5 is equal to v f and bracket all the terms which term will come. Only I can give you the hint this is 6.5 T right and x is equal to your 3 by 4 l; that means, what will happen this one, this one, this one, this one, this one, this one total 6 terms will be there in the bracket. So, your job will be to find out and you have to find out who can send me the mail. I will reply right, right or wrong. So, this one you will find out so that means, that lattice diagrams for current can also be drawn same way current also can be drawn; however, the fact that the reflection coefficient will current is always the negative of the reflection coefficient of voltage should be taken into account.

So, whatever reflection coefficient for the voltage there I mean current will be just negative the opposite sign that is the your; what you call that is all that already we have seen. Now we will take one example on lattice diagram. So, consider the circuit diagram shown in figure 11 a right, I will show you the circuit diagram right this figure 11, I mean this same circuit diagram just hold on. This is your, this is the same circuit diagram 11 a means this circuit diagram same circuit diagram right, 11 a and your and assume that the DC source is a one 1000 volt ideal voltage source and so that the internal impedance Z s is 0 and it is connected to the sending in of an underground cable. That means, in this circuit that internal impedance Z s is given 0 that is small v f is equal to capital v f that is actually given 1000 volt right.

So, and its connected to the sending end of an underground cable with characteristic impedance of 40 ohm and assume that the cable is terminated in a 60 ohm resistor right. So, characteristic impedance is your what you call 40 ohm and the cable is terminated in a 60 ohm resistor. So, you have to find out the following things.

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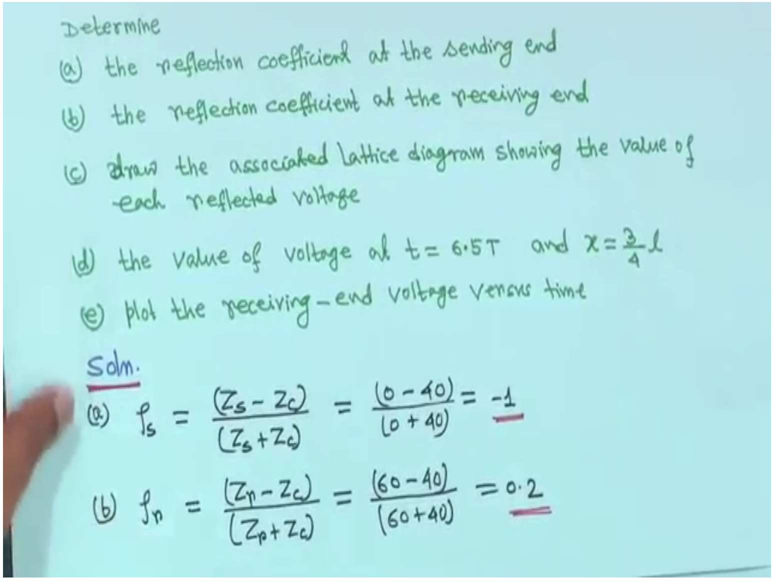

You have to determine the reflection coefficient at the sending end the reflection coefficient at the receiving end. So, the sorry draw the associated lattice diagram showing the value of each reflected voltage. The value of voltage at t is equal to 6.5 T and x is equal to 3 by 4 l and e plot the receiving end voltage versus time right.

So, first thing is rho s rho s is equal to sending end side reflection coefficient rho s is equal to Z s minus Z c, Z s plus Z c, but it is given in the problem that Z is actually 0 it is given here that that ideal, so that ideal voltage source. So, that the internal impedance Z s is 0 and it is connect to the sending end of an underground cable right. So, with your characteristic impedance everything is given. So, Z s is equal to 0. So, and Z c is 40 ohm right, because it is given that your underground cable with characteristic impedance of 40 ohm assume that the cable is terminated as 60 ohm resistor right therefore, Z s is 0. So, Z c is 40. So, 0 minus 40 upon 0 plus 40 that is sending end side reflection coefficient is minus 1 right.

And similarly be your receiving end side it is Z r minus Z c upon Z r plus Z c. So, actually Z r is nothing but r because line is terminated in resistance of 60 ohm. So, Z r actually nothing, but r. So, Z r is equal to r is equal to 60 and Z c is 40 characteristic impedance of the cable. So, it is 60 minus 40 divided by 60 plus 40 that is actually 0.2. So, receiving end side reflection coefficient is 0.2, this, these two data. Now, how to your draw the now a and b done, now you have to draw the lattice diagram right.

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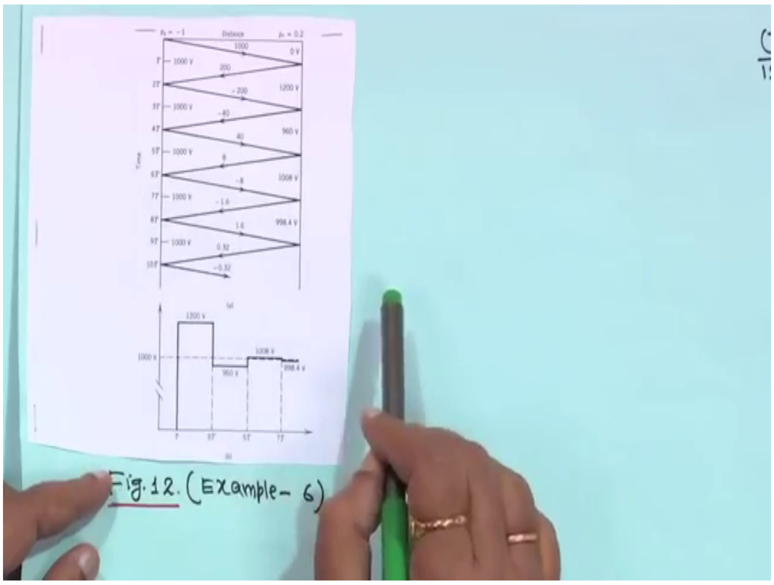

So, how one can do it? Look, this side sending end side look at the diagram sending end side this side is rho s is equal to minus 1 right and this is the distance a receiving end side it that is your 0.2. So, the ideal voltage source voltage is given 1000 volt. So, it is 1000 volt right. Now this side reflection coefficient is 0.2. So, 1000 into 0.2 means 200 volt. So, this will be going now from receiving into the sending end side right. Now sending end side reflection coefficient is minus 1 here it is minus 1 we have computed. So, this one will be multiplied by minus 1 at T 2 T. So, it will be minus 200.

Now, again from this side it will be reflected right and again it will multiply by 0.2, so minus 200 into 0.2 means minus 40. Now, again it will be reflected, reflected from sending end side and again it is minus 1 coefficient. So, minus 1 into minus 40 it will be 40. So, again it will come here. So, once it is come here again it will be reflected from here with rho this side is 0.2. So, 40 into 0.2 is 0.8 right. So, again it will be reflected here it is minus 1. So, it will be minus 8.

So, again this side will be reflected you are what you call 0.2 coefficient. So, minus eight into 0.2 means minus 1.6 and now this side is minus 1 sending end side so minus 1 into minus 1 0.6 this side will be 1.6 volt all right. And when you will be reflected here 0.2 into 1.6 is 0.32, so 0.32 is coming to the your sending end side and this side reflection coefficient is minus 1, so minus 1 to 0.32, so minus 0.32 and gradually decreasing right. So, this is the zigzag path, the Bewley's lattice diagram

So, now actually this is 1000 volt. So, when it will be your what you call forward wave plus a backward wave right is equal to v. So, it here it will be 0 volt then it is 1200 volt right after that your this minus 200 and minus 40, so minus 2 40. So, ultimately this will, here it will become your 960, 960 volt then again it is your this side is your 40 and this is your 8 right. So, this will be your 1008 volt. Now, this is your minus 8, so it will be 1000 again minus 1.6, so 998.4 volt and so on right.

So, this side T 2, T 3, T up to 20 it is drawn in this figure and this side the voltage is shown right this is Bewley's your lattice diagram it is as low draw the associated lattice diagram showing the value of each reflected volt value where your voltage. Now, you have to find out the voltage at t is equal to 6.5 T and x is equal to 3 by 4 l right. So, what you call this value actually at 6.5 T and your 3 by 4 l. So, if you take 3 by 4 l and 6.5 T means this is 6 T, this is 7 T. So, in between it is 6.5 T if you come to here and x is equal to 3 by 4 l it will be somewhere here. So, it will be like this. So, voltage if you go on adding all this thing you will get 1008 volt.

This you please do know if I already call calculations are shown here this is your 6.5 T this is 6 T, this is 7 T. So, this is your 6.5 T. So, from here if you draw a horizontal line right and then you this side is 3 by 4 distance you take 3 by 4 l you move up then you will see all these things will be added and it will be 1008 volt. So, this, the value of voltage at t is equal to 6.5 T and x is equal to 3 by 4 l it will be your 1008 volt and finally, plot the receiving end voltage versus time.

If you plot the receiving end voltage versus time it is T it will be too hard 1200 volt everything everything is given here then at 3 T it will be nine your 960 your, voltage is your what you call dropping from here to here 1200 to 960 then 1008 then 9 your 998.4 everything is shown T, 3 T, 5 T, 7 T right. This is that voltage diagram. So, everything is shown on the right hand side on this diagram only thing is that you have to make things correct. I mean the way we have derived as formula let x v x t x at any distance you can find out and automatically you can plot this one right.

So, this is actually your Bewley's your lattice diagram and this is the voltage waveform this. This much for Bewley's lattice diagram right.

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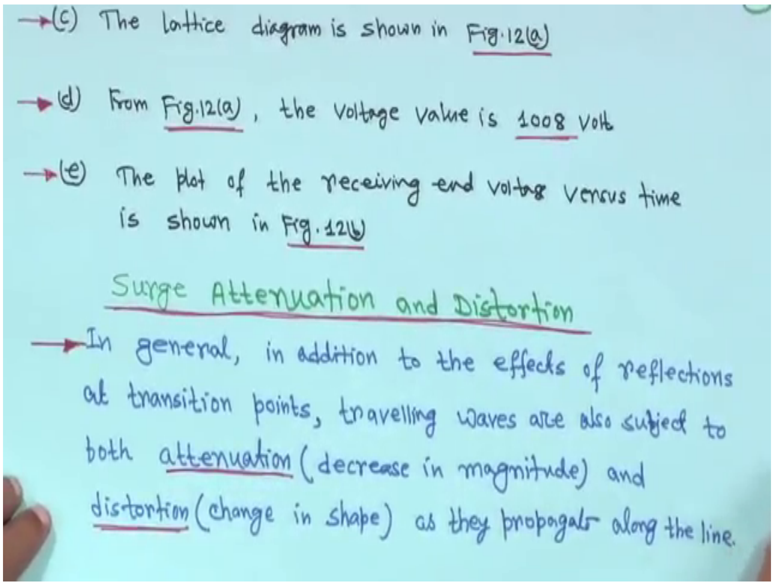

Now, Surge Attenuation and Distortion. Whatever we have assumed let us say we are what you call step function, but anyway in general addition to the effects of reflection at transmission point traveling waves are also subject to both attenuation, decrease in magnitude as well as distortion that is the change in shape right as the propagate along the line right because it cannot be your what you call constant value it will be attenuated as well as shape will also change right.

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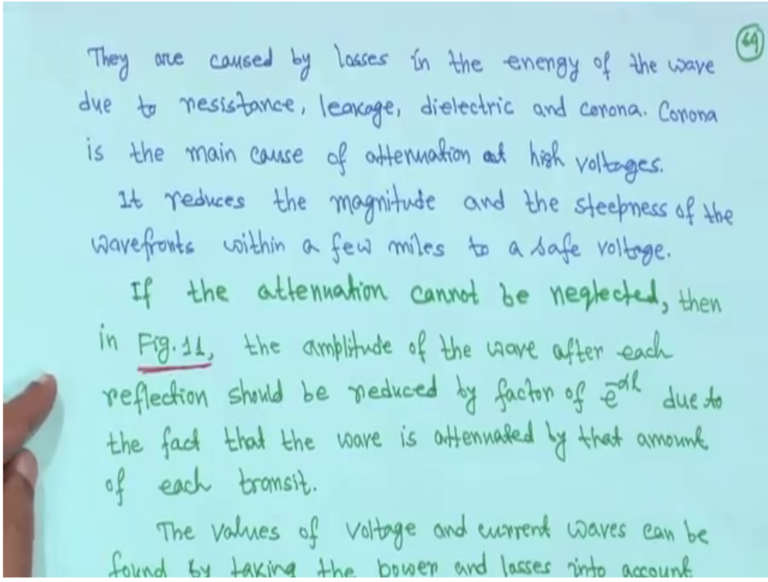

So, that thing that actually their cause by losses in the energy of the wave due to the resistance indicates, then dry electric and corona. Corona plays actually important role core after this topic we will see the corona loss right when this part will be over. Now, corona is the main cause of attenuation at high voltages.

I do not know whether you have when this whole your insulation coordination and these high voltage transients will be over we will take the corona loss. So, at that time I do not know whether you have observed corona or not particularly in the rainy season if you will and in the night time if you observe a high tensile line you will find some chattering noise comes from the overhead line. And if you observe carefully it moisture is more and the airs will be ionized around the conductor at that time you will see the violet glow will be coming and along the conductor area that we will see after end of this chapter right.

So, and the corona, corona actually is the main cause of attenuation at high voltages. It reduces the magnitude and the steepness of the wave front that corona it reduces both that your magnitude as well as steepness right, even a few miles to a safe voltage. So, if the attenuation cannot be neglected right then figure 11 the amplitude of the wave after each reflection should be reduced by a factor of e to the power minus alpha l; that means, that your figure 11 means this figure right just hold on I have showed you that the this figure where figure 11 has gone. Just hold on let me see all right, just hold on.

This is figure 10, figure 12, this is figure 13. Even it is not there does not matter just hold on otherwise see this figure also, but does not matter right.

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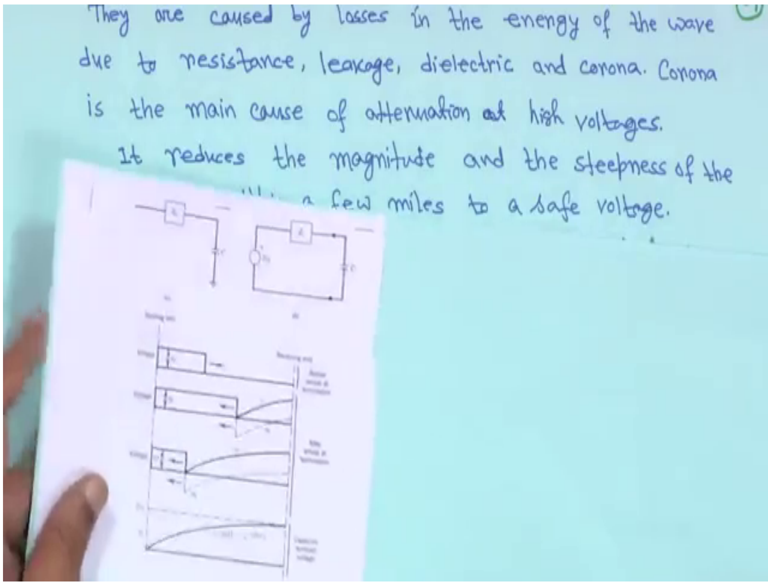

Whatever figures you see v f positive wave it may not be there I mean same thing right. So, in that case what will happen the amplitude of the wave after each reflection should be reduced to a factor e to the power your minus your alpha l, that just are just the example I showed you know that example I showed you, same thing right.

So, in that case it will not be a just not like a straight line. So, if it will have some what you call e to the power minus alpha l, what is alpha, what is l, will come later l is the distance or alpha is some constant. Due to the fact that the way we attenuated by that amount of each your each transit. So, therefore, the values of the voltage and current waves can be found by taking the power and losses into account you have to take the your what you call the power losses right.

So, if you do so, if you do so, then what will happen? That means, in Bewley’s lattice diagram whatever we have seen in that example it may not be the your what you call a not exactly straight line then.

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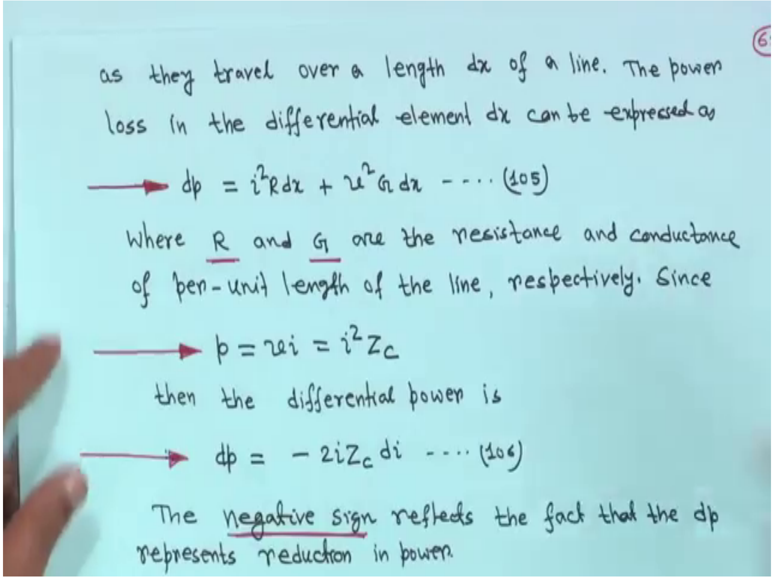

So, what will happen that as they travel over a length dx of a line suppose you consider a transmission line of small your dx though power loss in the differential element dx it can be expressed as a dp is equal to i square R dx plus v square G into d x, R is the resistance of the line per unit length (Refer Time: 17:25) why multiplied by dx right. And G is the conductance that is also per unit of the line that is multiplied by dx we have consider incremental in dx of the transmission line. Now, we know the power p loss for your power expression p is equal to v i is i square Z c.

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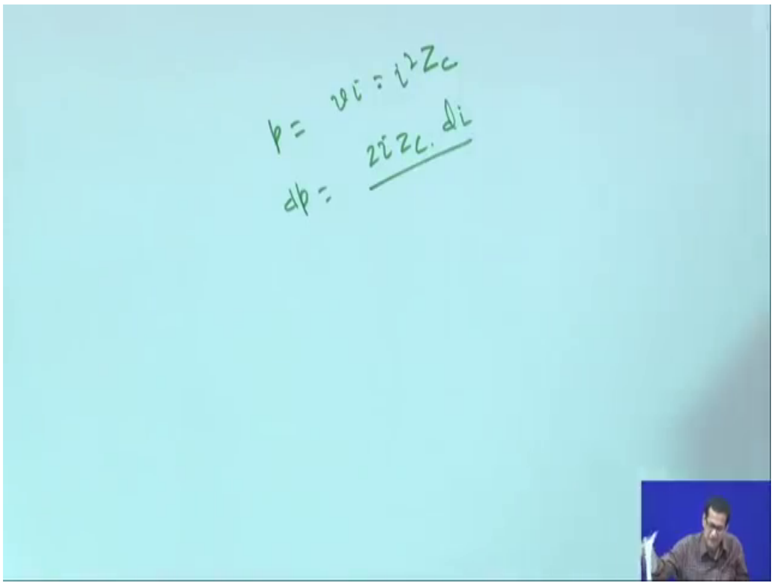

Now there the differential power is actually p is equal to, so p is equal to it is your v i is equal to i square your Z c the characteristic impedance therefore, dp is equal to we can write 2 I right into Z c then into your what you call d i, d i Z c d i.

So, this is the power, but because of this thing you are what you call, but in this expression this is the derivative this is correct. But we have considered one minus sign before it this is not the derivative minus sign, derivative is this one, derivative is this one right. The negative sign actually reflects the fact that the dp represent reduction in power right. So, that is why this minus sign is considered. So, otherwise dp is equal to this much minus we have put because it represents actually dp, dp reduction of the power. So, in that case what will happen you substitute this; that means, this minus 2 i Z c d I is equal to i square R dx plus v square G dx.

So, in that case what will happen that your just hold on.

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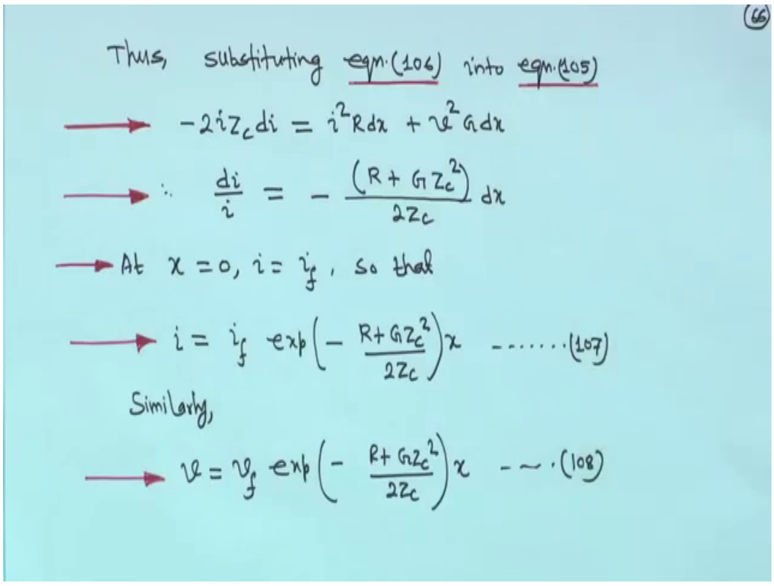

Substitute the equation you will get 2 i Z c d i is equal to i square R dx plus v square G into dx right or you can write d i upon i is equal to minus R plus G Z c square upon 2 Z c dx. Actually this derivation minus your what you call a 2 i zc d i this minus basically I told you again once again there should not be any contusion, this reflects the your that that dp represent reduction in power that is why your minus sign is considered here all right. That means, this expression you can write that d i upon i is equal to minus R plus G Z c square upon 2 Z c into dx.

Now, at x is equal to 0 that is at the sending end that is your i is equal to i f at the time. So, that your i is equal to f your e to the power this is exponential e to the power minus R plus G Z c square upon 2 Z c x right. So, this one what you have to do is you have to integrate this and apply this boundary condition and you will get this one this is directly I am writing that I is equal to I f exponential your minus R plus G Z c square upon 2 Z c x this is equation 107. Similarly you opt get the v your voltage v also, v is equal to v f exponential same thing minus R plus G Z c square upon 2 Z c into your x, x is the distance. That is why in that I told you that that multiplied by e to the power minus alpha l actually alpha is this one and x is equal to actually that l right.

So, similarly this one, this one v is equal to v f I asked you to derive right, very simple, it is you can derive of your own. So, this alpha l actually alpha x here both are say alpha term is same here also here also. So, it is minus is there; that means, it is exponentially decay right, but in the throughout for ours you know at undergraduate level for simplicity only we have considered the step waveform such that things will be understandable and if we again and again if we try to put this exponential term things will we you know it cannot be then straight line every time we have to make exponential graph.

But for easy understanding we have used the step function. But ultimately if you have a consider the loss you are what you call power and loss both then it will be act there will be your decrease will be in exponential way. So, these are the expression for v and the is equal to in terms of v f and this is i is equal to one exponential term your what you call added right here and here.

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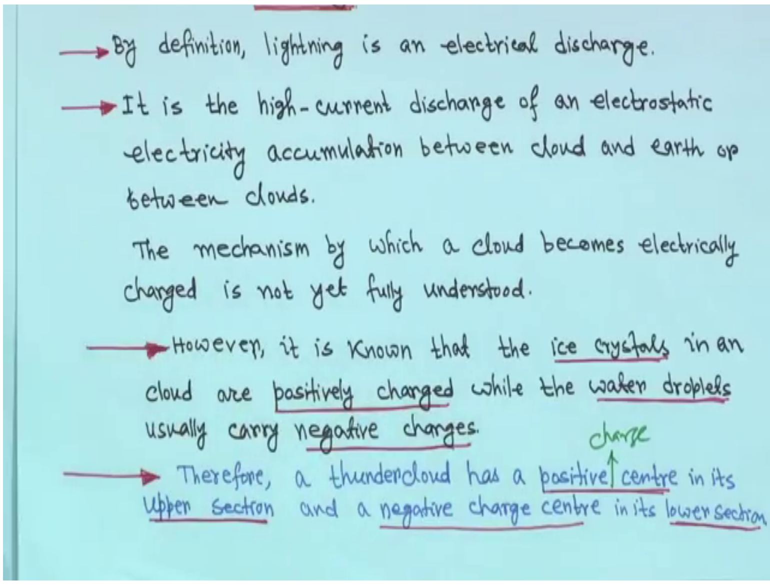

Now, one this is done then another thing next one is that your this is mainly this one is theory, that is lightening which is happening in front of your, in front of us all, I mean not in front of us I mean we can see every day. That is during your rainy season and when rain is offer you we can see the lightning stroke right.

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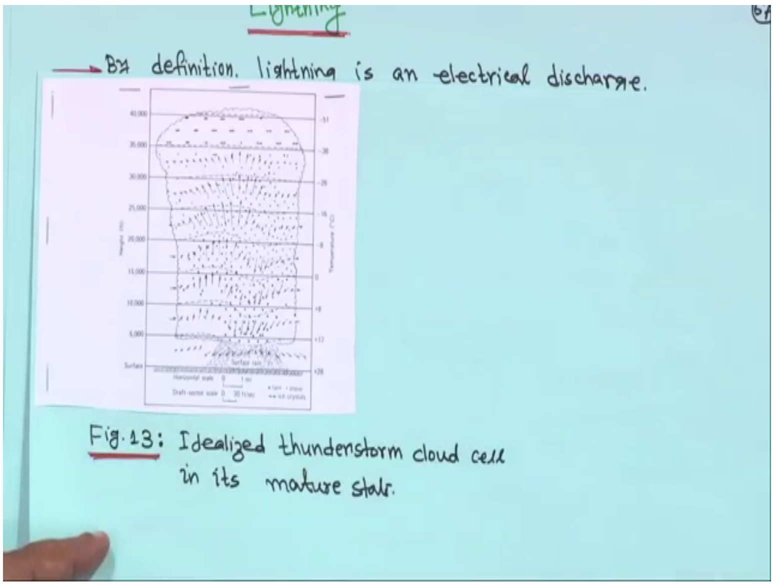

So, before telling the lightning stroke that when you are moving above the ground I mean when you are moving upwards the ground right. So, surface through it is somewhere up to 40,000 feet it is given it is idealized thunderstorm cloud cell in it is your mature slate right. So, when you are moving above the ground for any reaches nearly you know if I tell in terms of meter if you reaches reach above of course, it varies little bit at least 5 kilometer from the ground you will find temperature will be 0 degree and if you go a 10 kilometer or above the ground the temperature will be minus 30 minus 35 or minus 40 degree when you are moving upwards right I mean when you reach to a 5 kilometer above the ground temperature will be at least 0 degree. And after that temperature is falling like anything and it will it will go 10 kilometer above the ground you will find temperature will be minus 30 or minus 40 degree Celsius.

So, whenever it happens that your what you call before giving all these things that some high with the height is given here in feet not in kilometer or this thing this is in feet, feet you can convert it to kilometer no problem right and this is the temperature. So, nearly here it is showing nearly 15,000 feet that temperature is 0. I told you nearly 5 kilometers temperature will be 0 after that if you go above that it will be minus. So, in that case what happen that when a rain you know that, when rain falls actually that upper side of the that that the ice that the upper side will be crystallized and bottom side will be water drop droplet.

So, in that case what will happen? So, upper side actually at the exact phenomena of this lightning is not well understood, but that upper portion that is the ice portion of crystal, portion it is positively charged and water droplet it is negatively charged. So, this is basically suppose it is a cloud is shown and this you are what you call that ice crystals are showing by this arrow right the rain, then snow, all these things are shown in the diagram. So, you can different layer it is there. So, you can easily find out the ice crystal or snow, your bold one, rain is the bold one then snow also it is there and your ice crystal also showing by your double arrow right the here it is. So, you can many places you can see that drop both side arrows are there. So, ice crystal right. So, this is actually when cloud formation and rain right.

So, now, this is ideal idealized thunderstorm cloud cell in it is your mature slate right. So, mature state rather right. So, this is understandable. So, by definition lightning, light this is totally theory right. So, lightning is an electrical discharge this we know you also know. It is the high current discharge of an electro static electricity accumulation between cloud and art or between the clouds right. You can see from the your what you call from the earth surface that it is basically that you are what you call electricity and your high current discharge of an electrostatic your electricity accumulation between the cloud and earth or between the clouds.

So, when you even if you travel by airplane through this kind of the you know cloud you can see that there will be your lightning happening between the 2 clouds and similarly it is between the cloud and the earth which basically we call lightning stroke. So, the mechanism by which the cloud becomes electrically charged is not yet fully understood right, but it is known that ice crystals in an cloud are positively charged and the water droplet us usually carry negative charge. So, ice crystal will be their positive I told you that if you reach 5000 kilometer or so, above the ground temperature of 0 degree and after that it become minus. If you reach your 10 kilometer above this thing ground temperature is minus 30 minus 35 degree Celsius.

So, in air airplane travels in that such a high distances you cannot make out anything inside, but outside temperature particularly international airlines you can see there is there sometimes. So, in the temperature it will be minus 30 or minus 35 degree Celsius right. So, that is your therefore, a thundercloud has a positive your charge center; that means, it positive over the ice crystal it is actually positive charge center right a positive charge center in its upper section and a negative charge section in the lower section lower section is the that water droplet us right.

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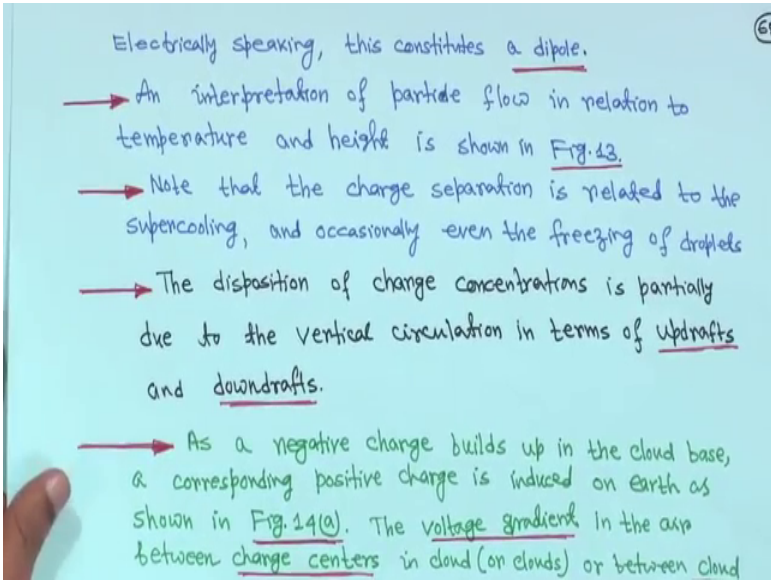

So, in this case the electrics your electrically speaking this consisted dipole because plus charge minus charge. So, we can consider it is a dipole. So, an interpretation of particle flow in relation to the temperature and height it is shown in figure 13, right just hold on. Just hold on. Actually it will be your this figure I have shown you that is your, this your, this figure I have shown you I mean this figure that cloud whatever that figure that temperature all these things I have showed you that this cloud one that is figure 13, that different height and your temperature that is figure 13 that I have showed you.

So, note that charge separation is related to the super cooling and occasional even the freezing of the droplet us right. So, the disposition of charge concentration is partially due to the vertical circulation in terms of updrafts and what you call your downdrafts right. So, these are the thing basically that charge concentration.

With that thank you very much. We will be back again.