**Power System Engineering**
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**Lecture – 14**
**Transient over voltages and Insulation coordination (Contd.)**

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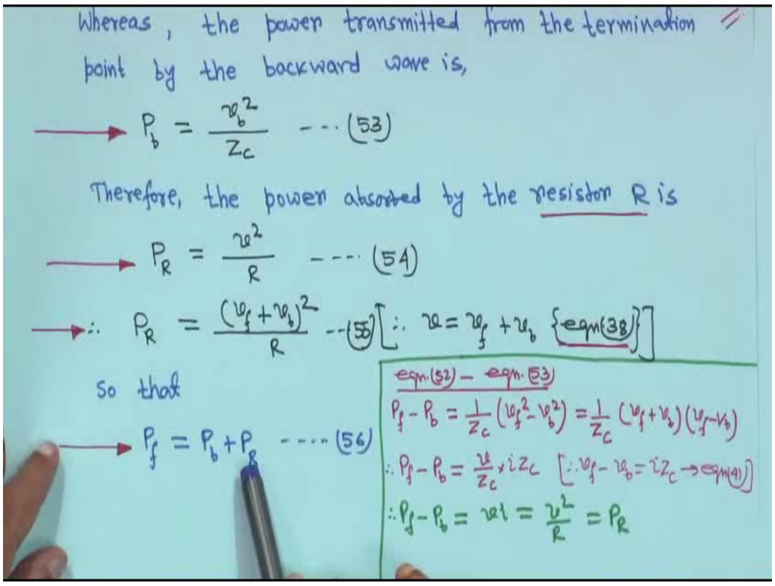


So, this one you have seen that P f is equal to P b plus P R all the derivations you have just we have seen right, that your P f minus P b is equal to it will be P R. So, P f is equal to P b plus P R. This we have seen this is actually line termination is resistance these are the different condition.

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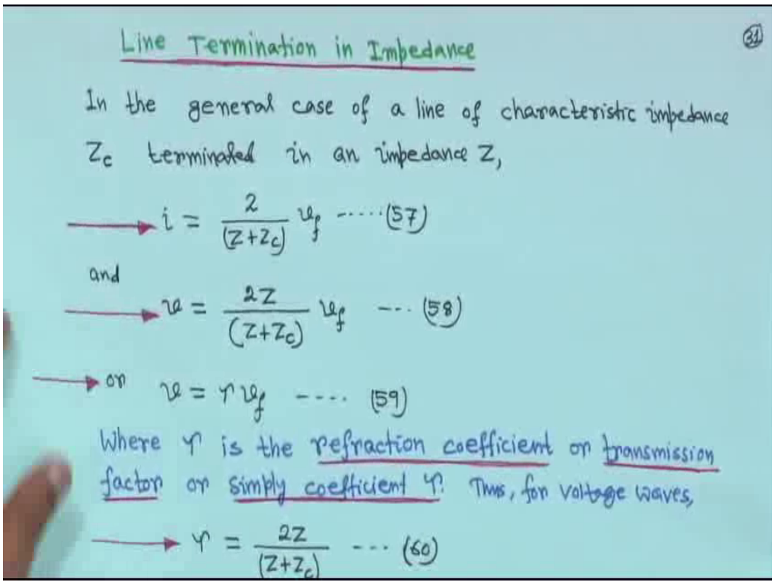


Now, second is that when line is terminated your in impedance. So, in the general case of a line of characteristic impedance Z c terminated in an impedance Z then we can write i is equal to 2 upon Z plus Z c v f because when line was your this thing we have derived when it was terminating in the resistance that it was i is equal to 2 upon R plus Z c v f and here your v is equal to 2 R upon R plus Z c into v f.

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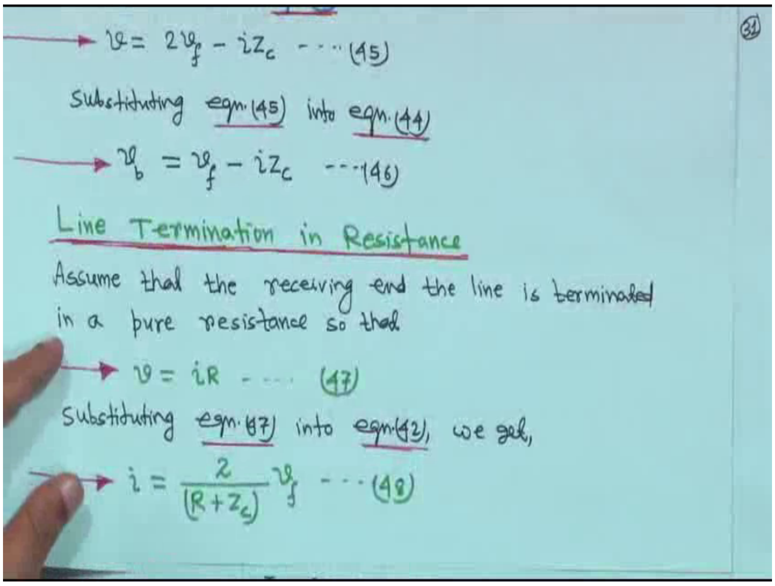


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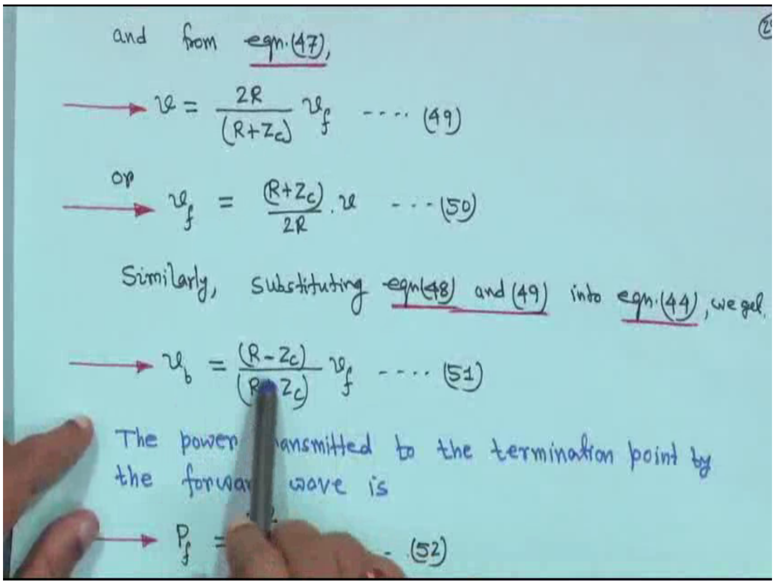


So, instead of R you replace R by Z because line termination in impedance. So, we assume that impedance is Z. So, this equation directly you can write one is equation 48 and this one equation 49 right. So, this one you directly you will get from equation 48, in equation 48 you replace R by Z then i is equal to 2 upon Z plus Z c into v f this is equation 57.

Similarly, in equation 49 when line termination in resistance R it was 2 R upon R plus Z c, but in this case it is terminated in an impedance Z therefore, v is equal to replace R by Z it will be 2 Z upon Z plus Z your Z c into v f or v is equal to you can define tau into v f where tau is called the refraction coefficient or transmission factor simply coefficient tau right, what we will do throughout this chapter we will use tau that it was refraction coefficient right. Thus for voltage wave tau this thing tau is equal to 2 Z upon Z plus Z c. So, in that case we can write that the from this equation if Z is equal to 0 then tau will be 0 right. So, and if Z is and your theoretically that means, theoretically this value actually will vary from your between 0 and 2 depending on the relative values of Z and Z c right. Or alternatively this equation we can write v f is equal to Z plus Z c upon 2 Z into v . So, v f is equal to Z plus Z c upon 2 Z into v.

Now, this v is equal to you are got 2 Z upon Z plus Z c similarly, this i also you replace you know that the relationship between your v f and i f right. So, in the case of v f v f is equal to i f into Z c so if you substitute i f into Z c so i will become 2 into Z c upon Z plus Z c. So, that term for the it is for it is the refraction coefficient tau when 2 Z upon Z c for the voltage I am making it for you just hold on I will make it for you.

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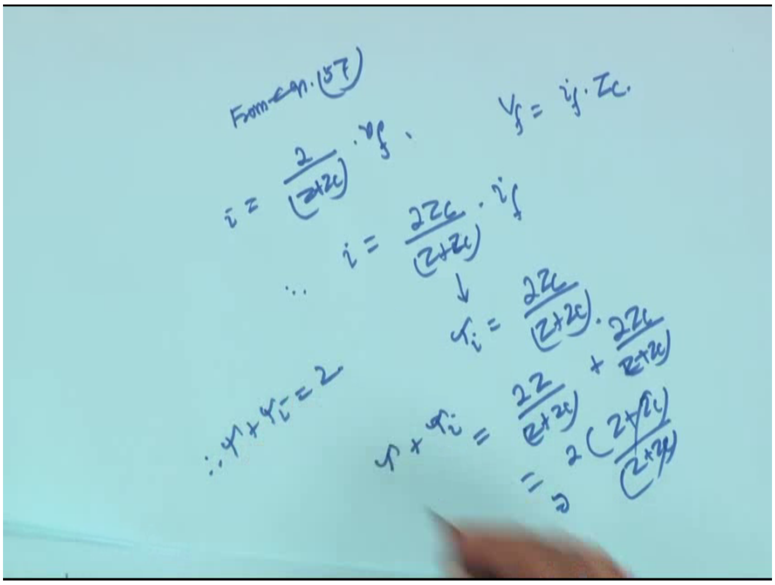

For example this i is equal to your equation from it is equation 57 right, i equal to your 2 upon Z plus Z c into v f right, but you know v f is equal to i f into Z c therefore, i is equal to 2 into Z c upon Z plus Z c into your i f right here we have made v is equal to 2 Z upon Z plus Z c v f here we have made i is equal to 2 Z c upon Z plus Z c. This term this one we have taken for voltage refraction coefficient for voltage actually and this term we can say we can make tau i is equal to 2 into Z c upon Z plus Z c right. That means, for the current refractor factor is your what you call tau i. If voltage it is 2 Z upon Z plus Z c and for your current refraction factor will be 2 Z c upon it is not shown here, but i think it is understandable to you right.

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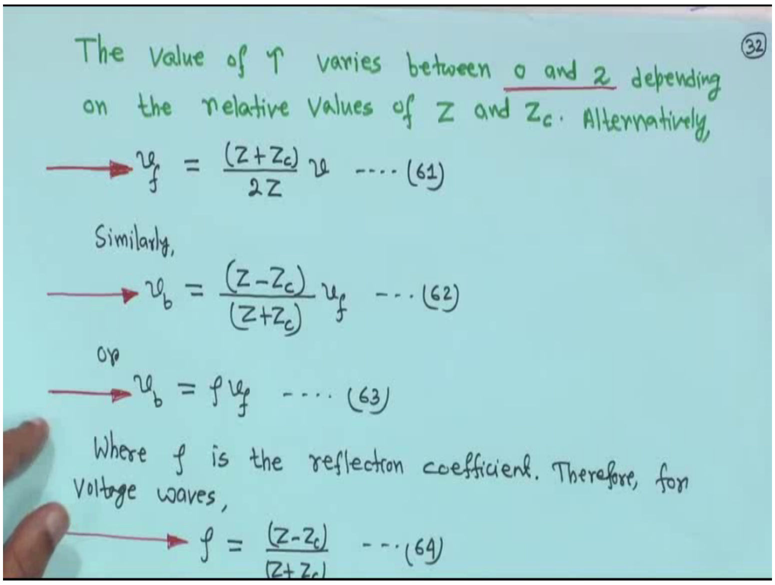


So, this thing so 2 i tau i is equal to 2 Z c upon Z plus Z c if you add these 2 tau plus tau i if you try to add this one it will become 2 right, if you add tau plus tau i that is your 2 Z upon Z plus Z c plus 2 Z c upon Z plus Z c that is actually is equal to 2 Z plus Z c divided by Z plus Z c. So, this one will be cancelled and this is equal to tau plus tau i is equal to 2 tau is the for voltage I did not write it is tau v i simply written tau it is for refraction coefficient for the voltage right.

So, tau plus tau i will be 2 so that means, this your what you call this tau actually varies between 0 and 2 that is for each case tau i also varies in between 0 and 2 and theoretically similarly tau for the your what you call the for the voltage refraction coefficient also varies in between 0 and 2 depending on the relative values of Z and Z c right.

Similarly, this v b, v b is equal to Z minus Z c upon Z plus Z c into v f because just hold on we have seen that your for when it was your resistive circuit right, resistive this one when line termination in the resistance we have seen v b is equal to R minus Z c by R plus Z c this is equation 51 right. So, from 50 and in this case line is terminated in impedance Z so in this case you replace R by Z. Therefore, your v b will be Z minus Z c divided by Z plus Z c if you already these equations are derived only you have to what you have to do is you have to replace R by Z that is all, right .

Now, therefore, this v b that is your reflected voltage on your backward wave right, that Z minus Z c upon Z plus Z c into v f this is equation 62 or we can make v b is equal to rho into v f so this is equation 63. Rho is the reflection coefficient or sometimes we call reflection factor right, reflection coefficient therefore, for voltage wave rho is equal to Z minus Z c upon Z plus Z c right rho can be positive or negative it depend on whether Z is greater than Z c or less than Z c this is equation your 64 right.

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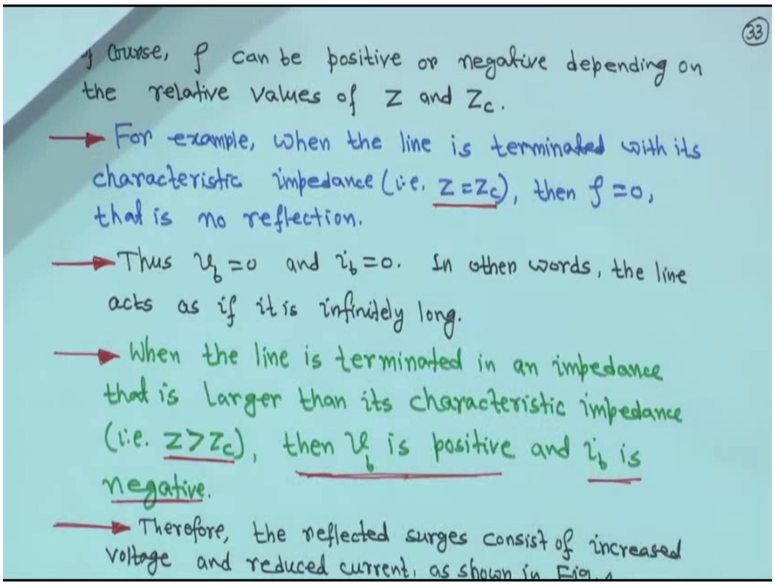


Of course rho can be positive or negative depending on the relative values of Z and Z c right, this one. For example, when the line is terminated with its characteristic impedance Z is equal to Z c if f Z is equal to Z c the rho is 0 then your rho will be 0. So, there will be so rho is 0 means there will be no reflection voltage so v b is equal to 0 then if rho is equal to 0 right. So, thus your v b is equal to 0 and i b is equal to v b by your what you call that Z c. So, as rho v b is 0 therefore, i b also will be 0.

So, in other words the line act as it is infinitely long line right, so in that case you have to imagine the line is actually infinitely long. So, when the line is terminated in an impedance that is larger than its characteristic impedance I mean if it is Z is greater than Z c right, if Z greater than Z c then rho is positive. That means, v b is positive and i b is i b will be your negative this is called this is your common phenomena right, if it is if rho is become Z minus Z c upon Z plus Z c you will take when you try to find out that v b is positive then earlier then your what you call that your current that one will be your what you call that your it is your negative that v b is positive then i b is negative and opposite if v b is negative i b will be positive this all this relationship actually we have seen previously just go through those equations. Therefore, the reflected surge consist of increase voltage and reduced current right and if you see the figure if you look into this figure right, look.

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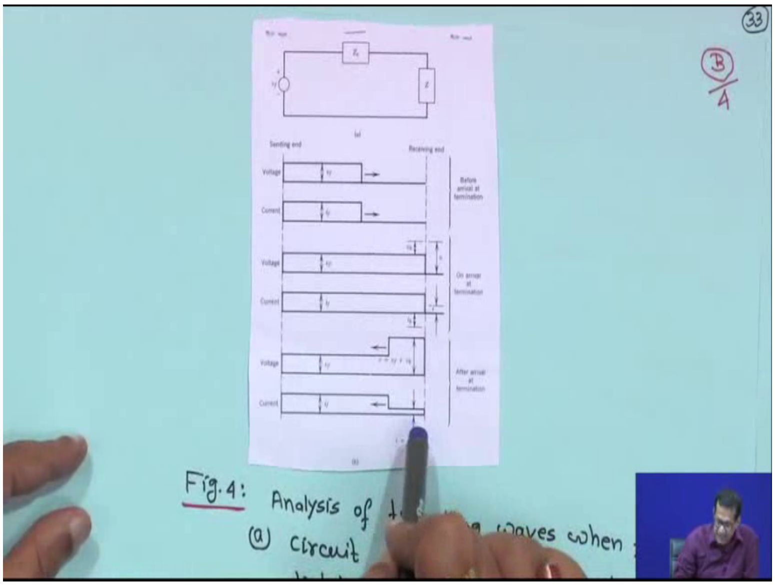


This is your diagram this is the voltage v f this is the voltage v f now this is your Z c and line is terminated impedance Z right this is up to this, this is before arrival at termination. So, generally we are considering a step function v f and i f right R and resistance and conductance is neglected and this wave is moving from left to right this is v f this is sending end voltage and this is i f the current now this is before arrival. When it is arriving when on arrival at termination right in that case what will happen that v b is your what you call backward wave is positive and it will move to this way now it is right to left it will move.

So, that is why when it is right to left it is moving v is equal to v b v f plus v b that means, it is increasing right, because on arrival at termination the back reflected voltage of v b or for backward wave this is positive that means, whatever v f was there then v b is this much. So, if you v f plus v b so v is equal to v f plus v b it is moving from right to left now, right and for the current on the arrival at termination that i b is negative if i b is negative that means, if you just add these 2 this one and this one ultimately it will go down.

So, that this is your i is equal to now i f minus i b right, because as i b is negative directly if you take direct negative value then i f plus i b when you are taking i is equal to i f minus i b means this magnitude has been taken positive in this equation. Otherwise you can write i f plus i b, but i b is negative, but for your understanding here it is given i is equal to i f minus i b.

So, this i b will be subtracted from this so this is the current wave now it has decreased magnitude it is moving from right to left right, so this is voltage, so this is before arrival at termination on arrival at termination this is the refracted wave magnitude v b and this is a reflected current wave, right and finally after arrival at termination when it is moving from right to left it is v is equal to v f plus v b and i is equal to i f minus i b. So, this is hopefully understandable to you, right. That means, this is actually that through the from figure 4 we have seen that surge consists of increased voltage and reduced current as shown in figure 4. I shown you the figure 4.

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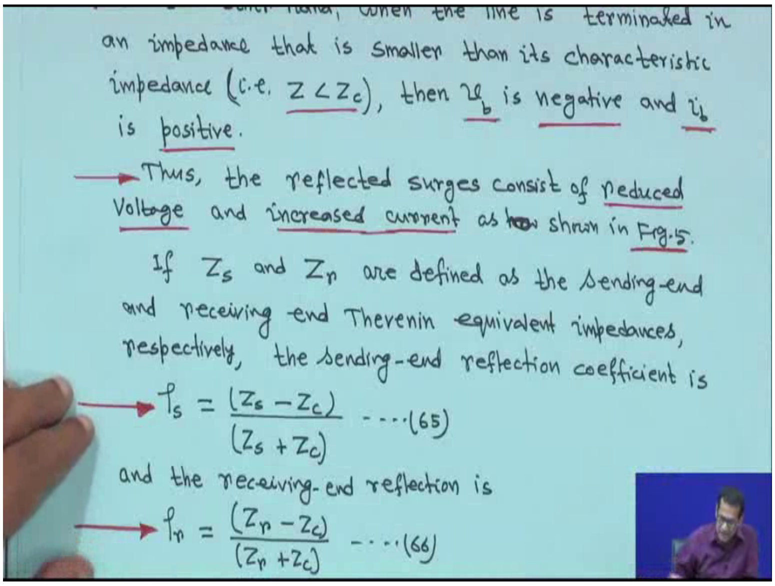


Now, on the other hand when line is terminated in a impedance that is smaller than its characteristic impedance when Z greater than Z c if Z greater than Z c then v b is negative from the same equation and i b will become positive just opposite thus the reflected surges consists of a reduced voltage and increased current as shown in figure 5 now when Z greater your Z less than Z c I mean this one when Z less than Z c that means, rho is negative this is negative that means, v b will be negative and i b will be positive. So, this is the diagram that it is Z c and Z again.

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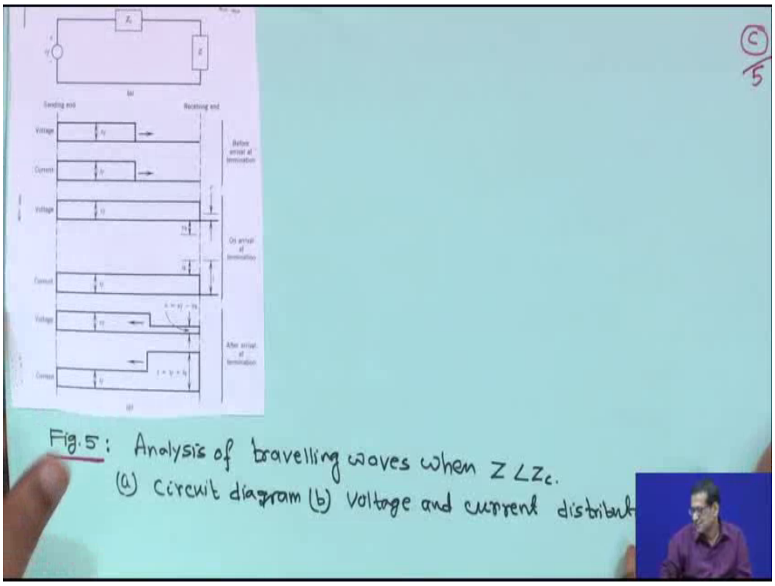


Now, this condition is when Z less than Z c; when less than Z Z c right, so before arrival this is same as before, now when it is when on arrival at termination v b will be negative so this is v b right and current will be positive. So, this is i b if one is negative another will be automatically positive if v b is negative current is positive if v b is positive then current is negative right. So, on arrival at the termination, so this is your voltage wave it is moving from this one moving from left to right distance is increasing right. So, an arrival at terminal this one, now this v b will be now reflected back at the arrival of terminal this is v f and this is i f, but now v b is negative i b.

So, when it is moving to the your right to left I mean from this side to this side when it is moving then v will be v f minus v b here v b is negative, but this magnitude for your understanding it is v f minus v b mean this v b will take plus here, such that v b minus v f minus v b so this, this magnitude this one is getting reduced. So, voltage magnitude will reduce, but current that i b is positive, so here it is moving now from right to left I mean this direction; this direction right to left so it is showing here. So, current will be added so i should be is equal to i f plus i b i b positive.

So, this way that your after arrival at your what you call at termination; that means, it is reflected. So, this is actually it is in figure 5 that is why analysis of travelling waves when Z less than Z c a, is the circuit diagram same as before and b, is the voltage and current distributions, right. Hope this will be understandable there should not be any confusion right.

Next one is now, thus the reflect this one we have seen in figure 5. Now if Z s and Z r are defined as the sending end and receiving end Thevenin equivalent impedance. Suppose if you define Z s is the sending end side and Z r is the receiving end side Thevenin equivalent impedance, right I think power system analysis course regarding this Thevenin equivalent those who have taken this course or seen that lecture this equivalent Thevenin how to one should get in a power system I explained there in detail right.

So, here I am not putting it again right, but Thevenin equivalent impedance how to obtain details I think I explained there. So, if Z s and Z r are defined as the sending end and receding end Thevenin equivalent impedances respectively, the sending end reflection coefficient is in that case it will be rho s will be Z s minus Z c upon Z s plus Z c using the same formula equation 64 you replace Z by Z s one case and receiving end side replace Z by Z r right.

So, Z minus Z c upon Z plus Z c right, so that rho s the sending end reflection coefficient will be then rho s will be rho is Z s minus Z c divided by Z s plus Z c this is equation 65, similarly at the receiving end the reflection is your it will be receiving end impedance is Z r here it is Z r therefore, rho r will be Z r minus Z c upon Z r plus Z c this is equation 66 right. So, this is understandable I believe this is understandable not much difficult one only understanding is required.

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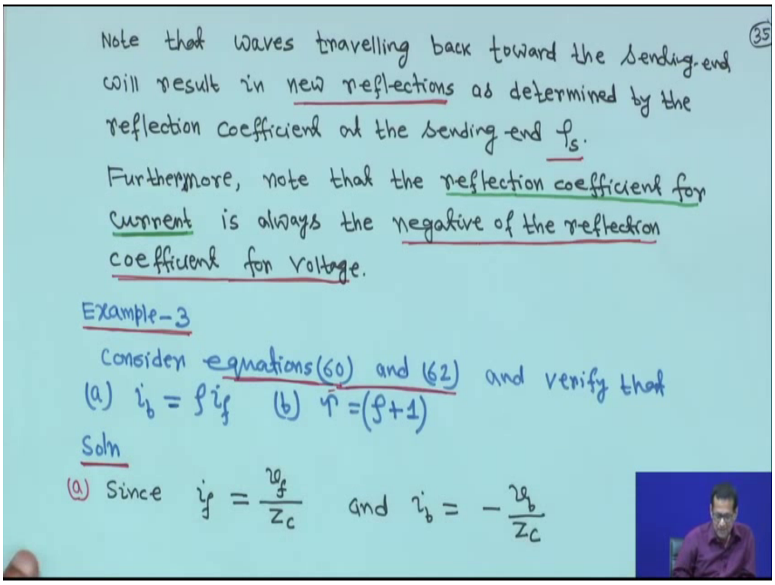


Now, note that waves travelling back toward the sending end will result in an it result in a new reflection as determined by the reflection coefficient at the sending end rho s just now we have seen this one rho s we have seen this one right. Furthermore, note that the reflection coefficient current is always the negative of the refection coefficient for voltage right. So, in this thing this is always we have seen that your whenever you will take that your reflection coefficient for the current is always negative of the reflection coefficient for the voltage. The previously when we were doing this just you try yourself you will find it will be just negative of this I mean that that is why if voltage is positive current is negative if voltage is negative current is positive.

Now, take a small example; small example is that consider equation 60 and 62 and verify that i b is equal to rho i f and tau is equal to rho plus 1. So, I have to go to equation 60 and 62 just hold on, right. This one, this is your equation just hold on this is your equation your 60 and 62 this is equation 62 and just hold on 61, this is 61, this is 61 62, this is equation 60, this is equation 60 tau is equal to 2 Z upon Z plus Z c this is equation 60 and this is equation 62 right.

So, you have to prove that i b is rho i f and tau s equal to rho plus 1 that is the voltage your reflection coefficient right, I did not write tau v suffix, but tau is equal to rho plus 1. So, since we know i f is equal to v f upon Z c and you know i b is equal to minus v b upon Z c this we know right. Therefore, v f is equal to we know Z c into i f this is your v f is equal to Z c into i f and v b is equal to minus Z c into i b right.

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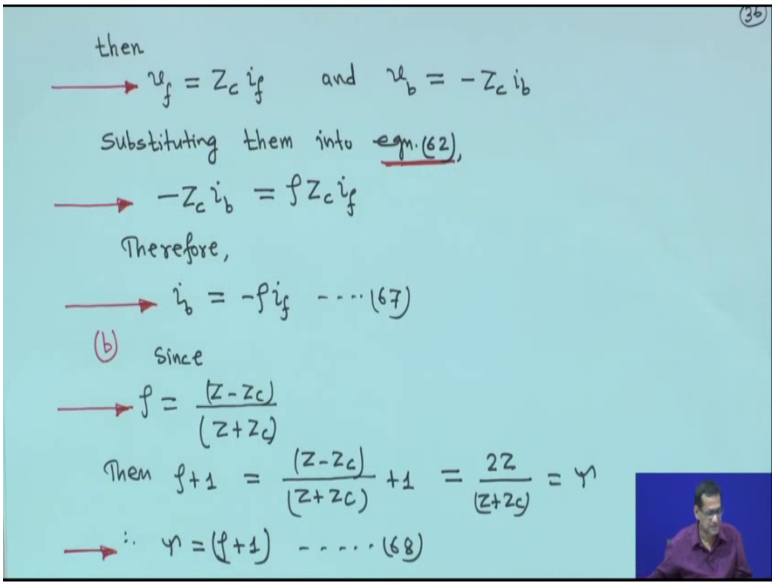


Therefore substituting them into equation 62 that means, in equation 62 you just substitute right, this is your where equation 62 just let me see. Till so many slides are there, but anyway directly we can write here it is 62 this equation you substitute there equation 62. So, if you substitute then you will find minus Z c into i b is equal to rho into Z c into i f right. Therefore, you will get i b is equal to minus rho into i f right, that means, if rho is positive then i b is your what you call that negative right and if rho is negative then i b is positive just vice versa that voltage and current.

Since rho is equal to Z minus Z c upon Z plus Z c you know this, then both side you add 1. So, rho plus 1 is equal to Z minus Z c upon Z plus Z c plus 1 is equal to you can write 2 Z upon Z plus Z c, but we know 2 upon Z plus Z c is equal to tau hence tau is equal to rho plus 1 equation 68. So, this is proved, right the tau is equal to so and i b is equal to your minus rho i f here verify that i b is equal to minus 1 minus sign i think i have missed it should be minus. So, that is your what you call that i b is equal to so this thing are very simple right. So, next is your what you call an example take an example so this is example 4. Suppose a line has a characteristic impedance of 400 ohm and resistance of 500 ohm right, if z c is 400 and r is 400, right. The so assume that the magnitudes of forward travelling voltage and current waves are 5000 volt and 12.5 ampere respectively.

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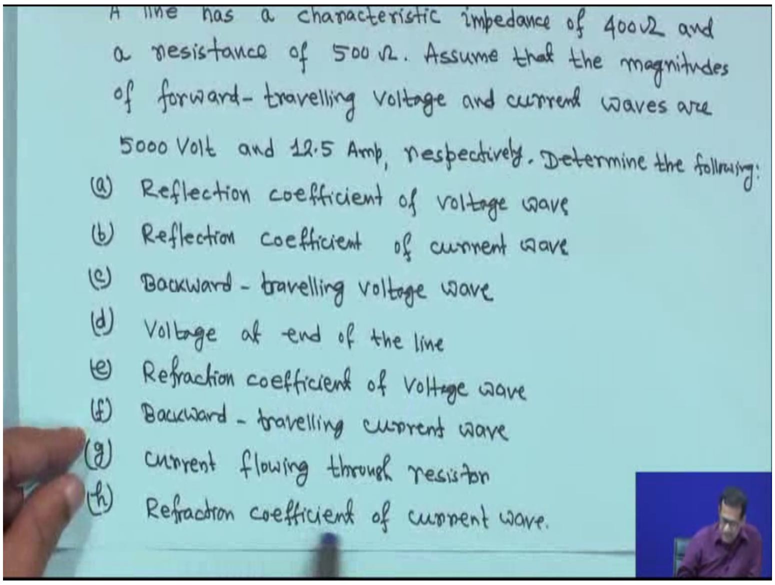


Determine the following: 1, reflection coefficient of voltage wave, reflection coefficient of current wave, backward travelling voltage wave, voltage at end of the line, refraction coefficient of voltage wave, backward travelling current wave, current flowing through resistor and refraction coefficient of current wave, right. So, these 8 quantities you have to obtain from the given data these are very simple one right very simple one.

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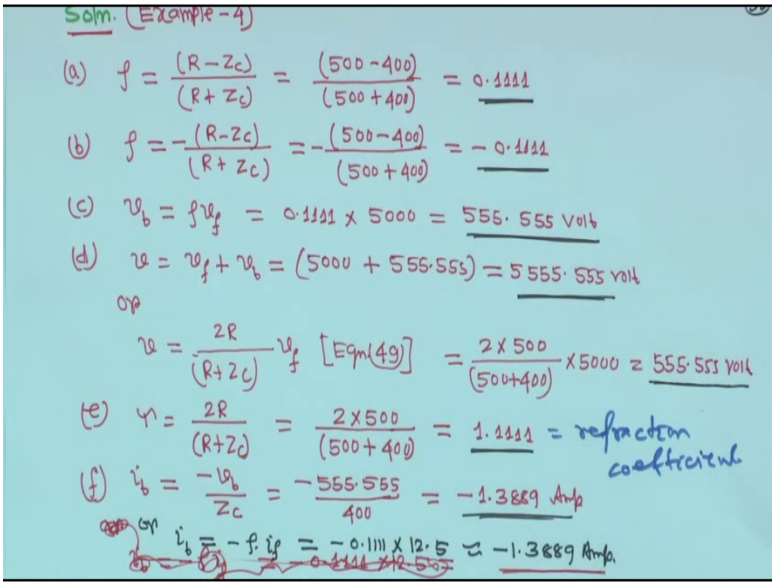


So, first one let us see I will write the, but this is basically when line is terminated at resistance R. So, we know example the first one we know rho is equal to r minus z c upon r plus z c. It is given r is equal to 500 ohm and z c is equal to 400 ohm. So, 500 minus 400 by 500 plus 400 is equal to 0.1111, right and therefore, in b it is it will be minus i in b it has been asked that you find out reflection coefficient of the current wave. So, reflection just now we have seen in general that if wave is for voltage if it is positive current it will be negative so it will be minus R minus Z c upon R plus Z c.

So, minus of same thing 500 minus 400 by 500 plus 400 is equal to minus 0.1111 we have taken up to 4 decimal place. We know v b is equal to rho into v f this also we know, so v f is equal to 5000 volt because it is given the forward travelling wave voltage and current v f is equal to 5000 volt and i f is equal to 12.5 ampere this is given, right.

Therefore v b is equal to rho into v f so it is 0.1111 into 5000, that is 555.555 volt up to 3 decimal place it is taken. Now v is equal to then v f plus v b so it will be you 5000 plus 555.555, so it will become 5555.555 volt. That is that means, your that v b is positive so when it is reflecting back the voltage is increasing, right or v is equal to I mean for this thing if you make the cross check v is equal to 2 R upon R plus Z c into v f this is equation 49. Same thing here we got directly by multiplying rho, but another equation is there equation 49 that also you can write v is equal to 2 R upon R plus Z into Z c into v f that is actually 2 into R is equal to 500 divided by 500 plus 400 into v f, v f is this voltage this 5000 volt, right into 5000, so 555.555 volt same thing right this one also you can use.

Now, tau is equal to you have to find out the refection coefficient for the voltage if you see tau is equal to 2 R by R plus Z c right. So, in that case your 2 R upon R plus Z c that is your 2 into 500 divided by 500 plus. So, this is 1.1111 .111, right just hold on just find out that equation just 1 minute, right. The tau is that your this thing the refraction coefficient because it is something like a light, right some reflection will be there.

So, tau is the refraction coefficient so but philosophy here it is different. So, tau this equation is coming actually here we are writing 2 Z upon Z plus Z c that is 60, but previously that you Z here the line is terminated by resistance R it will be 2 R upon R plus Z c. So, this one actually refraction coefficient tau is equal to 2 R upon R plus Z c so it is 2 into 500 R is 500 by 500 plus 400 that is 1.1111 up to 4 decimal place I have taken the refraction coefficient and i b is equal to your minus your v b upon Z c, right.

So, v b you have got this 5555.555 so substitute here, now v b backward voltage sorry v b we got 555.555 this is v b right. Therefore, i b is equal to minus 555.555 upon 400 so minus 1.3889 ampere or other way you can do it, i b is equal to minus rho into i f and rho you have got 0.1111. The minus 0.1 into 12.5, because i f is given 12.5 ampere, this is i f. So, if you do so you will also get minus 1.3889 ampere I mean the way you want you can do it, right.

So, tau is the refraction factor just hold on right, that means, your anyway later we will see that refracted volt later we will see. So that means, all the quantities state forward you can get it this one actually this one tau actually this is your refraction coefficient right, such that when you will listen to this there will be no problem refraction coefficient, so that means that i is equal to your v by R right.

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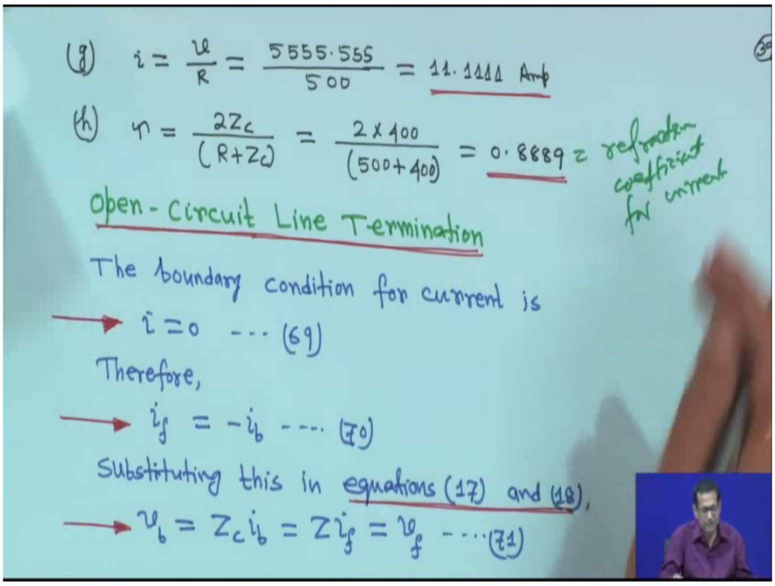


So, that; that means, that last one it has been asked that is, so g that is it has been asked the current flowing through resistor, that what is the current flowing through resistor this is g part right and refraction coefficient of the current wave. So, i is equal to actually v upon R, v you have got 5555.555, right when this thing and R is equal to 500. So, 11.1111 ampere and for the current tau is equal to 2 Z c upon R plus Z c so 2 into 400 Z c is 400 divided by 500 plus 400 is equal to 0.8889. So, that means, this is this one it is 1.1111 refraction coefficient this is for voltage and this refraction coefficient this is refraction coefficient for current right, this is for current. Now I showed you no I showed you that tau plus tau i it has to be 2.

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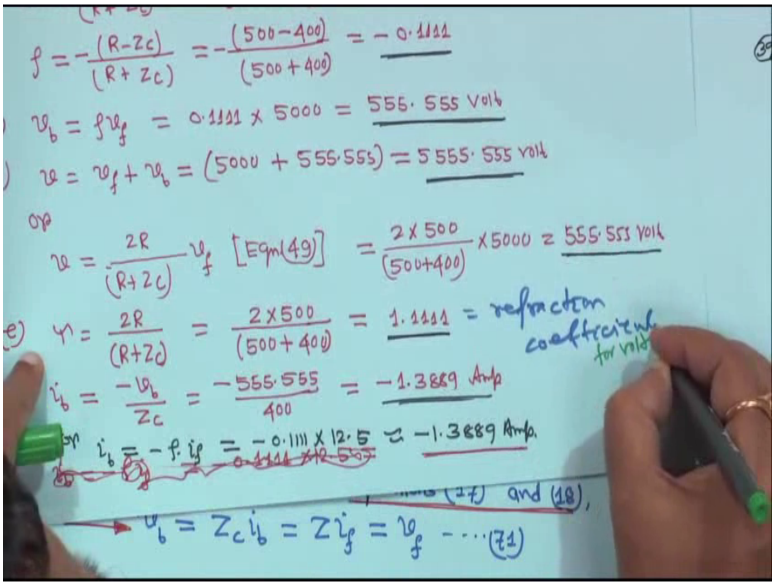


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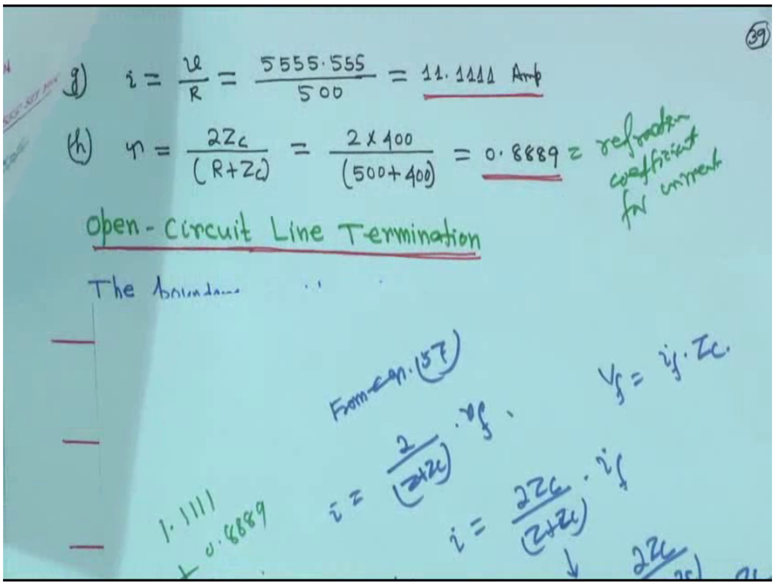


So, if you see there, that here it is for voltage it is 1.1111 plus this is for current 0.8889 so it is basically it will become 2 if you add this right it will become 2.

So, that is why that this is your tau is equal to this is the refraction coefficient for the current. So, total should be your what you call that to such that means, refracted if you take that for that this thing this refracted your refraction coefficient for voltage not shown here the diagram or computed, right. It is increasing whereas, the current in the case it is decreasing if one decrease another will increase if one become reflected also one become negative another will become positive and the refracted case if voltage increase current decrease if current increase voltage decrease, because that condition should hold good that refraction coefficient for voltage plus refraction coefficient for current must be equal to 2.

Thank you will be back again.