Power System Engineering
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Lecture - 15
Transient over voltages and Insulation coordination (Contd.)

Welcome back. So next is that open circuit line termination.

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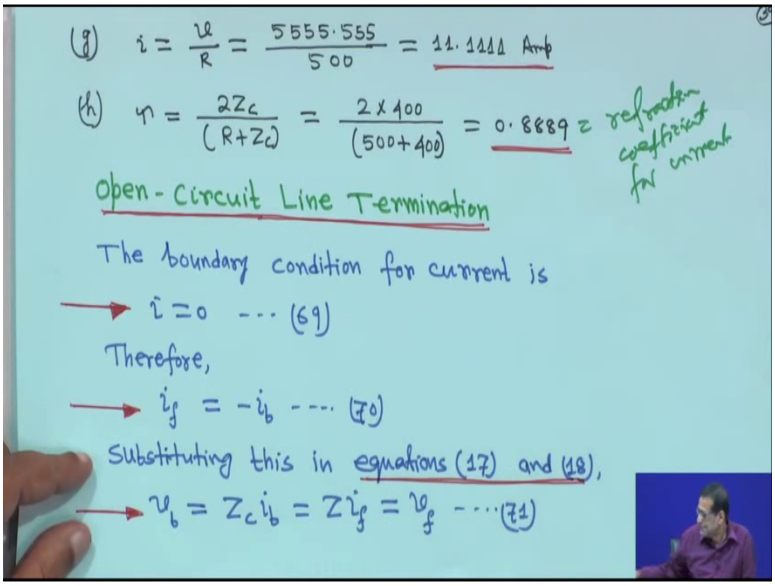

So, the boundary condition of the current is; it is open circuit. That is every transmission line is open; so no question of termination in that things are resistant nothing. So, in that case i will be 0; so, this is we are putting equation 69. Therefore, i f will become minus i b; it is very very simple one that, but it is opening your what you call that is line is open. So, if you substitute this conduction in equation 17 and 18; this is your equation 17.

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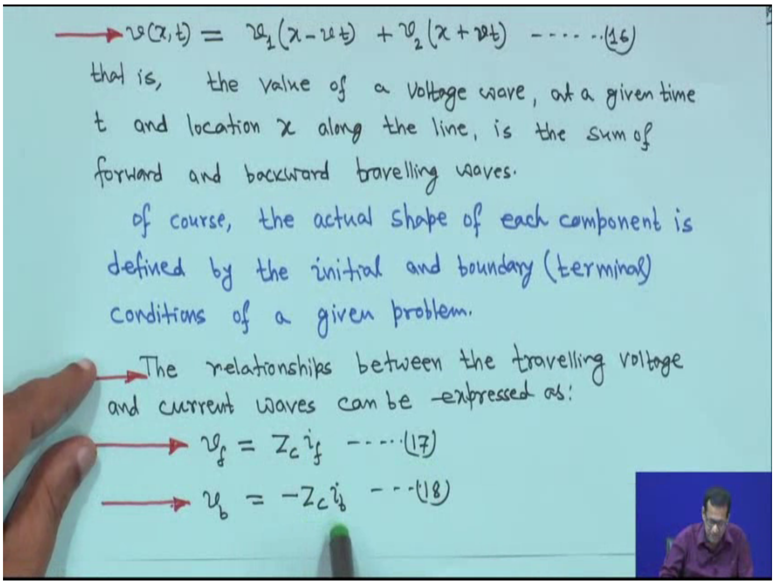

That is v f is equal to Z c into i f and v b is equal to minus Z c into i b; then substitute. If you substitute here then what you will get v b is equal Z c into i b is equal to actually Z into your what you call Z into i f and that will become your v b is equal v f; it will become.

Because i f is equal to your minus i b; so here it is v b is equal to your minus Z c into your i f. So, if we use these two condition and i is equal to your i f plus i b and in that your case your i is equal to 0. So, actually it is i is equal to i plus i b; as i equal to 0, so i f will become minus i b. So, in that case and if you substitute this equation 17 and 18 you will get your v b is equal to Z c into your i b is equal to Z into i f is equal to v f right this condition you will get.

So, just to put this one and do this simple mathematical thing; i think you will easy to understand. So that means, you will get v b is equal to your v f; so, if v b is equal to v f; that means, that you know v is equal to v f plus v b.

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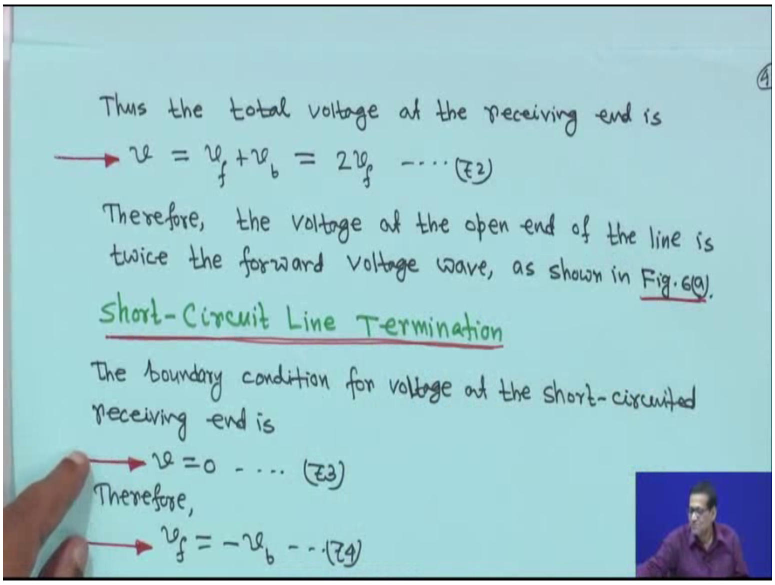

That means it will be v b is equal to 2 v f; that means your total voltage at the receiving end v should be is equal v f plus v b that is equal to v b is equal to v f we have got, for the boundary condition; so, it will be v is equal to 2 v f; this is equation 72. Therefore, the voltage at the open end of the line is twice the forward voltage wave, as seen in figure your 6 a.

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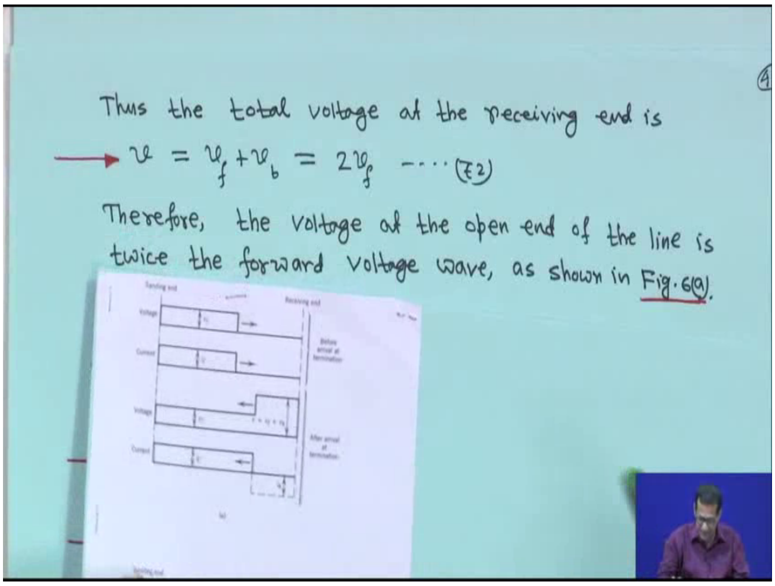

So that means, this one; you look at this figure; open circuit condition this figure. So, in this case that sending end voltage; current line is open circuit. So, in that case what will happen? That it is your forward end moving from your left to the right; so, this has the diagram before arrive at the termination, up to this it is before arrival these two arrival.

Now, after arrival of the termination in that case your v b is becoming v f; the double. So, v is equal to v f plus v b. So, it is moving now from your right to left, right to left; that means, v is equal to v f plus v b. Now in this case that depleted current i b will be is equal to minus i f; that means, when it is reflecting that; it is soon, if you see that this i f and i b is equal to minus i f. So, nothing is here no question of any state volt current or anything, it is negative; so it is compensating.

So, in that case reflection one; i b is equal to your minus i f means that it is totally nullified, so it is moving from right to left. So, that it is equal i b is equal to minus i f it is equal. So, that is why your what you call this is your travelling i f, when it is after arrival at the termination. So, this is your the forward voltage wave as well as current also shown; you can see you can easily you can interpreted this.

Similarly, if a short circuit line termination in this case at the receiving end is short circuited; that means, receiving end side voltage is here; that means, v is equal to 0; this is equation 73. Therefore, v f will is become minus v b because your you know that v is equal to v f plus v b; if v is equal to 0; that means v f is equal to minus v b.

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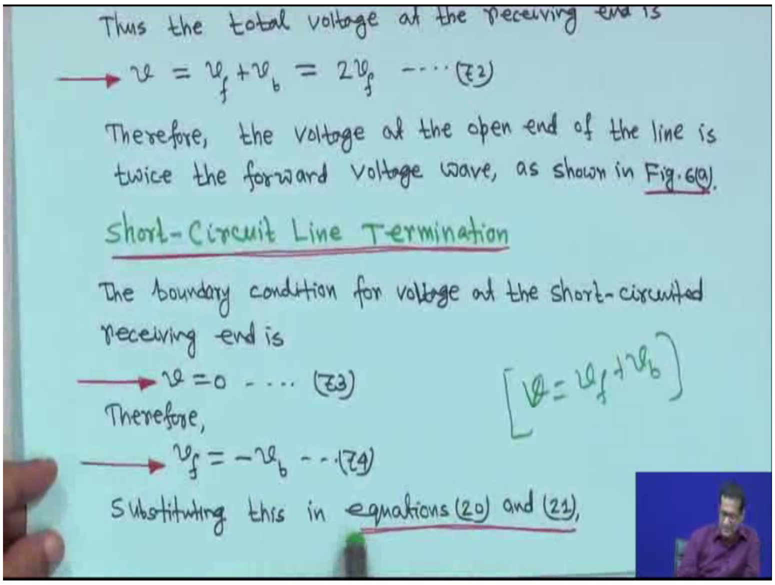

This is equation 74; now this one you substitute this one in equation 20 and 21. I am not showing you equation 20 and 21; same as before. The previous case; we substitute this thing equation 17 and 18; so, just you use this condition in equation 20 and 21; if you just put it those equations are simple equations; if you put that one then what we will get?

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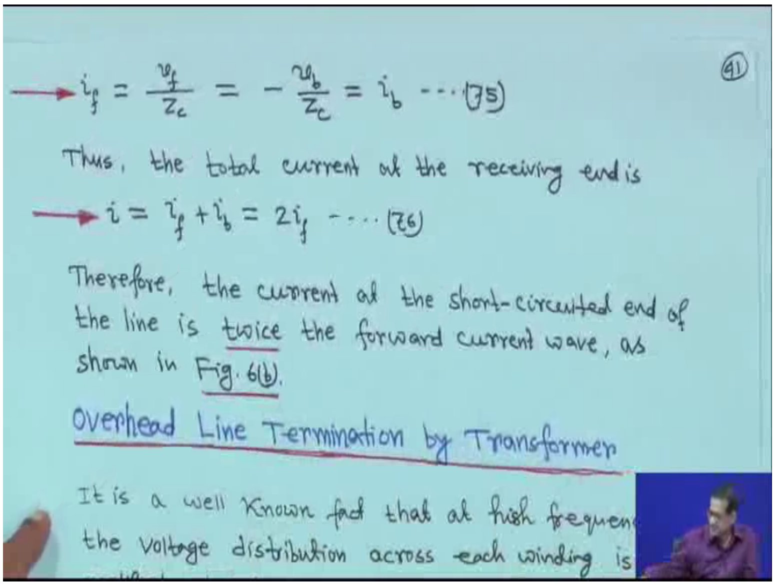

That i f is equal to v f upon Z c is equal to minus v b upon Z c; is equal to i b, this is equation 75. Just use equation 20 and 21 thus the total current at the receiving end, we know i is equal to i f plus i b, so it is becoming 2 i f. So, just opposite it is a duel actually; when it is open circuit and short circuit, it is just duel of open circuit.

So, i is again here i has become doubled 2 i f and i because i f is equal to i b and in that case; v f plus v b is equal to 0, so v f is equal to minus v b. Therefore, the current at the short circuit end of the line is twice the forward current wave as down in figure 6 b.

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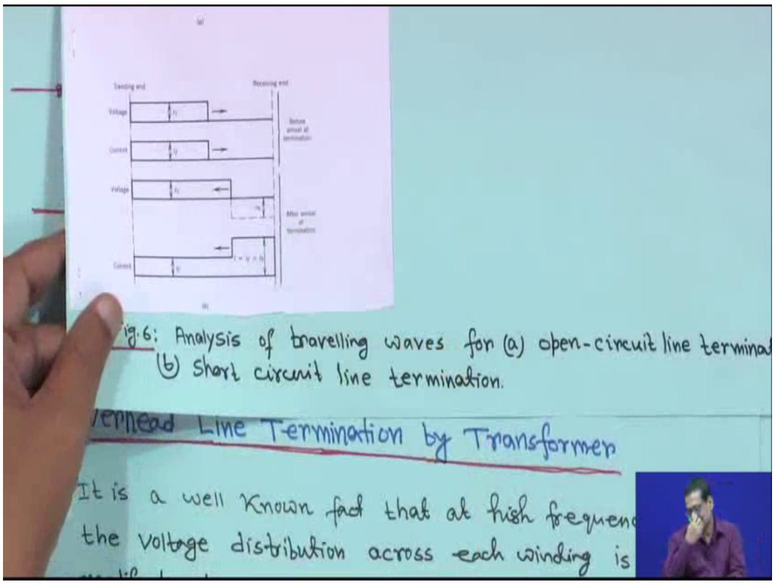

So, this one; this figure, so this figure look these two are forward voltage wave and current wave moving from left to right. So, before arrival at the termination and then after arrival; there will be no, this v b is negative. So, it is just showing this line and this is v f; v f is equal to minus v b, so it is it nullified; v f and this is your v f and this v b and v b is equal to minus v f.

So, it is just a along this line only, but current is doubled this is i f and this has; this is i b. So, i f plus i f is equal to i b; that means, it is moving from your right to left. So, i is equal to i f, so current has becomes doubled after arrival at termination, after refraction; so this is understandable to you that how things actually happen. Next one is; so, this is understandable open circuit and short circuit.

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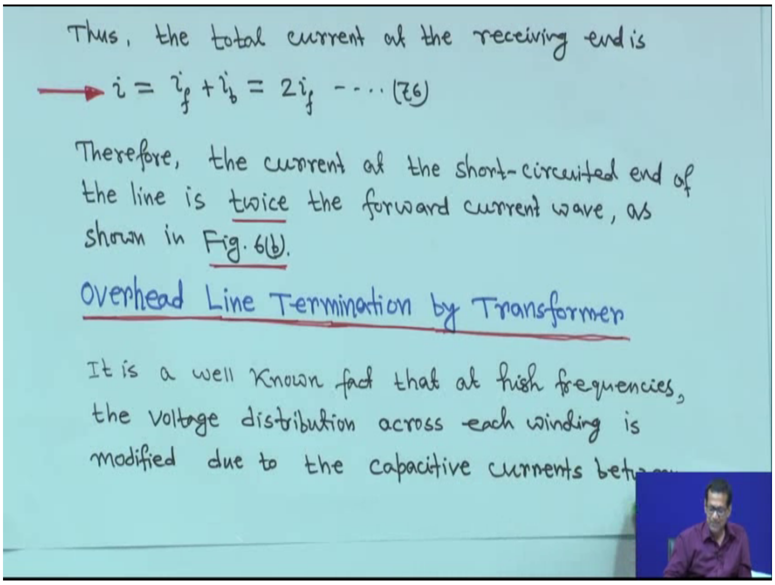

Next one is overhead line termination by transformer; briefly we will discuss this. So, it is well known that your i mean overhead line termination by transformer; this is another phenomena interesting thing. It is well known that at high frequencies, the voltage distribution across the winding is modified; due to the capacitive currents between the transformer windings, between the trans of each winding.

So, i mean particularly it happens at high frequencies. So, across the each winding is modified due to the capacitive currents between the transformer windings; between the trans of each winding and between each winding and the grounded iron core.

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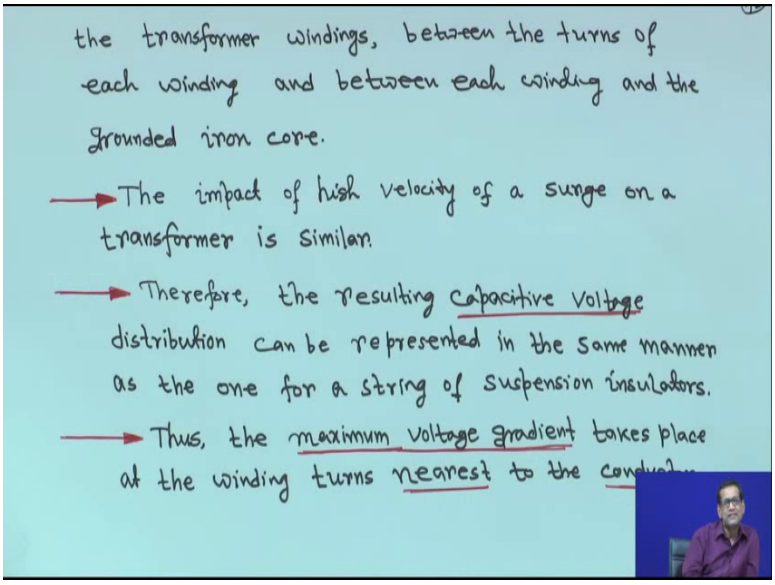

So, at high frequency this can happen; so what will happen? The impact of high velocity of a surge on a transformer is similar. So, I mean whenever it is terminator resistance of impedance of whatsoever, the impact will remain same and it can damage the transformer insulation and transformer can be totally damaged.

Particularly this happens during lighting stroke; we will see later. Therefore, the resulting captive voltage distribution can be represented in the same manner though we have done it for insulator. That is for a string of suspension insulator; the way we have done it same way we can analyse, but here we will not analyse; we will just tell the cause.

Therefore the maximum voltage gradient takes place at the winding turns nearest to the conductor. For suspension type of insulator; we have the voltage gradient is maximum; that disk or piece which is very close to the your conductor; where conductor is connected very close. And what you call that voltage gradient your stress; the stress is less, the insulator disks or pieces which are added from the conductor. Same philosophy for transformer also, so maximum voltage gradient takes place at the winding turns nearest to the conductor.

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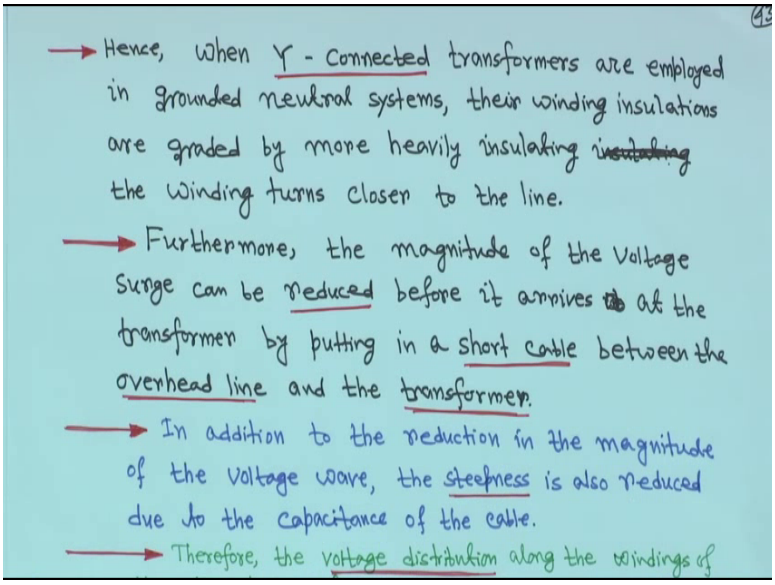

And therefore, when star connector transformer employed in grounded neutral system; when neutral is grounded, just me tell you once again when in the power system analysis class all sort of combination; data, star, grounded, ungrounded all sort of combinations have been explained, so here and no need to explain further; so everything is explained there. I mean I explained; I took lot of time to explain those things.

So, when star connected transformer are employed in grounded neutral systems their winding insulations are graded by more heavily insulating the winding turns closer to the line. That means, winding turns which are very closer to the line; where it is connected right is heavily insulated. Otherwise during lightning stroke because of this heavy or what we call voltage shoot out later we will see, but it can damage the transformer there are many such events are there.

So, further a magnitude of the voltage surge can be reduced; what they do? In reality you can see it also before it arrives at the transformer; we are putting a short cable between the transformer and the overhead line. This actually reduce your voltage magnitude; your and what you call and steepness; both it reduce. Its analysis, we will not go because we have to cover many things.

So, this just for the purpose of explanation, but numerical case you can take any numerical you can solve; it is very simple actually. So, what they do is; they put a short cable between the overhead line and the transformer. If you do so then what will happen?

In addition to the reduction in the magnitude of the voltage wave; the steepness is also reduced due to the capacitance of the cable. So, we will see later when your numerical we will take; when an overhead line and cable both are connected from that this philosophy will remain same; from that your idea will cleared.

So, that is why; what they do actually; they put a short cable between the overhead line and the transformer. So, this actually it is reduction the magnitude of the voltage wave; the steepness is also reduced due to the capacitance of the cable. This is a common phenomena, you can observe this is in reality.

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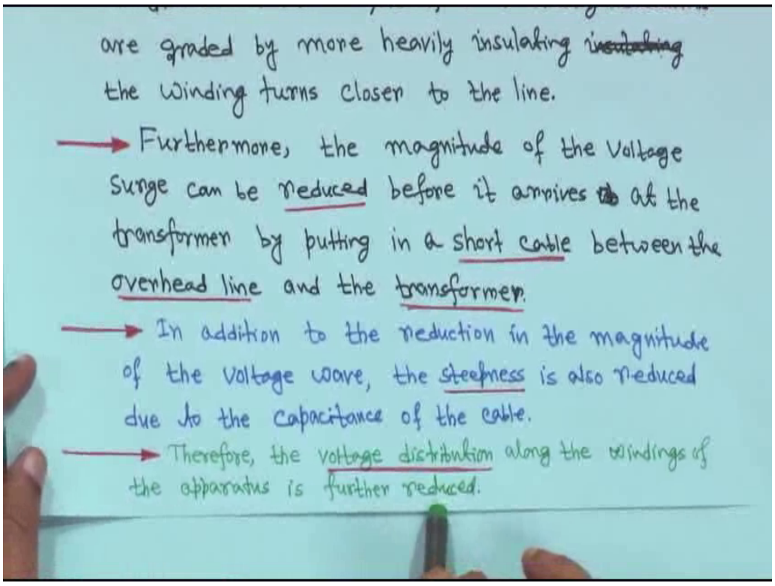

So, therefore, the voltage distribution along the winding along the operators is further reduced. So, this is your what you call that transformer when; that means, whenever you have a connecting a transformer; I mean a termination at the end of this instead of resistance or impedance in transformer that in overhead line, connect the transformer through a very short cable; I mean certain short length.

So, next is junction of two lines; so junction of two lines means just I will show the diagram; that is that is if you see the diagram.

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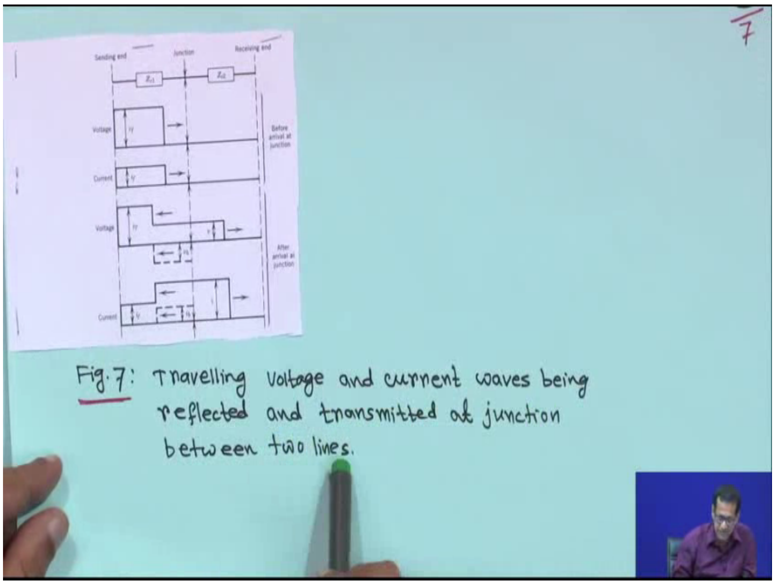

That this is two line sending end and receiving end and this is junction; this is a Z c 1 characteristic impedance, this side is Z c 2; these two junction, so this is figure 7; it is travelling voltage and current waves being reflected and transited junction between two lines I will come to this later on; so figure 7.

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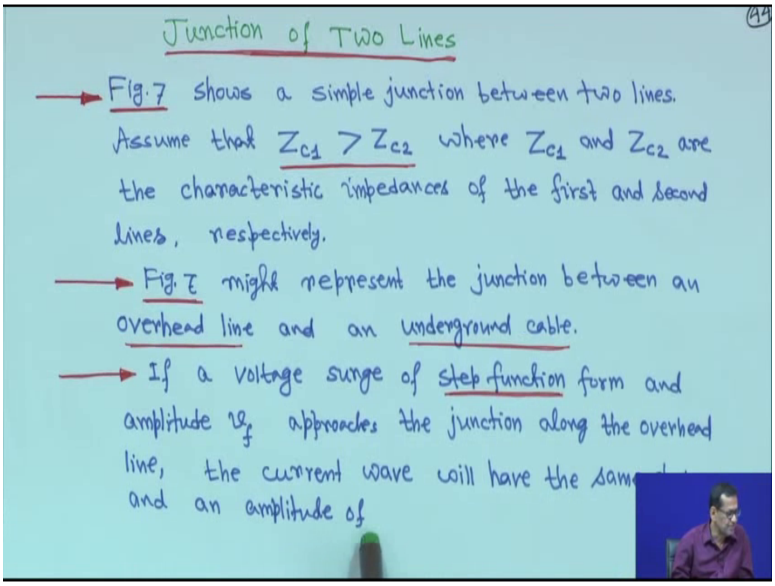

This is such a simple junction between two lines; there may two conditions, one is first you have to assume that Z c 1 greater than Z c 2. So, where Z c 1 and Z c 2 are the characteristic impedance of the first and the second line respectively; this is of first line this is of the second line and here they are connected.

So, this figure 7; in this case what happens, this is figure 7; this side may be cable, this side may be overhead line or this side may be overhead line this side may be cable also. So, figure 7 might represent the junction between an overhead line and an underground cable; that I told you, it is not overhead conductor either side may be your what you call; may be this side overhead, this side cable or this side cable this side overhead or may be two this side; this side both are cable or both are overhead conductor.

So, if a voltage surge of step basically all these things are taking step function. So, if a voltage surge of step function form an amplitude v f approaches the junction along the overhead line, the current wave will have the same shape an amplitude of i will give you what is this. So, before showing this diagram that just hold on.

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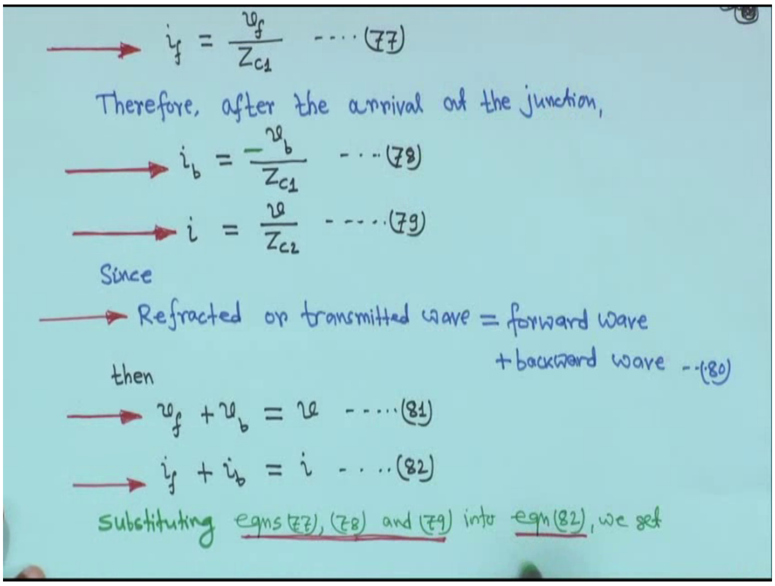

That i f is equal to v f upon Z c 1; therefore, after the arrival at the junction. So, i f will be v f upon Z c 1; forward wave it is moving, this is the junction and this is the forward wave moving. So, i f is equal to v f upon Z c 1; this is equation 77. Now after the arrival at the junction; i b will be minus v b upon Z c 1. So, as soon as after the arrival at the junction; what will happen? That i b should be is equal to minus v b upon Z c 1. This we know this; when is refracting back and i is equal to your v upon Z c 2 and i will be your v upon Z c 2. So, question is that since refractor or transmitted wave I mean because it is junction, after this it will be refracted to other side also; if it is moving from this the left side to right hand side.

So, in that case it is equal to forward wave plus backward wave; when we refracted wave, forget about transmitted wave one same thing. Refracted wave is equal to forward wave plus backward wave; that means, v f plus v b is equal to v; v we know i f plus i i b is equal to i we know. So, these are the condition that after arrival at the junction; i mean this junction, i b will be minus v b upon Z c 1 and i should be is equal to v b upon Z c 2.

Now this condition the refracted or transmitted wave must be is equal to the forward wave plus your backward wave. So, in this case these two conditions we know; now substituting equation 77, 78 and 79; into equation 82, here you substitute i f; i b and i f; i b and i you substitute here.

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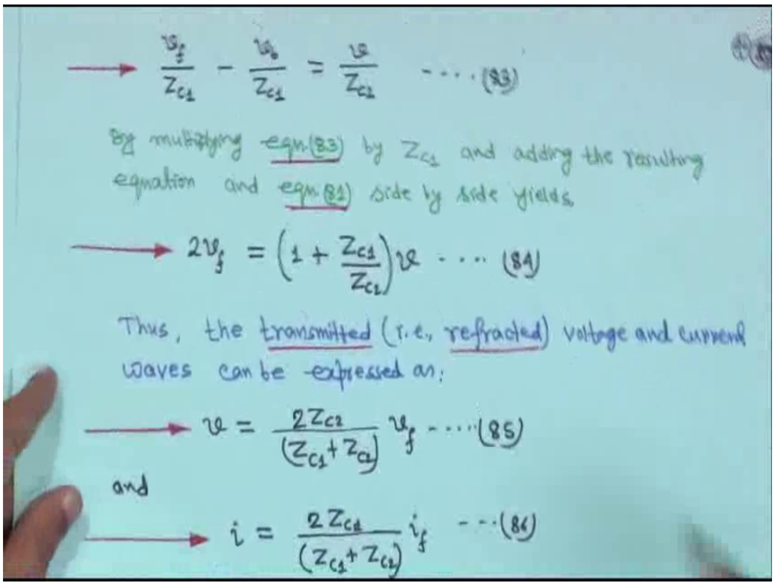

If you do so, you will get v f upon Z c 1; minus v b upon Z c 1 is equal to v upon Z c 2 because i is equal to v upon Z c 2.

So, this equation multiply equation 83 by Z c 1 this is 83, multiply both side by Z c 1; I think you can do it; I have done it for you. And adding the resulting equation and you multiply this one by Z c 1 plus equation 81; you multiply this equation by your what you call Z c 1; this equation multiply both side by Z c 1, with that you add equation 81; that means, this equation that v f plus v b is equal to v.

And then you just simplify; I am not doing it for you; this is very simple thing. you will get 2 v f is equal to 1 plus Z c 1 upon Z c 2 into v; this is equation 84. Thus the refracted or transmitted voltage and current waves can be expressed as; that means, v is equal to; from this equation you will get it v is equal to 2 Z c 2; upon Z c 1 plus Z c 2, this is v f this is equation your 85, from this equation only we will get this one.

Similarly, for current one you try yourself using those expression; only thing is that this Z c 2; will be replaced by Z c 1, just opposite. Because this is your i is equal to 2 Z c 1; upon Z c 1 plus Z c 2. Therefore, the transmitted wave; I mean this for the voltage and this is for the current, if you wired for voltage and current I showed you that tau plus tau i will be is equal to 2; you add these two, it will be 2. So, this is the coefficient 2 Z c 2 for voltage; Z c 1 plus your Z c 2.

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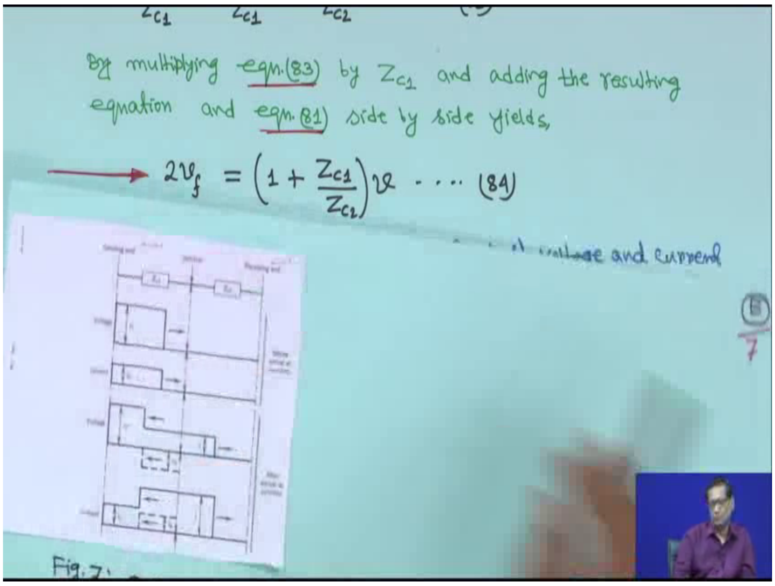

That means, this equation if you get; it will be 2; Z 2 upon Z c 1 plus Z c 2 that is for voltage. And for current refracted one; it will be 2 Z c 1 divided by Z c 1 plus Z c 2. Therefore, this is your what you call that your transmitted or refracted voltage and current wave. So, this can be expressed and these are the your refraction your what you call that refraction coefficient for voltage and this is the refraction coefficient for the current.

Therefore; that means, this figure 7; so, this is the voltage wave and diode this thing going. Now question is that that v b actually this is your that; v f is equal to; this v is equal to; this expression 2 Z c 2; upon Z c 1 plus Z c 2 plus v f. So, this is the refracted one; this v; so this is your v and this is your refracted side.

So, it is junction; this is junction, this is junction; so v is moving from the junction point to your right hand side; left to right side. And in that case the refracted one that v b; just now i showed that v b is equal to your, where it is gone? Just hold on; v b is actually this i b is equal to minus v b upon Z c 1. So, v b actually minus i b into Z c 1; so, v b is negative.

So, that is why this is your v b; so this side refracted one, it is actually going like this. So, decrease and that was same magnitude as your refracted one that is v; for the current case i b that v is equal to Z c 2; i or sorry this your v f is equal to you know i f into Z c 1; that is known and i is equal to v by Z c 2. So, in that case; in the case of current; your as v b is negative; so i b will be your what you call positive because one is negative means another will be positive right v b is negative, so i b will be positive.

So, that is why; as it is negative, your i b is positive, so, it is added up. So, the i; i f plus i b and your i i is equal to; that means, that refracted side also will have the same magnitude i and that is you are getting from this equation 2 Z c 1; upon Z c 1 plus Z c 1 into i f; this equation. So, that is your what you call that if it is a junction; that refraction will be there.

That is why it is going like this; part of this going like this and this is your; this side is refracted one and this side is your; what you call refraction one. If you look into that refracted side and this thing; these two magnitudes are same. Similarly for the voltage also; you see the refracted side and when it is moving from the junction; that is your from the junction to the right side and junction to the left side that these two are same, this you have to little bit understand understanding is required.

Just little bit you see this and look at this equation; so, easily you will be knowing the things very easily; I hope you have understood this. When you will study this; if you have any problem you can email to me; any doubt is there, I reply to everyone. But only it may take one or two days late because of our busy schedule, but all of them in the power system analysis course, I replied to all of them. I do not think, I have taken more than two days to reply, but i have replied to all of them.

Next therefore, this thing the refracted voltage and current waves can be expressed as; so from this whatever we have explained.

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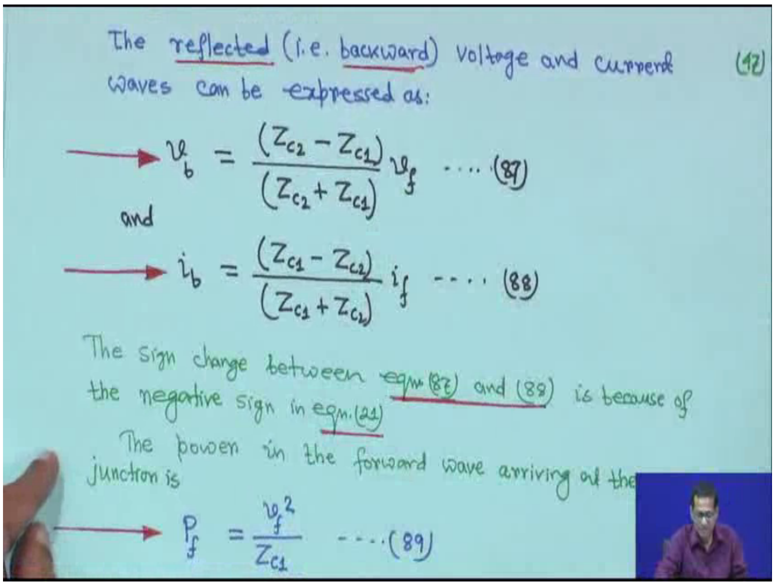

Now from this one; that reflected that is backward voltage and current wave; we know that v b will be Z c 2; minus Z c 1; Z c 2 plus Z c 1; v f this is you have seen before. So, this is the diagram; so v b will be Z c 2 minus Z c 1 upon Z c 2 plus Z c 1. And i b will be your what you call Z c 1 minus Z c 2; upon Z c 1 plus Z c 2. And if you have assumed; Z c 1 greater than Z c 2; then v b will be negative. But if you take; Z c 2 less than Z c 1; so, it will be just your opposite.

So, this is an exercise for you when you do this and you draw the voltage and current wave form and just do yourself; so, this is equation 87.

So, that is why the sign change between equation; because of the negative sign in equation 21; you can check the equation 21; at the beginning we have developed. So, next is the power in the forward wave arriving at the junction. So, at the junction power is this thing; P f is equal to v f square upon Z c 1; because this side influences Z c 1.

So, you will have take your what you call v f square upon Z c 1; that is forward wave arriving power in the forward arriving at the junction; it will be v f square upon Z c 1. Similarly the transmitted power that; it will be v square upon your Z c 2.

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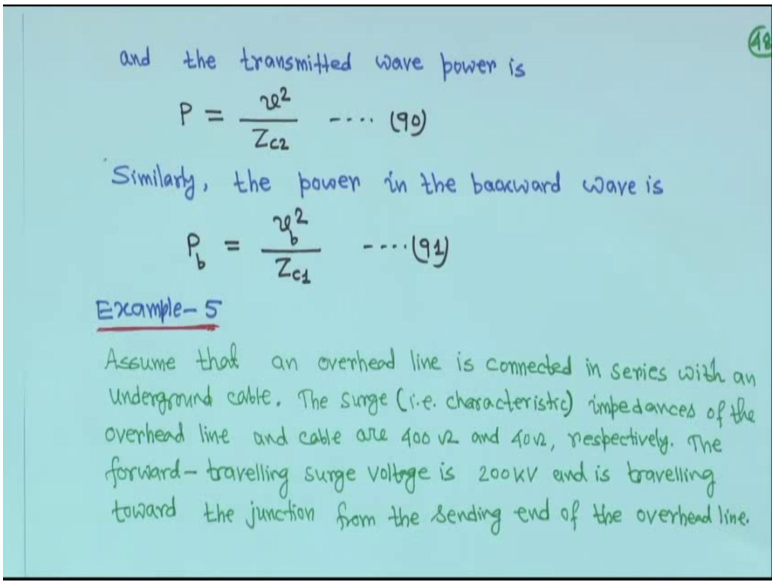

The transmitted power will be P is equal to v square upon your Z c 2 because transmitted voltage expression is going to v square v; this is known to expression also given. And Z c 2 is the characteristic impedance; so it is your v P is equal to v square upon Z c 2; so this is equation 90. Similarly the power in the backward wave v b, we have calculated; so P b is equal to v b square Z c 1; this is equation 91.

So, next is this an example; so, assume that this is example 5; assume that an overhead line is connected in series with an underground cable. So, one is overhead line; another is cable, the surge that is the in bracket I have written that is the characteristic impedance actually. So, surge impedances of the overhead line and cable are 400 ohm and 40 ohm respectively. The forward travelling surge voltage is 200 KV that is your v f is equal to 200 KV and is travelling toward the junction from the sending end of the overhead line.

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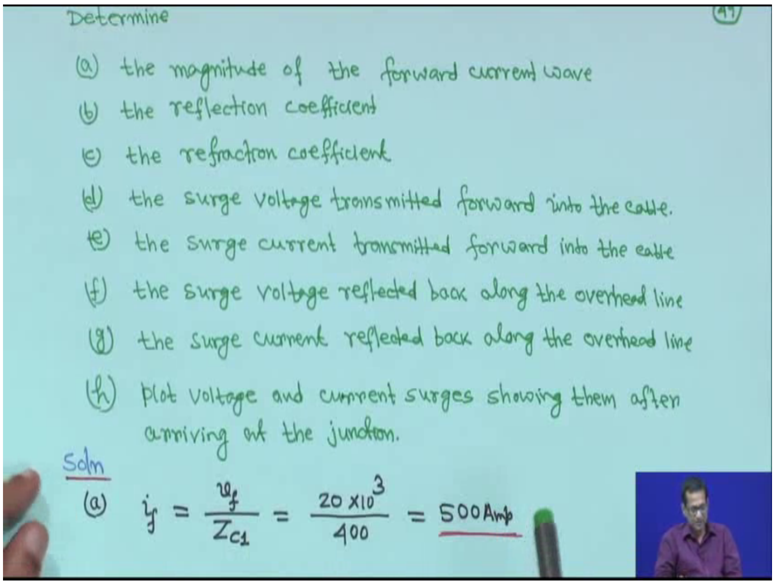

You have to determine the magnitude of the forward current wave, the reflection coefficient, the refraction coefficient; the surge voltage transmitted forward into the cable, the surge current transmitted forward into the cable. The surge voltage reflected back along the overhead line, the surge reflected back along the overhead line, plot voltage and current surges showing them after arriving at the junction.

So, these are your eight quantities we have to determine; we have seven quantities and last one you have to plot. So, first is you know i f is equal to v f upon Z c 1; so, voltage v f is given that is your 20 k v; it is 200 k v, I think it is one 0; I have missed, it is 200 into 10 to the power 3.

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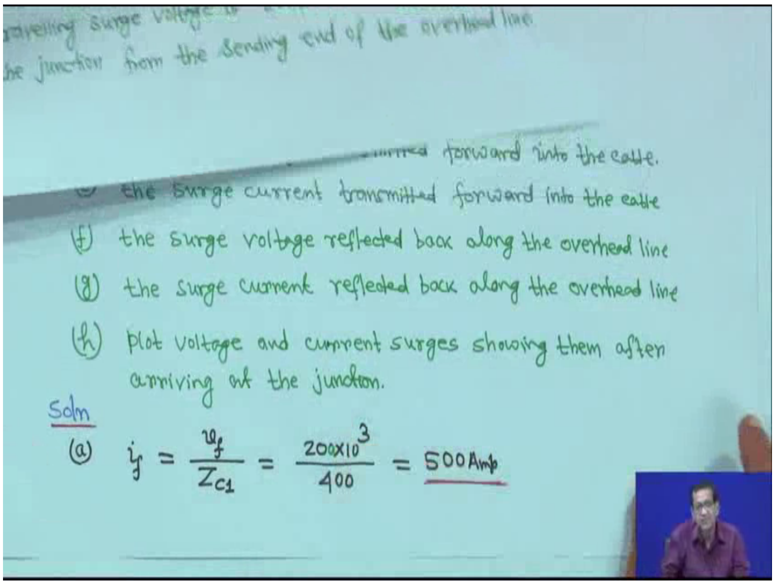

So this actually your divided by 400; so, it becomes actually 500 ampere; so this is your i f. Now part b is the reflection coefficient; so very easy, you know this formula that just now I have showed you.

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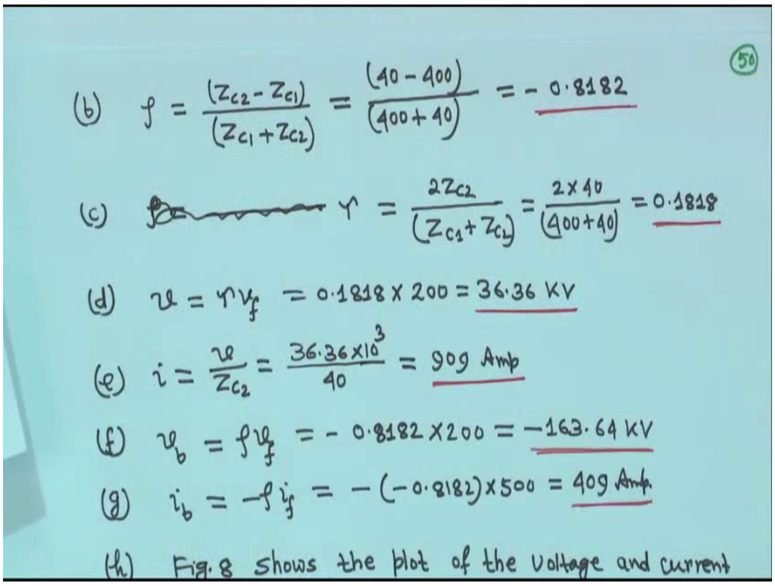

That rho is equal to Z c 2; minus Z c 1 divided by Z c 1 plus Z z c 2. Just now I have given; that is equation 87. This is equation 87; these are understandable to you from equation 87. This is actually reflection coeffienct; if you any doubt, in bracket you can right down; this is the reflection coefficient.

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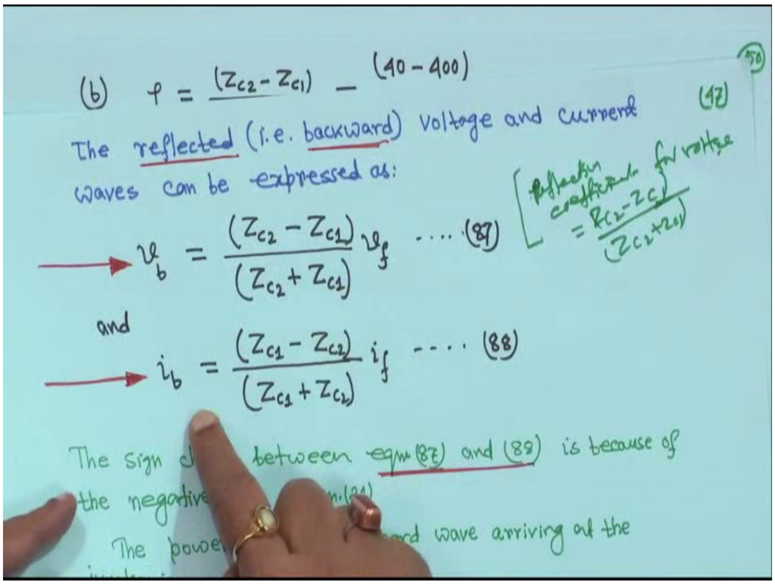


That is equal to your Z c 2, minus Z c 1; divided by Z c 2 plus Z c 1; this is refection coeffienct for voltage. So, similarly this is reflection coefficient for the current, but anyway; if this one you calculate, other one just take the minus sign of this. So, this one your 40 minus Z c 2 is your; this thing, what we call? 40; it is given that overhead line 400 and cable is 40; so, it is 40 minus 400 upon 400 plus 40.

So, it will become minus 0.8182 rho; then tau because this one is been at the your part c; c is the refraction coefficient, so tau this is refraction coefficient, it will better if you write this is tau and this is your rho, this is tau. So, refraction coefficient tau is equal to you know your 2 into Z c 2 divided by Z c 1. When refraction means; you will take the your what you call that junction point no other side of the junction impedance; characteristic impedance. So, that is actually Z c 2; very easy to remember that way; so 2 Z c 2 upon by summation of these two; Z c 1 plus Z c 2.

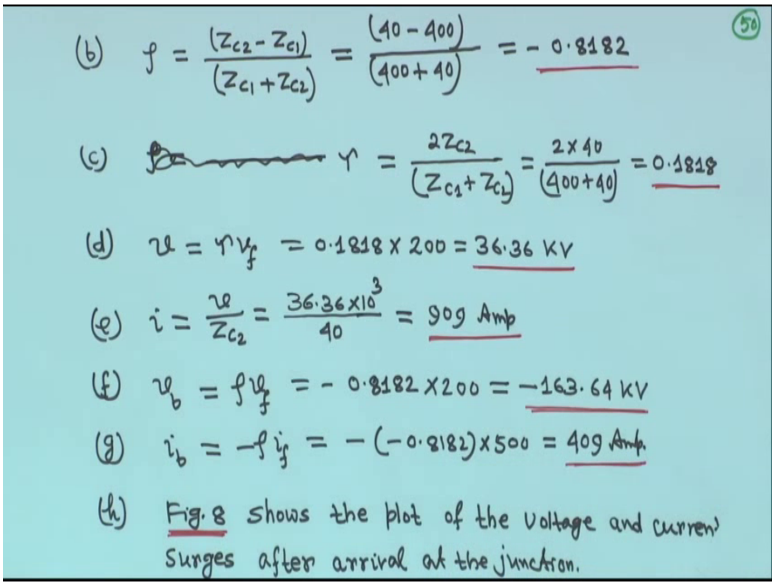
So, 2 into 40 because it is cable surge impedance is 40; so, 400 plus 40 is equal to 0.1818. Now we know v is equal to tau into v f that we have seen; so .0.1818 into 200, so 36.36 KV. Now i is equal to v upon Z c 2; naturally that your Z c 2 is the cable impedance and v voltage you this thing v upon.

So, v we know 36.36 KV that is at the other end receiving inside other side. So, whatever is refracted to other side; so it is 36.36; it is k v; so made it bold 10 to the power 3;

divided by 40, it will become 909 ampere. Then v b is equal to you know rho into v f; so it is minus 0.8182, you have got minus 0.8182 into 200; this is KV actually.

So, minus 163.64 KV and i b is equal to minus rho into i f; just opposite of your voltage. If rho is minus here; here automatically it will become plus because minus rho into i f. So, minus of minus 0.8182 into 500; so it is 409 ampere.

(Refer Slide Time: 29:45)



So, these are straight forward calculation and when you see the waveform; if you plot the waveform; which is this one. You look at that v and i and from there you can easily plot it; this is what you call the plot; that figure 8; example 5. This is overhead line, this side is cable; so it is v f, but v b you are getting actually minus 163.64 KV.

So naturally this actually this negative side it is not shown, but v f actually your v f; you have a 200 KV. So, 200 minus 163.64 means v will be 36.36 k v; so this is your v; this magnitude actually 36.36 KV and this v b; it is shown in upward, but v b is negative your what you call minus 163.64 means here it is shown upward instead of that, but that is actually subtracted, that is why it is shown like this and so this is the refracted one 36.36 KV.

Here it is not mentioned, but I am telling you; this is 36.36 KV and I; your i b is your this thing 409 ampere; i f is there, but i b is positive 409 ampere. So, i f your what you call;

this whatever value of the i f was there; just let me see, it was 500 ampere; i f you got 500 ampere; this is 500 ampere and here.

So, i b is also 409 ampere; so that is why i is 900 ampere reflected one; that is why, this is i f plus i b this is actually 909 ampere. So, this is actually that voltage at current wave upward; this is actually when you are moving from left to right, then reflected back and then it is going from from junction; it is this part is going from junction to the right hand side; I hope you have understood this.

Thank you very much, we will be back again.