Power System Engineering
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Lecture - 12
Transient over voltages and Insulation coordination

Next is that your: a further reduction in current carrying capacity occurs due to dielectric losses.

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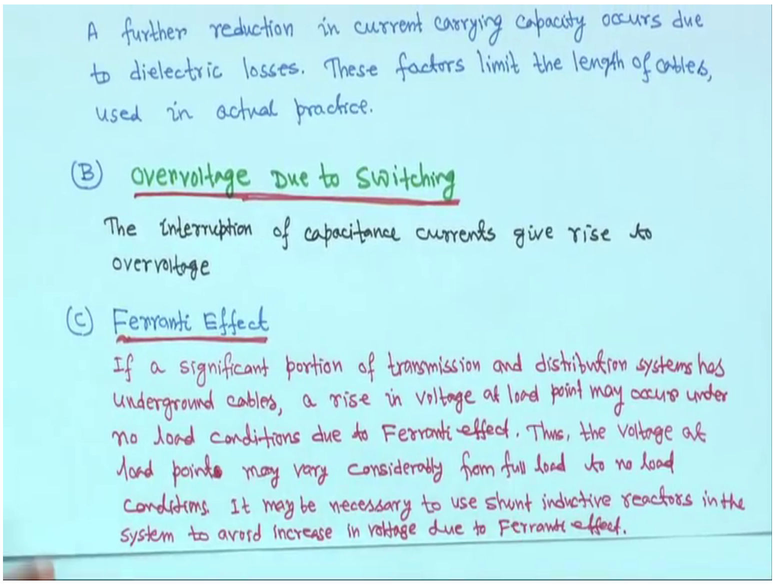

If there is dielectric loss means there is this thing, it will also help to increase the temperature, so these factor limits the length of cables used in actual practice. So that means, you have to consider all the; what you call factors for this different type of losses you have to consider for the cables. So, next is over voltage due to switching the interruption of capacitance currents give rise to the over voltage.

Now Ferranti effect; you know so if a significant portion of the transmission and distribution; transmission line also you have seen that under no load condition the receiving and voltage is your what you call higher than the sending in voltage. Same is applicable for the cable also. Therefore, thus, the voltage at the load point may vary considerably from full load to no load. So, in this case it may be necessary to use shunt inductive reactors in the system to avoid increase in voltage due to Ferranti effect.

I mean if the voltage rise; in general suppose if voltage rises within the permissible limits say 1.05 per unit; so, if it is within the limits. So, no question of the putting your what you call shunt inductive reactors otherwise you have to put your; what you call in shunt inductive reactors, such that what you call it will compensate the reactive power, your injected by the your shunt charging shunt capacitor.

So, that is why shunt inductor usually requires certain such that it will compensate each other; that is why this Ferranti effect. I mean in power system analysis course, in brief I have just told you that what is Ferranti effect? So, these are the things you have to consider.

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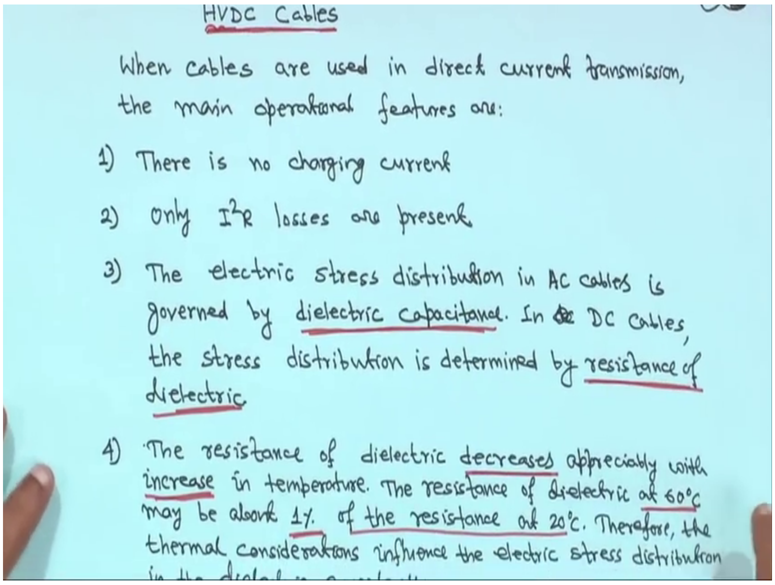

Next is some brief outline regarding HVDC cables: now when cables are used in direct current transmission; the main operational features as; for HVDC cable; high voltage DC cable there is no charging current because this is DC. Only I square R losses are present, the electric stress distribution in AC cables is governed by dielectric capacitance. In DC cables, the stress distribution is determined by resistance of dielectric; this is what you call comparison between AC and DC cables, but the resistance of dielectric decreases appreciable with increase in temperature.

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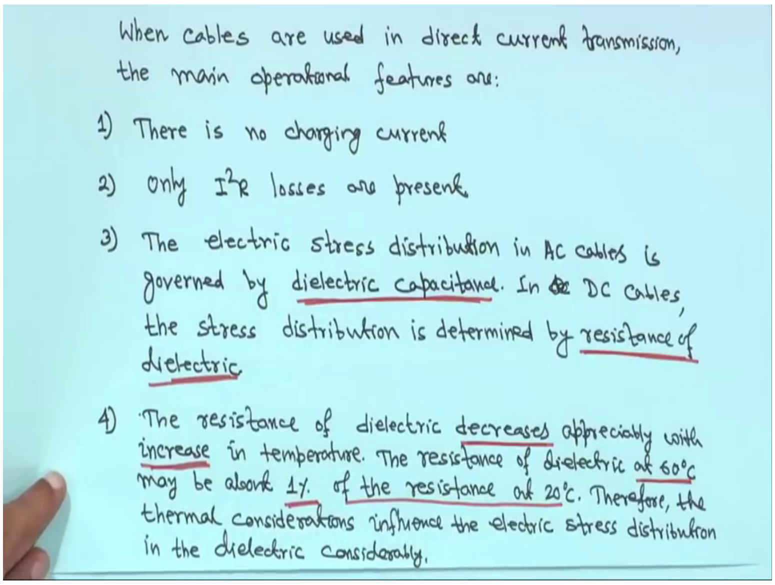

It is very interesting that the resistance of dielectric decreases appreciably with increase in temperature. The resistance of dielectric at 60 degree Celsius may be about 1 percent of the resistance at 20 degree Celsius; I mean drastic reduction. Therefore, the thermal consideration influence; the electric stress distribution in the dielectric considerably and this is very interesting.

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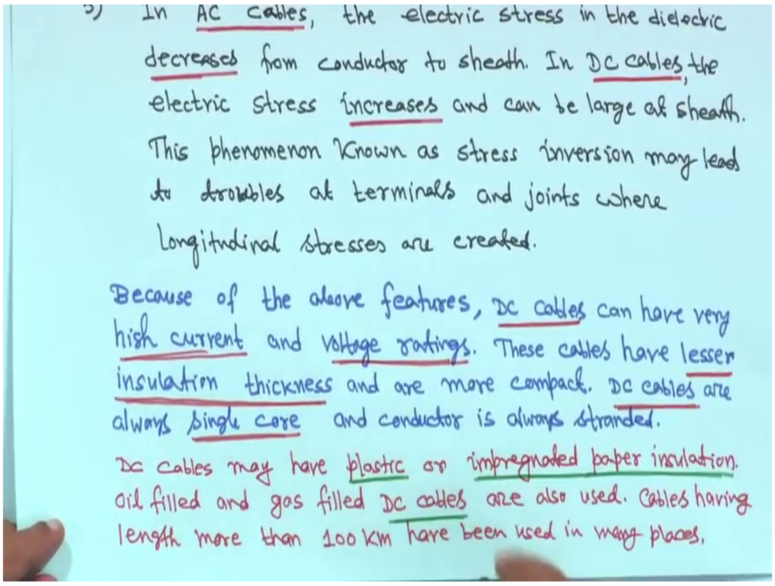

Now, so in AC cables the electric stress in the electric; in the dialectic decreases from conductor to sheath; that we have near the surface of the conductor that electric stress is higher. And when you are moving towards the sheath, it is less; in DC cables the electric stress increases and can be large at the sheath; just opposite.

This phenomena known as stress inversion may lead to a troubles at terminals and joints where longitudinal stresses are created. For HVDC cable, we will not study in detail because we have to compensate with that this; condense this cable part, just some brief idea regarding HVDC cable. And because of the above features, DC cables can have very high current and voltage rating.

So, because of this thing only; so these cables have lesser insulation thickness and are more compact. So, DC cables are always single core and conductor is always stranded and it is suitable for high voltage. So, and its cable may be plastic or impregnated paper insulation. Oil filled, gas filled, DC cables are also used; so, cables having length more than 100 kilometre have been used in many places.

So, compared to AC cable HVDC you can have use at high voltage level and then what you call; many places after 100 kilometre length; cable have been used. But you have consider all these things but one thing is there; that cable is expensive than the overhead conductor. So, this cost is the main factor till date otherwise the general idea of laying cable means that; as you know that even it during storm or heavy rain or shower that forever it conductor there is a possibility of fault and where there will be the power supply disrupted.

Whereas, in the case of cable that those things will not be there, but one thing is there that cable is expensive than your this thing; the overhead conductor. So, what you have learnt; that some ideas regarding what you call this cables and your something you have seen that different type of cables and current electric, dielectric loss and all other things. So, with that cables topic is closed now, and next we will come to the transient over voltage and insulation coordination.

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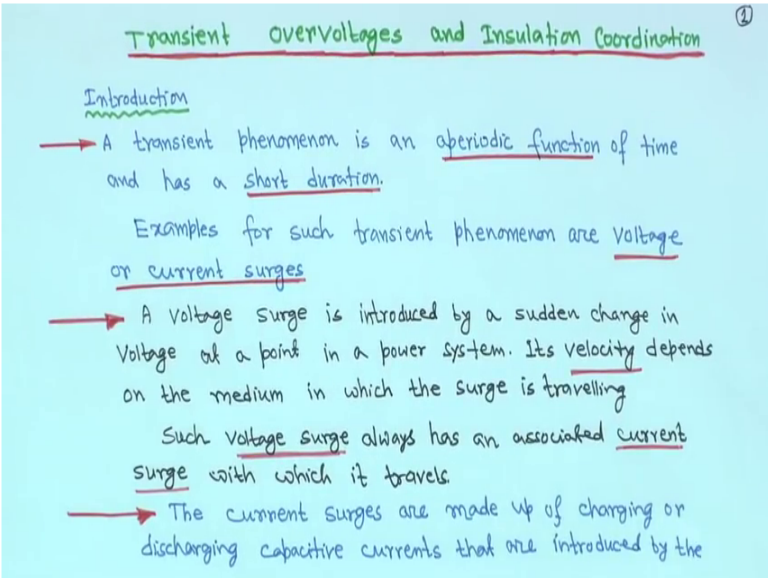

So, this is a new topic that transient over voltages and insulation coordination; let us see first what exactly it is. So, a transient phenomena is an aperiodic; function of time and has a short duration you know that.

Any transient phenomena is aperiodic function of time and very short duration. So, example process transient phenomena are voltage or current surges. So, we will start this thing I mean we will see step by step in a very simple manner. So, a voltage surge is introduced by sudden change in voltage at a point in a power system. If there is sudden change in voltage; so that is what called the voltage surge will be introduced.

And along with this a current surge will be always associated with that. So, for a common phenomena of this kind of thing is a lightning stroke say; we will come to that those things later. So, its velocity depends on the medium in which the surge is travelling.

So, surge voltage surge is always has an associated current surge with which it travels. If there is a voltage surge, then there will be associate current surge along with it will travel. The current surges are made up of charging or discharging capacitive currents that are introduced by the change in voltage; that was the shunt capacitance of the transmission line; that is your charging capacitance.

So, that is why the current surges are made up of; what we call charging or discharging capacitive currents that are introduced by your change in voltages, across the shunt capacitance of the transmission system.

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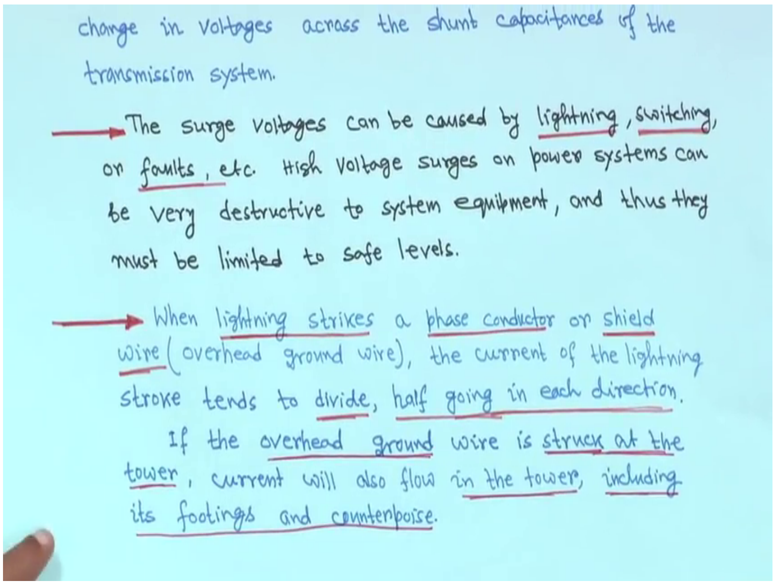

The next is; the surge voltage can be caused by lightning switching or fault, etc; lightning stroke; we will explain those things later on; that is you have seen again and again and switching or faults etc. So, high voltage surges and power system can be very destructive to system equipment because it will destroy everything. It can destroy transform or even if sometimes your lightnings arrester also; where it troubles from its a suppose some lightning stroke is there on the tower or on the shielded wire; that we will see later that in both side their travelling wave travels.

So, lot of protections we have to take care for this very very short duration that voltage surge; thus they must be limited to safe levels. When lightning strikes a phase conductor or shield wire; over head ground wire. If you look any tower, you will see that your ground wire will be there at the top of the tower. So, the current of the lightning stroke tends to divide half going in each direction and when lightning stroke happens that total over head actually moves both side half half.

If the over head ground wire is struck at the tower; current will also flow in the tower, including its footings and counterpoise. I mean you have to take care for this; your what you call from this lightning stroke because lightning stroke every common phenomena right. So, now the current of the lightning stroke we will see the surge impedance of the conductor or conductors.

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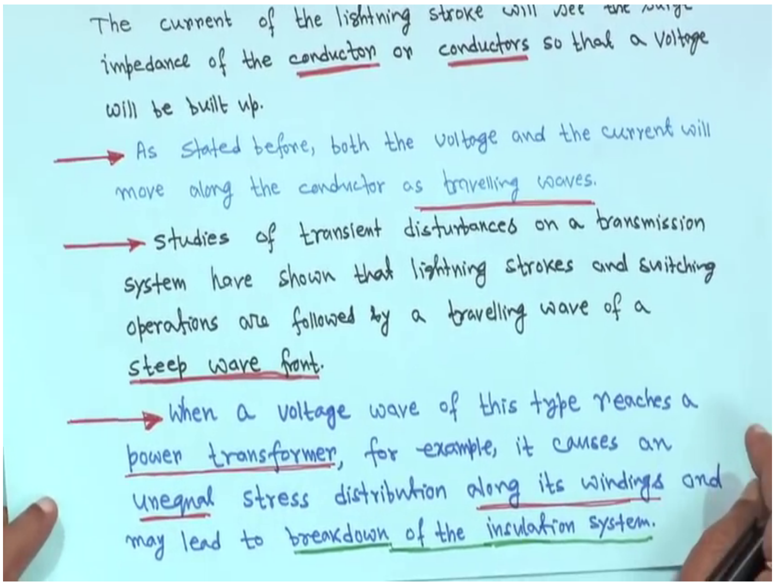

So, if you have your what you call; that many more than one conductors, in any phase or the three phases single conductor, three conductors are also there; so that a voltage will be build up.

So, as stated before both the voltage and the current will move along the conductor as travelling waves. So, if such strokes happen then that; both the voltage and the current will move along the conductor as a travelling wave, it is later we will see that; it happens in micro second.

So, studies of transient disturbances in a transmission system have shown that lightning stroke and switching operations are followed by a travelling wave of a steep wave front; it will be uni-directional. So, when a voltage wave of this type reaches a power transformer; for example, it causes a unequal stress distribution along its windings and may lead to breakdown of the insulation system.

Suppose very simple example is; suppose a transmission line that lightning stroke happens on the top of the tower or conductor of the shield wire, then lightening your what you call that; wave travels to the nearby substation is there; it will travel to that and substation you know steep of a steep down transformers are there. So, in that case what will happen? This kind of wave that it reaches power transformer say at the substation for example, it causes an unequal stress distribution along its windings and may lead to breakdown of the insulation system. So, that winding insulation that it will break down and transformer will be damaged.

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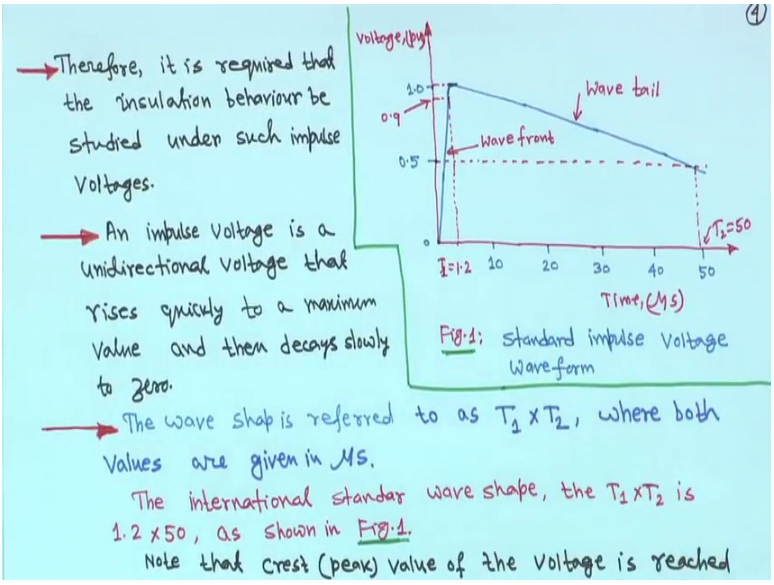

So, lightning is a lightning stroke particularly is a very strong phenomena where in you have to put it the power system. So, I will come to this figure later on therefore, it is required that the insulation behaviour we studied under such impulse voltages; that means, that is your what you call that whenever they go for; suppose manufacturers when the manufacture transformers for example, say they go for level phase stage that your impulse stage because it will last for micro second.

And whether that transformer insulation it can sustain or not. So, an impulse voltage is a unidirectional voltage; this is actually unidirectional voltage that rises quickly to maximum value and then decays slowly to 0. So, I will come to that the wave shape is referred to as T 1 into T 2; they call it is T 1 into T 2 where both values are given in micro second. For example, if you look at the graph, this side it is micro second and this side is a voltage per unit.

Now, if this voltage reaches; it is one point it is a microsecond; if it T 1 is equal to 1.2 microsecond if it reaches its crust value that is peak value that is 1 and finally, it is coming to that, your it is this is wave front and this is wave tail and if it reaches 50 percent of it; at 50 micro second. So, that is we call T 1 into T 2 as shown in figure 1, but let me tell you this is a standard case, but in reality it does not happen.

I have seen also that this kind of test and you found it may not be sometimes one point your what we call 2 microsecond; it will be 1.3; it may be 1.4 here also; all the time it cannot be 50; your microsecond it also changes, but it is a special case. So, this is your wave front as long as it is rising and wave tail, when it is decreasing the time is very fast in microsecond range. So, this is a international the standard wave shape that is they call it T 1 into T 2; it is 1.2 into 50; this is international standard, but in reality this may not happen; it may change this way or that way.

So, note that phase value of the voltage is reached point in 1.2 microsecond, this is 1.2 microsecond and the 50 percent point and the tail of the wave that is 50 microsecond.

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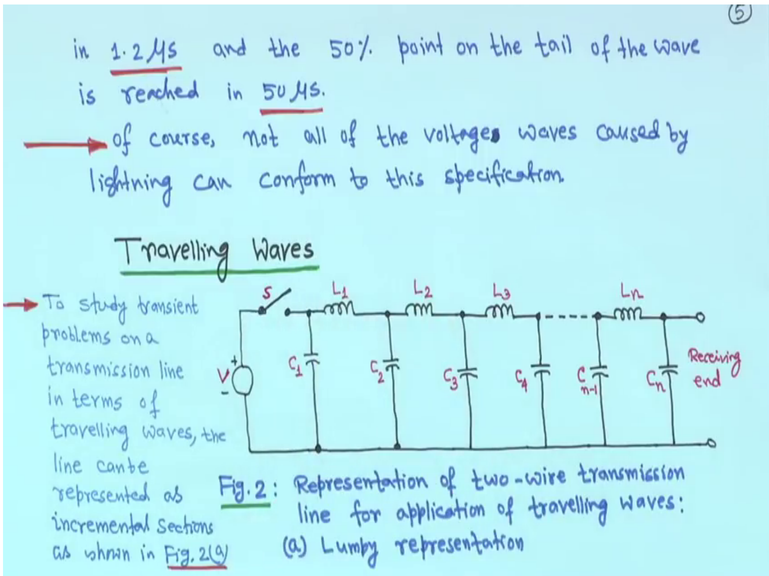

I told you this one of course, not all of the voltages waves caused by lightning can conform to this specification. Even if you go for laboratory test for impulse voltage test; you will not find that your what you call 1.2 or 50; it may change, but this is standard one of the travelling wave.

Before telling you all sort of things, this is a voltage source is given say and suppose representation of two wire transmission line for application of travelling waves and this is a lumpy representation; what you do? Suppose you have a transmission line resistance for the time being, we have neglected; this is sending end and this is receiving end and this capacitance C 1, C 2, C 3, C 4, C 5, C n minus 1 up to C n; these are charging capacitance lying to ground and this inductance also lines are lines are divided into infinite means small section; so, L 1, L 2, L 3, L n it is like this.

Now, suppose there is a voltage; voltage source and there is a switch. Now what will happen as soon as you know from the circuit theory; as soon as you close the switch this capacitance will be charged. So, this capacitance will be charged, but at the same time; at the time of switching your imagery; what you call imagery imagine, that these are infinite smaller; your section so, but this induct the; as soon as you switch on you know the, how the inductor will behave inductor will be open circuit.

So, if inductor is open circuit means the immediately the voltage across C 2 will not be developed, it will take some time. Similarly, when C 2 voltage will develop then C 3 then it will come; that means, a wave will travel from sending end to receiving end. This way I repeat that; suppose you have a voltage source, there is a switch and these are all the charging capacitance; an line, each line section it is taking infinite decimal small length.

So, inductance has given L 1, L 2, L 3, L n; the question is as soon as you close the switch, this capacitance will be charged immediately. Because you know from the circuit theory; that as soon as we switch on that capacitor will behave like a short circuit and inductor will be in open circuit; it will be charged, but it will remain open; it will be open circuit, it will act like open circuit neglecting the resistance of the line say.

So, similarly immediately voltage will not be build up here; it cannot get voltage immediately across it because it will act as open circuit. So, it will take some time similarly when voltage will get; the voltage across this will remain open. So, what will happen? This way, it will happen as if a wave is travelling from the sending end to the receiving end, so this is the philosophy.

Now, I have given the description; now to study transient problems on a transmission line in terms of travelling waves. The line can be represented as incremental section, this is all incremental section you have taken in figure two a right and so it is lumpy representation we calling that is figure two and this is your what you call a; S b will come later. So, this case the two more line is.

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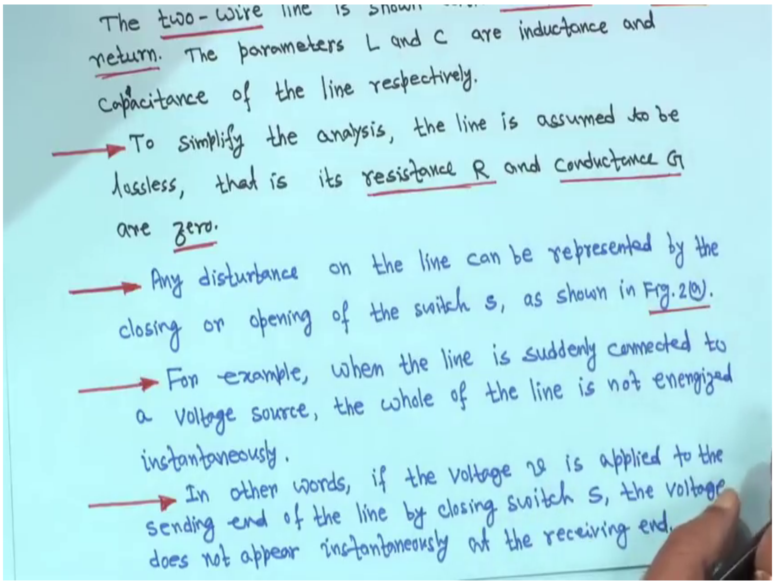

Shown with one phase and neutral return in one phase and neutral return; the parameters L and C you know inductance and capacitance of the line respectively. So, to simplify the analysis what we have done resistance and conductance G; we have assumed zero that is they are neglected you just for the purpose of you know explanation. So, any disturbance on the line can be represented by the closing or opening of the switches as shown in figure 2 a.

So, this is the switches and we have any disturbance is switch your what you call closing or opening will create a disturbance in the line. For example, when a line is suddenly connected to a voltage source the hole of the line is not energised instantaneously like I told you; if you close it hole of the line cannot be charged instantaneously. In other words, if the voltage V is applied to the sending end of the line like closing switches; that means, this voltage V by applied closing V by closing the switches.

The voltage does not appear instantaneously at the receiving end; I told you immediately it will not be appearing at the, it will travel the phenomena I have told you so; that means.

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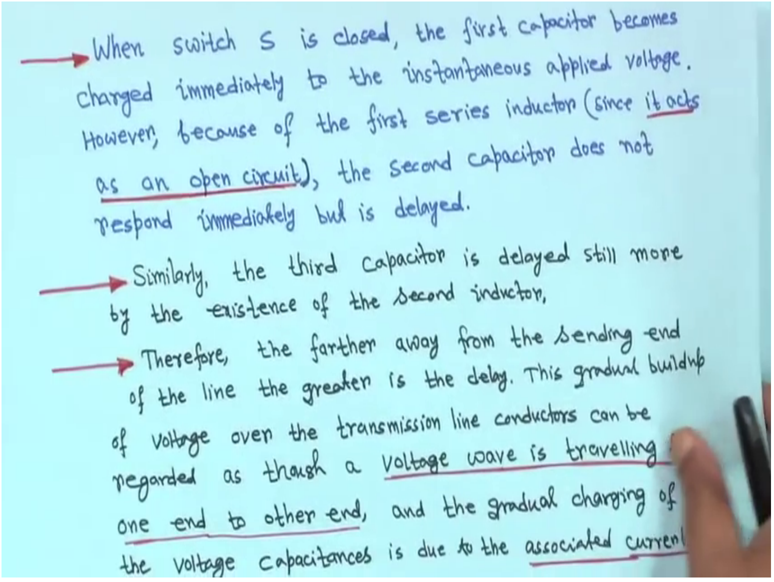

So, when switch S is closed; I told you all these things. Now retain something for you that when switch S is closed. The first capacitance becomes charged immediately to the intent instantaneous applied voltage; I told you immediately because capacitance acts as a short circuit and inductor will act as a open circuit. So; however, because of the first series inductor; since it acts as an open circuit, the second capacitor does not respond immediately say what is delayed; these phenomena will be happen from the sending end to receiving end.

Similarly, the third capacitor this one is delayed still more by the existence of the second inductor and so on. Therefore, the farther away from the sending end to the line the greater is the delay. This gradual build up of voltage over the transmission line conductors, can be regarded as though a voltage wave is travelling from one end to other end and leave this phenomena continues; when from the sending end to receiving.

And I told you; as if a voltage wave is moving and the gradual charging of the voltage capacitance is due to associated current wave. That means this any voltage wave I told you will be associated with current wave. So, due to this associated current wave; this all the capacitance will be charged and so on.

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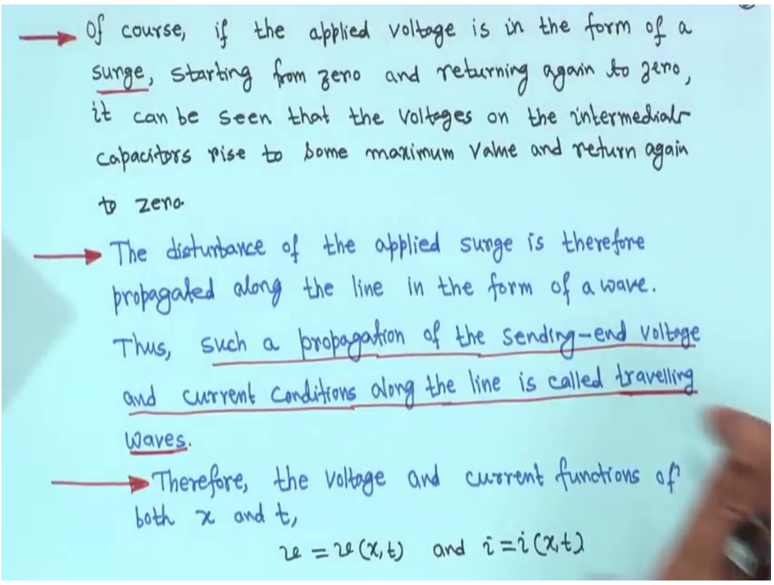

So, done and if the applied voltage is in the form of a surge suppose if the applied voltage is in the form of a surge; say this starting from 0 and returning again to 0. Suppose it is just a your what you call it is form of a surge starting from 0 and returning again to 0. Therefore, it can be seen that the voltages on the intermediate capacitor rise to some maximum value and again return to 0.

So, the disturbance of the applied surge is therefore, propagated along the line in the form of a wave. So, this kind of disturbance will be seen therefore, propagated in the form of a wave; I mean every voltage wave a current wave will be associated with it; the such a propagation of the sending end voltage and current conditions along the line is called travelling waves.

So, that is why its name is travelling wave; your sending end voltage and current along your along the line is called the travelling waves. Therefore, the voltage and current functions of both x and t; we can represent it that is it is v is equal; v function of x and t; I will show you what and I is equal to i x and t; I believe this is the direction, this is the later I will show you; this is the direction is x and moving along time. So, v is a function of your x and t and i also is a function of x and t; that means this.

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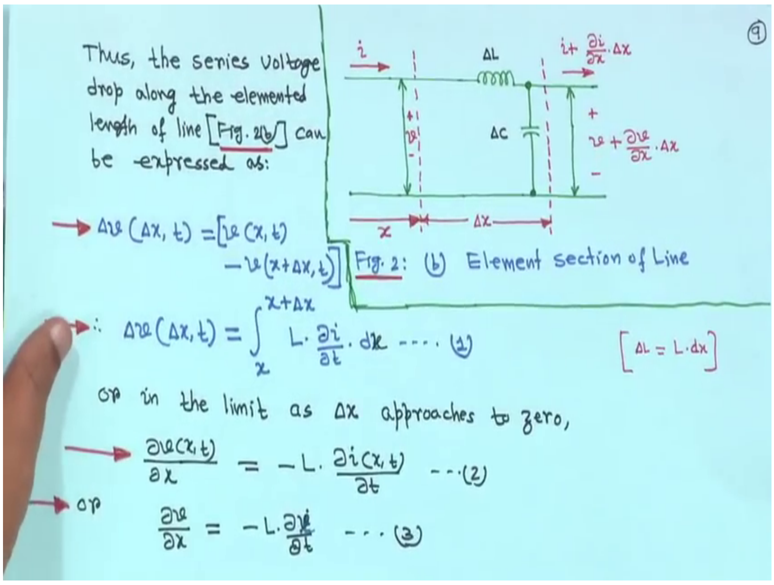

That is the series voltage drop along the your what you call elemented length of line that is small line can be expression. I mean now what you do? You consider a small section of line. This side current is i; this distance is measured from i mean from sending end to the receiving end I mean distance is increasing from sending end to receiving end. This way you have taken and voltage here is v; polarity is shown and as the; it is the small elemented section. So, inductance is say delta L right i mean delta L means; if total inductance is L.

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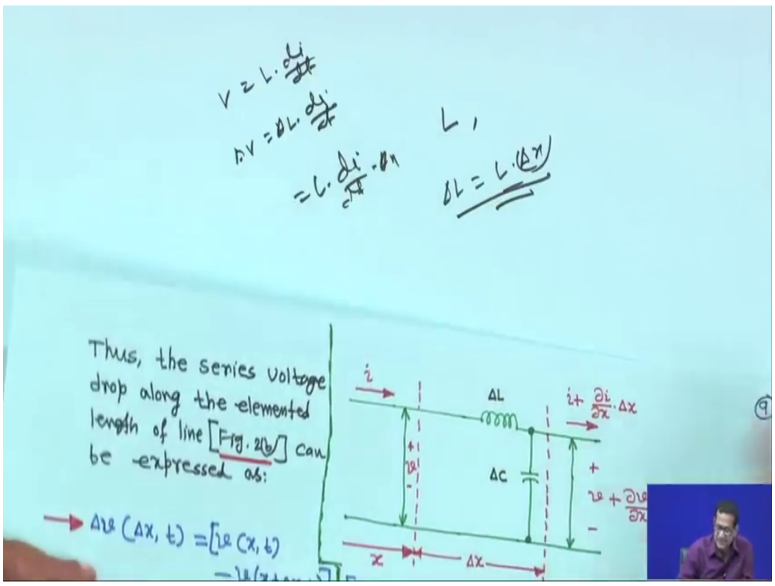

So, inductance is L and length is say d x delta x rather delta x; then delta L actually is equal to L into delta x. So, this is your delta L; that means, this L we are representing say Henry per meter say; may be Henry or Henry whatsoever. So, this is actually delta L same is applicable for capacitor.

Now, when there say this is a small section of course, if this is say sending end side or I will say this is input side, output side; the current will be i plus del i upon del x into d x. This is actually almost same type of representation like your long transmission line that analysis whatever you have studied and voltage here will be v plus delta v upon delta x into d x.

So, this portion; this elementary length is delta x and distance is increasing from your left to right left to right. The distance is increasing; this is element section of line therefore, delta v; this in bracket I am writing function of x and time. So, delta x comma t is equal to this side voltage, you can write here it is not shown in the function V in x t; x t again and again, but it is understandable i means; i function of i x t v means v function also x t.

So, delta v delta x comma; t is equal to v in bracket x t minus v; this side when it is coming x plus delta x; here it is x plus delta x. So minus v x plus delta x comma t, so this one; one can write delta v delta x; t integrate x 2, x plus delta x l into del i; del t into this thing.

I will just told you a actually it is your in general in general just; if when you write no v is equal to L into d i by d t you write. So, if it is a small voltage delta v is equal to delta L into d i by d t that you write. So, delta L is equal to L into d x that is L into d i by d t into delta x; so, we are taking partial derivative.

So, that is why this equation we are writing a L into d x means that is delta L. So, it is L del i; d d t d x. So, this equation actually are in the limit as x delta x approaches to 0; this limit you can write where I am writing in a function of t, but you can directly write del v at del x it is understandable del v; x t del x is equal to minus L, your del i; x t d t. Then why this minus sign is coming? I will come to that later so; that means, del v up del v; now I am not writing again and again. So, del v; del x is equal to minus L del i over d t that is equation 3.

So, here minus sign because x is increasing; you can write here also; if it is minus common it will be v x plus delta x comma t minus your v x t; anyway we will come to that later.

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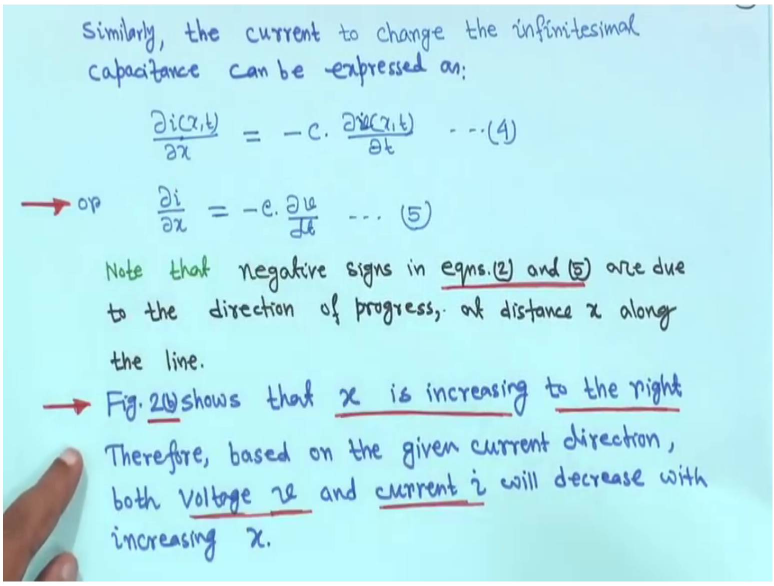

Similarly, the current to change in the change the infinitesimal capacitance can be expressed as you know that your; what you call del i del x; I am writing i is a function minus C into your del v d t v is a function of x t. So, this equation we can write like this I mean from this figure; from this one from this one. So, we can write that del i; del x is equal to minus C del i; x to d t; just once I have written after that again and again I am not writing i is a function of x T or V is a function of x t, but is understandable

That means, del i; del x is equal to minus C into d v by d t; actually your this same as same as before. If you take delta C also; it will be seen to your delta your delta x, so that is why you can write del i; del x is equal to minus C into d v by d t equation 5; this one same philosophy. Now note that negative sign in equation 2 and 5; this is equation 2 and this is equation 5 are due to the discretion of progress at distance x; along the line as it is moving from left to right it is increasing.

So, if you try to make it like this that delta v x t your writing v x t minus; this thing, it will be minus common. It will be v x plus delta x t minus v x t; automatically it will come this come to this. So, it is their x is increasing from left to right left to right; so, figure 2; b shows that in; this is the figure it is 2 b; this figure it shows that x is increasing to right.

Therefore, based on the given current direction both voltage v and current i will decrease with increasing x; that means, as both x is increasing both left to right. Therefore, the both voltage v and current I will decrease; so it increasing the value of the x. Now though; so I can be eliminated from equation 3 and 5 by taking the partial derivative of equation 3; that means this equation with respect to x and equation 5 with respect to t. Now equation; 3 is this one equation 3 is this one right equation; you come back to equation 3, that is this one you take the derivative this one with respect to x.

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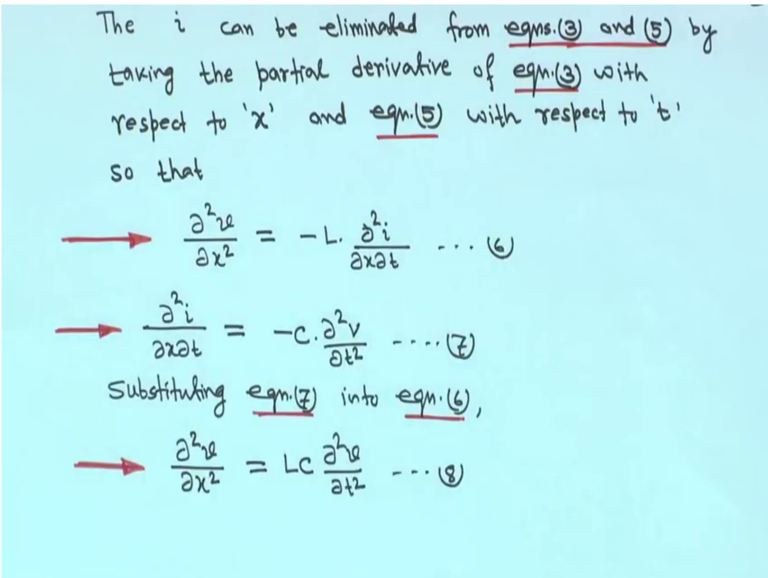

So, this will become del square v del x square that is del square v del x square is equal to minus L it is L into del i del x del t minus L into del I del x del square i del x del t this equation 6. Similarly, these equations 5; if you take derivative with respect to t this equation 5 with respect to t. Then del it will be your del square i del x; del t is equal to minus C del square v del t square; this is equation 7.

So that means, equation 3 you take derivative with respect to x, and equation 5 you take derivative with respect to t. Therefore, after getting these two equations you substituting equation 7 into equation 6; that means, if you substitute this one equation your 7; that is del square i; del x del t; is equal to minus C del square v d t square. Here you substitute this one here; so minus minus plus; so it will be L C; the del square v del x square is equal to L C, it will become your del square v d t square. This is equation 8.

We will come back again.