Fundamentals of Electrical Engineering
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Lecture - 26
Capacitors & Inductors (Contd.)

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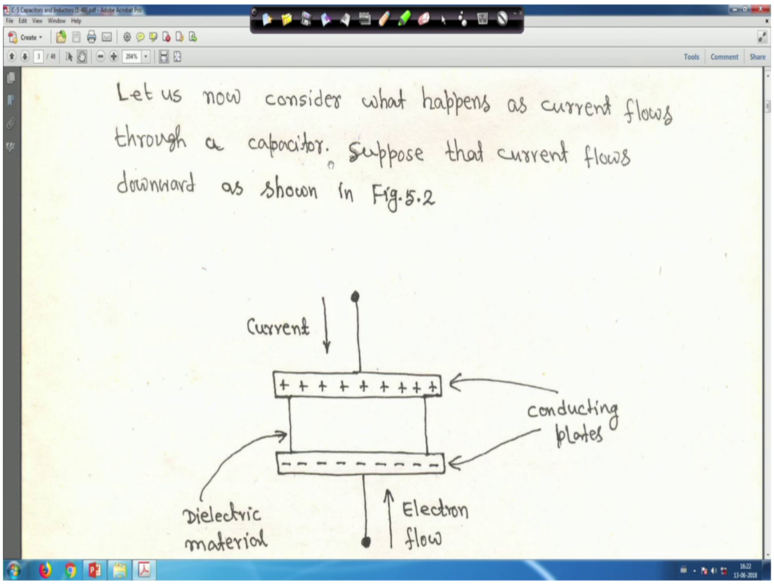

Ok, so let us come to this topic capacitors and inductor. We have just started with that right. So, now you know let us consider what happens as current flows through a capacitor right. Suppose that current flows downwards as shown in this figure, in this figure right.

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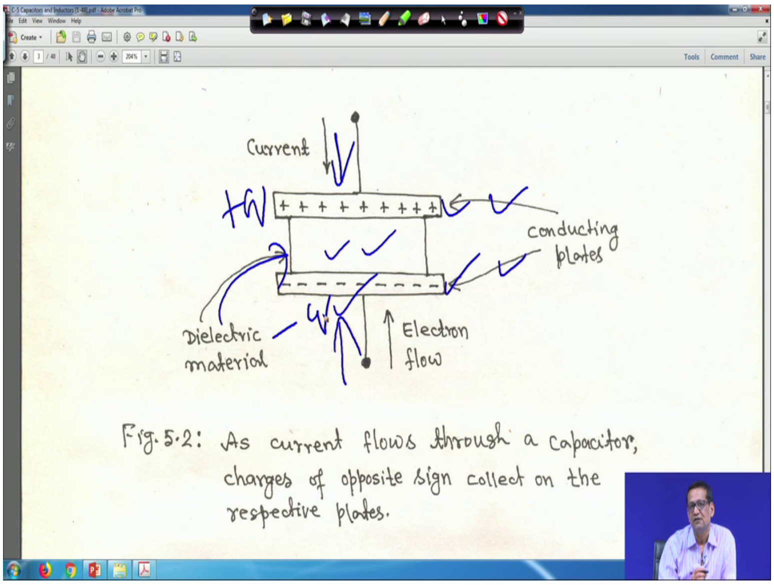

So, it is this is this is shown the direction of the current that current flows; and electron it is given that flowing upward actually and in between this is your dielectric material. And these two this one and this one these two are conducting plates. So, as we have taken the direction of the current moving upward. Generally in any metals right that you are what you call that whenever current flows means it is basically your what you call that moving of your electrons right.

Just in that your what you call, if current direction, we will take upwards, electrons move just in opposite direction. So, electron flow will be upwards So, this is that electron flow. So, because of that that electrons actually it this is your this is your upper plate and this is that bottom plate say..

So, here that it here that what you call electrons will be here in the bottom plate. This means that negative charge actually will be accumulated or will be collected, in this your what you call bottom plate that is why it is shown minus, minus, minus, then your negative charge. So, because of this there will be an electric field will be will be created in this dielectric material and electric field will be created. And because of that you are in between these two plates. And this will force the electrons to leave the upper plate to leave the upper plate the at the same rate the way it was accumulated at your that the bottom plate right.

In that way the and the (Refer Time: 02:11) direction of the current will be downwards. And if voltage your what you call that applied across the your these two plates, so and if charge gets accumulated in other way, so our voltage if you apply across this, your two plates naturally your what you call that your charge will your accumulate either at the bottom plate or at the top plate.

But remember that total charge will be either, if the bottom plate, this will be plus q or here it will be minus q, but total will be 0. Upper plate or lower plate, total will be 0 right. But question is that when you say that total charge accumulated on this of the capacitor means it is either upper plate or at the lower plate right.

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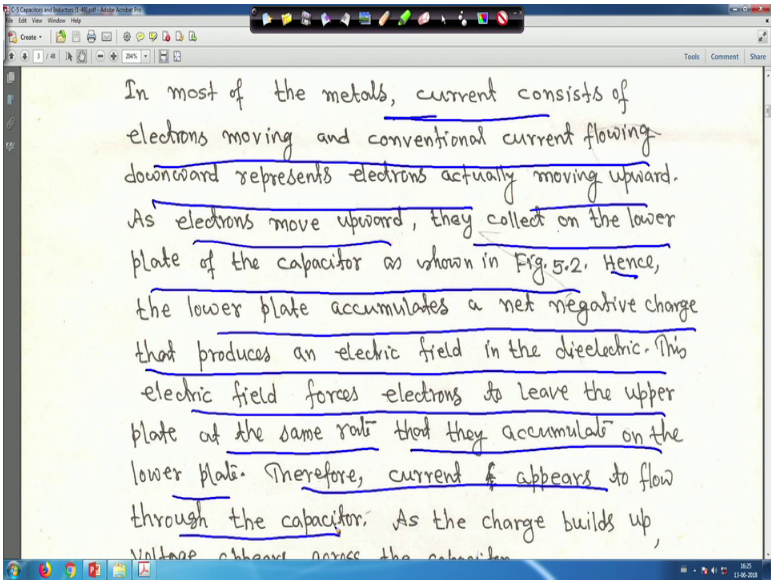

So, let me clear it. So, all this explanation is this is the diagram and all this explanation is here. Whatever, whatever I said that in most of the metals right in most of the metal right, the current consist of electrons moving and conventional current flowing downwards your right represents that electrons actually moving upward right as shown in the diagram. As the electrons move upward, they collect on that lower plate of the capacitor as shown in figure 5.2. Just I showed you the figure.

Whatever I told hence the lower plate accumulates a net charge your negative charge that produce an electrical field in the dielectric. And this electric field forces electrons to leave the upper plate at the same rate that they accumulate on the lower plate right.

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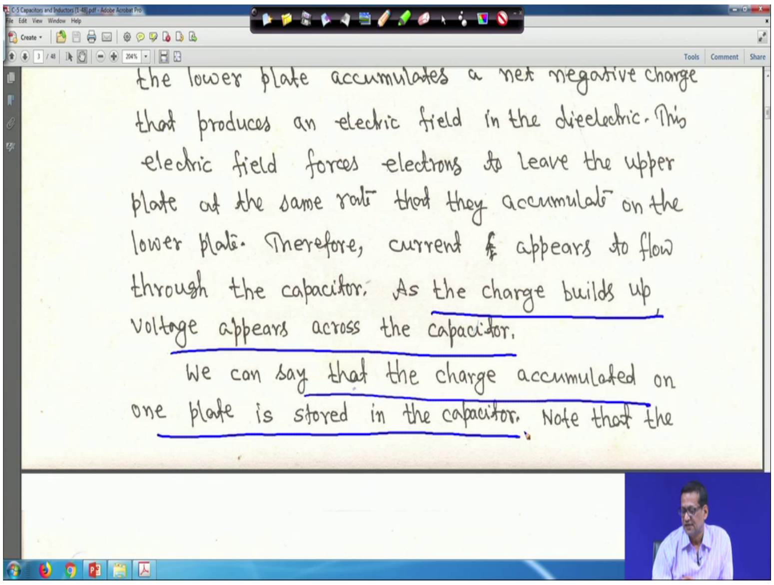

Therefore, current appears to flow through the capacitor rise. And as the and as the your what you call the charge builds up right, voltage appears across the capacitor right So, as the as the charge builds up, voltage appears across the capacitor. So, we can say that that the charge accumulates on one plate is stored in the capacitor. Because if one plate is plus charge and another will minus, but two both the plates if you say, then it will be 0, so as the that is why we can say that the charge accumulated or one plate is stored in the capacitor right

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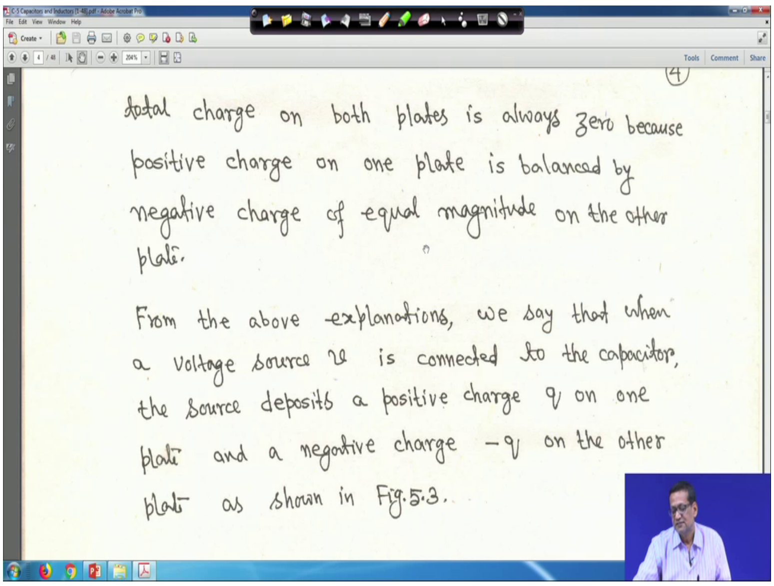

So, if you go to the next, then note that the total charge on both plates is always zero, because positive charge in one plate suppose is balanced by the negative charge of equal magnitude on the other plate, so, total will be 0. So, when we say the total charge it is either of the two plates. So, from the above explanation we say that where a voltage source v is connected to the capacitor, the source deposit a positive charge q on one plate and the negative charge minus q on the other plate as shown in this figure.

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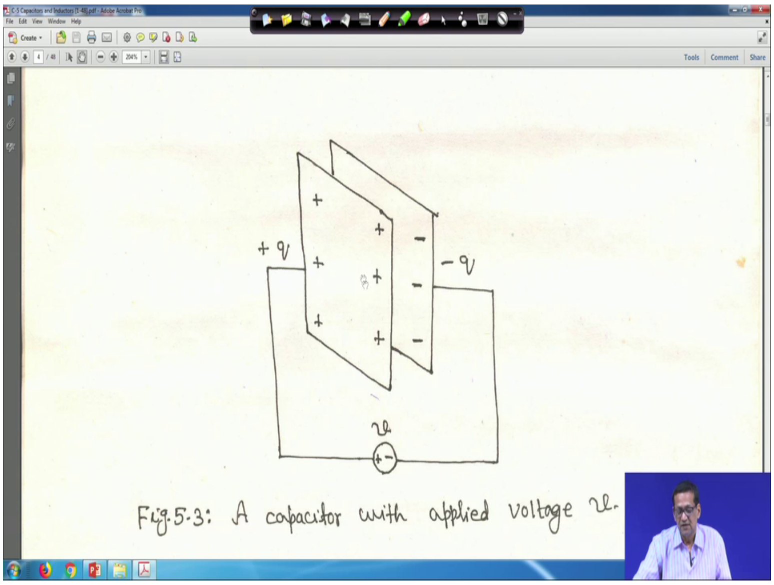

Suppose a voltage is applied between the two your two plate the two plates, so this side this is the plus terminal of the voltage right source and that is why plus charge is accumulated and minus q will be accumulated and total charge will be 0 right. So, when you says to capacitors total charge if the either of the plate, it is plus and this is minus. So, this is simple diagram.

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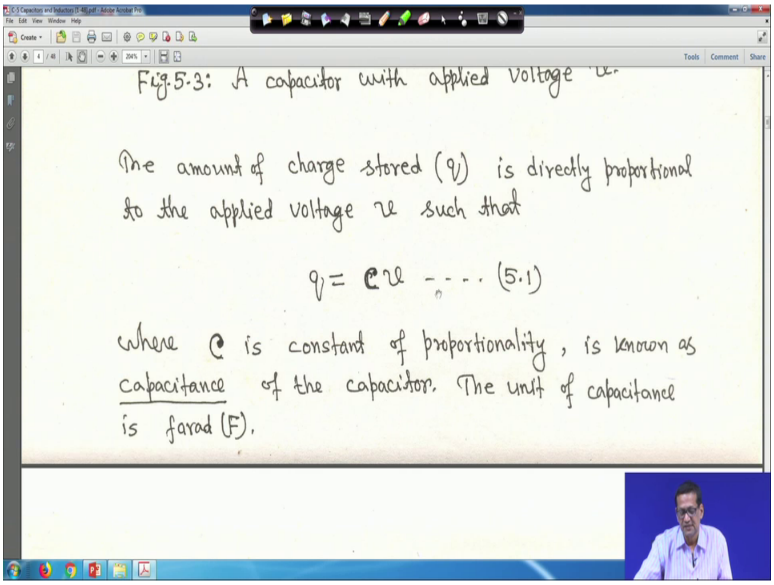

So, the amount of stored amount of charge q is directly proportional to the applied voltage v such that q is equal to c v this is you know also from your physics right, so as similarly physics. So, as c is constant of proportionality is known as capacitance of the capacitor right. And the unit of the capacitance is farad right. So, this you know that q is equal to c v.

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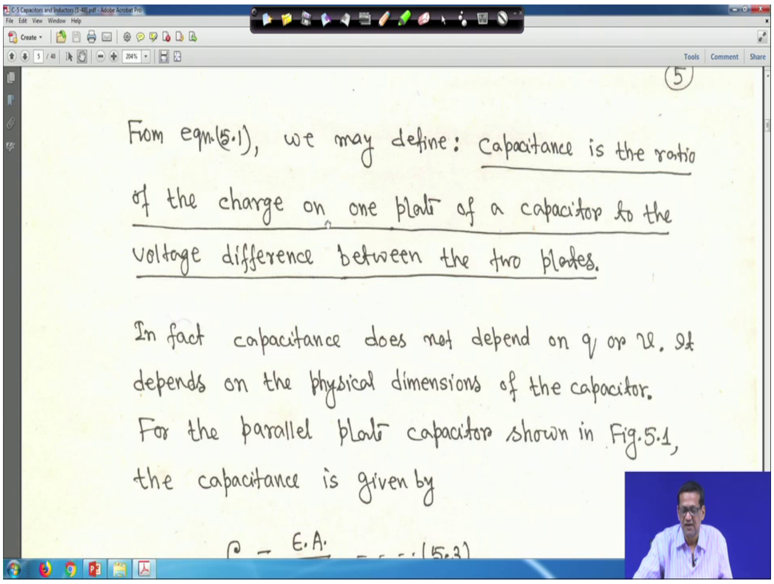

So, from equation 1, one may we may define that capacitance is the ratio of the charge on one plate of a capacitor to the voltage difference between the two plates right. So, in fact capacitance it does not depend on q or v right. So, it depends on the physical dimension of the capacitor. For the parallel plate capacitor as shown in the figure 1, figure already I have shown, so C is equal to epsilon into A into d.

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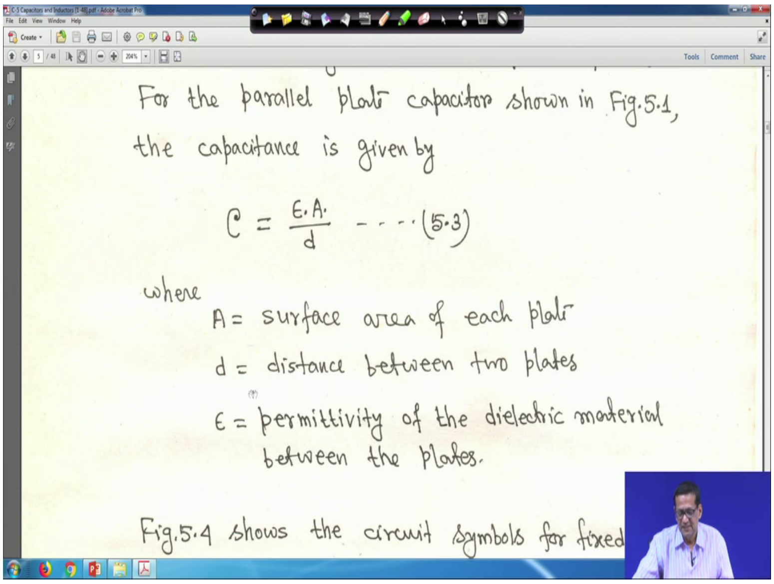

Where A is the surface area of each plate, d is the dielectric distance between two your distance between two plates right and an epsilon the permittivity of the dielectric material between the plates right. So, this is known to us this equation you are familiar with these from your higher secondary physics.

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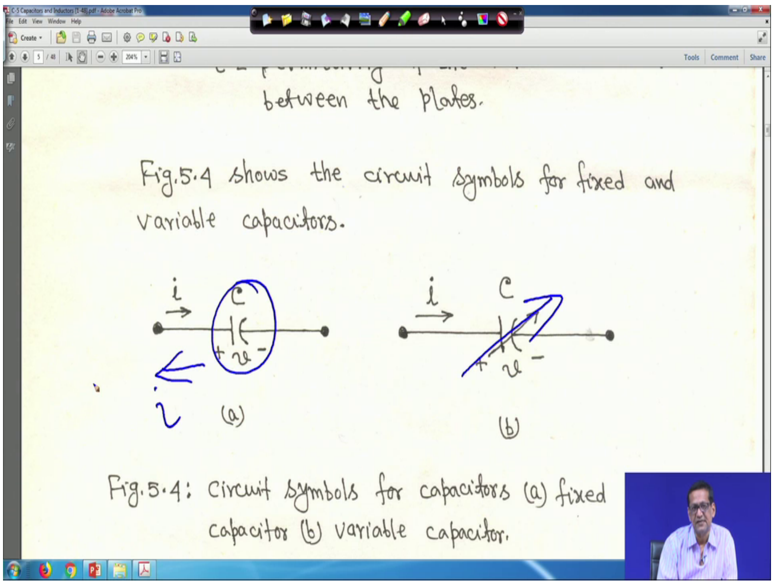

So, from figure 4, now this one shows the circuit symbols for the fixed and variable capacitor. In this case, in this case, variable means just to make a just to make an just to make an arrow, now this is variable now. When the current i is entering in to the positive terminal of the capacitor, now we have marked it here that means in this state the capacitor is charging right, which is charging. If the current leaves from the positive, what you call that positive terminal, if this current leaves from this positive terminal, so capacitor is discharging right. This is the convention we will follow.

So, let me clear it. So, this is the fixed capacitor symbol. And this is the way we have shown the your variable resistance that way we have shown same way. And this is circuit symbol fixed, this is for fixed and this is for figure b for variable capacitor right.

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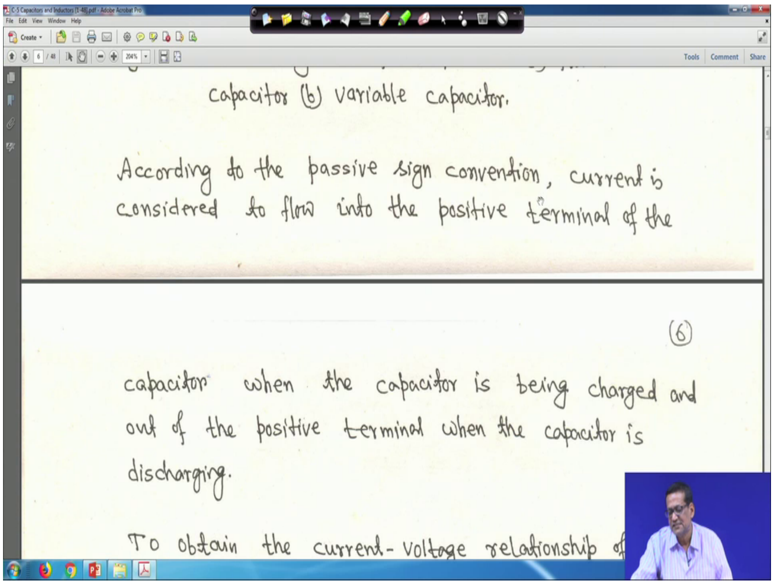

So, just now I told you according to passive sign convention, current is considered to be flow into positive terminal of the capacitor, when the capacitor is being charged right. And your and out of the positive terminal I told you, when the capacitor is discharging.

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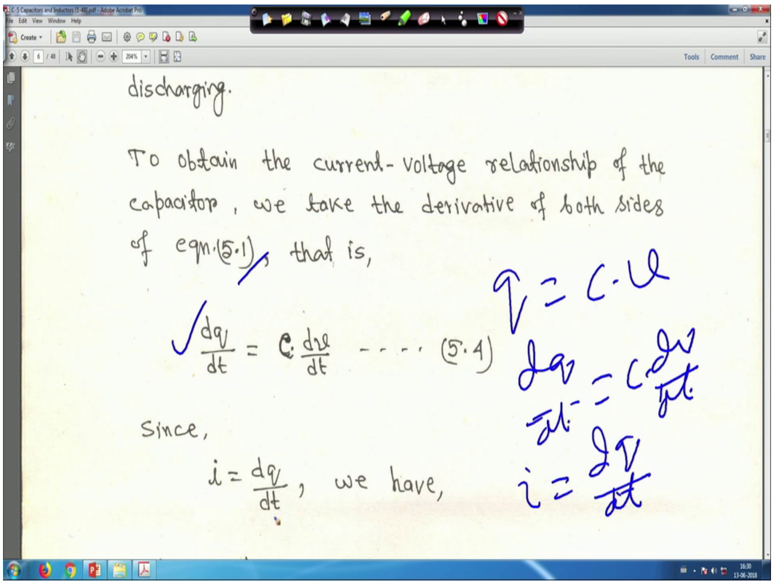

Now, to obtain the current-voltage relationship the capacitor that we have we can take the derivative of that is your q is equal to the in the equation 1 that q is equal to c v, therefore, dq by dt is equal to c into db by dt that is where we are writing here I taking that derivate of this equation 1 with respect to time right. So, dq as we know from the very first chapter the basic concept that i is equal to dq by dt. We also know that i is equal to dq by dt right. So, therefore, i is equal to dq by dt. So, let me clear it so that is your that means, i is equal to therefore, i is equal to dq by dt left hand side.

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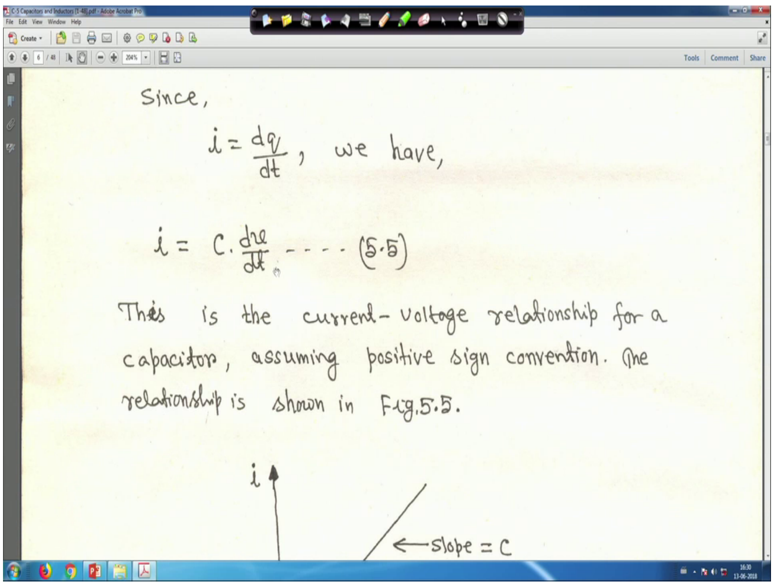

Therefore, i is equal to c into db by dt right. So, this is equation 5.

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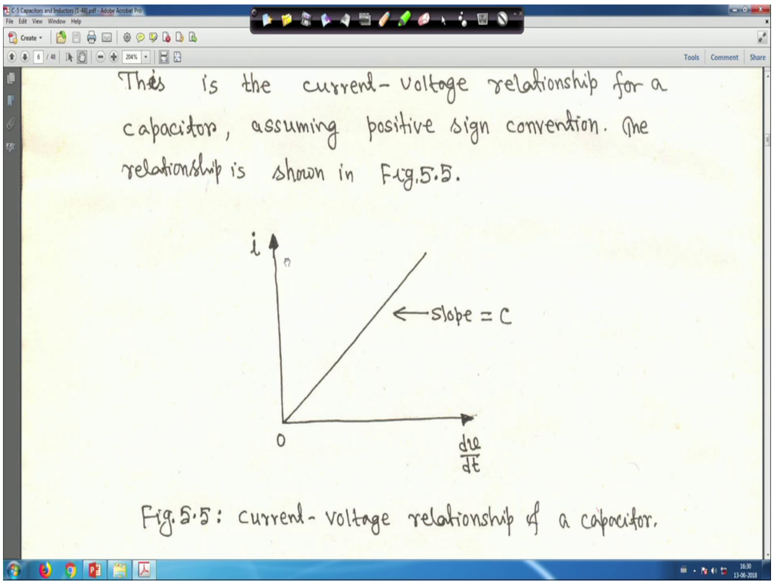

This is the current and voltage relationship for a capacitor, assuming positive sign convention the relationships shown in figure 5. This side is i. This side is dv by dt the rate of change of voltage; this is i and this is the slope c right. So, it is a linear it is it is a linear equation basically right. Therefore, c when c is independent of i your db by d.

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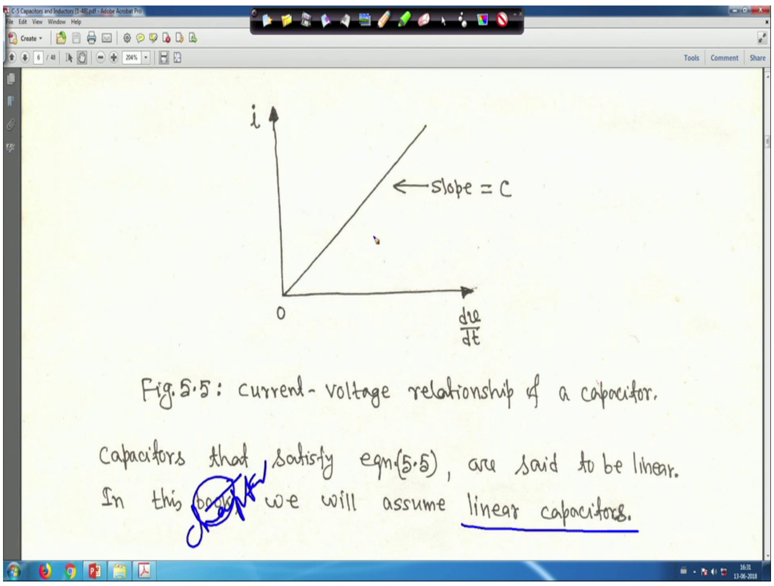

So, that means capacitors that is satisfies equation 5 are said to be linear the from this characteristic also. You can find that this said to be linear. So, here one thing is there many places you will find it is written book. It is not book. You please write chapter in this chapter right not book, book was not never completed actually right. I have not it not completed. So, we will assume that it is a linear capacitor right. So, because of this relationship we will say c is completely independent y (Refer Time: 09:47). So, it is a linear capacitor.

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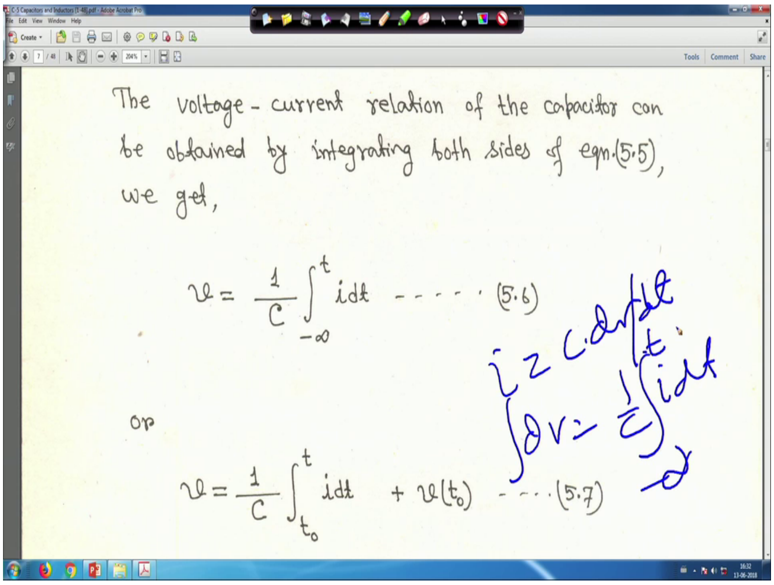

So, next is that next is the voltage current relationship the capacitor can be obtain by integrating both sides of equation 5 we will get, because here we know that i is equal to c into dv by dt right ah. So, dv by dt right, that means, my dv will be 1 by c idt. So, if we integrate both side right, if we integrate both side, it will be minus infinity to t some limit you get right. So, question is now that let me clear it. Now, question is that this limit we have put minus infinity and we are writing actually v t 0 as that 1 upon c t 0 t i dt plus b t 0.

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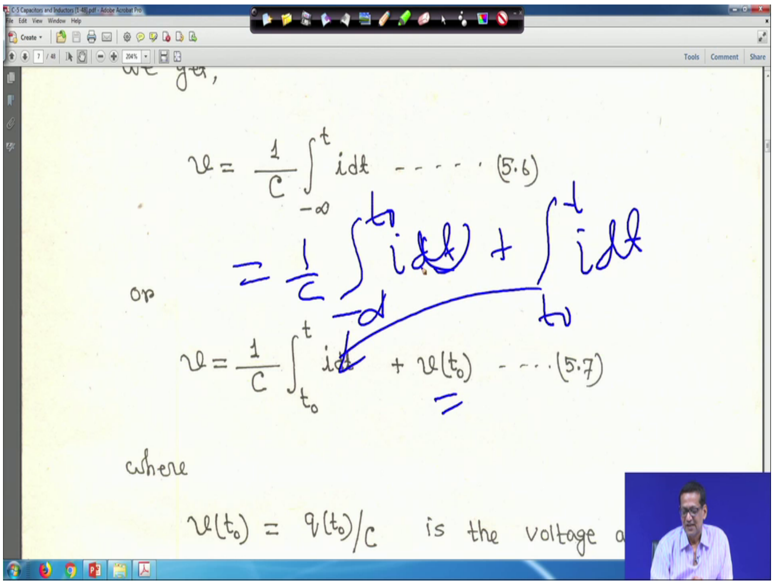

Actually this equation this equation this equation if I write like this, 1 upon c sometime say minus infinity to t 0 right. If we write i dt right, so if we right i dt then plus then t 0 to t then i dt this way you can write. So, this equation is here, this is this equation right t 0 to n. So, this equation 1 by c you are writing actually your what you call that is v t 0 here what you call v t 0 this equation you are writing actually. This let me clear it.

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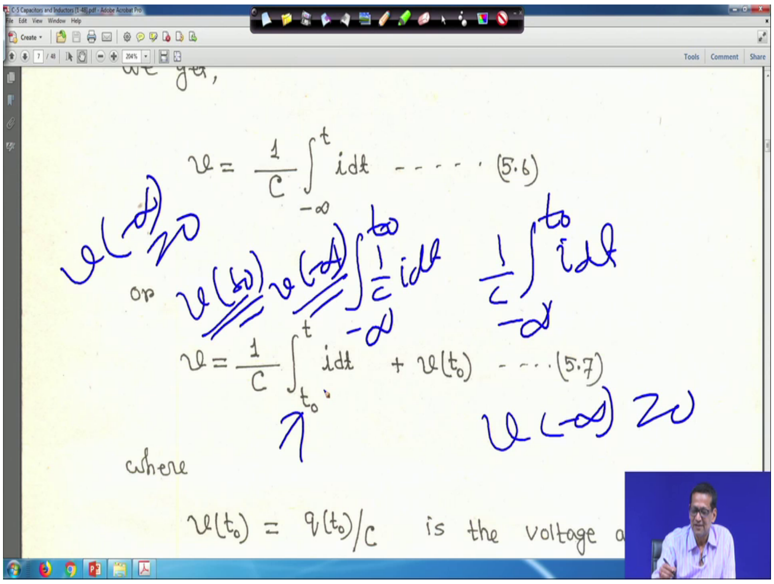

Actually this term that 1 by c when you write minus infinity to t 0 right your then i dt if you if you try to write this equation this way, we you know that your what you call that in in some in the past sometime that your what you call that your in that capacitor right that voltage may be 0 that mean that v minus infinity at some time in the past it was 0 right. There was no there was no voltage then write capacitor was uncharged. So, and this this part that means, this part if we write like this, this basically if you make it like this that 1 upon c id dt and minus infinity to t 0 right.

If you make t 0 is some initial some sometime right and from t 0 t that this part is here. So, if you write like this, and if you try to integrated because of 1 upon c i dt will be basically your say your whatever we whatever we have done that is your dv right. If you integrate this, it will be if you integrate this one, it will be v t 0 minus say v minus infinity.

So, and the some part some here what you call sometime in the past that may be this v minus infinity was is equal to 0 right, so that that means, that you are what you call that your capacitor at that you can say that there are there is no voltage that was the capacitor be some part some part of the time in the past right. So, in that case what will happen only v t 0 will be there that is why this is let me clear it, that is why this equation is there t o to t and this v t 0 it is actually should have been v t 0 minus v of minus infinity, but v of minus infinity should be 0 right.

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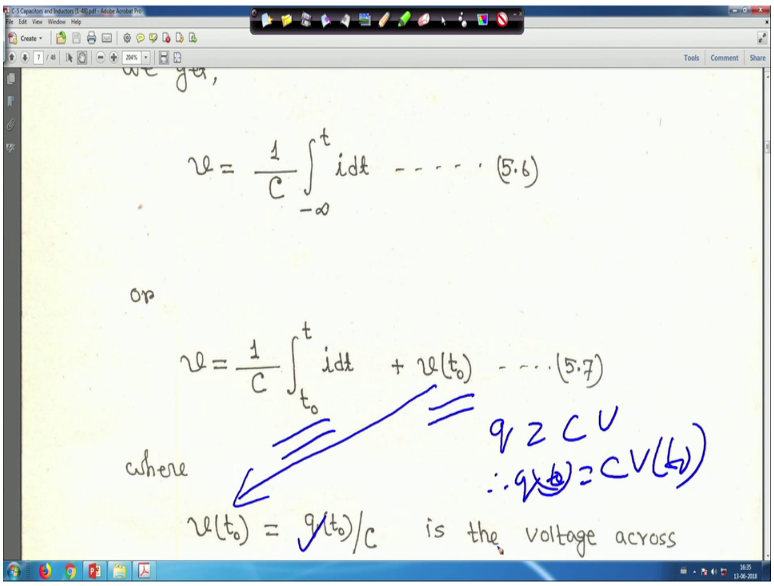

Or we can write from the relationship we know from the this equation your what you call you know this one that q is equal to c v or qt at time any time t 0 q t 0 is equal to c v t 0 right. This is what we have written v t 0 is equal to q t 0 upon c that means, this term, this term right is the voltage across the capacitor at time t is equal to t 0. Hope this you have understood this actually whenever you take this one that is basically will take this past history of the current flowing through the capacitor right that is the idea. So, anyway let me clear it. And just hold on.

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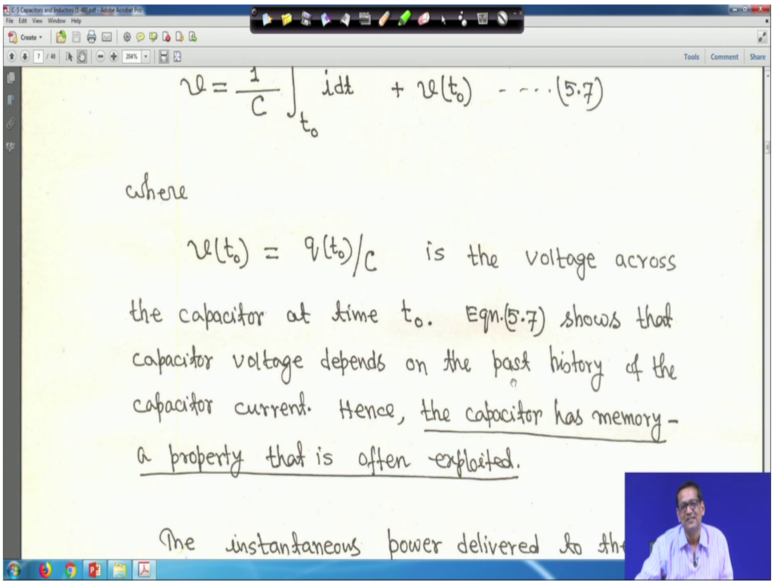

So that means, v t 0 is equal to qt 0 by c is the voltage across the capacitor at time t 0. Therefore, this equation 7 that means, this equation 7 shows that capacitor voltage depend on the past history of the capacitor current right and because of that that v t 0 is here. So, hence the capacitor say we can say has memory that is a property that is often exploited right, so that is why these equation we are writing that from the past we have taken at some time at present t so minus infinity to t 0 plus t 0 to t that what I wrote previously.

And I told you that v minus infinity will be 0. So, in that case, so this instantaneous power delivered to the capacitor is p is equal to v i right, but i is equal to c into dv by dt. So, upon substitution if I am not writing here it is understandable.

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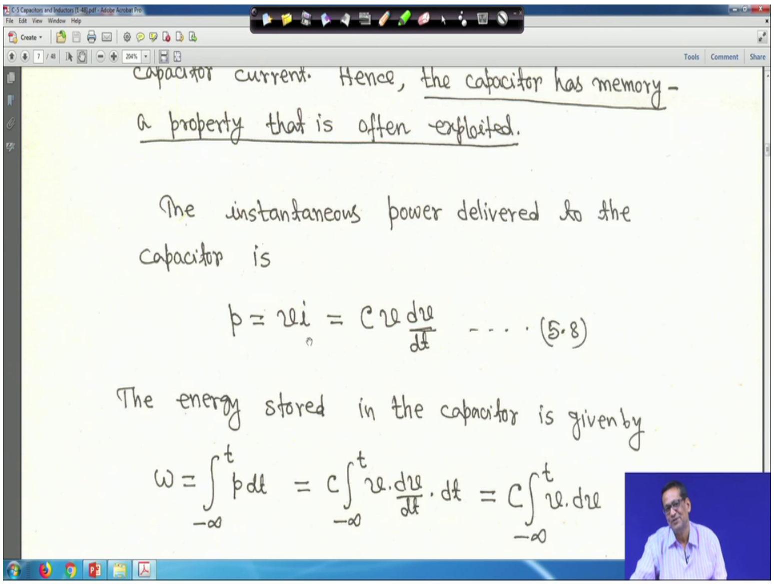

So, put i is equal to c into dv by dt here. So, it will be cv dv by dt, this is equation 8. Now, the energy stored same as before in the capacitor is given by minus infinity to t p dt right. So, it is p into dt say p is the power v i and multiplied by time. So, this is energy and minus infinity to t. So, is equal to you can write c into minus infinity into t and your t is equal to cv dv by dt you put here expression of t if you put here it is cv dv by dt; c is a constant taken outside of this integration, and then v into dv by dt, so dt dt gone. So, it will be c integration of minus t v into dv right. Now, if you integrate if you this is understandable simple thing.

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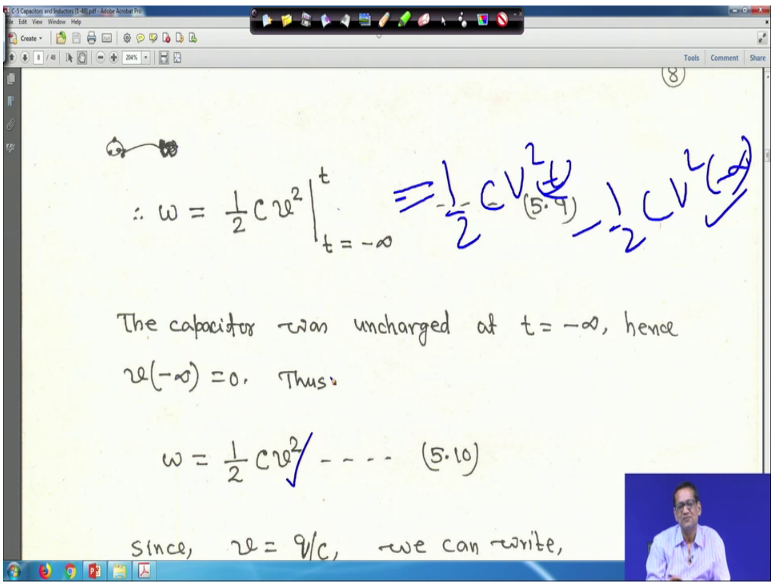

If you integrate, then it will be half c v integration will be c v square by 2, so half c v square t is equal to minus infinity to t right. Therefore, the capacitor was un charged at t is equal to minus infinity. I told you that at the past in the past at some time, capacitor will remain uncharged. So, v minus infinity will be 0, I told you right. Therefore, if that it will be half c, it will be half c v square minus your it is understandable. Actually it is v t square, but t here omitted just put v square minus it will be half c v, minus infinity square actually it should be like this. It will be actually half c v square if you take function of t, then minus half c v square minus infinity, but v minus infinity is 0. So, t is omitted here we simply written half c v square. So, this is equation 10 right.

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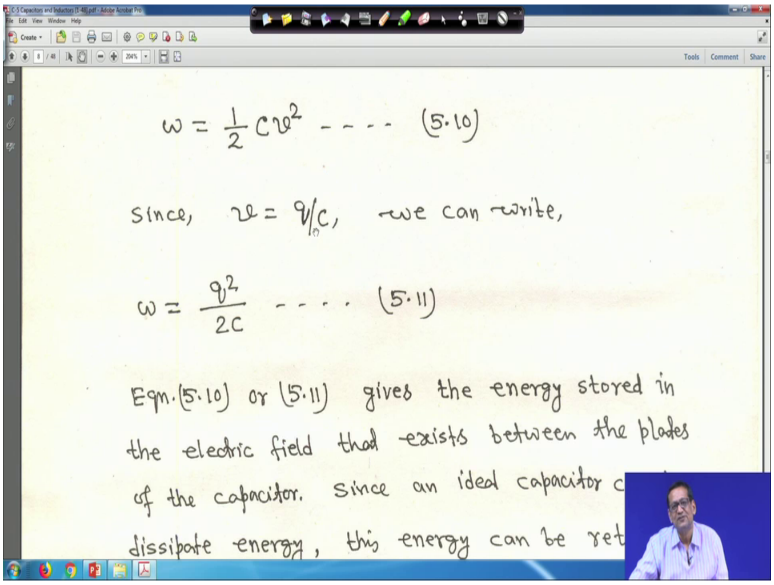

So, next you next you take that v is equal to q by c, we know that q is equal to c v. And substitute here if you put it here, then you will get w is equal to q square by 2 c. This is equation 11 right. So, this equation is what you call that in a energy equation right. This energy stored in the capacitor that that is your what you call half cv square or half c q square right.

So, equation 10 and 11 give the energy stored in the electric field that exists between the plates of the capacitor. That you have capacitor you have two plates, so energy stored in the, what you call in the electric field that exist between the plates of the capacitor. Since an ideal capacitor cannot dissipate energy right. This energy can be retrieved like resistor the energy is dissipated in the form of heat. But in this case, when the case of ideal capacitor it cannot dissipate energy, energy can be this energy can be retrieved.

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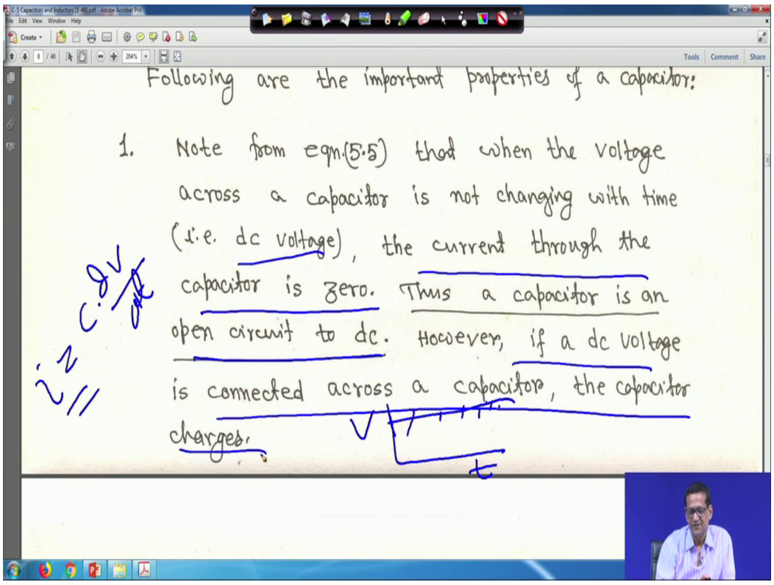

So, following are the important properties of a capacitor first one is from equation 5 that when voltage across the capacitor is not changing with time that means, your i equal to that is equation 5 dv by dt when voltage across a capacitor is not changing with time that is your dc voltage. Suppose, for example, I am making it for you. Suppose, this is time right and this is voltage and if you take a dc voltage, it is a constant. So, any time any place any point you take the derivative dv by dt will be 0. Therefore, if it is dc voltage, so I will be is equal to 0 that means, when the voltage across the capacitor is not changing in time the current through the capacitor is 0 right. This is of course, a steady state condition when we apply dc voltage.

When will see the dc transient after this topic at that time will see the behavior of capacitor as well as inductor that we will come later. So, thus the capacitor is an open circuit to dc when you going for steady not at the time of switching, switching at the time of switching things different right, but thus a capacitor is open circuit to dc. However, if a dc voltage is connected across a capacitor, the your what you call the capacitor charges. Suppose, you connect a dc voltage across a capacitor, capacitor will be getting charged right. So, let me clear it.

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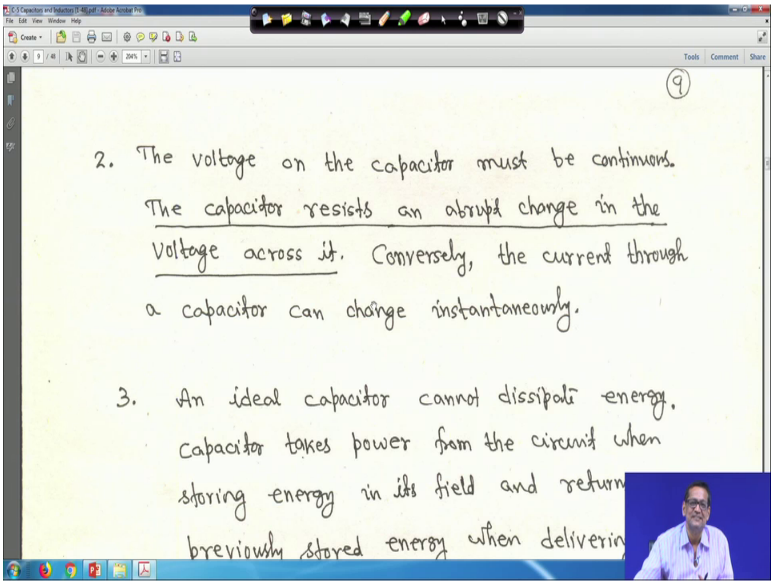

So, so second point is the voltage on the capacitor must be continuous right; it must be continuous. The capacitor resist and abrupt change in voltage across it. I have underlined this right. Conversely, the current through a capacitor can change instantaneously that will see in the dc transient time right not now. So, conversely the current to a capacitor can change instantaneously.

So, particularly after learning this the behavior of capacitor in that term particular steady state condition; but when we will consider a dc transient after covering this topic at that time we will know much more about behavior of the capacitor as well as inductor during your what you call that transient condition I mean switching right. So, that is why your conversely the current though a capacitor can change instantaneously right. So, this is one thing.

And next one is an ideal capacitor cannot dissipate energy, I told you earlier right. Capacitor takes power from the circuit when storing energy in its field right and returns previously stored energy when delivering power to the circuit right. So, now this is this is all about capacitor. So, because we have to we have to consider dc transient, so that is that is why that at the same time while we consider ac circuit at that time resistance capacitance all this you what you call inductance all will come. So, that is later that is your after completing dc transient, we will go for single phases circuit at that time will know much more right. And of course, we will not study ac transient as far as your as far as I can say that first year engineering syllabus is concerned right. So, next we will take some example say some examples.

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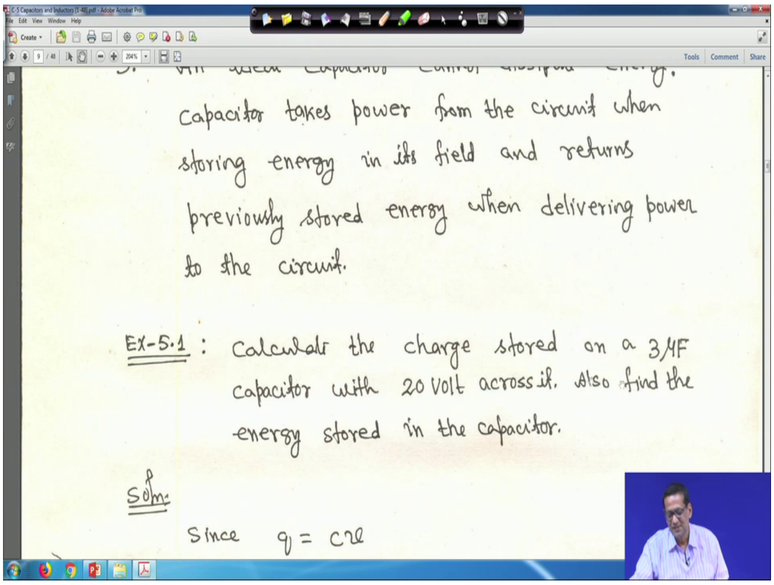

For example, that calculate the charge stored on a 3 micro farad capacitor with a 20 with 20 volt across it also find the energy stored in the capacitor very simple thing. It is given 3 micro farad; q is equal to cv, so c is 3 micro farad; that means 3 into 10 to the power minus 6 farad. And voltage is 20 volt, so it is 60 micro coulomb right.

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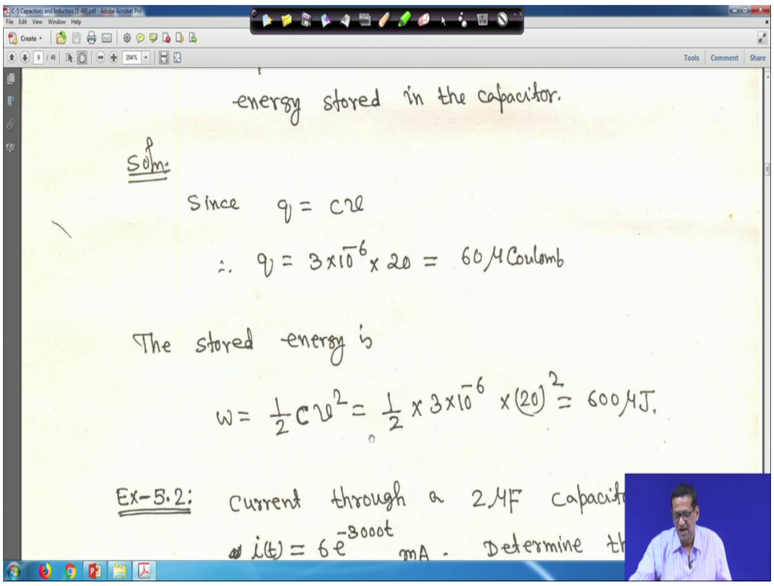

So, store energy half cv square half c is 3 into 10 to the power minus 6 farad micro farad you convert it into farad. So, half into 3 into 10 to the power minus 6 into v square 20 square that is 600 micro joules right.

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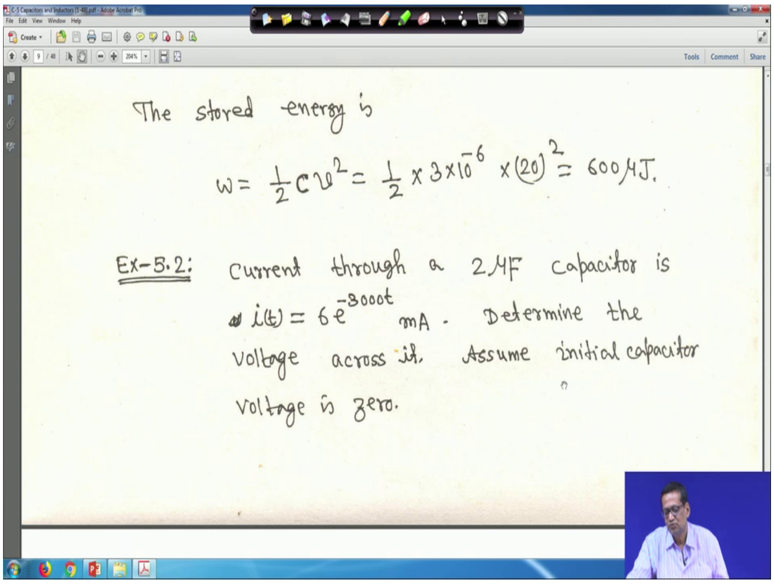

Next one is it is given that current through a 2 micro farad capacitor is i t is equal to 6 into e to the power minus 3000 milli ampere. You have to determine the voltage across it assuming initial capacitor voltage is 0 right.

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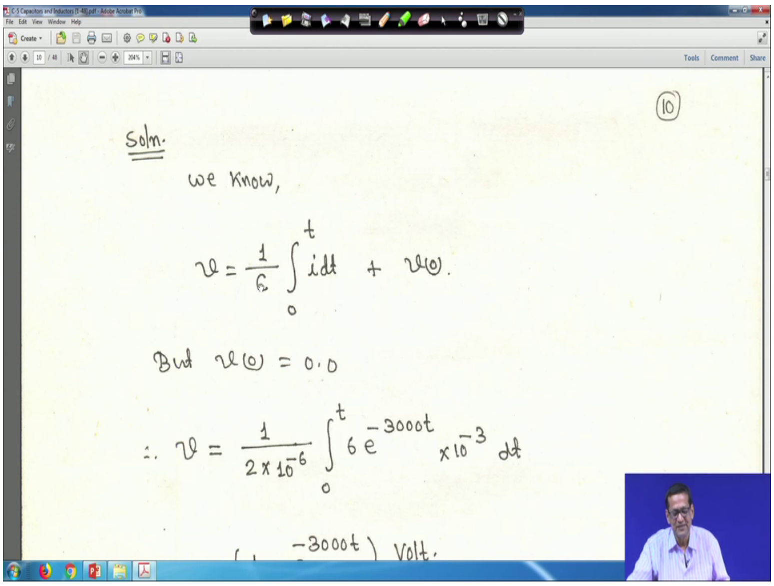

So, we know we know this formula that v is equal to 1 upon c 0 to 2 integration of i dt plus v 0. I mean if you go back that mean this equation this equation right I am going back. So, this equation v is equal to 1 upon c idt. This is the equation 7 right. Then it again will come down. So, in this case, you assume the this equation, this equation 7 right. So, it is 1 upon c 0 to t i dt plus v 0. We have taken initial time t 0 is equal to 0. But v 0 is equal to 0 in the problem it is given current through a 2 micro farad capacitor is the determine the voltage across it assume that capacitor voltage is 0 that is initial capacitor voltage is 0 that is v 0 equal to 0.

So, here it is v 0 is equal to 0, and c is 2 micro farad. So, 1 upon c that is 2 into 2 into 10 to the power minus 6, it is 0 to t that 6 into e to the power minus 3000 t into 10 to the power minus 3, because this current was given in milli ampere 6 into e to the power minus 3000 milli ampere, you are converting into ampere. So, multiplied by 10 to the power minus 3 so, that is why here it is multi into dt. If we have to integrate it mu will be 1 minus e to the power minus 3000 t volt, this is the answer right.

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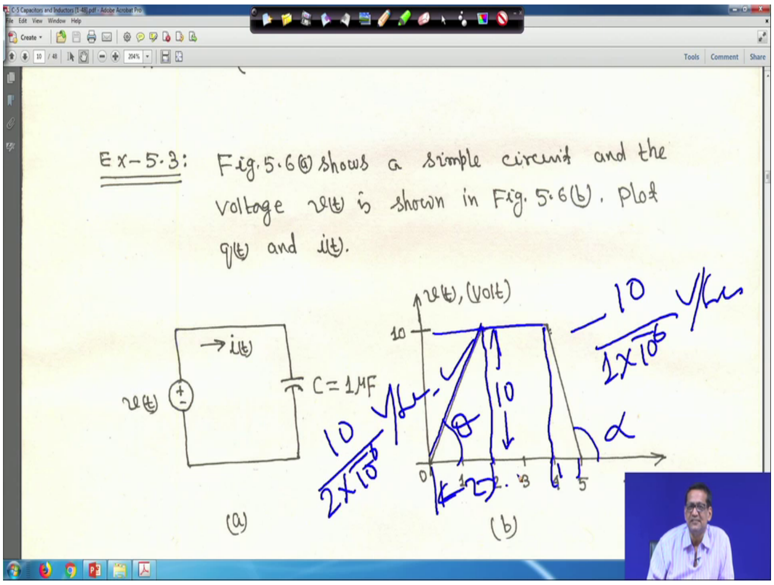

So, this easy example easy example, now, next one is figure 5.6 say that is I will say 6.a because that it is chapter five. So, is a simple circuit? And the voltage v t shown in figure 5 this 6 b. You have to plot q t and i t. Now, question is it is given your this circuit is given. This simple series circuit and one voltage source is connected with the capacitors c in series; c is equal to given 1 micro farad. And i t is and current flowing through the i t right. And here it is your what you call that waveform of the voltage is given.

So, actually drawing this drawing is little bit like this, it will be actually here right. So, it is actually if you take the, if you take the before telling, if you take the slope of this straight line. So, this is 10 volt and this is in micro second, it is micro second. So, if you take the slope of this straight line, it will be this is 10. So, here it is 10 and this is your what you call this is your 2 right. So, the slope will be 10 divided by it is micro second 2 micro second that means, 2 into 10 to the power minus 6 whole power second. This is the slope of the straight line right. If this is the slope this is the slope. So, tan theta this is the slope.

Similarly, let similarly for this one, this is the slope. So, this is the slope. In this case here for this straight line here it will come, so it is it will 1 second only, 4 to 5 means only 1 second. And this is 10, so and this is the angle is more than 90. So, this is one what you call slope will be negative, so it will be minus 10 and 4 to 5 means this is 1 micro second, because it is in micro second.

So, it will be 1 into 10 to the power minus 6 volt per second. This is actually slope of this straight line. And this is constant and this is constant; from 2 to 4 second, it is constant right. So, this is the voltage that means, voltage from 0 to 2, it is a time varying. And again from 4 to 5 micro second, it is time varying; in between 2 to 4 micro second, it is constant; this voltage source is given right. So, let me clear it.

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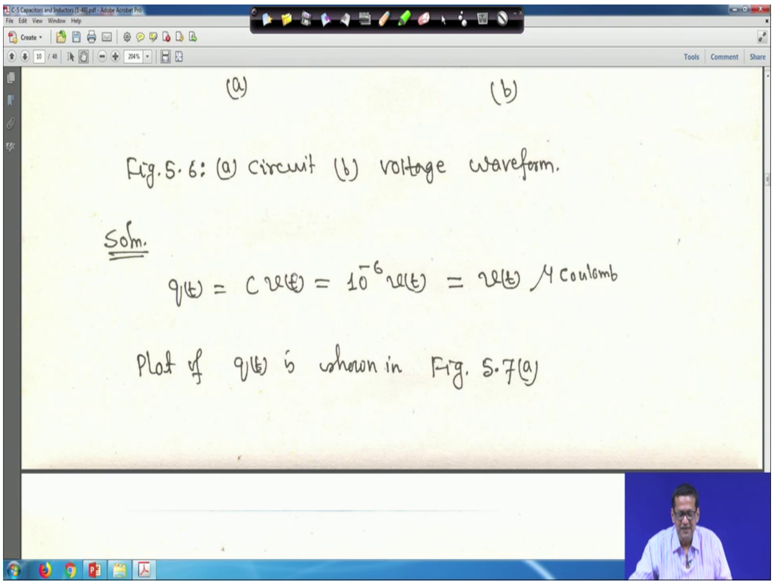

Now, we know we know that q q is equal to c v. So, in general we can write q t is equal to c v t right. And c here is 1 micro farad that means 10 to the power minus 6 farad. So, it is 10 to the power minus 6 into v t that means, we can write that your unit of q q is coulomb. So, it is v t into it is 10 to power minus 6. So, v t micro coulomb right, there should not be any confusion in case 10, 10 to the power minus 6 and converted this v t micro coulomb right.

Now, plot of q t shown look the plot of q t will be q t is equal to v t micro coulomb right. So, q t is actually your directly your coming to v t that means this shape of that q t will be same as your v t, because q t is equal to v t micro coulomb. So, whatever shape is there for v t, it will be same shape right; only thing is that unit will change.

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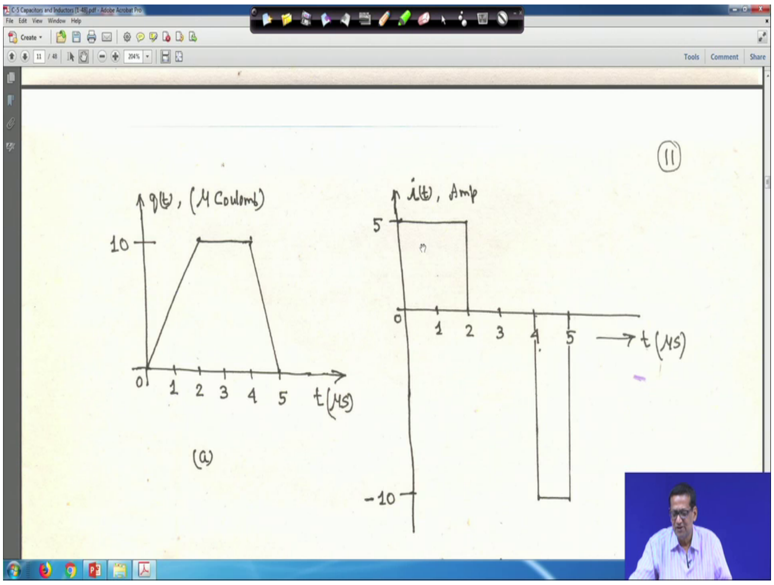

So, if you look at the graph that qt this is this is my q t y axis is q t and this is my t micro second, but this micro coulomb, it is 10 the shape remain same everything will remain same right only thing is that unit will change because q t is equal to basically v t right. If we have taken that c is equal to 1 micro farad, had it been some other value then this 10 it should not have been 10, it should be something else right. Now, second thing is that i t also we have to plot that how will plot the i t.

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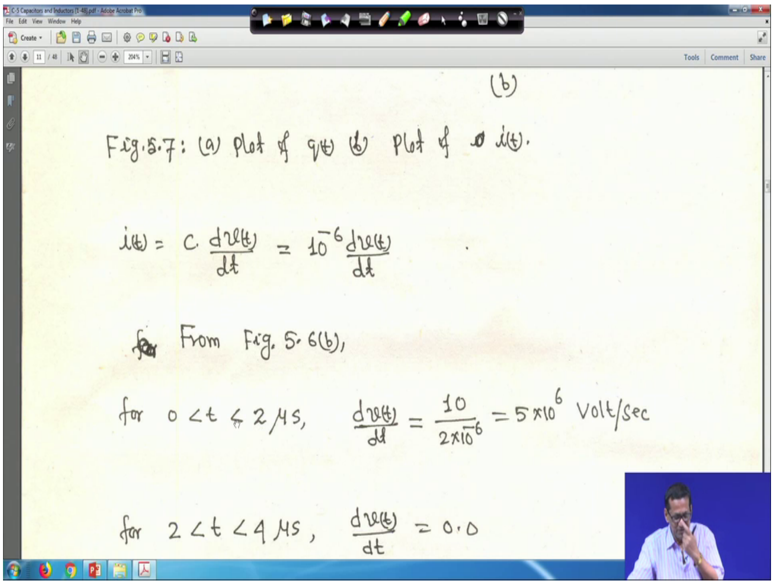

So, now it is it is given we know that i t i is equal to you know c dv by dt that you know. So, in general you can write it is equal to c dvt by dt. C is equal to 1 micro farad. So, here you put 10 to the power minus 6 converted to farad that is why 10 to the power minus 6 into dv by dt, because c is given 1 micro farad. Now, from figure 6 b that means, this is figure 6 b, this is figure 6 b, now this your what you call that 0 to your slope we have seen that 10 upon 2 into 10 to the power minus 6 and that and this is passing through the origin.

So, basically you know that any equation of a straight line passing through the origin y is equal to mx plus c. So, c is 0. So, basically from that you can find out actually y axis is v t. So, i will slope is 10 by 2 into 10 to the power minus 6, so v t will be is equal to your 2 into your 10 by 2 into 10 to the power minus 6 into t.

So, if it is if it is given, we will come to the figure later. So, in between 0 to first find out in between 0 to to your 2 second dvt by dt will the slope is 10 by 2 into 10 to the power minus 6 that slope will come computed initially I told you. So, it will be 5 into 10 to the power 6 volt per second. And in between 2 to 4 second dvt by dt 0, because it is at the time it is a it is your what you call if your dc quantity right it is a time varying, it is independent of time 2 to 4.

So, its derivative will be dvt by dt is 0 right. And another thing is in between 0 to your, what you call in between 4 to 5 second, I told you minus 10 by 1 into 10 to the power minus 6, so basically minus 10 into 10 to the power 6 volt per second right. Therefore, for this all this all this your what you call all this rate of change of voltage in different time interval now have been computed.

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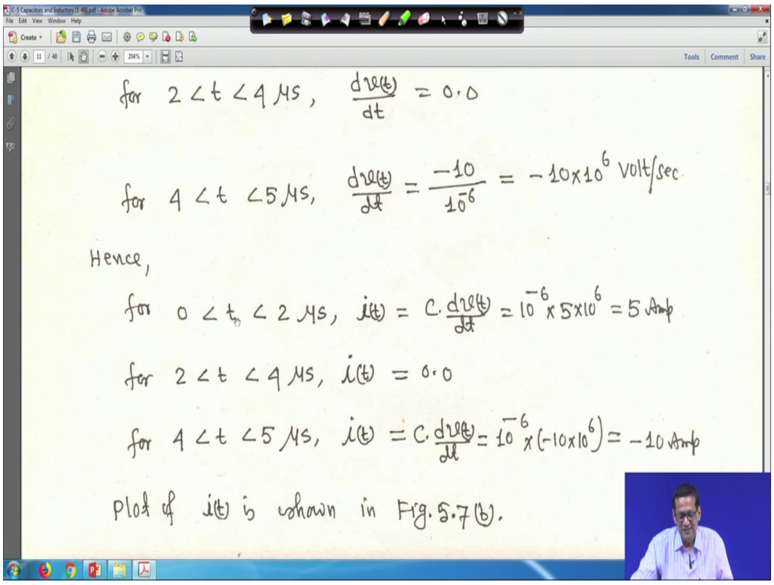

Now, we know that in between 0 to 2 second, we know it is equal to c into dvt by dt. So, c is equal to 10 to the power minus 6; and dvt by dt 5 into 10 to the power 6 is equal to 5 ampere right in between 0 and your 0 to 2 second. Now, in between 2 to 4, i t is 0 because dvt by dt is equal to 0; this dvt by dt is equal to 0 right.

And similarly in between 4 and 5 second, i t is equal to c into dvt by dt. So, dvt by dt 10 to the power minus 6 a what you call that minus 10 into 10 to the power 6 volt per second. So, in in the in this case your c is 10 to the power minus 6 that is farad 1 micro farad, so 10 to the power minus 6 farad into minus 10 into 10 to the power 6. So, 10 to the power 6 and 10 to the power 6 cancel, it will be minus 10 ampere right.

So, plot of i t is shown in this figure. Now, therefore, in between your 0 to 2 micro second, it is 5 ampere, it is 5 ampere. It is a constant. We have calculated. Then 2 to 4 second, it is 0, so it is 0. And then 4 to 4 second, now it is minus 10, your what you call ampere, so that is minus 10 that 4 to 5 this is the plot for i t. I hope you have understood this one right. So, this simple thing very simple thing only you have to understand step by step. Now this is that your what you call that just for your understanding only each and every step I have computed for you such that we such not you know I mean you should not face any problem for solving. So, figure already I have shown.

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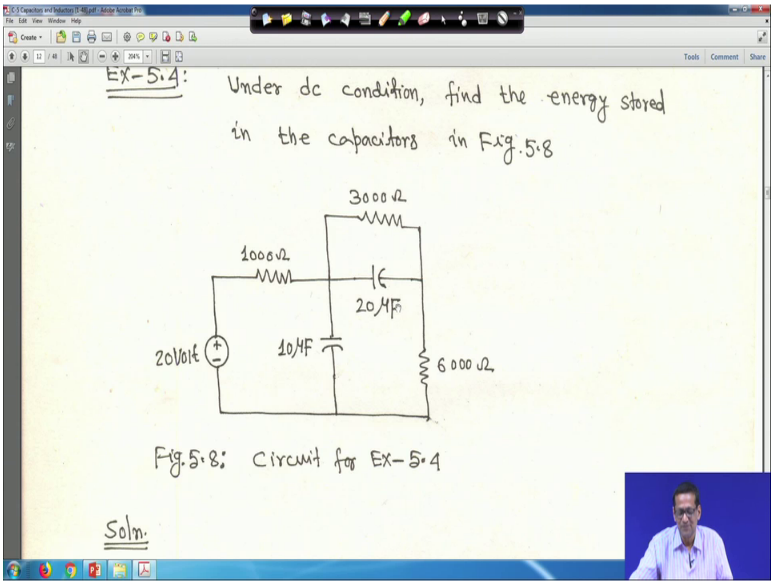

So, now under dc condition now find the energy stored in the capacitor in figure 5.8.So, this is my figure 5.8. We will have to find out that what your the energy stored in the capacitor. So, this is 1000 ohm, 3000 ohm, 6000 ohm, and this is 20 micro farad, this is 10 micro farad. Now, we will we will redraw the circuit right under dc condition that that 10 micro farad 20 micro farad it will be open at steady state right; and 20 volt dc is applied. So, if you read out the circuit, this is open.

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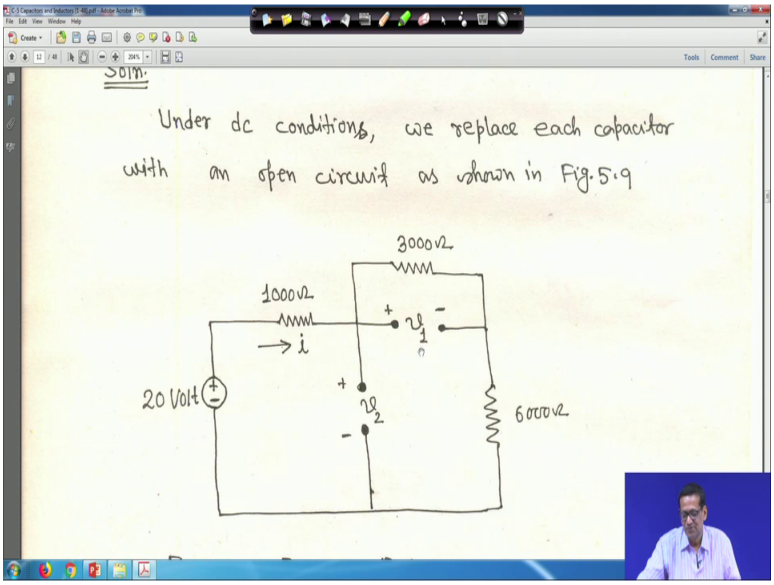

Say voltage across this 20 micro farad is b 1, this voltage is b 1, and this voltage is b 2 right. So, this is open. So, this is open. So, this current is i, this i is flowing like this; i is flowing like this right because this is open this is open right. So, 1000, 3000 and 6000, so 10,000 ohm right.

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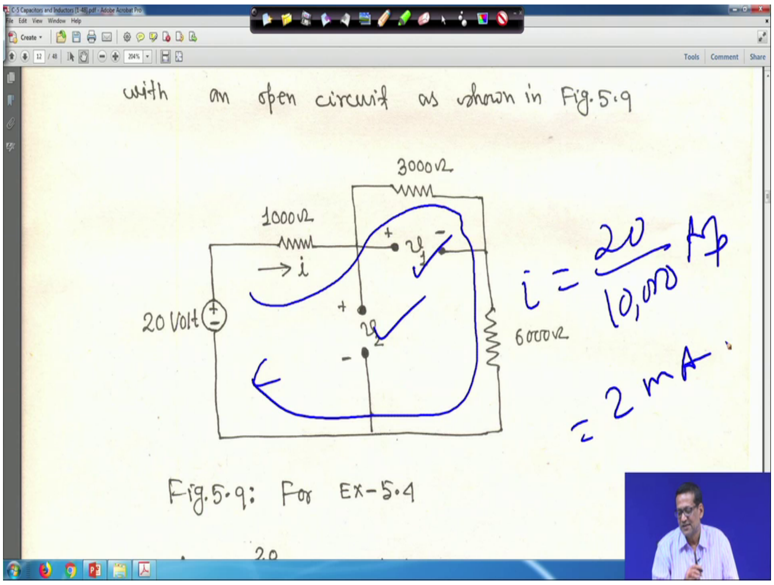

Therefore, i is equal to your 20 by your 10,000 ampere right. This is your what you call this thing that means that is equal to actually 2 milli ampere right. So, this is your i that i i once you comp once you compute the i, then you can easily compute the b 1 and b 2. So, before showing you the calculation, so if you see the what will be b 2 because same i say just 1 minute.

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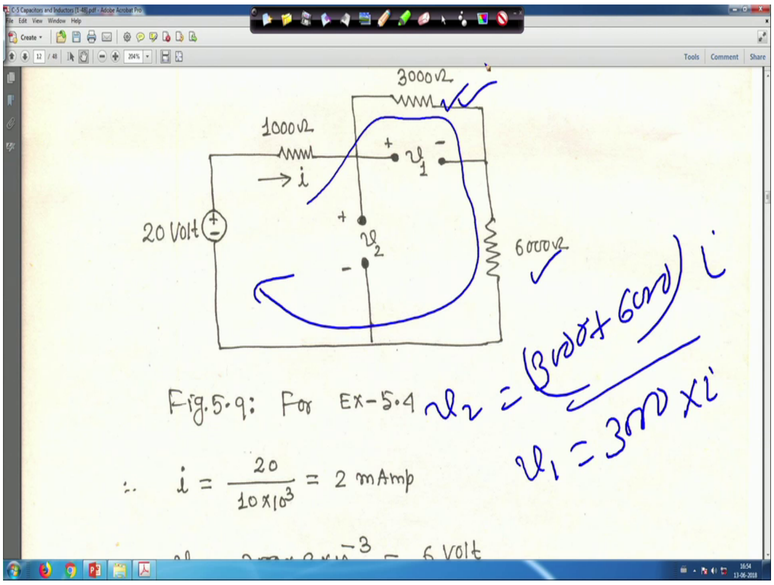

This same current i is flowing through this right. So, b 2 will be actually b 2 will be this 3000 and 6000, 3000 plus 6000 into i that will be your b 2 because this 3000, 6000 are in series right. And b 1, b 1 will be 3000 into your i because this is the voltage across b 1 is the voltage across the 3000 ohm resistance. Once you get this b 1 and b 2, you know c 1 and c 2 you can calculate half c v 1 square and half cv 2 square the energy stored right.

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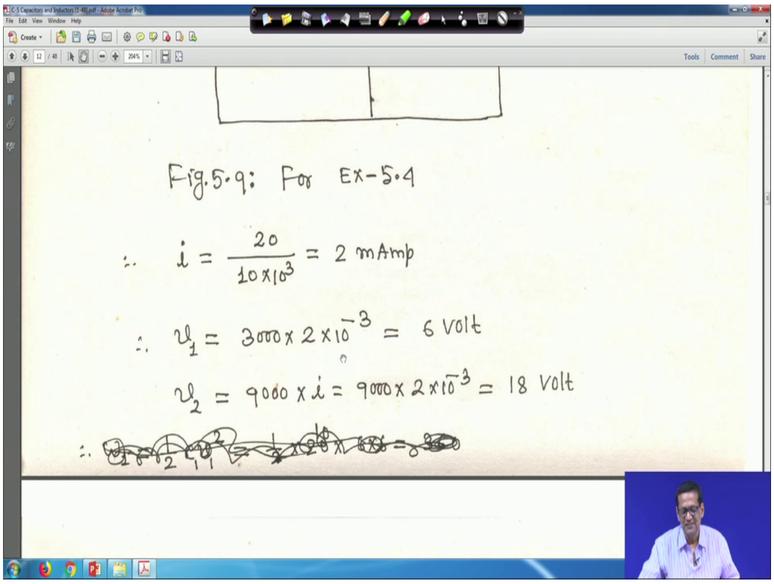

So, now you will get that your what you call that i is equal to i told you the 2 milli ampere; b 1 I told you that 3000 into the current i 2 into 10 to the power minus 3 that is 6 volt. And b 2 is equal to 9000 into i I told you it is 9000 into 2 into 10 to the power minus 18 volt you this milli ampere means 2 into 10 to the power minus 3 ampere. So, this is a 2 into 10 to the power 2 into 10 to the power minus 3 ampere. And this is 2 into 10 to the power minus 3 ampere, 18 volt.

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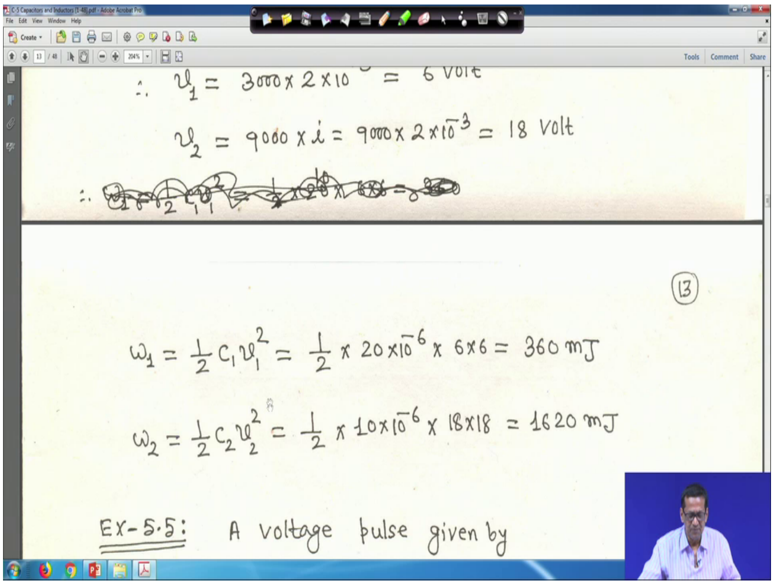

Therefore, w 1 is equal to half c 1 v 1 square. So, half c 1 is given 20 micro farad, so 20 into 10 to the power minus 6 into b square, so 6 into 6, so 360 meg a milli joule, it is in terms of milli joule right because 10 to the power minus 6 is there. Similarly, half c 2 v 2 square is equal to half into your c 2 value 10 micro farad. So, 10 into 10 to the power minus 6 farad into volt square 18 into 18 it will be 1620 milli joule right. So, this that means, how to that means whenever steady dc is applied right, capacitor will behave like open circuit that is why capacitors are open and circuits solution is very easy right. So, this is very simple thing only we have to understand few basics.

Thank you very much, we will be back again.