Power Electronics

Prof. B. G. Fernandes

Department Of Electrical Engineering

Indian Institute of Technology, Bombay

Lecture No – 12

Let me recapitulate whatever I did in my last class. We discussed, full wave rectification using centre tap transformer. We found that and that 1 diode conducts at a time. 1 diode conducts at a time and voltage rating of the diode is twice the peak value of the secondary voltage of the transformer. See, why am I saying, 1 diode conducts at a time? In other configurations, there may be more than 1 device conducting at a time. See, these are the issues that have to be discussed or these are to be taken into account while calculating the efficiency. See, 1 diode conducts at a time. So, the voltage across the diode is of the order of 1.5 volts or so depending upon the power rating. So, if the input voltage itself is low, more than 1, if the 2 diodes are conducting, 3 volts is the drop across the diodes, so the input voltage is high that 1.5 volts or 3 volts may be insignificant value.

So, it is all depends on the input value input value of the voltage and the number of devices that are coming in the main path of the power flow. The second 1 is a common cathode configuration. We found that diode whose anode potential is maximum, will conduct. The third point in common anode configuration, diode whose cathode potential is least will conduct.

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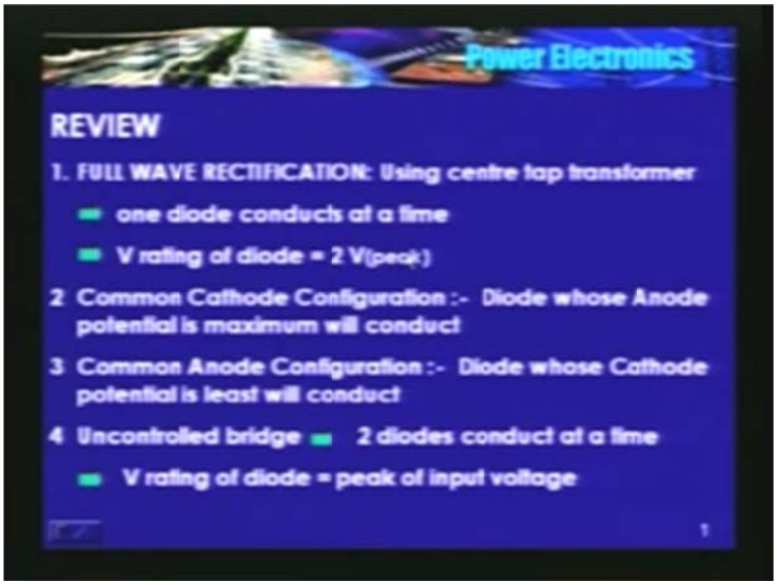

Then in uncontrolled bridge, single phased bridge, we found that 2 diodes conduct at a time. Voltage rating of the diode is peak of the input voltage. See, just the opposite. In full wave rectification using a centre tap transformer; 1 diode conducts at a time, voltage rating is twice the peak of the secondary voltage, whereas here, 1 2 diodes are connecting at a time. Voltage rating of the diode is peak of the input voltage.

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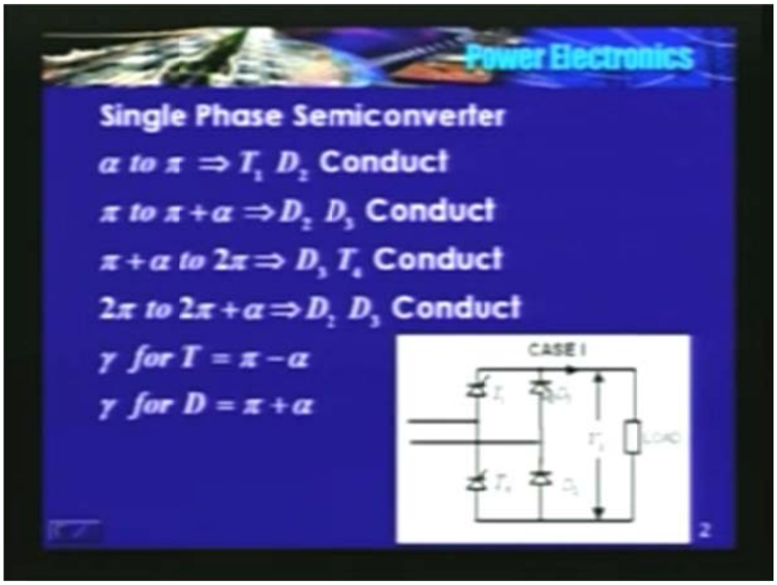

We also discussed 2 configurations in single phase semi converter. In case 1 shown here, 2 thryristors are in the same leg and 2 diodes are in the same leg. Alpha to pi, T_1 and D_2 conducts. From pi to pi plus alpha, D_2 and D_3 conducts. When these 2 diodes conduct, voltage applied to the load is 0. Source does not supply power to the load. When freewheeling diode, D_2 D_3 are conducting, source does not supply power to the load. Source supplies power only when T_1 and D_2 are conducting, in the positive half.

A source supply power, even in the negative half when T_4 and D_3 conduct from pi plus alpha to 2 pi and from 2 pi to 2 pi plus alpha, again D_2 and D_3 conduct. Load current is unidirectional, whereas, source current flows only from alpha to pi, in the positive half and from pi plus alpha to 2 pi, it is a almost a square wave.

If I assume a current, if I assume the load current to be a constant and ripple free, source current is going to be a square wave. So, what conclusion did we draw in the last class? Conduction period for thyristors is pi minus alpha radians. So, as alpha increases, we found that the duration for which thyristor conducts also reduces, whereas, the conduction period for diode is pi plus alpha. As alpha increases, conduction the duration for which the diode conducts also increases. So in other words, average current rating of the thyristors is less compared to that of diode, for any value of alpha other than 0. The average current becomes same only when alpha is 0.

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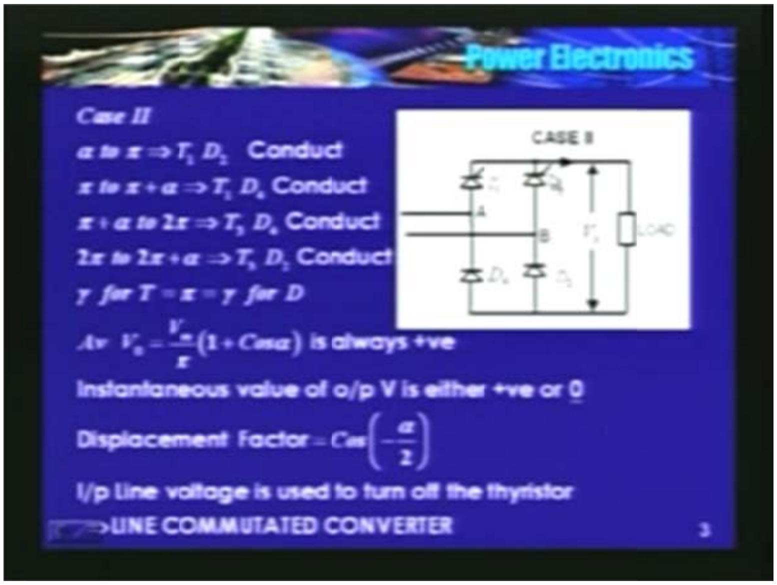

In the case 2, second case, we have 2 thyristors forming a common cathode configuration. So, we have almost a symmetrical configuration. Thyristor and diode in 1 leg, even in another leg we have another thyristor and a diode. Again in the positive half, at alpha T_1 and D_2 are at alpha T_1 is triggered, from alpha to pi, T_1 and D_2 conduct. Source supplies power to the load, at pi plus alpha D_3 and D_4 are triggered. So, what happens from pi to pi plus alpha? We have a common anode configuration here and 2 uncontrolled devices, remember, whereas we have a common cathode configuration, but then both are controlled devices. So till you triggered them, they as if or they are in forward blocking mode, they block the voltage.

Since we have 2 uncontrolled devices forming a common anode configuration, the diode whose cathode potential is least will start conducting. So, D_4 starts conducting at omega t is equal to pi plus. So therefore, from pi to pi plus alpha, current free wheels through T_1, load and D_4. So, again from 2 pi to 2 pi plus alpha, current free wheels through T_3 and D_2. So, wave forms of output voltage, the source current are the same. Only thing is the device, all the devices conduct or duration for which the device conduct is the same. Average value of the output voltage, we found that is always positive. It is given by V_m pi into 1 plus cos alpha, where alpha is a triggering angle. It can take a value anywhere from 0 to pi radians.

When it is 0, it is equivalent to uncontrolled bridge, when it is pi is equal to alpha, output voltage is 0. sorry when the trigger angle alpha is equal to pi, output voltage is 0. What is the displacement factor? Or the displacement angle is the angle between the fundamental component of the input voltage and the fundamental component of the source current. We found that this angle for half controlled bridge or a semi controlled bridge is alpha by 2. So, displacement factor is cos minus alpha by 2. This minus sign indicates that power factor is lagging, sorry displacement factor is lagging.

So, how do we turn off either T_1 or T_3? So, T_1 is turned off by turning on T_3. So, when we turn on T_3, a negative line voltage, input voltage appears across T_1 and in turn, it turns off the conducting thyristor. Hence the name, line commutated convertor because the input line voltage itself is used to turn off the conducting thyristor. Hence the name, line commutated convertor.

So, how many pulses are there in 1 cycle, from 0 to 2 pi? There is 1 pulse from alpha to pi, another pulse from pi plus alpha to 2 pi. So, there are 2 pulses in 1 cycle. So therefore, this convertor is also known as 2 pulse convertor. I have to show something for you. So, here is a single phase uncontrolled bridge.

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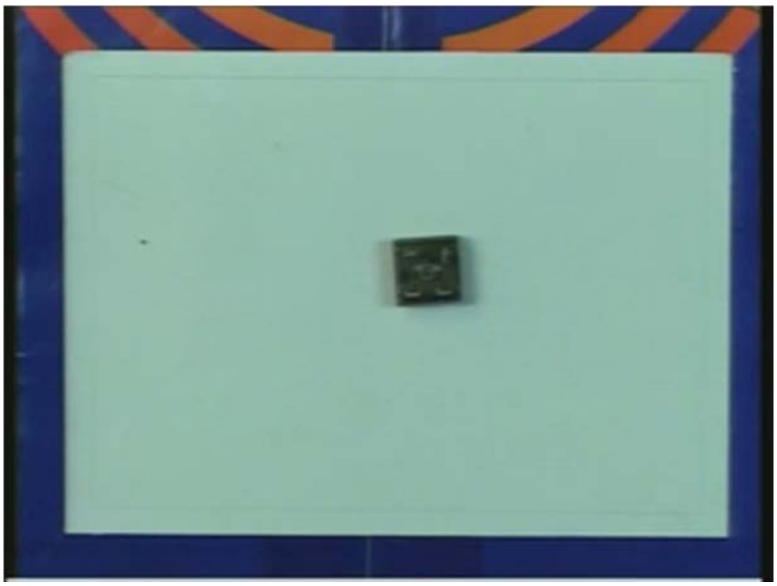

There are 4 terminals. These 2 are inputs, positive DC bus and negative DC bus. Current rating is 25 amperes, 600 volts. When I am saying 25 amperes, it can carry 25 amperes of current and it can block 600 volts. So input voltage, theoretically, peak value should not exceed 600 volts. These are all ideal values, theoretical values.

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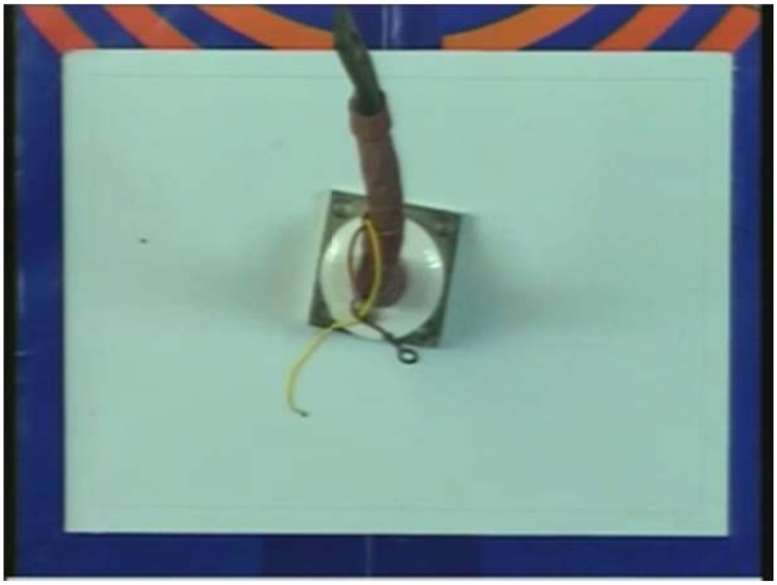

Here is a high current, high voltage thyristor. See the size, it can carry 400 amperes and it can block 2 KV. Cathode anode, it is generally mounted on a heat sink and this was a gate signal, wire for wire to supply the gate current. See the size of the cross section area of the conductor that is used to supply the gate current, very thin. So, very small current that is required to turn on an SCR. See the cross section area of the conductor that is used to that is used in the for the cathode circuit.

The main power flows in this conductor whereas, a small current flowing through the gate. It can carry theoretically, as per the rating, 400 amperes and it can block 2 KV. So, you can use in any circuit, wherein that voltage does not exceed 2 KV at any given instant. These are theoretical values but this the values that should be taken into account while designing, we will discuss at the appropriate time, all this issues, we will discuss.

What is another issue we discussed? Let me discuss RLE load and current is continuous. I said if the current is continuous, whether the load is RLE or not, alpha minimum can be 0. In other words, diode starts conducting, diode that is coming in the forward path or in this bridge.

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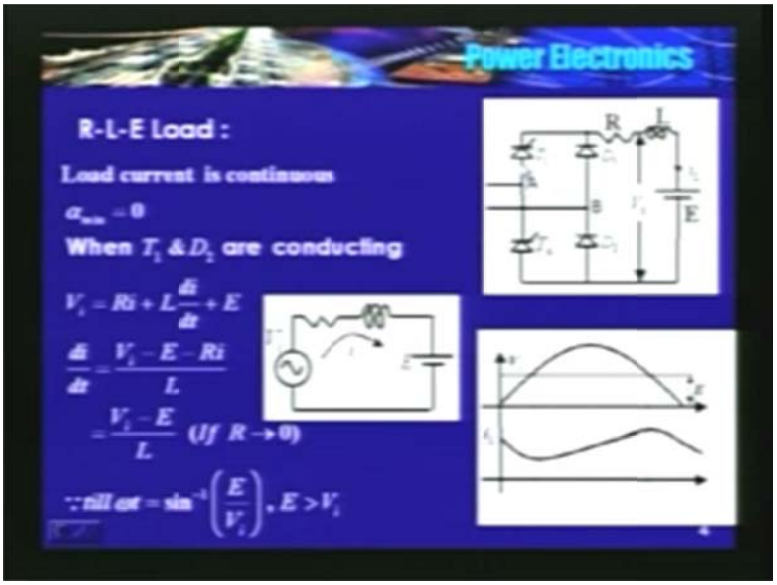

If I have an uncontrolled bridge, diode D_1 and D_2 will start conducting in positive 0 crossing and if I have, since I have thyristor here, I can trigger this thyristor at alpha is equal to 0, independent of the load. If current is continuous remember, thyristor can be trigger at alpha is equal to 0. But then, what happens to the current? Whether current is increasing or decreasing or how that is possible? Take for example, the equivalent circuit when T_1 and D_2 are conducting, so the equivalent circuit is given here. Source, we have a source, T_1 is a short circuit when it is conducting, R, L and E, D_2, back to source.

Current is continuous, so this is the path, KVL has to hold good. So, KVL gives V_i is equal to R into i plus L di by dt plus E. So therefore, di by dt is V_i minus E minus Ri divided by L. So, if I neglect R, it is given by V minus E divided by L. So, di by dt is positive when the instantaneous value of the input voltage is higher than E. So remember, I might have said yes, if the current is continuous, thyristor can be triggered at the positive 0 crossing. That does not mean that di by dt is positive. So, first thing that comes to my mind is when the positive of D_1 and D_2 are conducting, when I say that, I can assume that current may be increasing or in other words, di by dt is positive. It is not necessarily true.

If the load is, even for that matter, even if the load is RL or RLE, di by dt need not be positive or it is not positive, the moment you trigger the thyristors. It all depends on the value of L, it also depends on E. So, in this case we found that till omega t is equal to sine inverse E divided by V_i, E is greater than V_i. So, cathode potential need not be, so, di by dt is always, di by dt is negative till this region.

See the wave form, voltage, the current. I might have triggered, the current is flowing, di by dt is decreasing. So, at this instant it starts increasing, of course, provided R is 0. If R is finite, it is beyond this region, beyond this point, current starts increasing. Current increases again at this point, again, V_i minus E divided L, they are equal. So, di by dt is 0 that means this peak starts decreasing. So current is, how the current is flowing even though magnitude of V_i is less than E? It is because of L di by dt and L di by dt is negative, di by dt is negative, current is decreasing.

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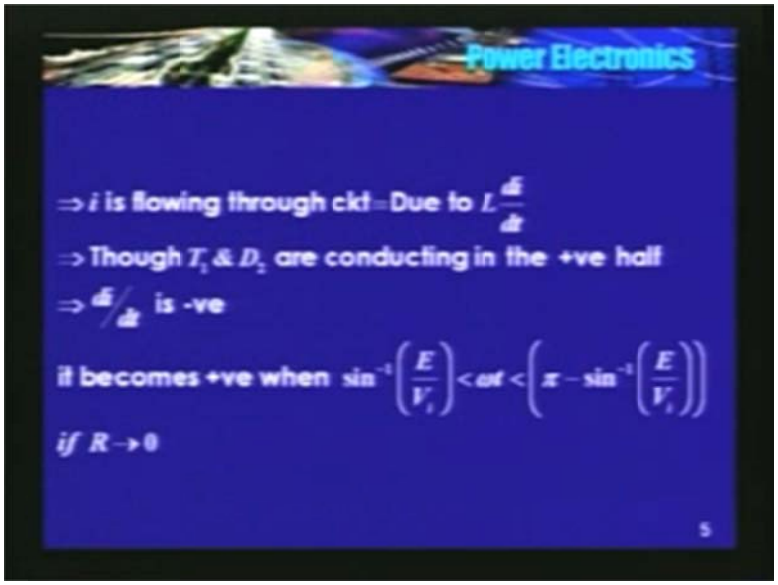

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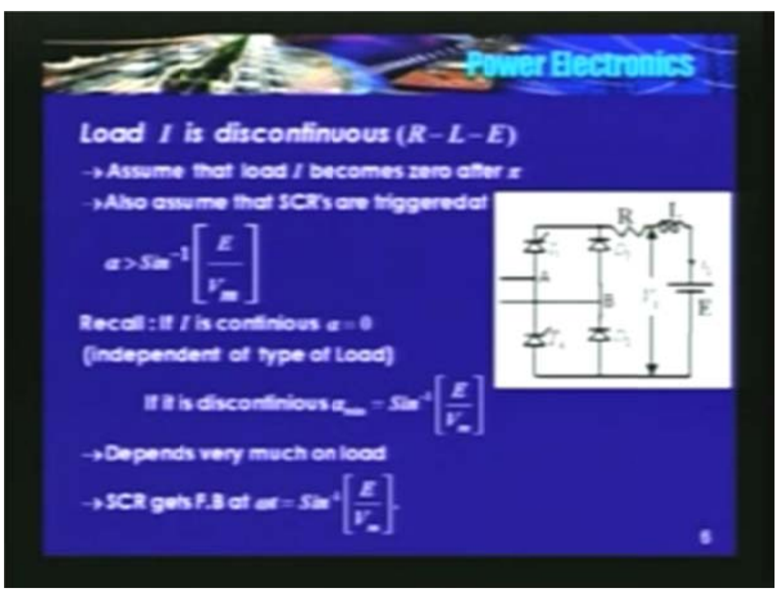

The problem starts, what happens when the current discontinuous? If the current is continuous, you do not need to know the type of load. You can trigger the thyristor wherever you want. So, di by dt is positive or negative, depends on instantaneous value of E and the load parameters. And, when the devices are conducting, input voltage is same as the output voltage or V_0 is same as V_i and if the freewheeling diodes are conducting, output voltage is 0. We do not need to know the type of load at all, if the current is continuous.

The problem starts when the load is discontinuous. Things are not very straight forward, listen to me carefully. 1 assumption that I am making is assume that i becomes 0 after pi. I am assuming it, see, need not be, current may become 0 anywhere. See it attends a peak value here and it starts decreasing. If I have a high value of E, it current may become 0 much before pi. It is all, what you need to find out is we need to know the value of L, E and R.

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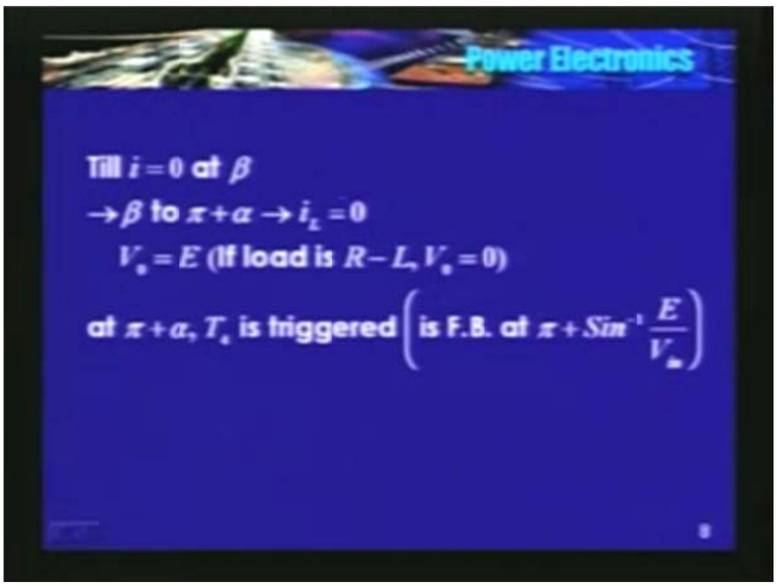

I am assuming that current becomes 0 after pi. Positive L di by dt should be equal to negative L di by dt and equate the areas or solve the differential equation and you can find out where exactly the or you can find out the point at which the current becomes 0.

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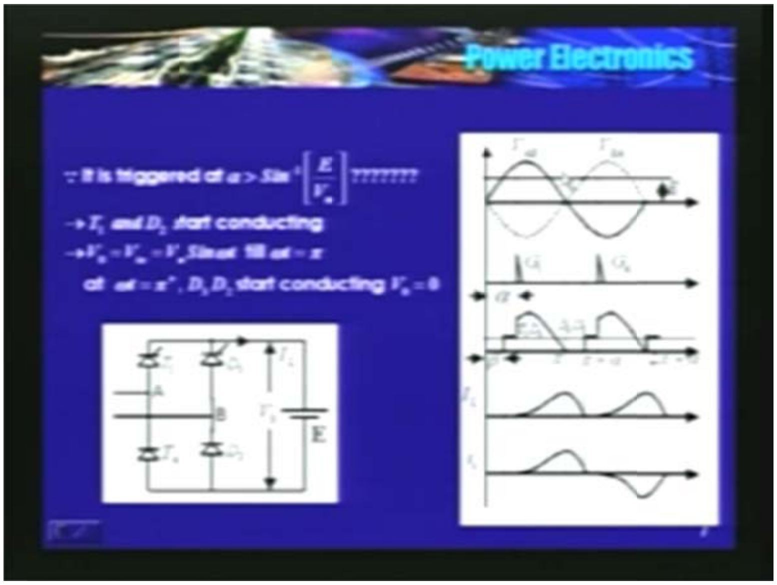

So, at alpha which is higher than sin inverse E divided by V_i V_m, I am triggering T_1.

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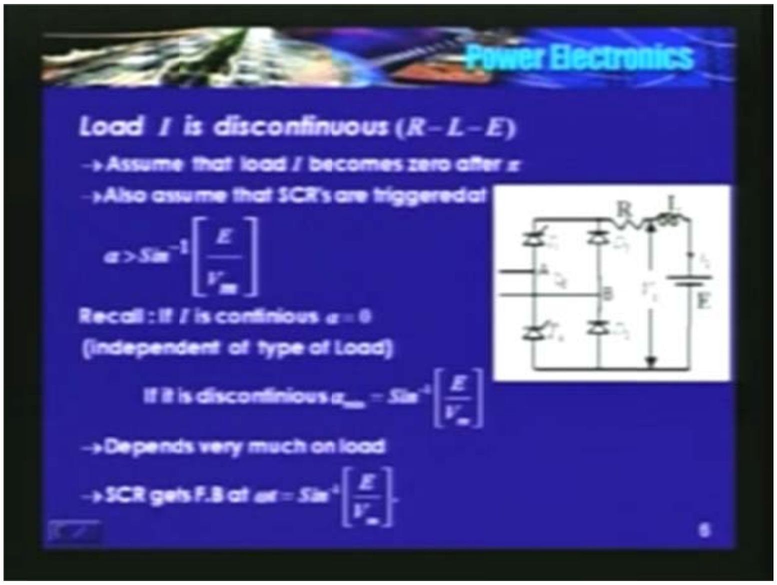

The moment I am triggering T_1, they start conducting, T_1 and D_2 starts conducting. Source supplies power to the load and starts flowing. What happens at omega t is equal to pi plus? In the upper half, we have a diode and a thyristor forming a common cathode configuration. So, omega t is equal to pi plus, D_3 gets or anode potential of B is higher than the potential of A. So immediately, D_3 starts conducting, T_1 turns off. In the lower half, T_4 is not triggered. It gets triggered only at pi plus alpha. Till then, this is in the blocking mode.

So, current start flowing through the load, D_2, D_3. In other words, load is freewheeling through D_2, D_3. Source current is 0, source current sorry source current is 0, source current is 0 and load voltage is also 0. If the current is continuous, D_2 and D_3 would have continued to conduct till you trigger T_4. The moment T_4 starts, the moment you trigger T_4, T_4, D_3 starts conducting and source supplies power. Unfortunately, in this case, current has become 0, much before you trigger T_4.

So, what happens now? What is the load, what is the voltage appearing across the load? Listen to me, if the load was, if the load is passive, there is no current, so there is no voltage. Since, we have considered load to be RLE, voltage appearing across the load is E. So, the instance from the current becoming the 0, till you trigger the other thyristor, that is T_4, voltage applied to the load is E. See here, somewhere at this instant current has become 0, next thyristor triggering is only at pi plus alpha. So, from this instant to pi plus alpha, voltage appearing across the load is E. At pi plus alpha, you trigger T_4, T_4 D_3 starts conducting. Voltage applied to the load is again the input voltage, is a sinusoidal.

See the load current, unidirectional, source current, sorry, source current is 0 here, it should have been, this is the source current wave form. So, you should be extremely careful while drawing the load voltage wave form when the thyristor is, when the current is discontinuous. You need to know the type of load. If the current is continuous, you do not need to know the type of load, because the load voltage is either the input voltage or 0. It depends on whether thyristors are conducting or the freewheeling mode.

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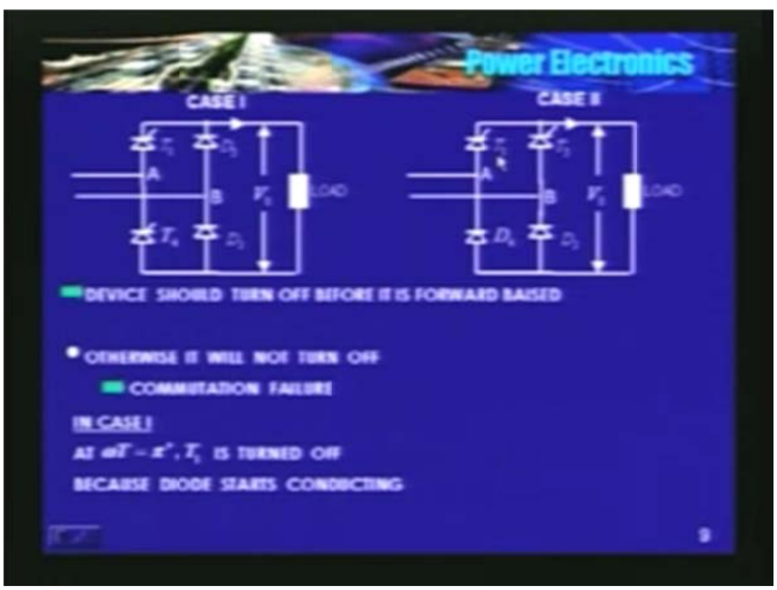

Now we discussed case 1 and case 2, 2 different configurations. 2 thyristors in 1 leg and in another second case second case is 1 thyristor and 1 diode in 1 leg, other then gama being not the same. What is the difference between these 2? What is the difference between these 2 bridges or when do you prefer? or what I said, both are line commutated convertors, line voltage is used to turn off the conducting thyristor.

Remember, I discussed this point in the while the divided while discussing the devices that device should be completely turned off before it is forward biased again. I repeat, device should attain its blocking mode before it is forward biased again. What happens in case 1? At omega t is equal to pi plus, D_3 start conducting. In the positive half, omega t is equal to pi plus, in the sense, positive half end set pi, at omega t pi plus, D_3 starts conducting, independent of the instant where you trigger T_1. Whether alpha is 0 or alpha is pi by 2, alpha approaches pi, it does not matter. At omega t is equal to pi plus, D_3 takes over from T_1.

What happens in case 2? We have a common annual configuration. In lower half, assume that alpha approaches pi.

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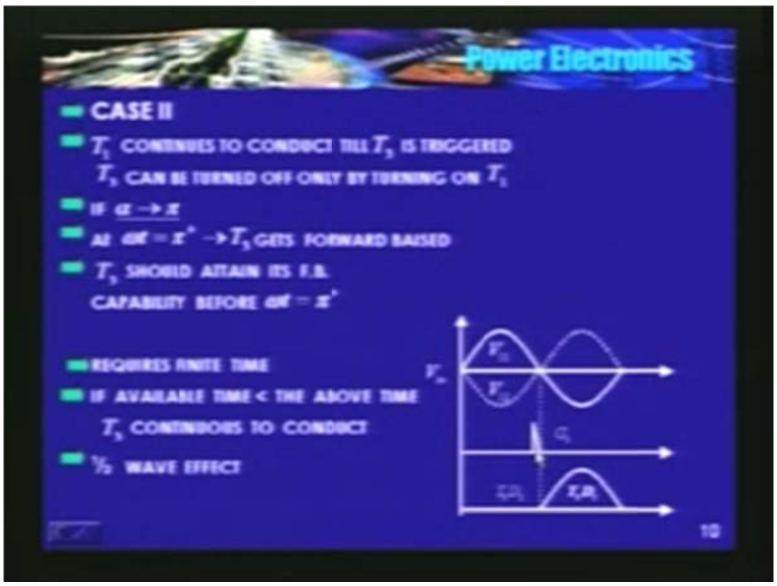

So, somewhere nearing pi, you want to trigger T_1. In the positive half, prior to T_1 triggering, current was flowing through D_2 and T_3. In the positive half, since alpha is approaching pi, so entire positive half, T_3 and D_2 were conducting. So, load voltage is 0, current was freewheeling through T_3 and D_2, source current is 0, all most the entire part of positive half. At omega t approaches pi, you want to trigger T_1. You have applied a gate signal to T_1, somewhere approximately when approximately near to pi. T_1 tries to turn on. So, potential of A is same the cathode potential. A small positive voltage appears across T_3, sorry, a small negative voltage appears across T_3, because potential of B is slightly higher, slightly less than potential of A.

I will repeat, I made a when you trigger the T_1, potential, cathode potential of T_3 is same as potential of A. Alpha is approaching pi. We find that, you know, potential of A is approaching 0, same as the potential of B is also approaching 0. At omega t is equal to pi, both are 0. So, as you approach the negative 0 crossing, voltage appearing across, the magnitude of voltage appearing across T_3 also reduces. A small negative voltage is appearing across T_3. The device is, in principal, it is reverse biased. Time to turn off, I said, device is non ideal. It has, it will take its own time to turn off. Basically, thyristors are slow devices. As it tries to turn off at omega t is equal to pi plus, again a positive voltage appears across it, isn’t it? At omega t is equal to pi plus, what happens? Potential of B is higher than potential of A. We might have triggered T_3 just near the negative 0 crossing.

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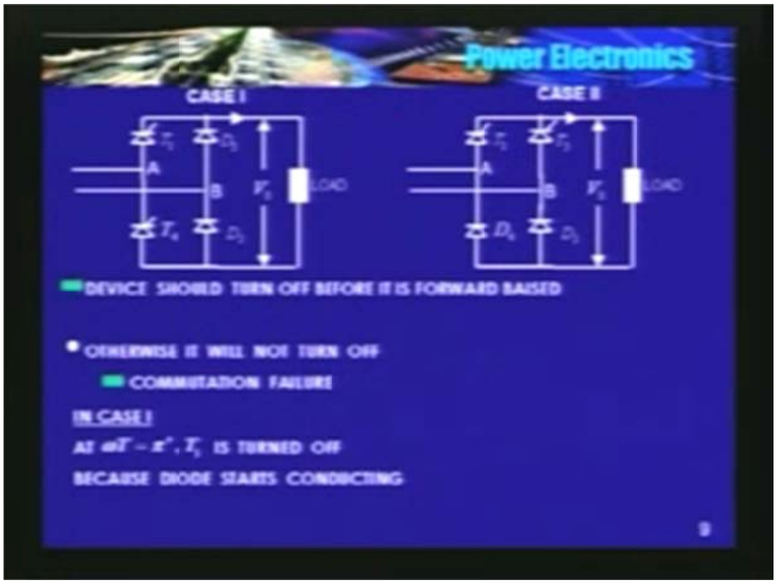

A negative voltage appeared across $T_{3,}$ device is trying to turn off. At that instant, may be, instantaneous value of the input voltage become 0, omega t is equal to pi plus and immediately after that potential of B becomes higher than potential of A. A positive voltage appears across $T_{3.}$ Unfortunately, it may so happen that T_3 may not have attained a positive blocking capability.

So, it was trying to turn off, some current was flowing, current was increasing, immediately it is started getting forward biased. So therefore, T_3 continues to conduct, T_1 cannot turn on. … It was trying to, T_3 was trying to turn off because you have triggered $T_{1,}$ T_1 was trying to turn on, T_3 was trying to turn off. But then, as it was turning off, it was getting forward biased. So, some sort of a commutation failure we have here. Thyristor does not turn off, so it continues to conduct. T_1 does not turn off. So, what did happen from 0 to pi till 0 to alpha where that alpha was approaching pi? Current was flowing through T_3 and $D_{2.}$

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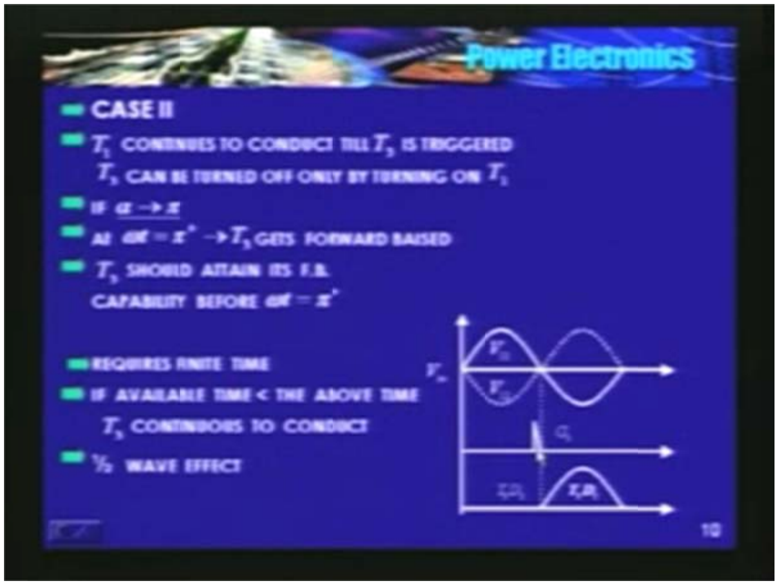

At omega t was approaching pi, you triggered T_1 and I told you that T_4 did not turn off. We had some sort of a commutation failure there and again it starts conducting in the entire half cycle. Now, T_3 and D_4 starts conducting at omega t is equal pi plus, because in the lower half we have a common anode configuration. D_4 immediately starts conducting. This was trying to turn off, it did not turn off. It continues to conduct, so we have a powering mode now.

There is power flows through T_3, load, D_4 and source. So the entire negative entire pi radians, D_3 and D_4 conduct. See the voltage wave form, we have an uncontrolled rectification. May be, as if I have only a single diode, conducting for the entire pi radians and here, output voltage is 0. So, this wave form is similar to that of half wave rectifier. Half wave rectifier, similar to that of a half wave rectifier. We had a source, 1 diode coming in series and a resistive load or I have 1 source, 1 diode, freewheeling diode and load. If I have that sort of a configuration, I get this wave form.

I will repeat, if I have a source, 1 diode and the load or source, 1 diode and a freewheeling diode and the load, I get this sort of a wave form. This is nothing but a half wave rectification. Hence the name, half wave effect. So, in case 2 we have half waving effect which is not there in case 1. So remember, whatever, there are certain advantages or disadvantages, nothing like, this is the perfect system and this is a bad system, no. Out here, in case 1, the average current rating for alpha not equal to 0 is not the same or the conduction period for the devices not the same, whereas in this case, conduction period, conduction duration for all the devices is the same. But then, as alpha is approaching pi, we have half waving effect, whereas, this effect is totally absent.

So, certain plus points, certain minus points. That is the way the life is all about. We have certain plus points, certain minus points. There is nothing like, this is the perfect system and this is the totally a useless system. In nature, some of nature, in nature, we do not have such a system.

Let us see, let us solve some problems. We will start from simple problems then we will increase the complexity. May be, will if you try to solve this problem, you may be able to appreciate this subject more.

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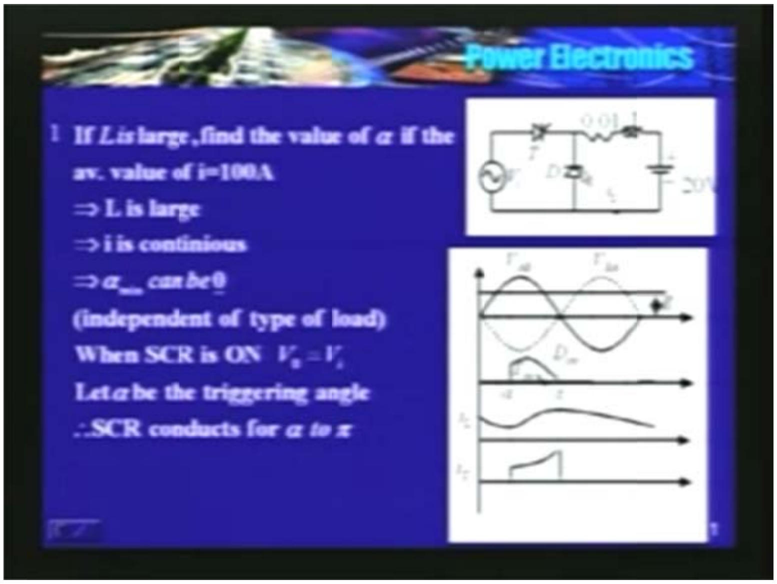

A simple problem here, half wave rectification, half wave controlled rectification, the freewheeling diode. I have put the thyristor, 1 thyristor, 1 diode or LE load. The problem says L is large. The moment when I say L is large, first thing that should come to your mind is current is continuous and someone says that L is large, you can safely assume that current is continuous, because we know that the current cannot change instantaneously. So, L is very large. First of all L is very large, so can safely assume, the current is continuous. The moment current continuous, I am telling you, problem solving is going to be very simple, because, I know that when the thyristor is conducting, output voltage is same as the input voltage. The freewheeling diode is conducting, output voltage is 0. The problem starts when the current is discontinuous.

So fortunately, L is current is continuously here. So, the problem is, find the value of alpha, what should be the trigger angle if the average value of i is 100 amperes? The average value of i is 100 amperes, how do I solve that problem? I will plot the input voltage which is a sinusoid, this is the value of E, this 20 volts. Input is 230 volts, 50 hertz single phase supply. So, this peak is around 230 into root 2, is of the order of, may be 325 volts. E is 20 volts, so somewhere here.

L is large, E is very small, R is also very small, so there are very good chances of current becoming continuous, because as this value of E comes down, the duration available for the current to increase, di by dt also increases. Is only when instantaneous value of the input voltage is higher than E, current starts increasing. Let us assume that thyristor is triggered at alpha. Current is continuous, do not worry, so the moment you trigger at alpha, input voltage appears across the load. At alpha you have triggered, input voltage is same as the output voltage or output voltage is same as input voltage.

At omega t is equal to pi plus, since the load is inductive, current continuous to flow. But then, the moment instantaneous value of the input voltage is becoming negative, the freewheeling diode starts conducting, because you cannot have a positive voltage appearing across the diode, because beyond pi, this potential is higher than this potential.

If T conducts, this potential is same as this potential. So, a positive voltage appears across diode, not possible, so diode starts conducting, turns of the thyristor T. So, in the entire negative half, since the current is continuous, current D conducts. See, I have if there was no diode here, thyristor would have continued to conduct. Beyond pi, a negative voltage appeared across the pi, decay would have been faster. So, current would have become 0 somewhere in between pi to 2 pi. So, I have achieved, what I did here? I have connected a freewheeling diode, voltage appearing across the load beyond pi is 0. So, the forcing function is 0, current decays slowly. Second is, I have used a very large inductor, so current continuous to conduct and that too very slowly. What happens in the positive half from 0 to pi?

If I had a diode replacing the thyristor, it would have started conducting at omega t is equal to 0 plus. In the second cycle or at steady state in the positive 0 crossing, main diode would have started conducting. Since the current is continuous, you can trigger the thyristor at omega t is equal to 0 plus and when as soon as I trigger the thyristor, in the positive half, now a negative voltage appears across D and diode turns off. So, till you trigger the thyristor, source voltage does not appear across diode, because we have an open circuit here. We have an open circuit across the thyristor, because you have not triggered the thyristor, we have an open circuit here.

So, at steady state current is continuous. From pi to 2 pi freewheeling diode was conducting, it continues to conduct till you trigger the thyristor even in the positive half. You can trigger at omega t is equal to pi, omega t is equal to 0 plus, you can trigger it. So, till you trigger the thyristor, diode, freewheeling diode continuous to conduct even in the positive half. Remember this, because we have an open circuit there, T does not conduct, it is not triggered. So, source voltage does not appear across the diode, because we have an open circuit, remember. Do not make a mistake while drawing the wave form. If your wave forms are correct then you need to find out just the average value of it, you have to integrate it. Anyone can do, even an eleventh standard or twelfth standard student can do.

The first thing is you need to understand, the how the circuit works? Draw the wave forms, having drawn the wave forms correctly, you are through, you are done. Let me tell you 1 thing, answer, you may, you can afford to make a mistake while integrating. As a teacher, I may not deduct any marks if you make a mistake while integrating. But then, since the, because it is not a mathematics, course on mathematics, it is a course on power electronics. Fine, you may, you can make a mistake. You can afford to make a mistake. I may try to overlook that. But the, since, it is the course on power electronics, I would expect you to draw the correct wave form.

If the wave form is correct, I know that student knows the subject. He must have made a silly mistake in a hurry, he might have made a mistake while integrating, is pardonable. So, try to the first point is, draw the wave form, try to understand the functionalities, how the circuit works. The second is, draw the correct wave forms, you are done, problem.

So, diode continuous to conduct, so at steady state, N cycles are over, from 0 to alpha, D_1 was conducting, from alpha to pi, thyristor starts conducting and N pi to N pi plus 1 alpha, D_1 continues to conduct. When the source supplies power? Source supplies power only when thyristor mean thyristor is conducted. So, thyristor conducts from alpha to pi. So, there is only 1 pulse in 1 cycle. Even output voltage also, there is only 1 pulse in 1 cycle. So half wave rectifier, they also known as single pulse convertor or 1 pulse convertor.

So before solving, we try to see the source current wave form. The moment diode starts conducting, source current instantaneously become 0. When the thyristor is conducting, the load current is same as source current, it is. So, at the moment thyristor is triggered, diode turns off. Whatever the current that is flowing through the diode, starts flowing through the thyristor. So instantaneously, it jumps to the load current, increases, follows this load current, reaches a peak then starts coming at pi at pi, omega t is equal to pi plus, D starts conducting. Immediately T_1 turns off. This is because I am assuming, in the beginning of my course I told that let us neglect the source inductance. If you take the source inductance into account, what happens, we will see sometime later. Let us not worry now.

So, source supplies power in only in 1 cycle. There is only 1 pulse per cycle. Input is a sinusoid, appears sinusoid, current is a non sinusoid. But then, it supplies only between alpha to pi. There is only 1 pulse. So, if I try to take the Fourier series of this wave form, it has an average component. In other words, A_0 plus the sigma AN into cos omega t plus BN into sin omega t. So, if find that if A_0 is finite, it has an average component. Average component is nothing but a DC component. So, I am drawing a DC component from the source. I will repeat I am drawing a DC component from the source. What happens when I draw a DC component from the source? After all, this current has to come from transmission lines, transformers, secondary, it as to flow from a secondary transformers, what happens?

We will discuss this point in detail. I will solve a very interesting problem sometime later. A very interesting problem: putting a diode across the transformer or putting a diode in the secondary of the transformer. Apart from the average component, it has other frequency components also. Write as Fourier series, A_0 plus AN cos omega t sigma plus BN sin omega t. you will find that it has other frequency component also. Only the fundamental component that D_1 sin omega t is responsible for power transfers, because input is odd function that is some sin omega t. So, source current which a component of a source current whose frequency is same as omega and sinusoidal is responsible for power transfer.

The remaining higher frequency components flow in the transformer, secondary transmission lines. The effect of higher frequency components, this higher frequency components are also know as harmonics, hence forth I will say the higher frequency components has harmonics. These are nothing but the higher frequency components which are present in the source current will definitely affect the source and other circuits. The effect of harmonics on other circuits, we will discuss in detail sometime later. So we found that now let us solve this problem, source current flows from alpha to pi, load current is continuous, increases, decreases. How do I solve?

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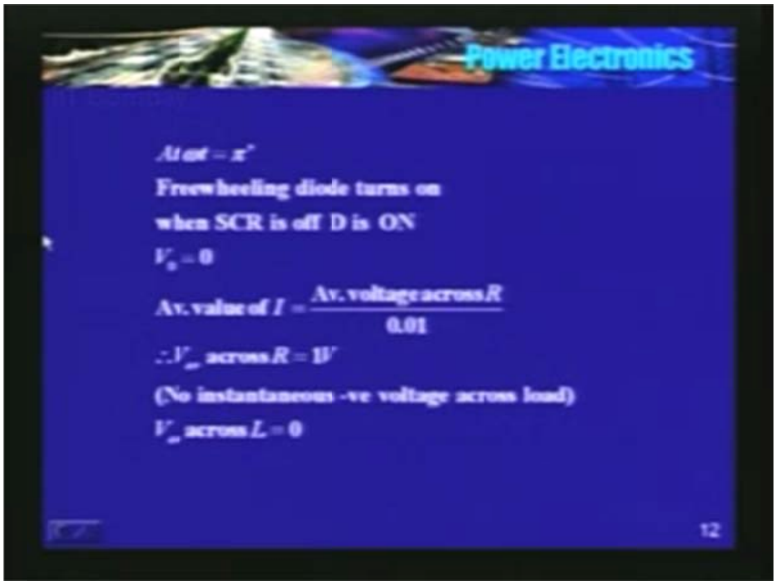

Said, average value of current is average voltage applied to the load minus E divided by R. Are you with me? Average value of current depends on the difference between the average value of the output voltage minus E. In other words, V average is equal to i average into R plus E. L di by dt average is 0.

It is only RE and V average will determine the current flowing in the circuit, will determine the average value of the current. So, average value of i is average voltage across R divided by the value of R. Value of R is given by 0.01 ohms. So, average voltage across R becomes 1 volt, since the value of i is 100 amperes.

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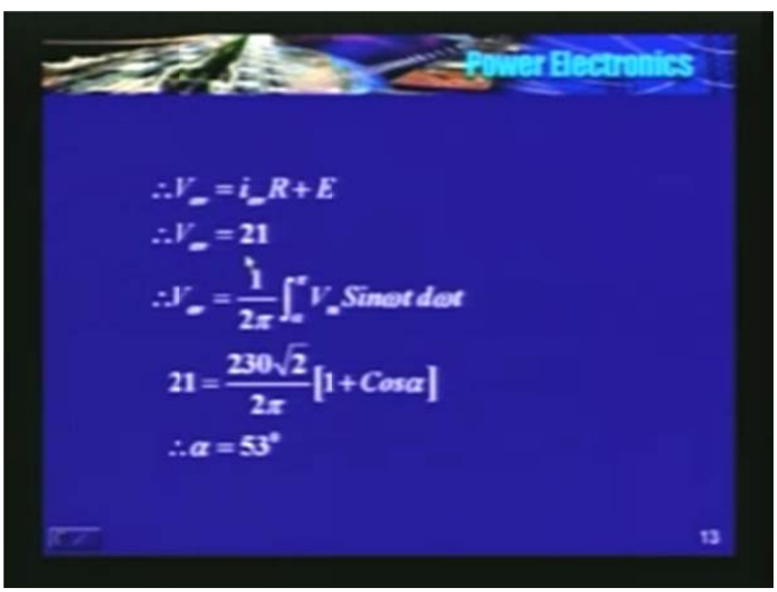

This is the equation, V average is equal to i average into R plus E. So therefore, V average is 21 volts. Isn't it? E is 20, i average into R is 1. Therefore, E average is 20. So, what is the average value of the output voltage? 0 to alpha it is 0, alpha to 2 alpha to pi, it is V_m sin omega t and pi to 2 pi, it is 0. So 0 to pi, alpha to pi, V_m sin omega d omega dt, Vm is 230 into root 2, 1 plus cos alpha. So, alpha you get it as 53 degrees. Alpha is equal to 53 degrees.

So by solving this problem, I have brought out various issues. 1 is in a half wave rectifier or single pulse converter, average value of the source current is finite. In other words, we are drawing a DC component from the source, also there are high frequency component in the source current. Effect of DC, effect of high frequency component in the source, we will discuss sometime later.

If there is a controlled device here, freewheeling diode conducts even in the positive half cycle, if the current is continuous, remember. If the current is continuous, freewheeling diode conducts even in the positive half till you trigger the thyristor, because till you trigger the thyristor, source voltage does not appear across the diode. So, if the current is continuous is only when the thyristor is conducting, input voltage is applied to the load and for the entire remaining entire duration, voltage applied to the load is 0.

Thank you.