Power Electronics

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Lecture - 14

So far we have discussed uncontrolled bridge, wherein all the 4 devices were diodes. We replaced 2 diodes by 2 thyristors and the resulting bridge, we called it as half controlled or semi controlled. What are the characteristics of this semi controlled bridge? For alpha, from 0 to pi, output, output voltage is always positive, is given by V_m by pi into 1 plus cos alpha. Current is always unidirectional. So, the operation is always in quadrant 1 or 1 single quadrant converter. Now, we will replace the remaining 2 diodes by thyristors. The resulting bridge is known as a fully controlled bridge.

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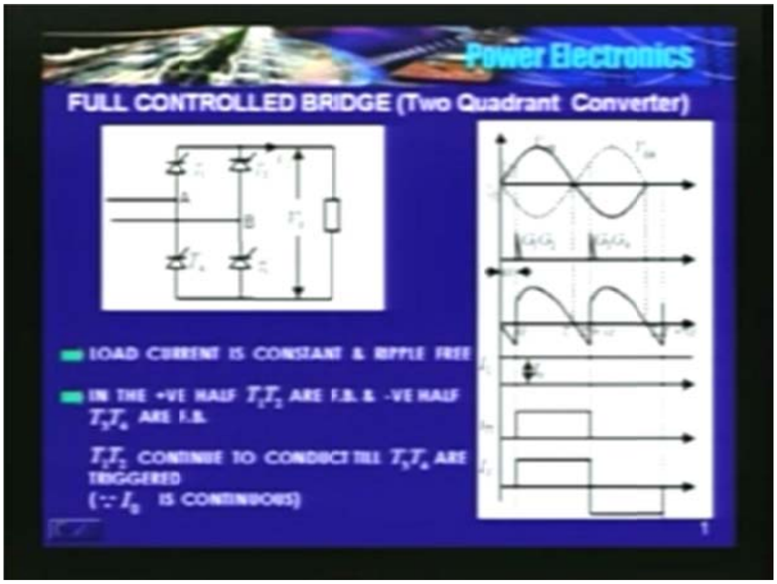

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FULL CONTROLLED BRIDGE (Two Quadrant Converter)

- LOAD CURRENT IS CONSTANT & RIPPLE FREE
- IN THE +VE HALF T_1T_2 ARE F.B. & -VE HALF T_3T_4 ARE F.B.

T_1T_2 CONTINUE TO CONDUCT TILL T_3T_4 ARE TRIGGERED
($\because I_0$ IS CONTINUOUS)

That is, here is the configuration; T_1 to T_4, they are thyristors. In the positive half, T_1 and T_2 are triggered and in the negative half, T_3 and T_4 are triggered. The assumption that we made for uncontrolled or semi controlled bridge are still valid. Same assumptions we will make, the input voltage is sinusoidal and load current is constant and ripple free. So, input voltage V_{AB}. V_{AB} is positive in the positive half and V_{BA} is positive in the negative half.

So, at alpha T_1 and T_2 are triggered and at pi plus alpha, T_3 and T_4 are triggered. Till you trigger T_1 and T_2, T_3 and T_4 continue to conduct in the positive half. Remember, load current is continuous. Therefore, at any given time, 2 devices should be on. So in the previous negative half, we have triggered T_3 and T_4 at pi plus alpha. So, till you trigger T_1 and T_2, they continue to conduct even in the positive half.

So, since T_3 and T_4 are conducting, potential of B is same as the positive DC bus and potential of A is same as the negative DC bus and we know that in the positive half, potential of B is less than that of potential A. So, we get minus or negative of the input voltage or we get output voltage is V_{BA}. $V_{BA,}$ this is $V_{BA.}$ So, this is the output voltage, negative, till you trigger the incoming T_1 and T_2 thyristors.

Remember, in the positive half though potential of A is higher than potential of B, we have a common cathode configuration. It is fine but then T_1 is in blocking mode. In the sense, we have not applied the trigger pulse to $T_{1,}$ so T_3 continuous to conduct. Same is true in the lower half.

Just prior to alpha, what was the output voltage? Output voltage was V_{BA}. Now, at alpha we have triggered T_3 in the upper half and we have triggered, sorry, in the upper half we have triggered T_1 and in the lower half we have triggered $T_{2.}$ The moment you trigger $T_{1,}$ potential of A is the same as the positive DC bus that is the cathode potential of T_3 and a positive voltage appears sorry a negative voltage appears across $T_{3,}$ it turns off. Hence, the name line commutation.

So, at alpha plus T_1 and T_2 starts conducting. Another potential, load potential is $V_{AB.}$ Let me repeat, just prior to alpha, output voltage was V_{BA} because T_3, T_4 were conducting. Immediately after alpha, the output voltage is $V_{AB.}$ So at that instant, input voltage is $V_{AB,}$ this value. So instantaneously, this voltage jumps to V_{AB}. So, once the devices are turned on, output voltage is same as the input voltage. It is V_m sin omega t till pi plus alpha. So, whatever that happened at alpha will happen at pi plus alpha and the processes continuous.

So, from alpha to pi, T_1 and T_2 and at pi plus alpha to 2 pi plus alpha, it is T_3 $T_{4.}$ What is the conduction period of each device? Conduction angle or each device conducts for pi radians. This is this thyristor current wave form, I have assumed that the current is constant and ripple free. So, thyristor T_1 starts or T_2 starts from alpha to pi plus alpha. When the thyristors are on, source current is same as the load current. So, it is just a square where it is continuous, unlike in half controlled bridge.

In half controlled bridge; from alpha to pi sorry alpha to pi, it is the load current, from pi to pi plus alpha, it is a freewheeling period. Source does not supply power and again from pi plus alpha to 2 pi is the same load current flows from the source. So, see the difference in the load. The source current is a continuous wave form. How does a fundamental component of I_s looks like? It is a sinusoid, starts, it cuts that x axis at alpha itself, something like this. What is the value of the output voltage, average value of the output voltage? I need to integrate this wave form.

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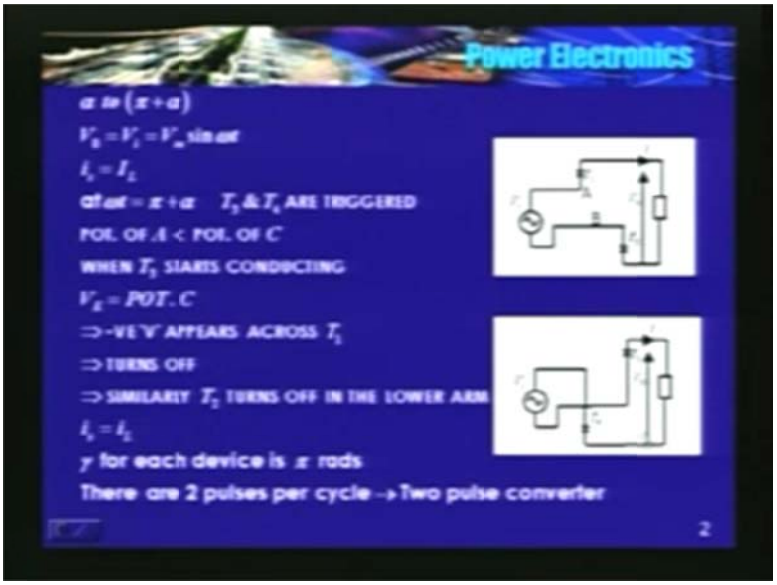

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α to $(\pi+\alpha)$

$V_0 = V_s = V_m \sin\omega t$

$i_s = I_L$

at $\omega t = \pi+\alpha$ T_3 & T_4 ARE TRIGGERED

POT. OF A < POT. OF C

WHEN T_3 STARTS CONDUCTING

$V_K = POT.\,C$

⇒ -VE 'V' APPEARS ACROSS T_1

⇒ TURNS OFF

⇒ SIMILARLY T_2 TURNS OFF IN THE LOWER ARM

$i_s = i_L$

γ for each device is π rads

There are 2 pulses per cycle → Two pulse converter

So, these are the equivalent circuits. In the positive half, T_1 and T_2 are triggered. In the negative half, this is the equivalent circuit. Since there are 2 pluses per cycle, this converter is also known as 2 pulse convertor.

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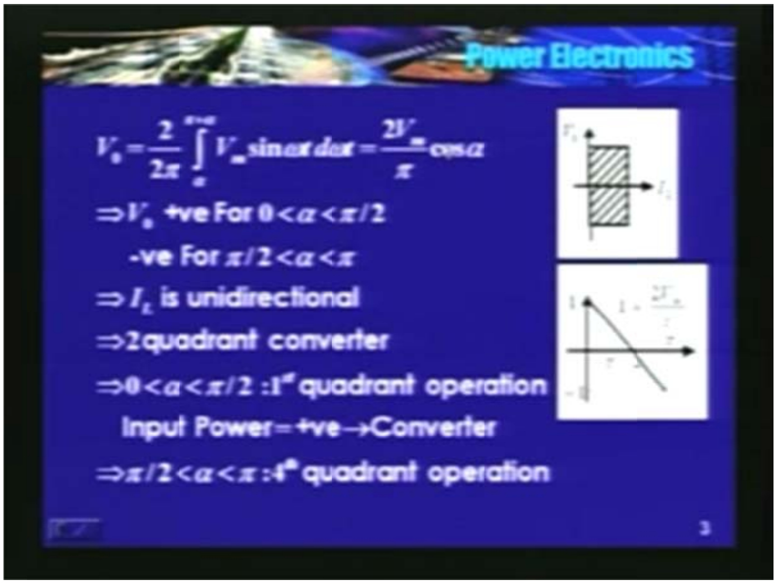

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$$V_0 = \frac{2}{2\pi}\int_{\alpha}^{\pi+\alpha} V_m \sin\omega t\, d\omega t = \frac{2V_m}{\pi}\cos\alpha$$

⇒ V_0 +ve For $0<\alpha<\pi/2$

-ve For $\pi/2<\alpha<\pi$

⇒ I_L is unidirectional

⇒ 2 quadrant converter

⇒ $0<\alpha<\pi/2$: 1st quadrant operation

Input Power = +ve → Converter

⇒ $\pi/2<\alpha<\pi$: 4th quadrant operation

Same, in the sense, average value of the output voltage is given by this expression; alpha 2 pi plus alpha V_m sin omega t d omega t, it is given by 2 V_m by pi into cos alpha. It is 2 V_m by pi into cos alpha. So, V_0 or the average value of the output voltage is positive for alpha varying from 0 to pi by 2 and becomes negative for alpha varying from pi by 2 to pi.

Let me repeat, at pi average value of the output voltage is 0. At sorry, at pi by 2, average value of the output voltage is 0. From 0 to pi by 2, average value is positive and from pi by 2 to pi it is negative. So we have 2 quadrant operation, from 0 to pi by 2 is positive, average voltage is positive, current is always unidirectional and from pi by 2 to pi it is negative. We have 2 quadrant operation, hence the name, 2 quadrant converter.

I said, in the positive, in the first quadrant, V is positive, I is also positive. So, average power input to the bridge is positive. Whereas, in the forth quadrant or when alpha greater than pi by 2 and if the current is continuous, average value of the output voltage is negative. Current is always positive. So, average power input to the bridge is negative.

So, if I called the first quadrant operation as conversion, in the sense, it converts AC power to DC power or this source supplies power to the load, I will call the operation from pi by 2 to pi as inversion. Load supplies power back to the source. So I will repeat, I had called the operation from 0 to pi by 2 as conversion because source supplies power to the load. Now, from pi by 2 to pi, input power to the bridge is negative. In other words, load is supplying power but the source, I will call this process as inversion.

Remember, average value of the output voltage is negative or this expression is valid only if the current is continuous. Just because it is a full wave controlled bridge, do not straight away, you do not use this expression to determine the output voltage. First you find out whether the load current is continuous or not. If it is discontinuous, you cannot use this expression directly, remember.

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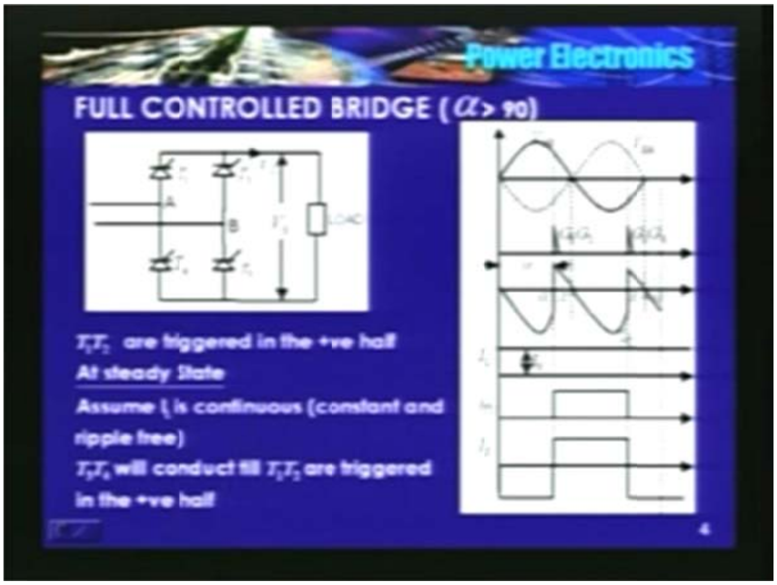

FULL CONTROLLED BRIDGE (α> 90)

T_1T_2 are triggered in the +ve half

At steady State

Assume I_L is continuous (constant and ripple free)

T_3T_4 will conduct till T_1T_2 are triggered in the +ve half

Now, see the wave form. Let me draw the wave forms for alpha greater than 90. So, here are the waveforms. Till you trigger T_1 and T_2, T_3, T_4 are conducting, V_o, output voltage is V_{BA} which is negative in the positive half. So, I have a negative voltage at this point. At alpha, we have triggered T_1 and T_2. Now, output voltage jumps to V_{AB} and it continues.

So if you find, you will find that average value of this waveform is negative. Area under the curve from 0 to alpha is much higher compared to that from alpha to pi. Small area here, large area here, therefore, average value is negative. Now, source current waveform the same, it just shifts, it is negative from 0 to alpha, alpha to pi plus alpha it is positive and so on.

So, here are all the equivalent circuits, same equivalent circuits. Whatever that we did for operation, for alpha 0 to pi by 2 is still valid here.

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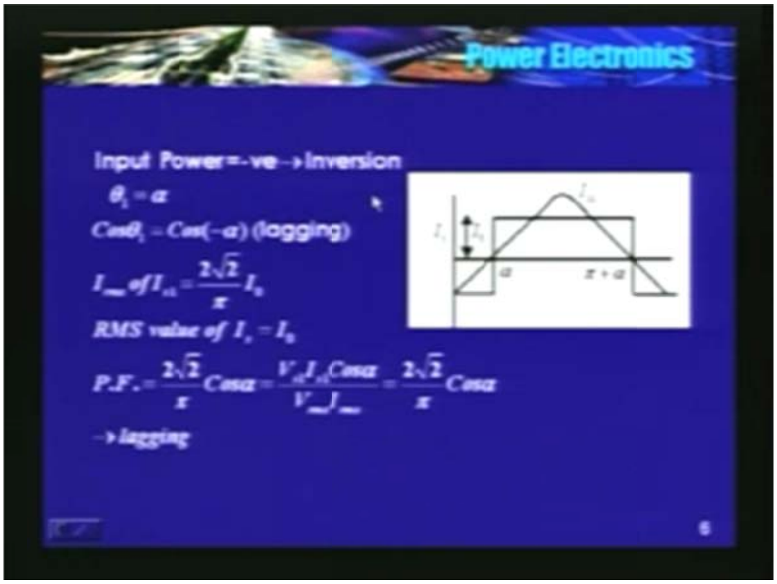

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Input Power=-ve→Inversion

$\theta_1 = \alpha$

$Cos\theta_1 = Cos(-\alpha)$ (lagging)

I_{rms} of $I_{s1} = \frac{2\sqrt{2}}{\pi} I_0$

RMS value of $I_s = I_0$

$P.F. = \frac{2\sqrt{2}}{\pi} Cos\alpha = \frac{V_{s1} I_{s1} Cos\alpha}{V_{rms} I_{rms}} = \frac{2\sqrt{2}}{\pi} Cos\alpha$

→lagging

Now coming to power factor, how does, what is the expression for power factor for a fully controlled bridge? Source current is a square wave, the value of the magnitude of a source current is I_0 from alpha to pi, alpha to pi plus alpha and it is minus I_0 from pi plus alpha to 2 pi plus alpha. So, if I write the Fourier series, average component is 0 because it is an odd function. All cosine terms are 0. You have only a sinusoidal terms or only sin terms; sin omega t, sin 3 omega t, sin 5 omega t and so on.

What is a magnitude of sin omega t term? It is found that the peak value of the sin omega t term is 4 by pi into I_0 where I_0 is the magnitude of the square wave. The RMS value is 2 root 2 by pi into I_0. So remember, of course, you do not need to remember, you can always prove or you can find that the peak value of the fundamental component - this has to be a sinusoid- the peak value of the fundamental component that is I_{S1} is given by 4 by pi into I_0, this is I_0.

So, the RMS value is again root 2 times. So, 2 root 2 by pi into I_0. What is the RMS value of this wave form, source current wave form? What is RMS value? RMS value is same as I_0. So, what is the expression for power factor? Power factor is $V_1 I_1$ into cos alpha 1 divided by V_{RMS} into I_{RMS}. It is the mean input power divided by the input volt amperes.

I told you that only the fundamental component of voltage and current are responsible for power transfer and we have assumed that input voltage is a sinusoid. So, RMS value of the fundamental component of the input voltage is same as V_{RMS} itself. I_{RMS} is I_0, fundamental component of the load current. The RMS value is 2 root 2 by pi into I_0.

Displacement factor is cos alpha, displacement factor is cos alpha is the angle between the fundamental component of input voltage and the fundamental component of the source current is alpha itself. In fact, it is minus alpha, so cos alpha cos minus alpha is cos alpha itself. So, power factor is given by 2 root by 2 into cos alpha. Mind you, it is lagging.

Power factor here is 2 root 2 by pi into cos alpha, remember. In the second quadrant, I told that source is receiving power. In other words, load is supplying power back to the source. How is that possible or what sort of a load can supply power back the source? What happens if I connect a load, connect a purely resistive load to the load terminals of the fully controlled bridge? Or in other words, the fully controlled bridge is feeding up purely resistive load. Can the current be continuous?

If the purely, if the fully controlled bridge is supplying power to a purely resistive load, current becomes 0 when the instantaneous value of the applied voltage is 0 and in the negative half current cannot flow. Are you with me?

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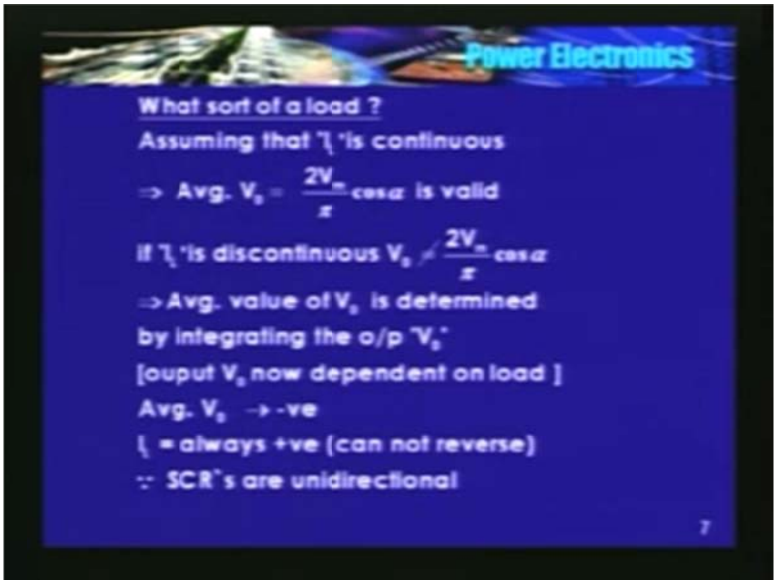

What sort of a load ?

Assuming that 'I_L' is continuous

$\Rightarrow$ Avg. $V_o = \frac{2V_m}{\pi}\cos\alpha$ is valid

If 'I_L' is discontinuous $V_o \neq \frac{2V_m}{\pi}\cos\alpha$

$\Rightarrow$ Avg. value of V_o is determined by integrating the o/p 'V_o'

[ouput V_o now dependent on load]

Avg. V_o $\rightarrow$ -ve

I_L = always +ve (can not reverse)

$\because$ SCR's are unidirectional

If the current can flow through a resistor only when the instantaneous value across it is positive. If the instantaneous value is 0 or negative, you cannot have that condition at all, you cannot have that situation at all in the case of a resistor, the DC. So, current is going to be discontinuous from 0 to alpha. Source supplies current from alpha to pi, at pi instantaneous value of the applied voltage to the load is 0 and tries to become negative. So, current has also become 0 at omega t is equal to pi.

SCR's T_1 and T_2, they have turned off of their own because current has become 0. We did not turn them off. Remember, we did not turn them off. They turned off of their own because current flowing through them has become 0. So, there is a difference. If the current is continuous, I have to trigger the other 2 to turn the previously conducting thyristors. Since, the load is resistive and alpha is finite and greater than 0, beyond pi to pi plus alpha, there is no current. So, the average value of the output voltage is definitely is not equal to 2 V_M by pi into cos alpha, remember.

So, average value of the output voltage across the resistor is always positive, current is unidirectional. So, the resistive load absorbs power and that power is dissipated as heat.

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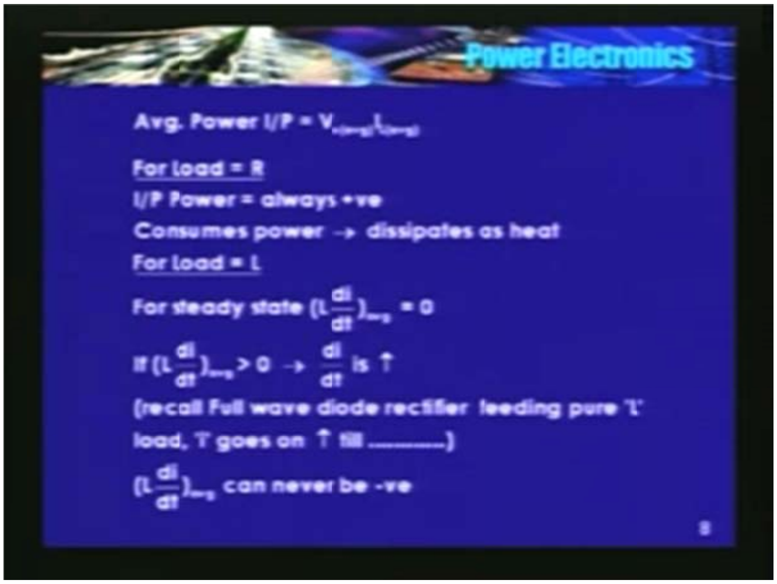

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Avg. Power I/P = $V_{o(avg)} I_{o(avg)}$

For load = R

I/P Power = always +ve

Consumes power → dissipates as heat

For load = L

For steady state $(L\frac{di}{dt})_{avg} = 0$

If $(L\frac{di}{dt})_{avg} > 0 \rightarrow \frac{di}{dt}$ is ↑

(recall Full wave diode rectifier feeding pure 'L' load, 'I' goes on ↑ till ....)

$(L\frac{di}{dt})_{avg}$ can never be -ve

What is what happens if the load is purely inductive? At steady state, average value of the voltage across it should be 0. In other words, average L di by dt should be 0. If average value of L di by dt is positive, it implies that di by dt is positive or in other words, i goes on increasing.

So, in other words, there is no steady state. Remember, I did this topic while doing the uncontrolled bridge. In the case of half wave rectification, inductor current continuously flows for 2 pi radiance, it becomes 0 at 2 pi, it attends a peak at omega t is equal to pi. Whereas, if I, in the case of a uncontrolled bridge, current goes on building up because at omega t is equal to pi plus, again we are applying a positive voltage.

So, in other words, L di by dt is positive. So, current goes on increasing till the device fails or the inductor fails or the source fuse blows off. So, current goes on increasing till inductor saturates or the device fail or the input site, this, the fuse blows off. So, there is if L di by dt, average value of the L di by dt is positive, there is no steady state. But, can it be negative? It can never be negative, average value of the voltage across it can never be negative.

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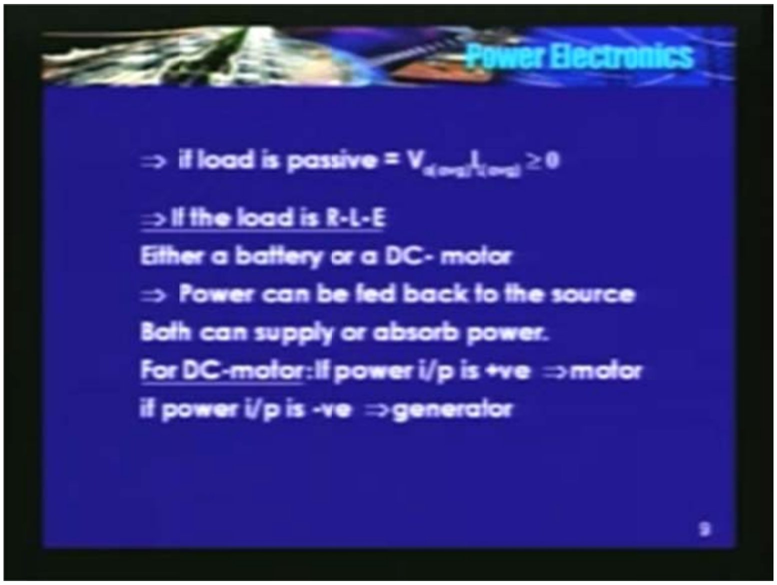

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⇒ if load is passive = $V_{d(avg)} I_{L(avg)} \geq 0$

⇒ If the load is R-L-E

Either a battery or a DC- motor

⇒ Power can be fed back to the source

Both can supply or absorb power.

For DC-motor: If power i/p is +ve ⇒ motor

if power i/p is -ve ⇒ generator

So, in other words, if the load is passive, average value of the output voltage into the average value of the load current is either 0 or it is positive. It is 0 for an ideal inductive load and if it is positive for RL load. So, when can I have inversion or in other words, when can I have average value of the output voltage in negative? It is possible only when the load current is continuous.

So, either a load should be RLE type or either we should have a battery there, at the load side or have a DC motor. Because, a battery can either absorb the power or supply the power. Similarly, I have machine, if the input power to the machine is positive, it converts the electrical energy to mechanical energy, known as the motoring operation. Whereas, if the input power is negative, it implies that the machine is act like a generator. It converts the mechanical power to electrical power.

So, if the input power is positive, it is known as the motoring action, if the input power is negative, in other words, machine is supplying power or source is absorbing power, it is known as the generating action. So, if I have a RLE type of load, either a battery or a DC machine, it is possible to have a continuous conduction in the 4th quadrant or for alpha is equal to greater than pi by 2, it is possible to have continuous conduction.

In other words, average value of the output voltage can be negative. Therefore, powers input power to the bridge can be negative. In other words, in the source can absorb power only when I have a DC motor or a RLE type of load. Now let us see, how this regeneration takes place or how the machine can supply power back to the source when it is being fed from a converter?

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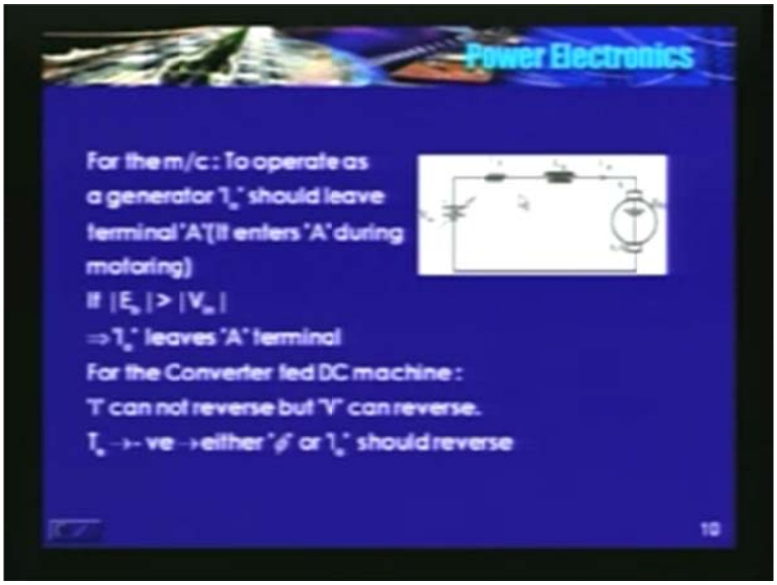

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For the m/c : To operate as a generator 'I_a' should leave terminal 'A' (It enters 'A' during motoring)

If $|E_b| > |V_{in}|$

$\Rightarrow$ 'I_a' leaves 'A' terminal

For the Converter fed DC machine :

'I' can not reverse but 'V' can reverse.

$T_e \rightarrow -ve \rightarrow$ either 'ϕ' or 'I_a' should reverse

Take this example, I have a variable DC source, V_{in} which is given by 2 V_M by pi into cos alpha, provided the current is continuous. R_A is the armature resistance, L_A is the armature circuit inductance, generally, tau V_A is very small and E is the back EMF. So, if I consider this as a source supplying power to the machine, current enters the terminal A.

So, these are the 2 popularly used terminals, A and AA. The current enters here, it is known as the motoring action and if the current leaves A, it is known as the generating action, our machine teacher has told us during the machines lab. Now, if E_b is higher than V_{in}, current can reverse, current leaves the terminal A.

By the way, why are we doing all this? Initially, we are operating the machine as a motor, now you want to operate as a generator. What are the advantages? Why do you need a 2 quadrant converter? Let us see.

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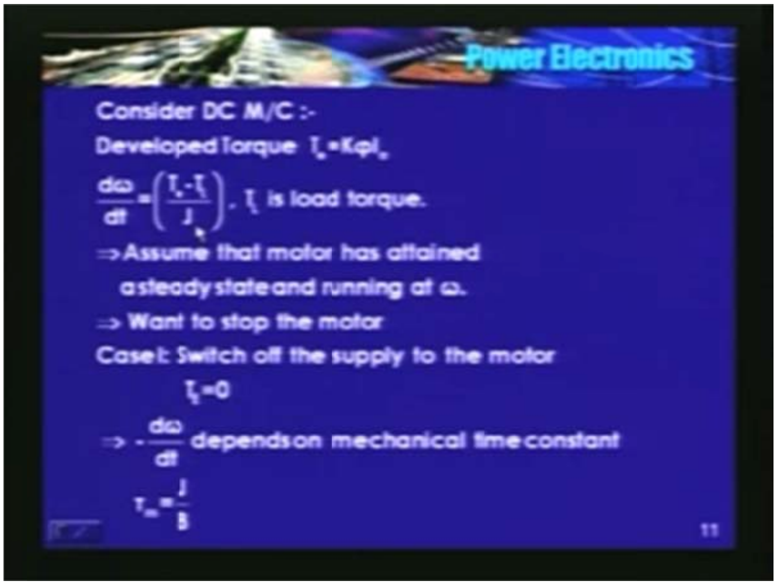

Consider DC M/C :-

Developed Torque $T_e = K\phi I_a$

$\frac{d\omega}{dt} = \left(\frac{T_e - T_L}{J}\right)$. T_L is load torque.

⇒ Assume that motor has attained a steady state and running at ω.

⇒ Want to stop the motor

Case I: Switch off the supply to the motor

$T_e = 0$

⇒ $-\frac{d\omega}{dt}$ depends on mechanical time constant

$T_m = \frac{J}{B}$

Consider DC machine, developed torque is K into 5 into I_A and d omega by dt is given by T minus T_L divided by J. I am neglecting the frictional torque. Now, assume that motor has attend a steady state, running stably at some omega. Now, I want to bring the speed down to 0. In other words, I would like to stop the machine.

1 option is put off the supply. So, I_A is also 0, pi is also 0, torque will be 0. So, machine will decelerate. Whatever the stored energy, the stored kinetic energy in its inertia is dissipated as heat to overcome the friction. So machine, depending upon the mechanical time constant and plus depending upon if the machine has a large inertia, machine speed will reduce very slowly. The stored energy in the inertia is dissipated as heat.

The second way to bring the speed down to 0, instead of making T_E is equal to 0 or in other words, instead of switching off the supply, can I make T_E negative? I can make T_E negative. In other words, it is possible to make T_E negative by making either I_A negative or making pi negative.

Now, as of now, we will concentrate on reversing armature current. So, in principle it is possible to make T_E negative. What it is the advantage?

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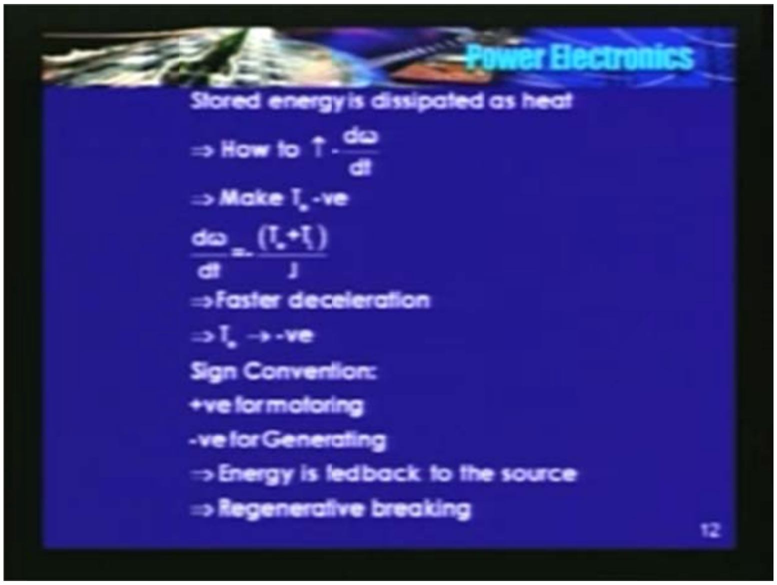

Stored energy is dissipated as heat

$\Rightarrow$ How to $\uparrow -\frac{d\omega}{dt}$

$\Rightarrow$ Make T_e -ve

$\frac{d\omega}{dt} = -\frac{(T_e + T_L)}{J}$

$\Rightarrow$ Faster deceleration

$\Rightarrow T_e \rightarrow$ -ve

Sign Convention:

+ve for motoring

-ve for Generating

$\Rightarrow$ Energy is fedback to the source

$\Rightarrow$ Regenerative breaking

Now, d omega by dt is minus of T_E plus T_L by J. So, rate of deceleration is faster. Second is I have made T_E negative, T_E is positive for motoring action, now T_E is negative for generating action, whatever the stored energy in inertia or the kinetic energy is converted into electrical energy. For we are achieving 2 things: faster deceleration and saving electrical energy. Stored energy is converted back to electrical energy.

I will just give an example; in the sugar mill, generally, the rating of the motor is of the order of 90 to 100 kilowatt or so and it has to stare the molasses. Basically, it has a large inertial load. So, when you put on the supply, machine takes a large time to accelerate because it has to overcome the, J is very large, so it draws a rated current, takes a longer time, much longer time to accelerate and attain a steady state.

Once it attains a steady state, d omega by dt is 0. Now, it would have just overcome the friction and some sort of viscous torque. So, at steady state, it is drawing a very fraction of its rated current, I am telling you. While accelerating, it took the rated current, slowly accelerates, attains the steady state, now extracts a very small current because load torque is completely or most of the load torque is the inertia torque, J d omega dt type.

Now, if you want to put off the supply, I was told that it takes of the order of 90 minutes 1 and a half an hour. It stops, come down to 0 after 90 minutes or so and all the energy, so called energy stored in the inertia is dissipated as heat. So, if the driver strips, it takes 1 and a half hour to come down to 0 speed then you have to give some time for motor to cool down.

Again, if you want to put on the motor, it will take its own time to accelerate. See the wastage in the time because no work is being done and all the energy is dissipated as heat. So, using a 2 quadrant converter, you can achieve faster deceleration, saving in electrical energy. At what cost? I need to have a 2 quadrant converter.

So since, I am bringing the motor to halt or I am decelerating at a much faster rate and I am converting the stored kinetic energy into electrical energy, this sort of a breaking is known as regenerative breaking. May be, in your under graduate level, your teacher might have talked about plugging, dynamic breaking, this is regenerative breaking.

What is regenerative breaking? Stored energy, stored kinetic energy is dissipated as sorry as converted back to electrical energy. So, these are the advantages.

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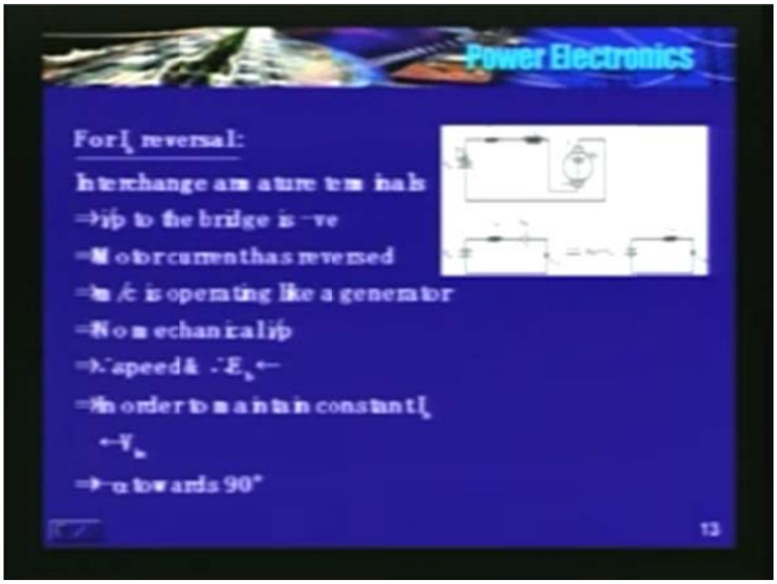

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For I_a reversal:

Interchange armature terminals

⇒ i/p to the bridge is –ve

⇒ Motor current has reversed

⇒ m/c is operating like a generator

⇒ No mechanical i/p

⇒ ∴ speed & ∴ E_b ←

⇒ In order to maintain constant I_a

← V_{in}

⇒ α towards 90°

13

Now, coming back to the 2 quadrant convert fed DC motor, operating as a generator, I said I_A should reverse. I have flipped the armature terminals. Now, it is connected to AA. Current for the machine, current has reversed. Now, it is leaving AA, but then for the converter, current is still, the direction of the current cannot reverse for the converter, whereas, the voltage has reversed. Now, if I have neglect L_A, the equivalent circuit is V and here is the E_b and R_A. This is equivalent circuit.

Machine was prior to regenerative breaking it was running as a motor. Input is electrical, output is mechanical. Now, it is act like a generator. Mind you, there is no mechanical input. Kinetic energy is converted to electrical energy, so speed will fall. As the speed falls, back EMF also falls, E_b falls. So, as speed falls E_b , E_b fall, E_b will reduce. Now, in order to maintain the current, armature current, I need to change or I need to reduce this voltage.

So therefore, alpha should be decreased towards 90 degrees, remember. Initially, E_b was high. So, V_{in} is also high, magnitude, so alpha was nearly maybe, around 165 or 170. Theoretically, may be, 180. But you cannot achieve that any way. Now, speed is falling or as speed reduces E_b is E_b reduces. I have to maintain the current, so V_A has to be reduced. How do I do? Reduce alpha towards 90 degrees.

So, you need to have some sort of a closed loop. More about it, you will study in electric drives. It does not fall in the scope of power electronics course. Just now I told you that either flux I can reverse or armature current I can reverse. Now, which is better? Whatever you do in your life, you have to pay a price. The armature time constant is very small compared to field time constant.

So, if you want to have a fast response, I will be going for flipping of armature current or interchange the armature terminals. Armature current reverser rather than the flux reverser because time constant is very large; flux has to die down and then it has to attain a negative value, it takes a much longer time. But then when I am saying that I am flipping the armature terminals, we know that armature current is much, much higher compared to a field current.

So, if I use a just 2 quadrant converter and a contactor which interchange the armature terminals, it has to handle a large current. Momentarily, I am breaking an inductive circuit, after all that is an inductance or invariably we connect an inductor in the DC link also to reduce the current pulsation. So, I am breaking an inductive circuit, a large current, so sparking may occur. So, that is what I said; faster response, contactor has to carry a large current, slow response, then it going for a field current.

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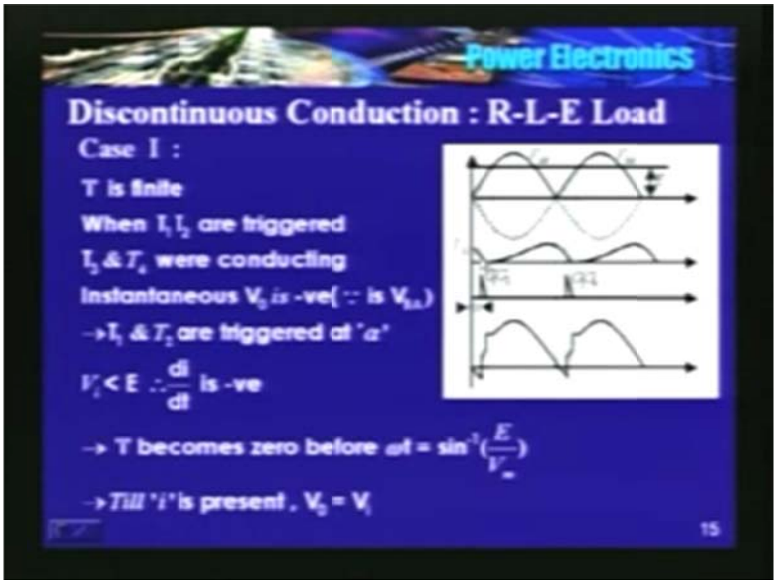

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Discontinuous Conduction : R-L-E Load

Case I :

T is finite

When $T_1 T_2$ are triggered

T_3 & T_4 were conducting

Instantaneous V_0 is -ve(∵ is V_{ba})

→T_1 & T_2 are triggered at 'α'

$V_i < E \therefore \frac{di}{dt}$ is -ve

→ T becomes zero before $\omega t = \sin^{-1}(\frac{E}{V_m})$

→Till 'i' is present , $V_0 = V_i$

15

So far we discussed about the continuous conduction. Now, let us discuss about the discontinuous conduction. Load is RLE, it is bit difficult here, there are various cases, I will consider case 1.

Case 1, the current is finite when T_1 and T_2 are triggered. In other words, somewhere here at this point you have triggered the T_1 and T_2, current as finite. So, T_1 and T_2 start conducting. Prior to this instant, T_3, T_4 were conducting. Current is finite, SCR's T_1 T_2 are forward biased that is why you can trigger at alpha which is less than alpha min where alpha min is E divided by V_m.

SCR’s have started conducting in the positive half. Since, E is higher than V_{in}, the instantaneous value of the input voltage di by dt is negative. I have discussed this before, di by dt is negative. So what happens is? Current becomes 0 much before alpha min, when alpha is equal to alpha min much before this instant, current become 0.

So, prior to triggering, T_1, T_3 were T_4 were conducting. Output voltage is V_{BA} which is negative. You triggered, at alpha T_1, T_2 starts conducting. Now, load voltage is V_{AB} which is positive. Somewhere at this instant, current became 0. Now, the output voltage is E. So, it jumps to E. Now, where will the conduction start again? If there is only 1 pulse, 1 triggering pulse, SCR will not conduct again.

If there are large numbers of pulses - I told you the gate circuit requirement in the beginning - if there are a large number of pulses and in case if there is a pulse present at alpha is equal to alpha min where that instant E becomes or instantaneous value of the input voltage becomes E, SCR starts conducting again. I am assuming that there are large numbers of pulses in the gate. So, again SCR starts conducting and cycle repeats.

So, current was finite, diodes, SCR’s started conducting, output voltage is same as the V_{in}, current became 0 because di by dt is negative, till V_i is equal E. So, at V_i is equal to E, gate signal was present, SCR gets triggered there again and starts conducting. So, in principle you need to have a 2, 3 sharp pulses like this. A number of sharp pulses are required. This is case 1.

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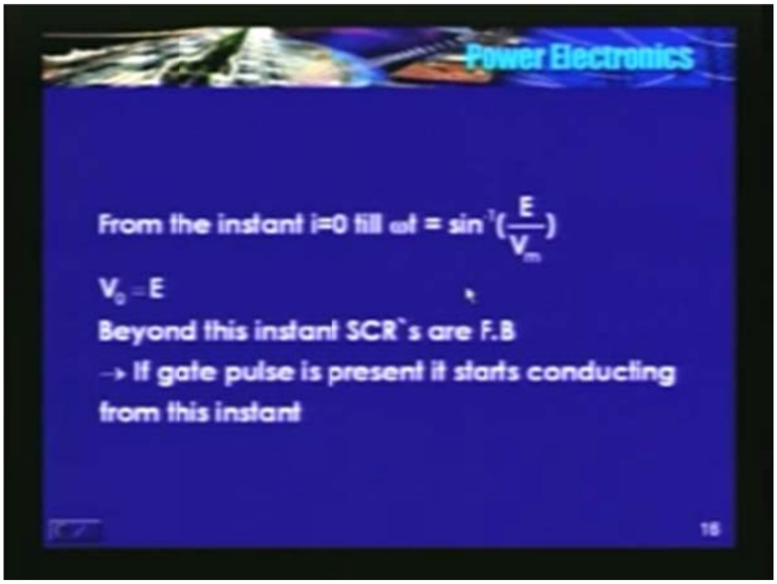

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From the instant i=0 till $\omega t = \sin^{-1}\left(\frac{E}{V_m}\right)$

$V_0 = E$

Beyond this instant SCR`s are F.B

→ If gate pulse is present it starts conducting from this instant

So, if the gate pulse is present, it starts conducting at this instant when E is equal to V_{in}.

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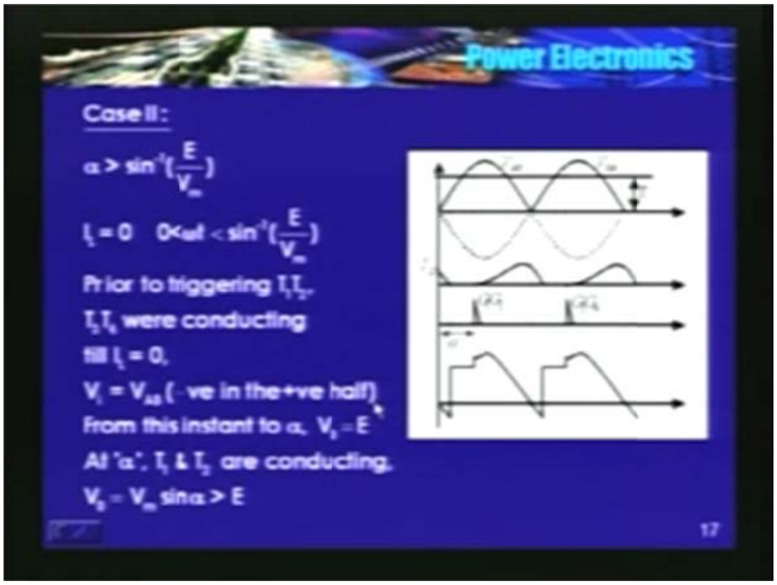

Case II:

$\alpha > \sin^{-1}(\frac{E}{V_m})$

$i_L = 0 \quad 0 < \omega t < \sin^{-1}(\frac{E}{V_m})$

Prior to triggering T_1T_2,

T_3T_4 were conducting

till $i_L = 0$.

$V_L = V_{AB}$ (-ve in the+ve half)

From this instant to α, $V_L = E$

At 'α', T_1 & T_2 are conducting.

$V_0 = V_m \sin\alpha > E$

What is the second case? SCR’s T_1 and T_2 are triggered beyond alpha is equal to alpha min. Current became 0 somewhere at this instant. So, till the current become 0, T_3, T_4 were conducting. Output voltage is V_{BA} which is negative, current became 0. The load voltage is now E. It jumps to E, it continuous till you trigger T_1 and T_2 at alpha. So, this alpha is higher than alpha min. The moment you trigger the thyristor, it starts conducting.

Now, here there is a jump. Why there is a jump here? Because the instantaneous value of the input voltage at alpha is much higher than E, you have triggered at this point. So, just prior to triggering T_1 and T_2, output voltage was E. Now, you triggered T_1 and T_2, now output voltage is V_{AB}. So, it jumps and continues. So, this is the second case. There could be few more cases, let us not discuss those now, will do some other things.

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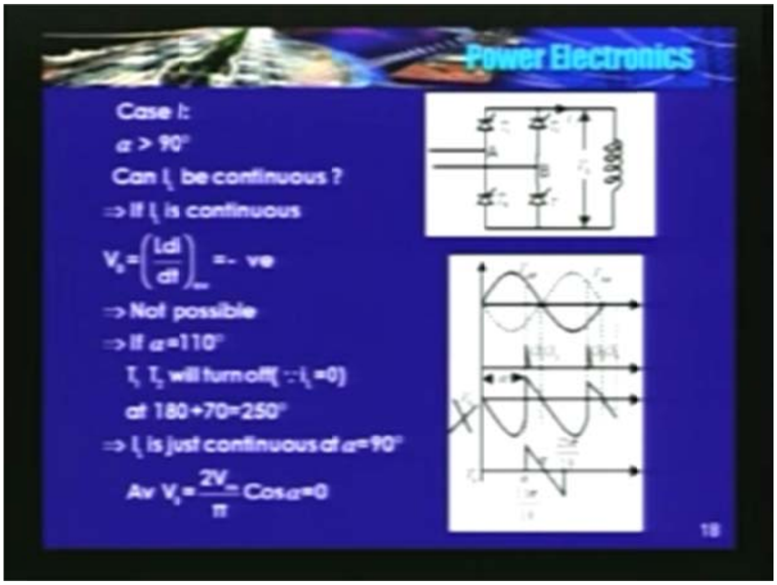
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Case I:

$\alpha > 90^\circ$

Can I_L be continuous ?

$\Rightarrow$ If I_L is continuous

$V_0 = \left(\frac{Ldi}{dt}\right)_{av} = -ve$

$\Rightarrow$ Not possible

$\Rightarrow$ If $\alpha = 110^\circ$

$T_1\ T_2$ will turn off($\because I_L = 0$)

at $180 + 70 = 250^\circ$

$\Rightarrow I_L$ is just continuous at $\alpha = 90^\circ$

Av $V_0 = \frac{2V_m}{\pi} \cos\alpha = 0$

Now, let us see a fully controlled bridge feeding an inductive load. Alpha is greater than 90, I_L be continuous. I said if I_L is continuous, 2 V_m by pi into cos alpha, alpha is greater than 90 which becomes negative. So, average output voltage becomes negative is just not possible. So, if you draw this waveform, it is wrong. This is wrong because this is for the continuous conduction.

So therefore, remember, average voltage across the inductor could be positive or 0. If it is positive, it has no steady state, at study state, it is 0. So, assume that if alpha is110 degrees, T_1 and T_4 will turn off of their own, I am telling you. T_1 and T_2 were triggered at alpha equal to 110, they will turn off of their own at 250 degrees because average voltage, this area should be equal to this area.

So, that is 11 by pi by 18, this should be 25 by pi by 18. So, it will turn off because current has become 0. Mind you, if alpha is 110, T_3 and T_4 will be triggered only at 180 plus 110 that is 290. The SCR's were turned off their own much before that. So, this is the waveform. So definite, now if you integrate it, if we find the average value of this is 0. This waveform, if you find, is 0.

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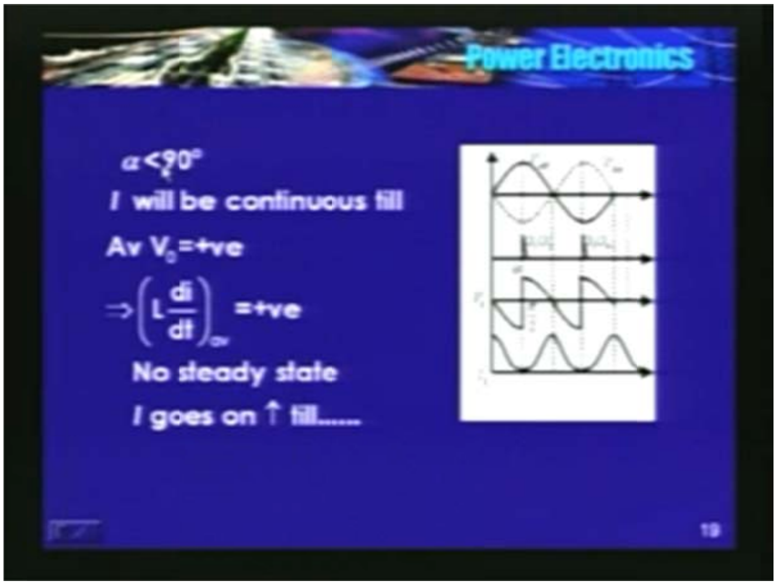

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$\alpha < 90°$

I will be continuous till

Av V_0=+ve

$\Rightarrow \left(L\frac{di}{dt}\right)_{av}$ =+ve

No steady state

I goes on ↑ till......

19

Case 2; so, alpha cannot be continuous even if the load is purely inductive for alpha greater than 90. For alpha less than 90, i will be continuous. I said that is why I have written, i will be continuous till, till even the SCR or the inductors fails or SCR’s will fail or the source input fuse will fail, it depends.

At alpha is equal to 90 degrees, current is just continuous because 2 V_m by pi into cos alpha, alpha is 90, it is 0. So, it was just 0, starts increasing, instantaneous value of the input voltage is 0 at omega t is equal to pi, at that instant i is equal to I_m or the peak value, a negative voltage is applied to the load. So, di by dt is negative, currents starts decreasing. So, it just becomes 0 when you trigger, if you trigger alpha is equal to 90 degrees.

So remember, even if the load is inductive, it is current is just continuous at alpha is equal to 90 degrees. If it is less than 90, it will be continuous. It goes on building up till something happens. For alpha greater than 90, current cannot be continuous if the load is purely inductive, remember this.