**Power Electronics**

**Prof. B.G Fernandes**

**Department Of Electrical Engineering**

**Indian Institute of Technology, Bombay**

**Lecture No - 13**

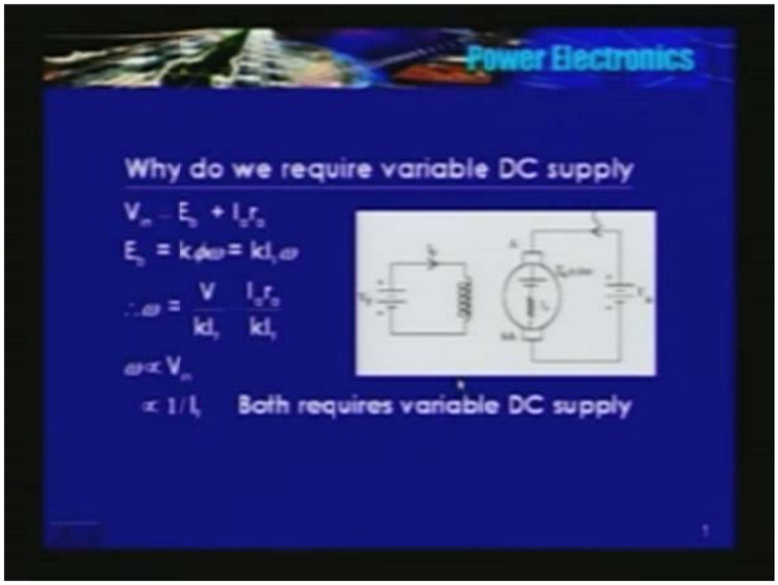
Let me recapitulate whatever that I did in my last class. In one of the configurations of half control bridge, we found that as alpha tends to pi, the incoming thyristor fails to turn on and therefore the outgoing thyristor fails to turn off. As a result, the output voltage wave form if I see, from 0 to pi we have a freewheeling period and from pi to 2 pi output voltage is same as the input voltage. So, there is source supplies power only in 1 of the half cycles and in the remaining half cycle, there is a complete freewheeling part provided, the load current is continuous.

So, output voltage is same as that of a half wave rectifier. In a very first lecture on converters, if you see the wave form, they are both the same. Hence the name, half waving effect. Then second point what we discussed was the expression for the average value of the output voltage; is given by $V_m$ by pi into 1 plus cos alpha. Remember, this expression is valid only if the load current is continuous. Remember, load current should be continuous, only then this expression is valid because we got this expression by integrating the output voltage.

The output voltage is $V_m$ sin omega t from pi to alpha to pi and pi to pi plus alpha, it is 0, is a freewheeling period and from pi plus alpha to 2 pi, again it is $V_m$ sin omega t. So, only when you integrate this wave form, you will get the average value is $V_m$ by pi into 1 plus cos alpha. So, only if the current is continuous, this is the output, output voltage is given by $V_0$ $V_m$ by pi into 1 plus cos alpha. Remember, invariably students make a mistake while solving a problem. The moment they see a half controlled bridge, they immediately, automatically, they write average value of output voltage is $V_m$ by pi into 1 plus cos alpha. Even though current is discontinuous, do not make this mistake.

Now, all this time we have discussing about controlled rectification. So, I have a question to ask. Why do we require the variable voltage DC supply? Why, why do we require variable voltage DC supply? Now, let me take a diversion, in the sense, I will go back to machines. In my introductory lecture I told you that in power electronics, to appreciate power electronics, you need to have a really a good back ground, a good knowledge of machines. Little bit of everything is there in power electronics, remember. So to appreciate power electronics, a reasonably good knowledge of machines is essential. Let me review DC machines.

(Refer Slide Time: 4:44)




A separately excited DC machine, very popular equation, $V_{in}$ is equal to $E_{b,}$ is the back emf plus $I_ar_{a,}$ $V_{in}$ is equal to $E_b$ plus $I_ar_a$, $E_b$ is the back emf which proportional to flux and speed. This flux is proportional to the field current. So therefore, $E_b$ is given by k into $I_f$ into omega. Therefore, omega is given by $V_{in}$ $V_{in}$, the input voltage to the armature; Input voltage to the armature, it is not the input voltage to the motor or something like that. In the sense, if I connect the resistor in series, so that is not $V_{in}$. $V_{in}$ is a voltage applied to the armature terminals A, AA, remember.

$V_{in}$ divided by k into $I_f$ minus $I_ar_a$ divided by k $I_f$. Your teacher would taught machines, he might have told you that for all the practical purposes a separately excited DC machine is a constant speed machine.

In other words, reduction in speed with load is not much. This term is generally small because armature resistance which comes in the path of the main power flow should be very small. If $r_a$ is high, i square $r_{a,}$ i square r losses are high, efficiency comes down. So, armature resistance should be as small as possible. Moreover, armature reaction armature reaction what it does? It tries to reduce the air gap flux. So therefore, armature reaction tries to keep the speed of the motor almost constant.

So therefore, for all practical purposes, separately excited DC machine is a constant speed motor. Application requires the speed variation in speed over a wide range. What should I do? I have to change the no load speed. This term is independent of the armature current. So, I have to change the no load speed.

So we found that omega, the no load speed is proportional to the input voltage to the armature, $V_{in}$ and inversely proportional to the flux or $I_f$. So, if I have to decrease the speed below the rated, I will apply a reduced voltage to the armature. So, speed is directly proportional to the input voltage to the armature. So, for any speed from 0 to the rated, $V_{in}$ should vary from 0 to the rated voltage of the machine and I will keep the flux constant.

If I want to increase the speed above the base or above the rated, I will keep voltage applied to the armature at its rated value because a general, a good engineering practice is; one should not apply a voltage higher than the rated to the motor, a general engineering practice, a good engineering practice. So, I will try to reduce the field flux. So, my speed, no load speed increases.

So therefore, from 0 to base speed, applied voltage to the armature terminals should be varied and from the speed above the base, decrease the field flux or decrease the field current. So, both these regions or  if I have to vary the applied voltage to the armature or if I have to vary $I_f$, I need to have a variable DC supply. You may say that I will connect a rheostat in series. That is what we do in our machines lab. It is basically, highly inefficient way of handling power.

Having done a course on power electronics, do not use a resistor in series of any circuit. It is crime. Having done a course on power electronics, your solution should not contain the use of, resistor comes in a main part of the power flow, just not accepted. That is what I said, one of the ways, may be our teacher, machine teacher, may the one know who taught machines, might have told that connect a resistor in series with the armature and connect resistance in series with field, vary them to vary the speed. That is fine in course 1 or that is fine in machines course.

Definitely, this solution is not acceptable once you do a course in power electronics. So, coming to power electronics again, both of them require a variable voltage DC power supply. So, I can have a semi control or half controlled bridge here. I can have a half, I can, let us see, as the power rating increases what modification do I need to make in the power circuit. One of the options is I can have, both the cases I can have a semi controlled bridge. May say, why not use half wave controlled rectification using 1 thyristor?

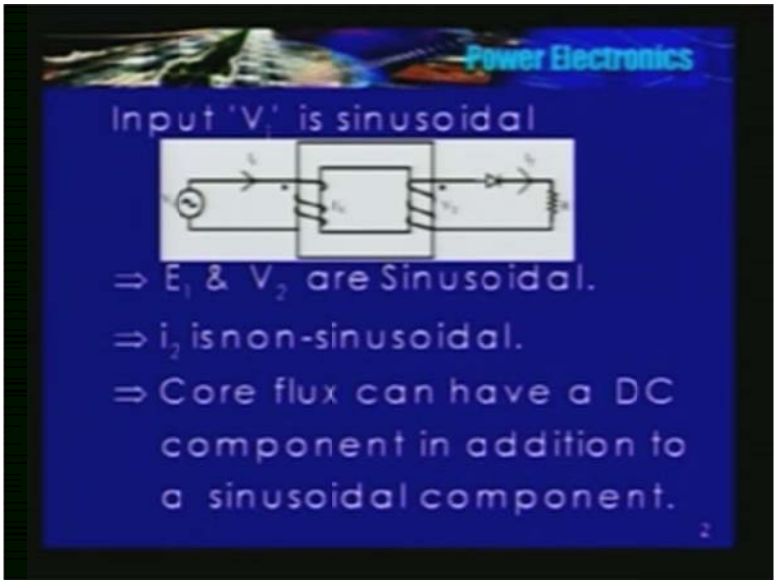
What did we found yesterday? I solved one problem, a very good problem. The moment I use only 1 thyristor between the source and the load or in other words, in half wave controlled rectification, we are drawing a DC current from the source. In other words, average value of the current drawn from the source is finite. Source does not supply any power beyond pi if I use freewheeling diode, you observed that.

So, there is a DC component coming from the source plus the harmonics. Harmonics are there even in both the cases, whereas, in this case if I use a semi controlled or half controlled bridge, DC component is 0. There is a pulse or source supplies power from alpha to pi in the positive half and pi plus alpha to 2pi in the negative half. So, average value of the source current is 0. So, DC component is 0.

So, half wave rectification could be a solution for a small motor, a small, a fractional hp DC motor, use of half wave rectification may be justified because small hp motor cost is very low. So, might controller also, the so called power processing equipment should also be very low. I cannot have a very expensive equipment to vary the speed of a small motor.

So, varying speed of a small motor, half wave rectification could be a solution because current that I am drawing from the DC, the average value the current I am drawing from the source is very small. I told you yesterday that I will solve a very interesting problem. See, a very interesting problem, lot of things are there, try to understand. It is not very simple but looks very simple.

(Refer Slide Time: 13:38)

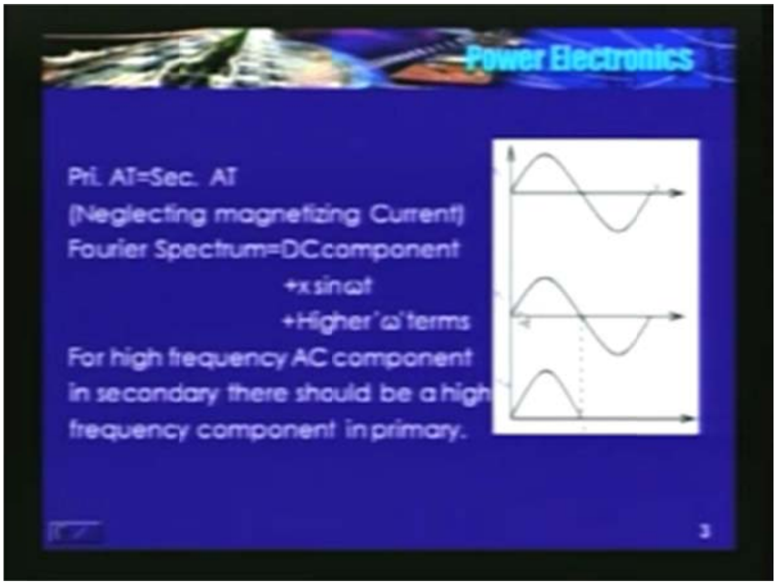



My sincere request to you is do not go by looks invariably, you know, you will get cheated. So, the circuit is very simple. May be, the performance may not be as simple as that, remember. I have a simple transformer, input winding, primary is connected to the source, secondary is connected to or secondary is supplying a resistive load through a diode.

The moment I connect a diode in the circuit, circuit is no longer linear, remember. Linear in the sense, the circuit does not or in other words, the law of super position does not hold good for this circuit. Circuit is non linear. Input voltage is sinusoidal, therefore I mean I am there is a very small winding resistance and may be a very small leakage flux also. So, if $V_1$ is sinusoidal, I can safely assume that $E_1$ is also sinusoidal.

Since, winding resistance and leakage flux are very small, I can safely assume that $V_1$ and $E_1$ are sinusoidal. $V_2$ is also sinusoidal. Output voltage, voltage across R is voltage across R is a half wave rectified.

(Refer Slide Time: 15:35)




The secondary voltage, output voltage across R. Load is purely resistive, current wave form is also half wave rectifier. So, current flows in the load, remember, current flows in the load from 0 to pi. The expression is given by secondary sinusoidal voltage divided by r that is if I say some x into sin omega t, so expression for i is x into sin omega t divided by r and from pi to 2 pi, current is 0.

So in other words, secondary does not supply any power to the load from pi to 2 pi. So, if I write the 4ier series or 4ier spectrum for the current, it has a DC component, I discussed yesterday. It has average value is finite. So, it has a DC component. Then I have a fundamental component, x sin omega t or the frequency of the first term is same as that of the input and it has a higher omega terms.

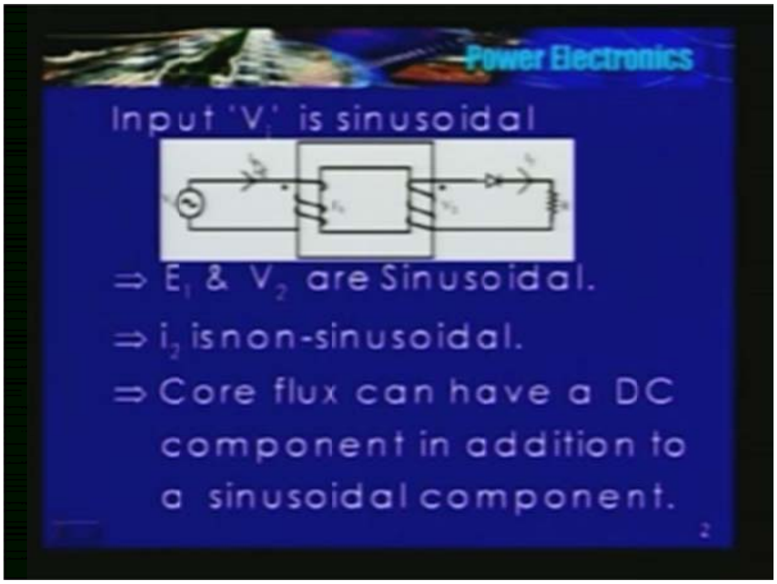
Now question is how does the source current look like? What are the principles? What are the, our machine teacher what has he has told us 1 thing that is in a transformer for the AC components, there has to be an ampere turn balance. If there is an AC current flowing in the secondary, there has to be an equivalent AC current in the primary. Neglecting the magnetizing current, ampere times $N_1 I_1$ should be equal to $N_2 I_2$, magnetizing current is neglected.

Secondary current has a sinusoidal, sinusoidal component has a DC component. I will repeat secondary current has a DC component. The flux in the core has a sinusoidal component which is produced by magnetizing current which induces sinusoidal voltage in the primary as well as in the secondary and it can have a DC component, because DC component in the core does not induce any voltage even in the primary or secondary.

I cannot have DC component in $E_1$ or the secondary voltage $E_2$. In other words, you cannot have a DC component either in $E_1$ or $E_2$. To have a DC component, Why am I saying this? To have a DC component in $E_1$ or $E_2$, flux is a ramp because E is d phi by dt. To have a constant E, phi is should be a ramp. In other words, if flux is a ramp then there is no steady state, is that okay?

So remember, the flux in the core has a DC component which does not induce any voltage in the primary as well as in the secondary. You cannot have a DC component either in $E_1$ or $E_2$. Why am I saying that? To have a DC component in $E_1$ or $E_2$, flux should be a ramp, should vary with t. So, if flux varies with t only then d phi by dt is a constant. Since, flux is varying with t, so there is no study state. So, we have to eliminate that.

(Refer Slide Time: 20:20)




The magnetizing the sinusoidal flux produced by the magnetizing current drawn from the source is sinusoidal. For every high frequency component which is there in the secondary, an equivalent current should be there in the primary, remember. For every high frequency sinusoidal component which is present in the secondary current, there should be an equivalent high frequency current in the primary. You cannot have a DC current in the primary, why am I saying this?

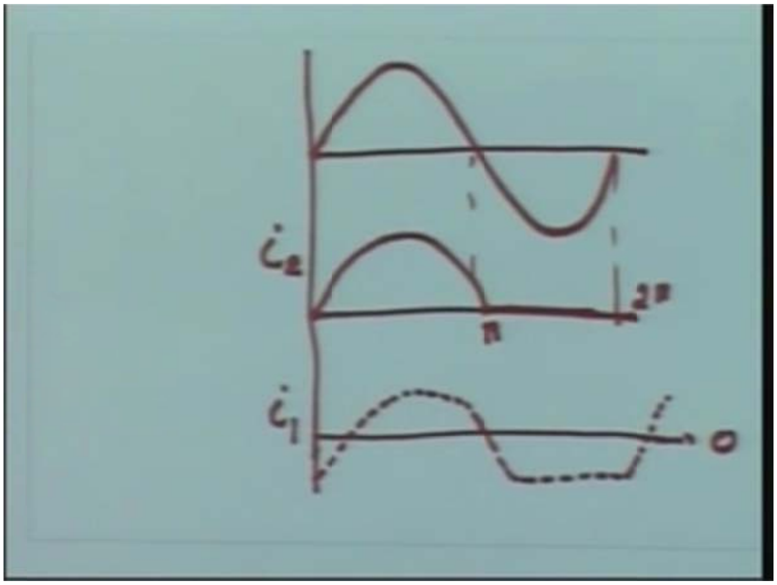
Assume that there is a DC component or if there is a DC component, see, there is a small resistance, winding resistance here. See, I will modulate an input voltage, a small winding resistance and $E_1$. I said $V_1$ is sinusoidal. I said $E_1$ cannot have a DC component, remember. So, if I apply KVL, it fails because if I have the DC component, if i average is finite, the DC component into r, an average DC voltage is required here. There is a voltage drop across r which is a DC. Input is AC which is sinusoidal, in this voltage is also sinusoidal, so KCL fails.

So, you cannot any circuit cannot violate the physical laws. Whether it is power electronics or any subject cannot violate the basic laws, remember. So far if you see, the entire, in my course I have used KVL and may be, maximum first order differential equation, R L and E and input is sinusoidal, only this much nothing else.

So, KVL has to hold good. So, I will repeat if there is a DC component in the source, I have told you that winding has a small resistance. i into r is going to be a DC voltage, input voltage is sinusoidal. Induced EMF is again sinusoidal. You cannot have a DC component there. So, KCL fails.

Therefore, your input current has no DC component. It has all the components of AC component of current which is there in the secondary, the equivalent and the fundamental component.

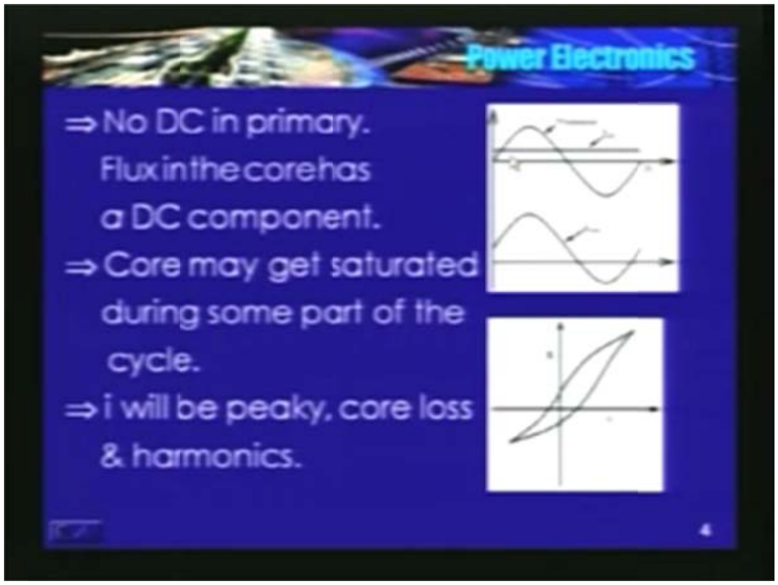
(Refer Slide Time: 23:52)



So, how does the primary current look like? Secondary current, the primary current should not have a DC component. Rest all the components should be there in the primary. So, primary current looks like this. It is like, I do not know how many of you have seen the waveform in the oscilloscope, if I keep a waveform which is having a DC bias and keep it in AC mode, how does it look like? The DC bias goes, I get a waveform symmetrical along x axis. If I keep in DC mode, automatically I get a DC bias. You go back and check if your if you not observed a waveform on the oscilloscope having a DC bias.

You give a sinusoid, using a signal generator give a DC bias, keep it in ac mode. The moment you keep it in ac mode, the DC bias disappears, vanishes. You get a waveform symmetrical about the x axis and if you keep it in DC mode; whatever the waveform be, the DC bias will come on the screen. So, same here, this waveform, actually is the waveform which you can see it in the oscilloscope with the DC bias. So, remove the DC bias I will get this waveform. So, source current looks like this. Source does not supply a DC component. But then, I told you that flux in the core can have a DC component. So what?

(Refer Slide Time: 25:46)




So, flux in the core has a DC component, phi DC and a sinusoidal component. This flux is produced by the magnetizing current. So, flux in the core is phi DC plus phi fundamental. So, I have a waveform, a sinusoidal waveform having a DC shift or DC bias. What is the effect? What is the consequence? What will happen if there is a flux, a DC flux in the core?

Again, our machine teacher might have told was that or told you that of course, the same machine teacher who thought me has also told me that invariably, we operate the machines or any magnetic circuit at the knee point. Knee point is a point wherein the saturation just begins to start. So, all the magnetic circuits when I apply the rated voltage, it produces a rated flux, rated AC flux, I am talking about AC now, AC flux. So, the operating point is the knee point, it is assumed.

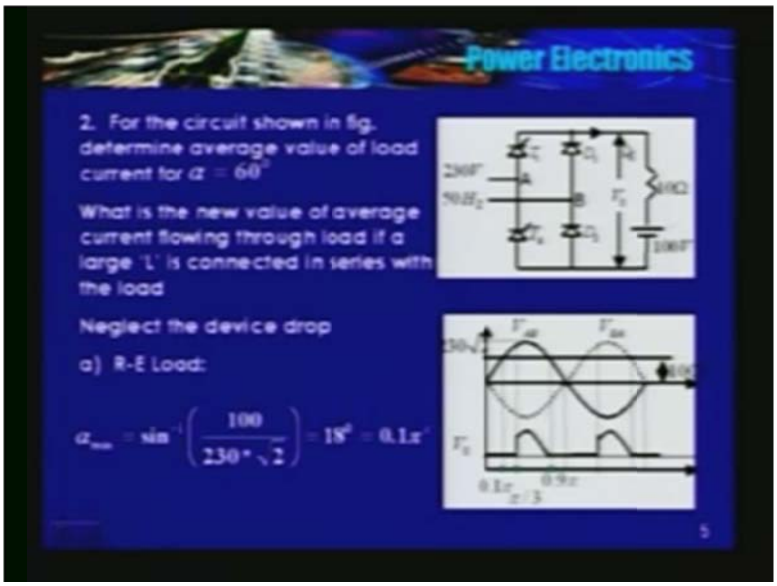
But then, in this case because of half wave rectification, there is a DC flux. So, my excitation has increased in 1 cycle or in 1 cycle there is an increase and in another cycle there is a decrease. So, what will happen to the bh loop? If I see, I have a non symmetrical bh loop. As the value of DC flux increases, I may have a flux in the core or the value of the DC flux may be equal to the peak value of this flux.

So, it may so happen that it may not even come down to negative and it may so happen that in that case, flux or core may saturate. What happens if the core saturates? They have been told that if the core saturates, core loss, your current is going to be peaky. The moment current becomes peaky, the harmonics, the effect of harmonics again, I will discuss sometime later. So therefore, if there is a DC flux in the core, in some part of the cycle, core may get saturated and if the core saturates, a source current drawn from the source may become peaky and the moment it becomes peaky, it is not a sinusoidal now, no longer a sinusoidal. Source cannot become peaky.

As harmonics and the effect of harmonics, we will discuss sometime later. Of course, core saturates, core loss also increase, core heating, what not? So, there is a problem with or this is the problem with half wave rectification. We are drawing a DC component. If this DC component flows in the transformer core, transformer core may get saturated; core loss, current becoming peaky and harmonics. So that is the reason, half wave rectification is only used for or used for low power application.

When I am saying low power, current drawn from the source is also very small. So, the effect of saturation is not much. High power you cannot use half wave rectification. So, I hope all of you understood the effect of drawing a DC current from the source. Magnetics may get saturated bottom line.

(Refer Slide Time: 30:23)




Let me solve another problem. A half controlled bridge, 2 thyristors in 1 leg, load is RE. The moment I am saying when load is RE, first thing that should come to your mind is load current is discontinuous. First thing that should come to mind is RE is, load is invariably discontinuous. The problem says determine the average value of load current for alpha is equal to 0.

Nothing has been said whether the current is discontinuous or current is continuous. By looking at the circuit, you should be able to tell that current is discontinuous, like a doctor. When he sees a face of a patient, he can understand whether the patient is having any illness or not. That is the way when you are doing, having done half controlled bridge or so far having done a course on power electronics, the moment I see the circuit, I should be able to tell or I should make a wild guess that whether the current is continuous or not.

Here I do not need to or you do not need to mention that current is discontinuous. By seeing the circuit, input is sinusoidal, output is R and E. E always opposes, R voltage across the R and current flowing there are in phase. So, current is discontinuous. See the waveform. We have a sinusoid, this EG. So, SCR gets forward biased only when instantaneous value of the input voltage is higher than 100 volts, again I am neglecting the device drop. It has been mentioned

that neglect the device drop. If I consider device drop, invariably we consider 2 volts for thyristor. May be, 1.5 volts for a diode, again, depends on the current rating.
Instantaneous value of the input voltage should be slightly higher than 100. So, having said that thyristor gets forward biased only at 0.1 pi or sin inverse 100 divided by 230 into root 2 is 18 degrees is 0.1 pi

So, beyond 0.1 pi if you want, you can trigger and thyristor starts conducting. But in the problem it is mentioned that thyristor is triggered at 60 degrees. So, 0 to 60 degrees, no current is flowing in the load. So, to draw the load voltage waveform, remember I might have told you many times that 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 when the thyristors in the powering mode when the source supplies power to the load, the load voltage is same as the input voltage and in the freewheeling mode, load voltage is 0. So, you have either the input voltage or 0, whereas, if the load is if the load current is discontinuous, you need to know the type of load. Here it is RE. So, load voltage is E, the magnitude of E.

So, 0 to 60 degrees output voltage is 100 volts. At 60 degrees, you have triggered the bridge. So, $T_1$ and $D_2$ starts conducting in the positive half. The equivalent circuit is $T_{1,}$ load, $D_2$ back to source. So, input voltage is same as the output voltage or output voltage is same as the input voltage if I neglect the device drops. Otherwise, it is less by a very small value, may be of the order of 4 to 5 volts. So, the input is 230 minus 4, does not matter, still 230 for an engineer.

Where does it stop conducting? Load is RE, I did tell you that the difference $V_i$ minus E is across R. So, voltage across R is nothing but i into R. So, V minus E is 0. So therefore, i should be 0. So at this, at pi minus alpha min, this is the instant. Wherein, E is equal to the input voltage $V_i$, current becomes 0. So, current become 0 at 0.91 pi.

I repeat you could have triggered the thyristor at 0.1. If I had diode here, T $D_1$ and $D_4$ instead of $T_1$ and $T_4$, $D_1$ would have started conducting at 0.1 pi and would have stopped conducting at 0.9 pi because they get forward biased at that instant. We have here thyristors and they are triggered at 60 degrees. It is forward biased, it starts conducting but then at 0.9 pi, instantaneous value of the input voltage is same as the value of E. So, $V_i$ minus E is 0. So, $V_i$ minus E is nothing but i into R. So, i has to be 0. So, current becomes 0 at 0.9 pi.

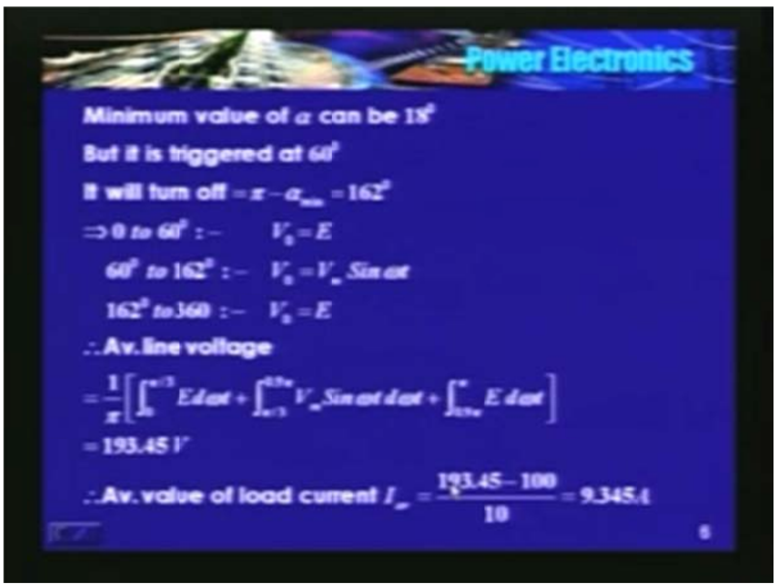
So, thyristor turns off, thyristor $T_1$ and $D_2$ turn off at 0.9 pi and from 0.9 pi till you trigger the next pair that is only at pi plus alpha that is at 240 degrees, current flowing in the load is 0. No, current flows. So, load voltage is the value of E. So, that is what. Be careful, half controlled bridge, alpha is 60 degrees. Mechanically do not write, $V_m$ by pi into 1 plus cos alpha. Invariably you will make this mistake, remember do not ever do this.

First you find out, first you draw the voltage waveform $V_0$ and then you find out the average value. You make, you can make a mistake while integrating. I told you, this is a course on power electronics. You cannot make a mistake while drawing the output voltage waveform. You can, may be you can make a mistake while simplifying, may be. I may not deduct, as a teacher I may not deduct any marks. But then, if you make a mistake while drawing the waveforms, definitely, I will deduct marks. It just gives to a feeling that you have not understood power electronics.

So, output voltage is from 0 to pi by 3. It is E from pi by 3 to 0.9 pi. It is $V_i$ sin omega t input voltage is same as input voltage is same as output voltage and from 0.9 pi till you trigger that is at 240 degrees, it is E. Now why there is a jump here, from E to straight away this value? Why there is a jump? It is E all of a sudden. It is because just prior to 60 degrees, what is the output voltage? It is E. If I neglect the turn on time of the devices at 6, just immediately after 60 degrees, what is the output voltage? Same as the input voltage that is 230 into root 2 into sin 60, a sin pi by 3.

So just before 60 degrees, it is E or 100 volts. Immediately after 60 degrees, it is 230 into root 2 into sin 60. So, input the output voltage instantaneously jumps from E to the instantaneously value of the input voltage at omega t is equal to alpha. So, there is a jump. So that is why there is a jump here. Again, I am neglecting the devices, the turn on time here. So we need to find out the average value of this wave form. So, if I know the average value of this wave form that is equal to i average into R plus E, KVL has to hold good. Isn't it?

(Refer Slide Time: 40:42)

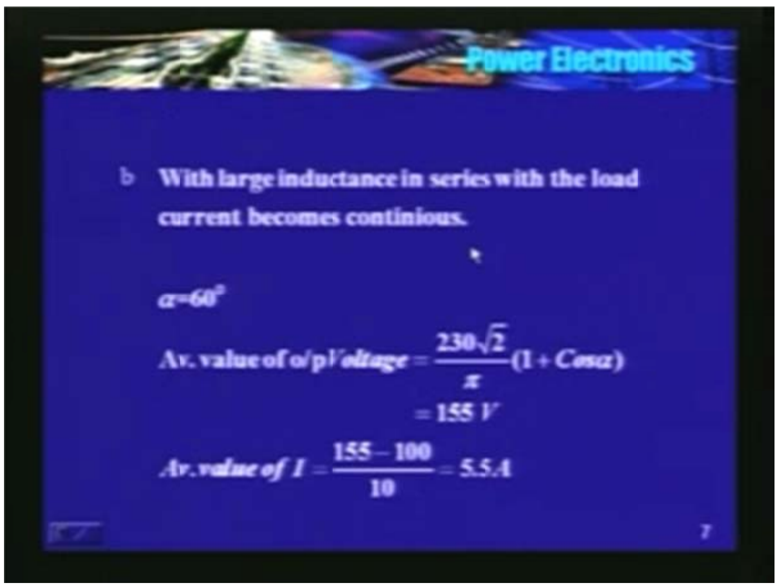



So, average value is 0 pi by 3 is E d omega t dt plus pi by 3 to 0.9 pi $V_m$ sign omega t plus 0.9 pi to pi, it is E dt. It is found to be 193.45 volts. Do not get bogged on with this value. So, if the wave form is right, any eleventh standard boy can write this equation and he can solve. I am not I have not in the sense, I did solve this, but then it could be, it is 93.45. Even if it is wrong do not say that sir it is wrong, does not matter. As long as you understand the subject, as long as you have drawn the wave form, fare enough, more than enough.

So, average value of i now, i average divided is equal to V average, average value of the output voltage minus E divided by R. So, 193.45 is the average value of the output voltage, sorry average value of the output voltage not average line. Average value output voltage, sorry about that minus 100 divided by 10 is 9.35 amps. What the part B says? What is the new value of the average current flowing through the load if a large L is connected in series with the load? The moment the problem says that a large value of inductor is connected in series, the first thing that should come to your mind is current is continuous.

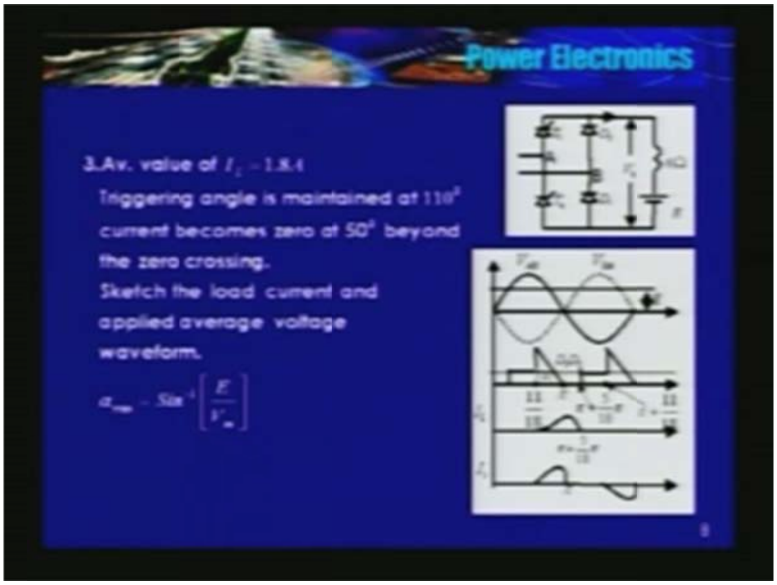
You do not need to mention that current is, specifically you do not need to mention that current is continuous. You just you have to tell that a large inductor is connected in series with the load. First thing that comes to your mind is current is continuous.
If the current is continuous, life is very simple man. In the sense, I just need to know that value of alpha, from alpha to omega t is equal to pi is output is $V_m$ sin omega t and from pi to pi plus alpha output voltage is 0 and again is $V_m$ sin omega t. I am not going to, I am not drawn the output voltage wave form.

(Refer Slide Time: 43:17)




It is same as the wave form which we have drawn for case 1 or case 2; 0 to alpha, output which is at 0, alpha to pi it is $V_m$ sin omega t and from pi to pi plus alpha, again 0 and from pi plus alpha to 2 pi it is $V_m$ sin omega t. So, average value is $V_m$ by pi into 1 plus cos alpha, so 155 volts. So, average value of I is same as average value of the output voltage minus E divided by the current value.

(Refer Slide Time: 44:06)




I will solve, I will get another problem; half controlled bridge, RE load, life is bit difficult when it becomes just a RE load. Life is very simple while the current is continuous. Trigger angle is maintained at alpha is equal to 110 degrees. Current becomes 0, 50 degrees beyond the … 0 crossing. I will repeat see, current becomes 0 at 50 degrees beyond the 0 crossing. … are load current and applied voltage wave form and also determine the value of E. E is not known, E is not known. Again same, where does one trigger the SCR or if I apply gate pulse, from where onwards it will start triggering?

Alpha min should be equal to sin inverse E divided by $V_m$. E is not known, definitely it should by less than, which value? less than? E should be definitely less than 90 degrees. If it is, sorry, alpha min should definitely, should be less than 90 degrees. I cannot have alpha min greater than 90. If that alpha min is greater than 90 it implies that, what does it implies? Maximum value of sin inverse, it implies that the value of E is same as the peak value $V_{in}$. So, there is no current at all, you cannot trigger the thyristor at all. Thyristor is trigger at 110 degrees.

The problem says that current becomes 0 beyond 50 degrees. In the sense, you have trigger at 110, current starts flowing and it becomes 0 beyond 50 degrees beyond this point. So, at steady state or may be at the end of the first cycle may be, current becomes 0 at 230 degrees or pi plus pi by 18 pi, this is the load current. So, similar wave form will be there. So it starts at 11 by 18 that is at 110 degrees, increases and becomes 0 at 18 degrees.

But how does the output voltage wave form look like? From 110 to 180, 110 to 180 degrees, $V_i$ is equal to $V_0$ or $V_{0,}$ output voltage is same as the input voltage. So in discontinuous mode, remember, in discontinuous mode, as long as thyristor conduct, input voltage is equal to output voltage in the positive half. I mean, it may so happen that I told you that current may become, if the current were to become 0 before pi, from 110 to the instant where the current becomes 0, the load voltage is $V_i$.

Fortunately, here current becomes 0 beyond pi. So, the load voltage is $V_0$ is same as $V_i$ from 110 to pi. 110 degrees to pi, it is $V_m$ sin omega t, from pi to 230 degrees or pi plus pi by 18 pi, freewheeling diodes are conducting now. Output voltage is 0, theoretically. Otherwise you may have around, may be 3 volts or so 0. At 230 degrees, current lies down, no current is flowing now. $V_o$ is same as E.

If I would have RL load, if I had RL load, output voltage is also 0. But, here we have RL, we have a RE load. So, at 230 degrees current becomes 0. From 230 to 290 that is 180 plus 110 or till you trigger the next pair of thyristor that is sorry next thyristor here $T_{4,}$ output voltage is same as E.

So, if you see here, current starts increasing from 11, from 110 degrees because you have triggered the thyristor. Current starts increasing, becomes 0 at 230 degrees, load current. So, from alpha to pi, source supplies power $T_1$ $T_3$ because current is flowing at that time. Output voltage is same as $V_i$. 0 from pi 2 pi by 18 pi that is 230 degrees, freewheeling diodes are conducting here, $T_2$, $T_1$ turns off because we have the common cathode configuration out of which 1 of them is a diode.

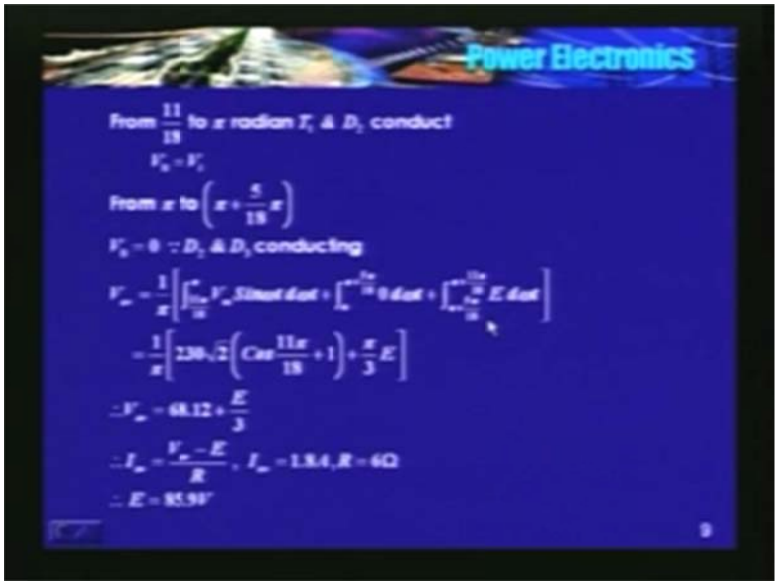
The moment B potential becomes higher than A, $D_3$ starts conducting which turns off $T_{1.}$ That half waving effect is not there here irrespective of alpha because immediately at in the negative half omega t is equal to pi plus, $D_3$ starts conducting, this turns off which is not the case if I put, replace $D_3$ by thyristor there and $T_4$ by a diode. If I interchange these 2 then we may have a half waving effect, I told you, because $T_1$ continuous to conduct till $T_3$ is triggered. Just to remind you, nothing to do with this problem, may be. So, this is the wave form.

So, from pi plus pi by 18 pi to pi plus 11 by 18 pi, it is E. Then again $V_m$ sin omega t. So, I need to find out the average value of this wave form. See, how does the source current look like? Source current is same as the load current in the powering mode. When is the powering mode? When $T_1$ and $D_2$ are conducting, it is a powering mode because source comes in series with the load and similarly in the negative half when $D_3$ and $D_4$ are conducting, source comes in series with the load. So that is the powering mode.

So, source current is same as the load current. At omega t is equal to pi plus, $T_1$ turns off. I have assumed source inductance to be 0. So, immediately $T_1$ turns off, so there is a step jump. from immediately, current becomes 0, source current becomes 0. Instantaneous, this is all most instantaneous because source current is source inductance is 0, immediately turns off but then the difference between load current, now the load current starts flowing through $D_1$ sorry, $D_2$ and $D_{3.}$ Same thing happens in the negative half.

So problem is very simple. I need know, I need to find out the average value. It is given by this equation, 1 over pi from 110 ten.

(Refer Slide Time: 53:12)




In the sense, 110 degrees to pi, it is $V_m$ sin omega t. From pi to 230 degrees, freewheeling period; d omega t, 0 d omega by dt. From the end of the freewheeling mode to till you trigger the next pair that is pi plus 110 degrees, it is E d omega by dt.

So, this is 1 complete, this is half a cycle. So, you substitute the value for $V_m$ is 230 into root 2, integrated. So, this is the average value. I got an average value in term of E. Now, I average is V average minus E divided by R. So, value of I average is 1.8 amperes, R is 6 ohms, it is given. These are the 2 parameters are given. So, E is 85.9 volts. Again, a very educative problem it is.

All most all the concept that are that which I emphasized are there. Again, I did not blindly use the output voltage, average value of the output voltage is $V_m$ by pi 1 plus cos alpha, alpha is 110 degrees, no, I did not use that. So, RE load, discontinuous, I drew the wave form then I found out the average value and determined my current.

So remember, very important concept, that expression is valid only if the current is continuous. Otherwise, it is not. The moment you get a problem, think for a while; spend some time with a problem, think for a while, draw the wave form. If you draw the wave form, I am telling you 90% of the problem is done. You are through, I am telling you.

Thank you.