Power Electronics
Professor G. Bhuvaneswari
Department of Electrical Engineering
Indian Institute of Technology Delhi
Lecture 9 - Numericals on Devices and Single-Phase Rectifiers

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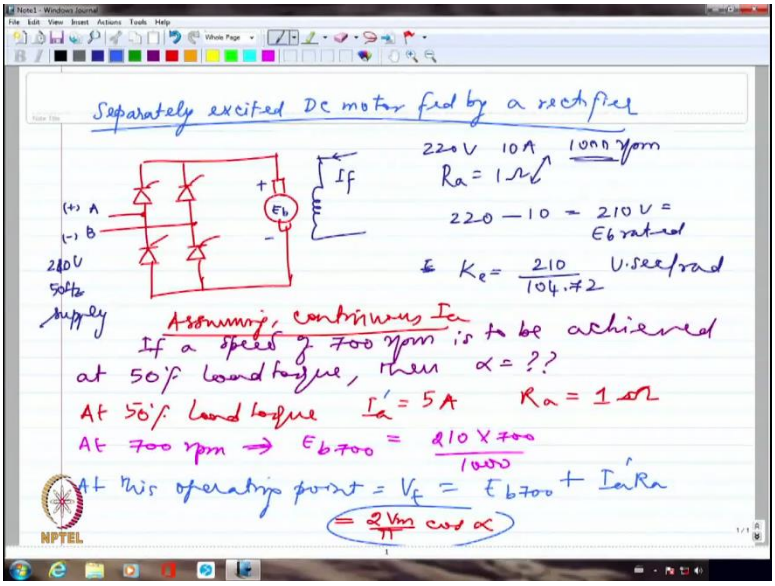

Separately excited DC motor fed by a rectifier: I would mainly talk about separately excited because I do not want the field also to get modified. So separately excited I will be able to keep the field completely separate and the armature completely separate. The two controls can be completely decoupled from each other. So, we are looking at a fully controlled single phase converter. I am just taking the single phase converter.

Three-phase would almost work similarly and then I am going to have the DC motor drive here. So, this is going to be my supply and let me assume, maybe this is positive, and this is negative during positive half cycle. And I am going to have a field which is excited by a constant excitation current, I_f. So the flux is not going to change at all. So what I get at E_b will be proportional to the speed because the field current is a constant.

So I will have this as plus and this as minus, Normally the rating of the DC motor drive will be given because of which you should be able to calculate the back EMF constant. So, if I am given for example 220 volts, 10 A, may be 1000 rpm, DC motor drive with may be R_a value is also given. Let us say R_a is 1Ω for example.

So, you should be able to write whatever is the output, it is not a big deal because you are going to write basically, $E_b = V - I_a R_a = 220 - 10 = 210$ V, which is the E_b rated. And if 1000 rpm is your rated speed, you can always calculate what is the back EMF. And if I know 210 volts is the E_b, E_b multiplied by I_a will give me the power that is developed internally and then you might have to subtract the mechanical losses.

If I want to run it at the rated speed, maybe I will have to apply to 220 volts. If I want to run it at any other speed, then how do I calculate the voltage to be applied and the firing angle? That is all is the matter with fully controlled rectifier. So if I say that my back EMF constant happens to be that is $K_e = \frac{210}{104.72}$ V.sec/rad. I am converting 1000 rpm into radians per second.

So this is volt second per radians. So if I have a back EMF constant and you are given the AC supply, of 230 volts. So if you are given 230 volts, 50 hertz supply or 240 volts, 50 hertz supply, then you should be able to calculate what is the firing angle if a speed of 700 rpm is to be achieved at 50% load torque, then α equal to what? This is the kind of question typically you may be able to calculate for.

So in this case, if it is 50% load torque, hopefully neglecting the no-load current I can say roughly the current is 5A. 10 A corresponds to 100 percent load torque. Load torque is always proportional to field current and armature current. Field current I am keeping as a constant, I am not touching the field current at all. So if I want 50 percent of the load torque, I should have basically 5 A.

So, I should be able to say, at 50% load torque, I_a = 5A.

$R_a = 1\ \Omega$, that is given.

At 700 rpm, I should be able to calculate what is E_b. Whatever is the back EMF at 1000 rpm which was 210, you can multiply that by 700 and divide by 1000. So you should be able to get that value, right at a constant excitation, everything is at constant excitation.

$$\text{At 700rpm}, E_{b700} = \frac{210 \times 700}{1000}$$

So I am going to get this as the back EMF. Once I have the back EMF, all I need to do is to add $I_a R_a$ drop, that will give me the terminal voltage. So, I should say, at this operating point terminal voltage $V_t = E_{b700} + I_a' R_a$. Let me call this as I_a'. I_a'=5A. So, I should be able to calculate exactly what is the value of terminal voltage. And this terminal voltage if I say it is fully controlled converter, I should be able to write this as $\frac{2V_m}{\pi}\cos\alpha$ provided what is the condition? $\frac{2V_m}{\pi}\cos\alpha$, is it valid all the time?

For a fully controlled converter without freewheeling diode, $\frac{2V_m}{\pi}\cos\alpha$ expression is valid only if the conduction is continuous. So if I do not give continuous conduction, you can always say, the question is ambiguous. So, unless I say it is continuous conduction, if it is whether it is continuous conduction or discontinuous conduction if I say there is a freewheeling diode, then at least you can say it is integrated from α to π. So if I am talking about fully controlled converter without a freewheeling diode, I have to specifically say it is continuous conduction.

So, I should say, assuming continuous I_a, I have to say I am assuming continuous armature current through the DC motor. Otherwise, it is not going to really make any sense to use this particular expression. This expression is not valid if there is discontinuity. I have to know where the β value is and then I can integrate only from α to β. So it is not really correct to apply this expression for anything else. So if I am given a firing angle with continuous conduction, I should be able to decide the operating point and vice versa.

If I am given a speed and torque, I should be able to definitely get what is the value of firing angle if I am knowing the motor parameters. I should know the motor parameters. If I do not know the motor parameters, I would not be able to do anything obviously. So I should know what is the R_a value, what is the kind of back EMF constant it has and so on and so forth. Only then I should be able to get this whole thing.

This is a typical DC motor drive control problem. You should be able to do the same thing for three-phase as well. For three-phase, only thing is, this expression whatever we have got here will be replaced by $\frac{3V_m}{\pi}\cos\alpha$, where V_m is line peak again. If I give a semi-controlled converter for three-phase, three-phase of course I have not still done, single phase, you have to change the expression. That is all is the difference. And you should know how to draw the waveforms also for these cases.

I do not think it is a big deal now that you have known all the rectifiers. Only thing is, we have not talked still about when $\alpha > 90$, we will have to look at what happens when in the same motor drive if I make $\alpha > 90$ or the speed becomes greater than whatever is supposed to be no-load speed, what happens we can discuss it a little later.

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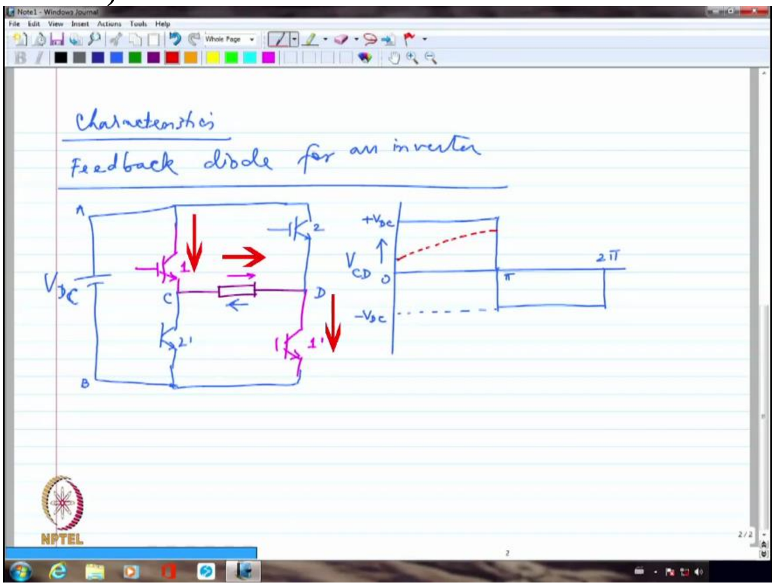

So what is the application of a feedback diode in an inverter? How does it function? So let us first of all look at the inverter circuit. I am going to show it with an IGBT. So this is one and I am going to have a load connected here. So we are going to have one more device like this. Let me call this as 1 and this as 1'. And similarly when I want the current in this direction, this is the way it is. And when I want the current in the opposite direction, I am going to have one device like this, and one more device like this.

So this is 2 and this is 2' and I am going to have the current somewhat like this. I am going to complete the circuit now. So this is how it is as far as an inverter is concerned when I want to convert DC to AC. So this is the DC apply, let me call this point as A, this point as B, this point as C, this point as D. So when 1 and 1'are conducting, I am going to have from A through 1, through C, D, and then through 1', back to the DC supply, that is how it is going to be.

And when 2 and 2'are conducting, it will be just the opposite. So let me first of all draw the kind of waveform that we are going to get when 1 and 1'are conducting. I am drawing basically the load voltage. So I am saying, V_{CD}. That is what I am growing. What is the voltage across CD, I am drawing. So when 1 and 1'are conducting, I am going to have if I say this is V_{DC}, I am going to have V_{DC} coming up right across CD because I am assuming that the other 2 devices are ideal, they are not having any drop.

So I am going to assume that it is going to be somewhat like this. And then after that, I am going to have a voltage which is somewhat like this. So this should be $+V_{DC}$ and this should be $-V_{DC}$. This is the way the voltage will be. If I have a resistance load, I will have the current exactly following the voltage. There is no difference whatsoever. Because of which I will have essentially 1 and 1'exactly stopping the conduction at this point.

If I may call this as 0, π and 2π because I am converting them into AC voltage, so this is how it is going to be. But if I am going to have an RL load, inductive load, R and L, then maybe the current would have started from some value, But even initially if I talk about, when the circuit was dead, the current would have increased until this π because $L\frac{di}{dt} = V - Ri$, that is the way it will be. Depending upon what is $V - Ri$ value, I am going to have definitely the current increasing further and further.

Anyway, the inductance would have built up some energy. So I would have actually maybe the current going somewhat like this, it would have increased until here. But the current cannot come down abruptly to 0. If I switch off 1 and 1', if there is no other path available for the current because the current is flowing in this direction, it can flow only through these 2 devices. If I turn them OFF and if I remove the gate pulses, both of them are going to turn themselves off right away.

This is having inductance. If I try to bring down the current to 0, $\frac{di}{dt}$ is literally infinity. Even if i is only 2A, dt is literally closed 0, so I will have $\frac{di}{dt}$ because of the denominator being very very small, it will reach infinity. If it reaches infinite value, this open circuit voltage here will be enormously high which means I am going to have both these devices facing the brunt of the inductance stored energy abruptly trying to collapse. So these 2 devices will immediately conk out.

If I try to put a circuit like this with RL load and if I try to turn OFF immediately the inductance load current, then I am going to see that these 2 devices can conk out. So to avoid that, I might like to put a diode called a feedback diode which will come exactly in antiparallel for each of these. So these are all called feedback diodes which come in antiparallel. Now the current had been flowing like this. Now if you look at this diode, they are conducive for the conduction in the same direction.

But only thing is that please note that this voltage source is connected exactly in the opposite direction to that of how it was connected with 1 and 1’. Because if you now look at the path, the path is going to be somewhat like this. It is the same current all right but this current is going to go like this and it is going to get into the positive of this particular battery. Please note, this is completing the path using this diode.

So you can see that the current flows again in the same direction but if you look at it from the battery’s of viewpoint, the battery is not supplying it anymore. It is rather taking the energy which was stored in the inductance. So if you look at it, this positive now is connected to D through the diode and this negative is connected to C again through the diode. So there is a reversal of polarity as far as the load voltage is concerned. So the load voltage will still be negative when feedback diodes conduct.

But the current here is going to start coming down. How fast or how slowly it comes down depends upon what is the kind of source voltage I have had and what is the kind of *Ri* drop I have had and what is the kind of inductance value I have had in comparison to the resistance. All these things dictate how much of energy would have been stored in the inductance. So I am going to have this. Now the negative voltage is applied. So it will obviously start increasing in the opposite direction.

And again, it will start. This will be the kind of current waveform, exponential rise and exponential fall. That is what you would see normally in the inverter circuit in an RL circuit basically. So I should say, if you talk about the devices that conduct, from here to here it will be 1, 1’. Whereas from here to here, if I may call this as D_2 and this as D_2’, this will be D_2 and D_2’ and from here to here, I should have had the other 2 devices, that is 2 and 2’ until here. And here, the corresponding D_1 and D1’.

So obviously this current should have started somewhere from the negative side. Although I have shown it as though it has started from positive, it should have started from the negative side because that current must have been inverting its polarity. It was flowing like this and then it is going like this. So I should have drawn a replica here too. So here I should correct it as though it is starting from somewhere here. Something like this, not this one. This is not correct.

Student: If there is no inductance, do we need the feedback diodes?

Professor: Inductance stored energy will make sure of that. If inductance energy had not been there, I do not have really the requirement or the presence of the diodes at all. The inductance is basically making sure that the current continues in the same direction. When it is making sure that the current is continuing in the same direction, automatically $\frac{di}{dt}$ is in the opposite sense because of which you will have a reversal of polarity of the voltage.

The moment you have a reversal of polarity of the voltage, the diodes will automatically make you now take advantage of that. That is how it is. So how long this current continues in that direction itself, it is continuing from here to here, that duration is dependent upon how much of inductance energy stored is there. How much of energy is stored and that is going to forward bias the diode. That energy as long as it exists it will forward bias the diode. The moment it is not sustainable, the diodes will be reverse biased, the current will come down to 0. So all of them happen naturally because of the energy stored and the energy is given back to the battery.

Student: What will happen if the inductance is negligible?

Professor: Then it is as good as R load. If you say that the inductance is negligibly small, that even before switching you know it is just giving away its energy, it does not have, that means it is as good as R load. In R load, you do not have to have the feedback diode but most of our circuits will contain at least some minimum inductance because even the copper wires, thick copper wires have some inductance. Just cannot help it.

So there is nothing like a pure resistive load except for maybe a few that you can mention as example for pure resistive load is your incandescent lamps, many of them are purely resistive, hardly any inductance. If you look at our heater what we have at home during winter, those things are immersion rods, most of them are having negligible inductance. Those are the typical examples of pure resistances. There is nothing like pure inductance.

There is nothing like pure inductance. Any copper wire will also have a resistance. It is hypothetical clearly. So, if it is pure inductance, I am going to have essentially $L\frac{di}{dt} = V_{dc}$. This is how it is going to be. So the current would have increased further and further until here maybe and during negative if I assume that I am going to have the same negative value here, it would have probably given back all the energy until here. So the diodes will, always the current will be positive.

I am assuming pure inductance. Then in all probability, always the current would have been positive provided I started off with a positive half cycle. If I had started off with a negative half cycle, always the current will be negative. Completely hypothetical. So it is not an inverter anymore. Voltage is alternating. The current is not alternating.

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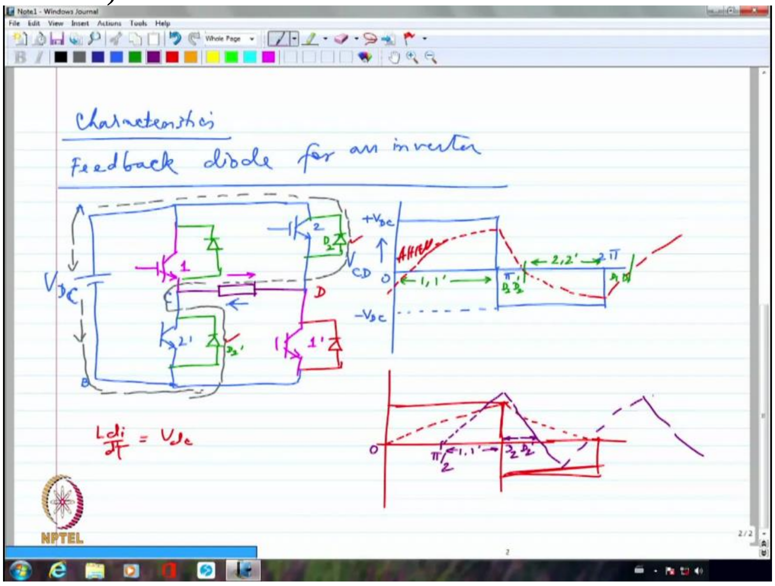

Student: Ma’am, in this it will start like not exactly from the middle of the sideline. So, it would oscillate.

Professor: You mean to say that if it is starting from here. Yes, so it must have increased until here and then it must have, yes. It would have been something similar but with maybe same frequency as the supply voltage. What he is asking is, if rather than assuming that I am starting from the beginning 0, if I had started with $\frac{\pi}{2}$, so what will happen? If I do like this, maybe the current would have gone like this, then it would have come down like this, again increased, decreased and so on.

These things are interesting questions to handle using PSIM. It is really worth looking at those things if you, just want to check how the whole thing functions.

Student: If the current does not start from zero, rather it starts from $\frac{\pi}{2}$, what will happen for pure inductive load?

Professor: No, at $\frac{\pi}{2}$, I have started the firing of 1 and 1'. See, you can imagine that still my frequency is actually from 0 to π and π to 2π, no doubt. 0 to π we are supposed to fire 1 and 1'. But it so happens that my computer or microprocessor or whatever it is starting at this point.

Arbitrarily, it has started from $\frac{\pi}{2}$. So, the current has increased until I had 1 and 1' fired, And it is pure inductance. So until then, the current would have increased continuously. After that, I have fired 2 and 2'. So 1 and 1' will cease to conduct. I will remove the pulses from 1 and 1'and give it to 2 and 2'. In an inverter, never ever will we fire the 2 devices in the same leg, never ever. If we try to do that, then this will be a dead shot. It will be called shoot through condition.

Shoot through is deadly. So we cannot have pulses going to 1 as well as 2'. Similarly 2 as well as 1'. I cannot have pulses going simultaneously. So the moment I fire 2 and 2', 1 and 1' anyway have stopped conducting. Now the inductance will take over. So inductance is trying to feedback the energy through the diodes. When it is feeding back the energy through the diodes, we said that this positive is connected here and this negative is connected here, so the voltage of the load has completely gone inverted. That is the reason why we are seeing a negative voltage.

And once the current reaches you know like if it reaches 0, then obviously I will not have these 2 diodes conducting. Rather, these 2 devices, the other 2 devices will start conducting, 2 and 2'. So in this particular case, I have to show as though 1 and 1' conduct here. And I am going to have D_2 and D_2' conducting here.

And after that, 2 and 2' will conduct for this duration and so on. When I have both voltage and current as positive, the power is flowing from DC side to AC side. When I have maybe one of them as positive and one of them as negative, the power is flowing the other way around, from the load into the battery. And if I am having both of them to be negative during this duration, I will have the battery supplying the power to the load and when I have one of them positive, the other one voltage negative, then I am going to have again the power going in the reverse direction.

That is how it will be. So, you have to see that if both of them are actually in the same polarity, then the power is actually getting converted into AC. Otherwise, it is as though the load is feeding back to the mains, the battery. So the power direction can change.

Student: While protection of diodes like when we use diodes in series, like you told we have to use 2 resistors in parallel with the diodes. But like this protection work can also be done with the help of 1 resistance only.

Professor: You mean to say that, protection of diodes, rather series connection of diodes.

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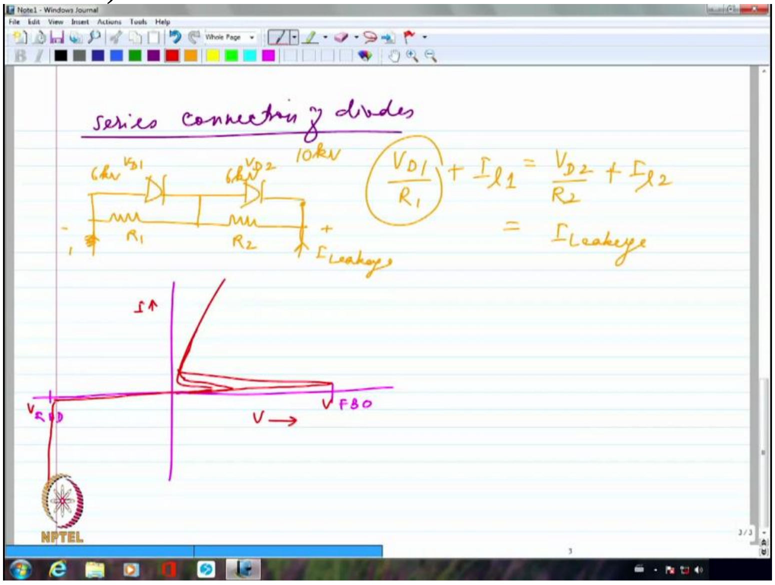

So you have one diode here, one more diode here and their leakage currents are different. Their leakage currents are different and they had to block a voltage. So this is plus and this is minus. So they are blocking a large voltage and normally we put something like this, 2 resistances we put in parallel. So you mean to say that only 1 resistance will do the job. That is, in this normally we what we write is that if I say, this is V_{D1} and this is V_{D2}, and this is the total current, *i*. I should rather show it the other way round because leakage, it is the opposite direction.

So this is the $I_{leakage}$, $\frac{V_{D1}}{R_1} + I_{l1} = \frac{V_{D2}}{R_2} + I_{l2} = I_{leakage}$. So if you are saying that let us use only one resistance such that these 2 are equated, that is what you were trying to say. See only thing is, it depends upon whether you want to have even minor discrepancy between V_{D1} and V_{D2}.

You say that maybe both of them have to block voltage of 10 kV. And each of them is may be rated for 6 kV. Each is rated for 6 kV. If I do not mind having a discrepancy of 1 kV between the 2 blocking voltages, that is one case and if I mind actually having any discrepancy at all, so in for both cases you try to calculate and see which case has a higher copper loss. Definitely, there will be copper losses.

Please check, how the copper losses will be. If I want exactly 5 kV division among both the diodes, that is one case. The other case is, maybe one can have 5.5kV, the other one can have 4.5 kV. You also take one of the examples from Rashid and see leakage current difference. Maybe one has a few milliamperes, maybe 20 milliamperes and the other one has 30 milliamperes or something. There are at least 3 such sold examples given in the diode chapter of Rashid.

So I feel that if you choose only one resistance, the copper losses could be much more. Maybe you try to calculate. Please try to calculate and check it up. I feel that it may be much more but this is the standard practice that is very commonly used in HVDC systems and so on because in HVDC transmission, we normally use 84 to 100 series SCRs. One device will correspond to about 84 to 100 series SCRs, that is how it is.

Student: Ma'am, can you explain the characteristics of SCR?

Professor: SCR characteristics is very very similar to diode characteristics except that by giving a gate pulse only, it is going to start conducting but beyond a particular forward voltage, it will break down, break over, forward breakover voltage. So, if you try to apply beyond this value, let us say it is rated for 10 kV, 7 kV, so may be that is 7 kV. If you try to go beyond that, it will be a destructive breakdown. It will not be able to come back to normalcy.

So you are going to see that this is the forward breakover voltage and similarly, I will have a reverse breakdown voltage. So I would be seeing that the device will break down in a destructive manner if I try to apply beyond that whatever is the rated voltage of that particular device. So in the reverse direction if I draw literally the current would be very very small, leakage current and then suddenly once you cross this, it has to increase quite a bit in the reverse direction.

So that is like a destructive breakdown. And in the forward direction, even before the break overvoltage, if I actually try to apply a gate pulse, the moment the gate pulse comes there will be a very very short, negative resistance kind of region which is transient, which you will not be able to operate the device continuously in that region and after that, you would see that it is really following something like a diode's characteristics, forward regular resistance whatever is the forward resistance multiplied by the current will be the voltage, that kind of characteristics.

So this is going to be I and this is going to be V. So this is V_{FBO}, V_{RBD}. And if I give the gate bias with a higher intensity. So this is with a higher intensity. If I have only a lower intensity, then it will take more amount of gate current. Only if I have more gate current, at that point it is going to probably start conducting. So if I look at actually the voltage that I have applied, whatever is the voltage applied, when it is very very minimal, I will require a large amount of gate drive.

If the voltage is somewhat higher, then I require only a lower amount of gate drive for the device to latch into conduction. To latch into conduction, it will require only less amount of gate drive. So this is going to be the different types of but ultimately, they all coincide. The moment it starts and latches into conduction, the characteristics are the same. But when I am applying a very very small value of voltage, at that point I might require a little bit more of the gate drive to latch the device into conduction.

So actually these characteristics are not so much of importance for us especially in power electronics because most of the times, we talk about 230 volts or 440 volts, compared to which the forward drop or anything is very very small and thyristors generally take a little longer to get into conduction and turn OFF also. Both takes longer. Because of that, 20 millisecond is still pretty small duration. It is not a very long duration but if we are talking about something like MOSFET or IGBT, then we have to worry about even the small duration from where it is rising from 0 to 5 volts or 3 volts or 4 volts. But in thyristor, we do not have to worry so much.

Student: Ma'am, at the point of forward break over, will the characteristics be the same?

Professor: It will go all the way and once it breaks down, again the resistance is going to be small, but it is gone. That is it. It may not respond to turning off at all. It is as good as you have short-circuited the device. If I think it will lose control. To be honest, I have never seen a thyristor break down so easily. Normally, mean time between failure (MTB) for thyristor, they say is infinity literally. Mean time between failures for SCRs, thyristors, very difficult to break them, like induction motors. They will not break down so easily. You have to really manhandle them. Then they will break down. Otherwise, generally SCRs are very rugged, extremely rugged.

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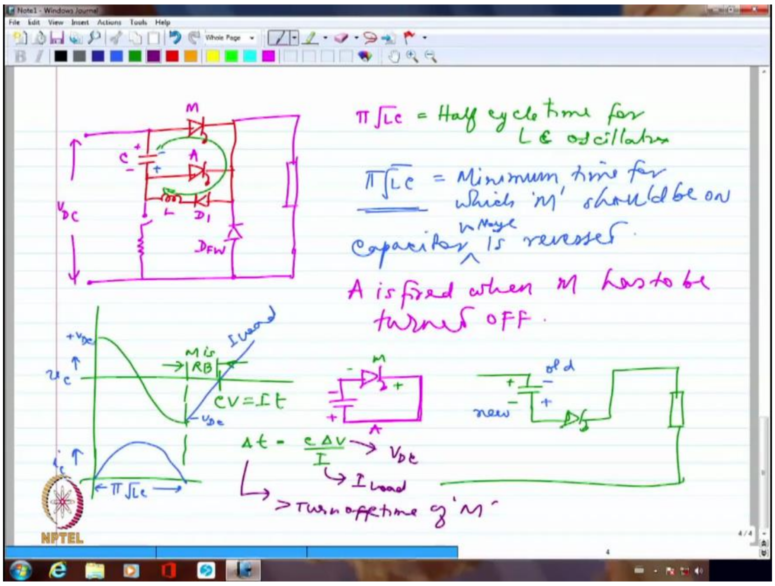

And we had a freewheeling diode here. This was the freewheeling diode and this was the load, whatever be the load. Freewheeling diode will not be there unless there is an RL load. There has to be an inductance, otherwise why would I have a freewheeling diode? So this is the kind of circuit that we discussed. So I gave some frequency of turning ON, turning OFF, I gave some minimum on time for the device and then I asked you to design L and C. I think that is what I had asked you to do.

This is the main thyristor, this is the auxiliary thyristor, this is L, this let me call it as D_1 and this is C. And we said that initial charging we are assuming maybe through a resistance or whatever. This is the initial charging; I want to charge the capacitor beforehand so that it is ready for the commutation process. This is what we had given. So in LC oscillation. Generally, $\pi\sqrt{LC}$ is the half cycle time for LC oscillation.

This plays a very very vital role in this because once you turn ON your M, the moment you turn ON M we said that this is going around like this, the current will go around like this .And we are assuming lossless devices. If it is lossless, I am going to have plus and minus in the opposite sense in the capacitor. So if you actually look at the oscillation, I am going to have the voltage going like this.

Whereas my current if I try to look at it, it will be somewhat like this. This is how the current will be, right? LC oscillation current will be like this. So I should say, this is voltage across capacitor, whereas this is current through the capacitor assuming lossless devices. So this timing is corresponding to $\pi\sqrt{LC}$ because this is half cycle time. So if the capacitance has to reverse its voltage, only then it is ready for commutating the main thyristor when I am firing the auxiliary SCR.

So when you are going to fire the auxiliary thyristor? If the main thyristor has to go OFF, I should have plus here and minus here. And that plus minus would happen only if LC oscillation at least takes place until the half cycle time. Because it has started with maybe $+V_{DC}$ and it will go until $-V_{DC}$. So it has started from $+V_{DC}$ and this will go until $-V_{DC}$. So I should have the main device on at least for $\pi\sqrt{LC}$ duration.

If the main device is not on $4\pi\sqrt{LC}$ duration, the current will not be really going through the complete half cycle so that the capacitance reverses its charge and only if the capacitance reverses its charge, I am going to have that capacitance ready to commutate the thyristor when I am firing A. So this $\pi\sqrt{LC}$ has to be the minimum time for which M should be ON, minimum time. Of course, it can be on for longer. Nobody is preventing that.

So if I say the chopper has for example 1 kilohertz frequency and I want it to be on at least for 10 percent of that 1 kilohertz frequency time, 10 percent will correspond to, 1 kilohertz is 1 milliseconds. So it has to be on at least for 100 microseconds. So I should say 1 millisecond is 100 percent. I am talking about 10 percent. 10 percent will be, I am going to have basically 100 microsecond. 1 millisecond corresponds to 1000 microsecond. I am taking 1000 microsecond is 100 percent.

So 10 microsecond 100 microsecond is going to be 10 percent. So at least for 10 percent of duration if I have to have this on, that means my $\pi\sqrt{LC}$, minimum duty ratio or minimum on time I want to have is 100 microsecond, then $\pi\sqrt{LC}$ has to be 100 microseconds. At least 100 microseconds. Maybe slightly less than 100 microsecond is even better because I have to make sure that the reversal takes place within that time. So this is one condition.

This $\pi\sqrt{LC}$ will give me an expression for $\sqrt{LC}$ together but how do I segregate L and C? I can always assume some L and say C is the other one, that is fine. But is there any other condition? The second condition is, the moment I turn on auxiliary thyristor, so capacitor has reversed its charge. So capacitor voltage is reversed. That is what I mean. Capacitor voltage is reversed in $\pi\sqrt{LC}$ time.

After that, the main SCR is still ON for some more time as long as the load is being fed. Now maybe I want to turn OFF the supply to the load. So I need to fire, A is fired when M has to be turned OFF. This is what we said. The moment you fire A, I am going to have basically this is my main thyristor, this is my capacitor voltage which was having plus here and minus here, auxiliary thyristor has become a short circuit.

The moment, so this is A. A has become a short circuit. When A is short-circuited, I am going to have plus here. Please note, this plus is applied here and the minus is applied here. So obviously, this thyristor is going to have a huge bout of reverse current trying to flow in the opposite direction. But that large current cannot flow because the device will not allow that kind of a current, so it is going to be quenched.

So the load current what you have is flowing in the forward direction and the reverse current is due to the capacitor and capacitor does not have a resistance path. It is having literally a short circuit. If at all something is limiting the reverse current, that is only the on state resistance of the thyristor; there is nothing else, no resistance in the path.

So the reverse current can be enormously high and because the reverse current is high, when you look at the subtraction of the forward current from the reverse current, the net current happens to be reversed which is not being allowed by the device. So the device just goes off. After the device goes off, the circuit will be somewhat like this. So this is M. M is gone off. Now I am going to have this as plus, this as minus.

This is my auxiliary thyristor and here is the load. That is it. This is the circuit. Freewheeling diode is there but freewheeling diode, nobody could care because currently this is the least resistance path. So it is going to charge the capacitor. The capacitor voltage was originally like this. Slowly from that, it will come to, so this is old polarity. Now this is the new polarity. So slowly, the load current will try to reverse the charge across the capacitance from this to this. But in the process, definitely it will go through a 0. So this is the voltage.

Now it is going to be a linear kind of charging. If assume that the load current is fairly a constant maybe RL load with inductance being pretty large, so I am going to have a linear charging. So this rate of rise will be corresponding to I_{load}. $I_{load}\, t$, that is what will be the charge accumulated. So I am going to have actually from this point until this point only, I am going to have the device reverse biased.

The outgoing device is M. That will be reverse biased only as long as the capacitor voltage is in this polarity. Slowly, it is going from this polarity to the upper plate being positive and lower plate being negative. So only from this point until this point, M is reverse biased. After that, M will not be reverse biased anymore because it will have a very nice conducive voltage with anode being positive and cathode being negative. So this time has to be greater than the turn off time or the recombination time that is required by the device.

This is clearly governed by the equation, $CV = It$. So I can say, $\Delta t = \frac{C\Delta V}{I}$. What is ΔV? ΔV will go from, this is if I say -V_{DC}. From -V_{DC} it will go to 0, that is all. Only until 0, it will be reverse biased. The moment it crosses 0, it will be forward biased again. So I should say, this ΔV corresponds to V_{DC}. And I corresponds to I_{load} if I say I_{load} is fairly constant or approximately a constant.

So this is going to be if I say that for example, there is a 100 volt supply and 10 ohm resistance with a 10 mH or a 20 mH inductance, large enough to make the current fairly constant, so 10 ohm resistance and 100 volt supply, 10 ampere could be the maximum current, nothing more than that. So I load could be only 10 ampere, not more than that. So 10 ampere, for 10 ampere, I can calculate capacitance value. Δt will now correspond to the turn off time. This has to be you know slightly greater than turn off time of the device.

So I have 2 equations and 2 unknowns, L and C. So I should be able to solve for both. So one is depending upon the reverse biasing time of the main thyristor which is going off and the other one is depending upon the $\pi\sqrt{LC}$ which is the half cycle time of the LC circuit. Any questions on this? Is this clear?

Student: Is the capacitor voltage equals to V_{dc}?

Professor: If I am connecting that to V_{DC} through the resistance initially, the current will cease to go through the capacitor after it reaches V_{DC}. If I assume R and L, the voltage can be more than V_{DC}. Because the inductance will try to make the current run for longer.

Student: Why do we have this ?

Professor: If I assume that the load, this is not I_{load}. I am talking about the slope of this is I_{load}. Slope is I_{load}. I am talking about basically the charge accumulation will be linear in the capacitor if I assume that the load current is fairly a constant. The load current is fairly a constant, then I will have the current going through the load will be charging the capacitor.

Student: So is this mentioned in the question?

Professor: I hope so that I have mentioned. If have not mentioned, then it is not, I should say highly inductive load with a resistance component of so and so. If I say highly inductive load, it is a given that the load current is devoid of ripple. It will not have ripples. The ripples can be neglected. And in most of the motors and other things, we do have the current oscillating very slightly because we will try to make the frequency of the chopper quite high that it will not have the sufficient time to come down and go up.

So it will just go through like this, very very small oscillations. That is the reason. We will anyway look at choppers also. So everywhere machines will creep in a little bit, not too much.

Student: Why is a wide pulse needed for triggering?

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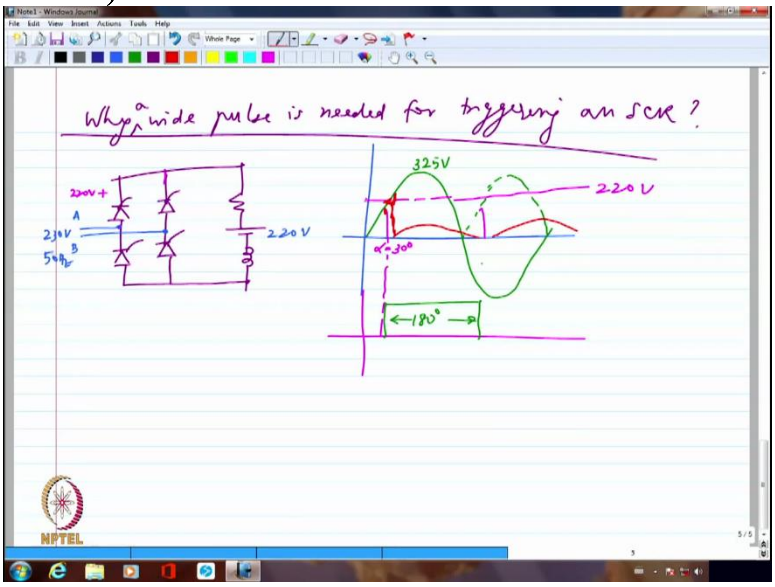

Professor: Let us say, now why wide pulse is needed for triggering an SCR? That is what you are asking. So let us say I have a single-phase fully controlled rectifier with the resistance and a battery. So current may not be continuous if I am talking about a large battery voltage. May be I am talking about a 230 volts supply, AC supply and the battery is of 220 volts magnitude. So what I have as the voltage is 230 volts rms .So here what I have is let us say a 220 volts battery.

So if I am drawing the waveform, I should show it somewhat like this. So this will be about 325 volts, the peak will be $230\sqrt{2}$ which is 325 volts. So I am talking about 220 volts as the battery voltage. So, it may be somewhere here. So, if I am choosing some α which is around 30 degrees, sin 30 is 0.5. So I may be actually trying to trigger it somewhere here and this is α=30.

So I would again try to trigger it here. If the current had been continuous, here the device will get triggered. Not a problem because only the supply voltage will matter. But if the current had not been continuous, basically this will come as the open circuit voltage. No current is flowing, so in the cathode I am going to get this +220 volts. Because there is no current lowing, it is open circuit, there is no resistance drop absolutely because there is no current, so the 220 volts will come here and I have to look at what is the voltage here.

That voltage is $\frac{325}{2}$ because sin 30, that is only around 160-165 volts, nothing more than that. So obviously, this particular device is reverse biased. It is not going to get fired even if I try hard. So how do I give it a chance to conduct? I give it a chance to conduct only if I give a wide pulse. So I try to give the pulse starting from here. I say α=30, alright but if the device is not able to take over, I may start from here and I will give until this portion.

So I give a 180 degree pulse 180 degree wide pulse to fire this SCR but I cannot give a DC, I told you because pulse transformer is being used, so I do the high-frequency ANDing and so on. Now it will be able to fire at this point. If it is not fired at this point, it will at least fire exactly where the two are meeting with each other. For example, whatever is 220 volts battery's value and the sinusoidal voltage that is coming in, if they are exactly meeting with each other, at that point at least I will start slowly forward biasing the device.

So that device will get fired after this. At this point, it may get fired. So I would like to give it a chance and for giving it a chance, especially in a battery charging kind of circuit, it may not happen in something else where I will not have any DC voltage which is coming up in the cathode of the device. This will come very clearly even in a DC motor drive. Back EMF is there.

So back EMF is definitely going to reverse bias the device if I do not fire it at a larger value of AC voltage especially without continuous current. When there is discontinuous current, I have to worry about the two values of voltages. Which is higher and which is smaller? I have to compare the two. So in this particular case, it will start conducting only from this point. And then it might probably end conduction somewhere here, possible.

And it will repeat itself again. So it may again start conducting from here and so on. This is how the current will flow. So when I have a battery, things become a little difficult for the devices to get into conduction.

Student: Ma’am when we have a continuous conduction, we do not require a wide pulse?

Professor: You do not require a wide pulse if you are sure that it is going to be continuous conduction. But who will give you assurance? See normally what happens is if it is a 220 volts battery, under completely discharged condition it may have a value of 208 or 210 volts and you might design your rectifier in such a way that it will give around 215-220 volts. So you will put a current limiting resistance normally to make sure that the huge current does not flow through the battery. But you have to limit the value of the current to whatever the battery can withstand.

So initially, the current will be larger. After it gets charged more and more, from 210 it will go until 220. When it goes very close to 220, the current will become extremely small. When the current is small, it has to be discontinuous because the inductance stored energy will also be minimal. So it cannot be continuous. So we generally say there are 2 modes of battery charging. One will be constant current charging which is initially done when the voltage is very small for the battery, minimum value of voltage, minimum charge condition.

Constant voltage charging, when it is almost full. So there are 2 modes of charging we normally adopt in battery, constant current charging and constant voltage charging. So there is no guarantee that it will be continuous current. It heavily depends upon the state of charge of the battery, what is the charge that is already accumulated in the battery.

Student: Ma’am, we know somewhere that it is a continuous current, then why do not we require 180 degree pulse?

Professor: You do not need but you are never given a guarantee. His question is, if you are sure that it is continuous current, why do you need 180 degree pulse? But you do not need, agreed. But you are not given any time and assurance. Because you are given a rectifier, you may use it for battery charging, you may use it for DC motor drive, you may use it for nothing. So it depends. So when you design, you generally design for a general case.