Fundamentals of Power Electronics
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Lecture – 89
Snubber circuits

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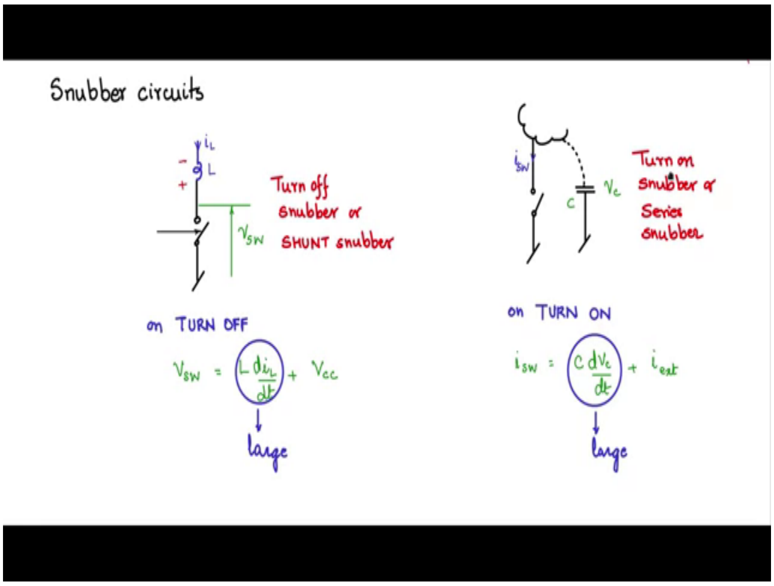

Let us discuss about couple of Snubber circuits. Snubber circuits are used to relieve the stress on the power semiconductor switches. There are essentially two types of Snubber circuits we will discuss couple of them. Consider a switch like that, and the switch is on it is conducting the current and switch is off it is supporting the voltage and it is a control switch. Now, let us say there is track inductance and let us say it is having a value L and a current i L flowing through the switch.

When it is flowing the polarity is in this fashion plus or minus and the voltage across the switch is given as V S W on TURN OFF meaning there is a current i L flowing through that, now you TURN OFF you are cutting open the switch which means i L is suddenly dropping to 0. So, there is a large negative d i by d t so the polarity will reverse and V S W will be L d i L by d t plus the external voltage I will put it as V c c, but this is a very large quantity. So, you will see a large spike across the switch and it will be so large that it can blow up the device or it will deteriorate it to a large extent.

So, this is a large problem and we need to address the term of stress. The other case is during turn on. So, you have a switch connected to the external circuit and through the external circuit there can be capacitances stray capacitances connected to the ground and when let us say there is a switch current when you TURN ON the switch at the time of TURN ON off the switch all the charge that is stored in these stray capacitance can flow into the switch.

And that can be a very large current because c d v by d t let us say this is on TURN ON call this as v c and c i s w is c d V c by d t plus all the external currents which is supposed to flow normally. The c d V c by d t can be really large and this TURN ON current can be so, large that it can blow up this switch. So, you need to protect against such a stress on the device.

So, during turn off the protection circuit snubber circuit is called turn off snubber or even called a shunt snubber in many cases because we try to put a capacitance across this device to address this L d i by d t problem so it is called a shunt snubber. That dual is this the turn on snubber or we put a inductance in series to address the problem of a large c d v c by d t current is called the series snubber. So, let us see how we design the basic turn off snubber and the basic turn onSnubber.

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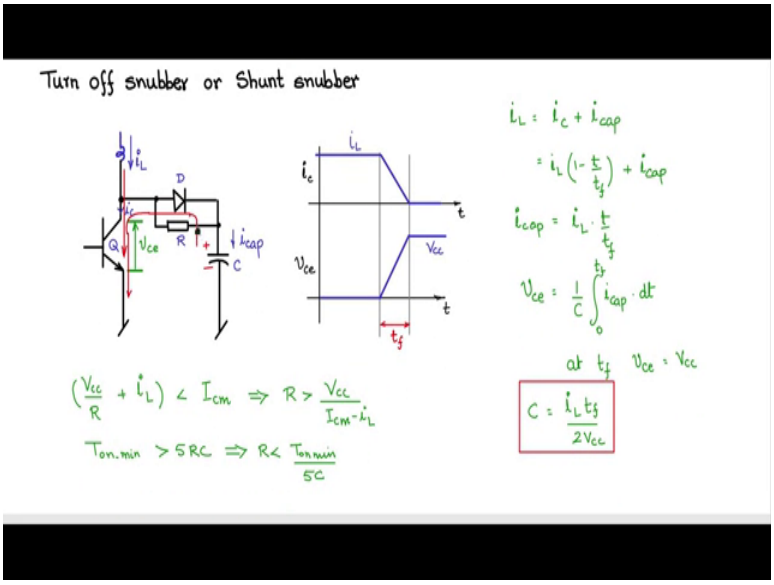

Let us now discuss the shunt Snubber or the turn off snubber and see how it works? Let me draw the switch or semiconductor switch it is a BJT switch that I am drawing here, but it could as well be a MOSFET switch or any other switch and this has a problem due to the winding inductances or the track inductances, the stray inductance and there is a current flowing through that and during the time of turn off there is going to be a large d i by d t spike due to these inductances.

So, let us say there is a current i L flowing through that through Q and the voltage across Q is V ce and let me plot V ce with time. So, during the time when during the time and here when Q is on so V ce is 0, let us say and during the time when Q goes from on state to the off state turn off because of this i L flowing through the stray inductances there is very large d i by d t.

But we want to prevent that stress appearing on the device and then we would like to see that the voltage across the transistor rises in a controlled manner to V cc and settles down at V cc. How can we do this? So, this is done by putting a shunt element a capacitance across the device across the switch.

So, we pass this current i L to freewheel. So, instead of having a large L d i by d t spike we will when you turn off Q, we will allow the current i L to freewheel through this diode into the capacitance. So, the capacitance will get charged and during the time when the transistor turns on again, we would like to discharge the capacitance and for that you need to have a discharge path. So, I will put a resistance path here because you cannot connect directly the capacitor across this it will be shorting and then there will be huge turn.

So, therefore, you pass it through the resistance in a controlled way there will be a discharge through it when Q turns on again and then it will be brought back to its original state. So, that it can receive again the stray energy from the stray inductances. Now that this is this portion of the circuit this d e r and c r is called the snubber circuit or the shunt snubber. So, I will call this as C this is D R and the current through C as i cap and the current through the collector of the transistor as i c.

Then let me also plot i c; i c would be high when the transistor was on and at the time of turn off the collector current linearly falls down to 0 in this fashion. Now, let us look at this wave shape and try to find out what should be the value of C. So, i L this i L is equal to i c plus i cap this from k c L you get that. And then if I take only t f fall time period during that period, i c that is current through the switch is of this shape it is linearly following I am approximating it as a linear fall. So, it is i L 1 minus t by t f linear fall plus i cap.

Now, i cap see i L is on this side. So, i cap i can take it to one side and then rearranging you can find i L is t by t f. So, this is the current through the capacitance. So, C d v c by d t is equal to i cap or the voltage across the capacitance because the diode will be the same as V ce.

So, you can say V ce is 1 by c integral of i cap d t, 0 to t f let us take only that time period then on integrating because i cap is known you substitute here. And at t f apply V ce should be V c c at t f boundary condition and then c will work out v i L t f by 2 V c c and this is the value of the capacitance that you need to use. So, that in t f time period you can in a controlled way give a smooth rise to the voltage across Q to reach V c c there will not be any spikes. So, this is the effect of the turn off snubber or the shunts snubber. How to find the value of r let us see that.

So, the capacitor would have charged up plus minus to V c c and now when the transistor is turned on next. The transistor is turned on next there are two currents that flow one is i L itself the other one is this capacitor will discharge through this R into the Q. So, that is one path this discharge path of the capacitance charge through Q and the other one is i L itself.

So, these two currents V c c which is the current which was the voltage across the capacitance by R will be the TURN ON instantaneous current V c c by R plus at that instant was i L. Now this should be less than I c m rating of the device of the Q is very important. So, continuous max the rating should be greater than this value.

So, from this condition R is one variable which is not known you can say R should be greater than V c c by I c m minus i L. So, this is one condition the other constraint is when this Q is on during that time the hole of Q charge on the Q should get discharged. So, there should be a minimum time for which Q should be on, so that it allows enough time for Q to discharge its charge and be ready for the next cycle.

So, the minimum on time T on minimum should be greater than five times R C time constant there is a R C time constant this discharge is exponential in nature having a time constant R C 5 times R C time constant means the steady state is reached. So, therefore, this constraint leads to R as T on minimum by 5 C, C of course, you know from this relationship.

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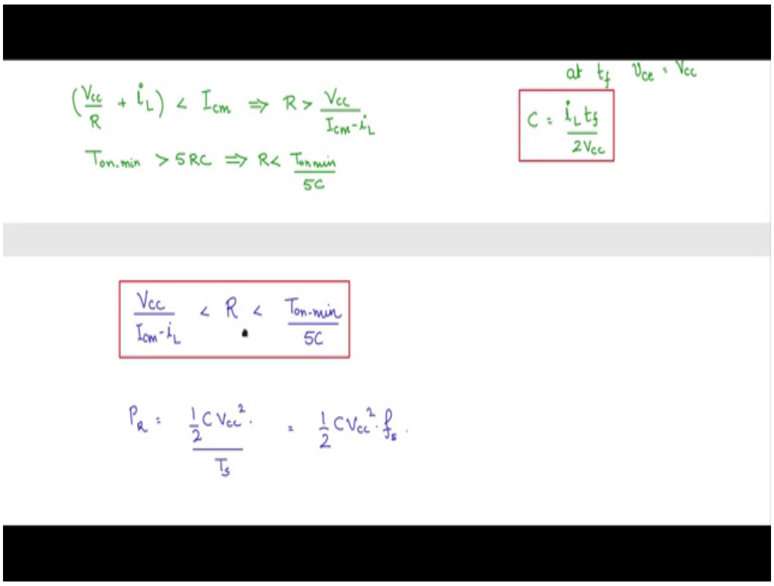

From these two constraints we get the range of R that which we should select from. So, V c c by i c m minus i L should be less than R which would be less than T on min by 5 C. So, we get the range of R that we should choose and the power dissipated in R P R is see we know that the energy that is dissipated is half C V c c square; and this is the watt seconds divided by time T s the period switching period, this will give you the power and therefore, half C V c c square f s will give you the power dissipated in R whatever be the value of R within this range.

So, in this way we know how to find the value of C and find the value of R and this is how you design turn off snubber or a shunt snubber as shown here like this.

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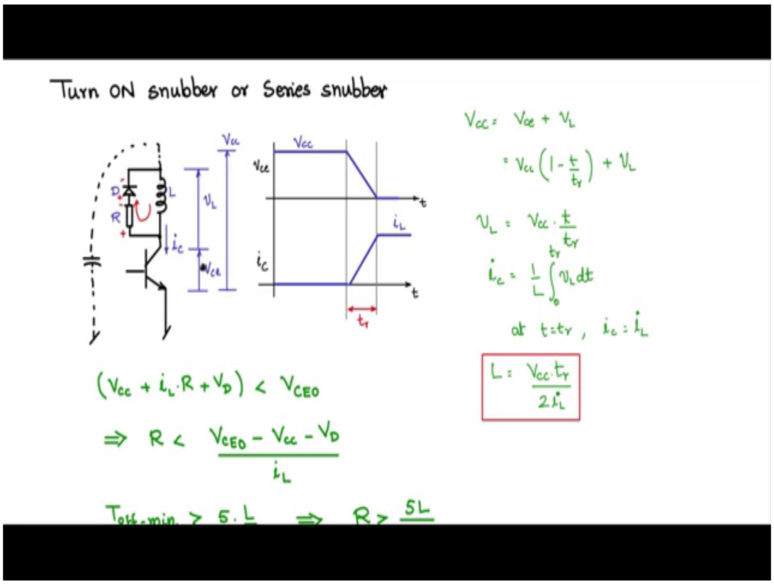

The dual of the turn off snubber or the shunt snubber is the TURN ON snubber or the series snubber, it has a dual effect. So, let us draw the switch I am using a transistor switch it could as well be a MOSFET switch.

Now, let us say there is a stray capacitance charged capacitance coming across the switch due to the external circuits; now this is charged to some V c c. So, when the switch is turned on, you can have a very large current flowing through the switch and it could also be fatal. So, let us draw the time waveform and I will take the current i c through the switch.

Now, i c is when the switch was off the current is 0 and now we are turning it on. When you turn it on there can be a huge discharge huge current surge current, because of the discharge because the on resistance of the power semiconductor switch is almost 0, you can have this V c c voltage divided by almost 0 a very large current flowing through that and this large d I can blow the transistor. So, instead we require that the current through the transistor i c rises in a controlled manner, and let us say this is the turn ON time it rises in a controlled manner and reaches i L gradually.

So, for that you need to interpose something a series snubber circuit and that is composed of L and if you have L you need to have a freewheeling path the demagnetising path diode and resistor as shown here. So, let me say this is L d and R and this voltage is V c c V ce and this voltage is v L. So, I will mark it V ce v L and the voltage together will be V c c now let us see what V ce would look like with time.

So, when the switch was off during this time V ce would have been high at V c c and then gradually comes down to 0 when it turns on. Using these waveforms and these Kirchhoff's the relationship let us develop the equation for finding the value of the L in the series snubber. So, V c c equals v L plus V ce, V ce plus v L and if I am I am talking about the time of interest t r rise time.

Now, during this time you see that V c e is falling in a linear fashion I am making a linear approximation. So, it is V c c into 1 minus t by t r plus v L. Now if I take v L into one side v L can be found to be V c c into t by t r. Now i c that is the current through the current through the collector is also flowing through the inductor. So, L d i c by d t will be the voltage v L or i c is one by L integral of v L d t. Let us consider the period of interest 0 to t r. So when you do the integration you substitute this V c c t by t r here and integrate and at t equal to t r you can take i c is equal to i L. So, L is equal to V c c t R by 2 i L. So, this will be the relationship for L

Now, if you look at the time when the switch is off the inductor current is freewheeling in this fashion. It is freewheeling in this fashion; and there is a positive drop from positive in this side a drop across R and drop across D in this fashion. So, what are the voltage across the transistor V ce. V c c plus i L R plus V D this is coming across. The transistor and it should be less than V C E o rating of the transistor. So, therefore, this condition gives R to be less than V C E o minus V c c minus V D by i L this is one condition.

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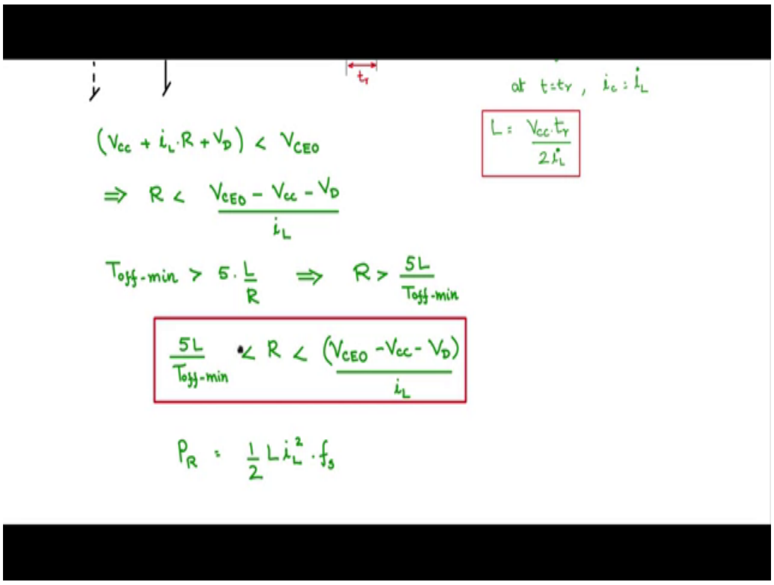

Another condition is the energy in the inductance should get removed released by the time this turns on again. So, there should be a minimum of time for this transistor T of min should be greater than 5 times L by R time constant so that inductor releases all its energy stored energy this means R should be greater than 5 L by T off min.

So, by this you get 5 L by T off min is less than R which is less than V c c V C E o minus V c c minus d by i L this is the relationship for finding the range of R for selecting the range of R. And what is the power dissipation in R? Half L i square amount of energy is removed every cycle divided by t s or into f s this will be participated in the R for whatever be the value of R that you choose in this range.

So, this is the series snubber or the turn ON snubber. So, every switch whether it be a BJT or a MOSFET or an IGBT should have a series snubber and a shunt snubber together. So, the series snubber or shunt snubber and over current protection along with the gate drive forms the complete power semiconductor switch.