Design of Power Electronics Converters
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Module: Snubber Design
Lecture 31
RC Snubbers Analysis - I

Welcome to the MOOC course on Design of Power Electronic Converters, we had started with the module on snubber design and in last lecture, I gave you an introduction to snubbers what is the need of snubbers and what are the commonly used snubbers. So, in that, we saw that your RC's snubbers and RCD's snubbers are really widely used ON, OFF snubbers. So, let us start analyzing RC's snubbers in this lecture.

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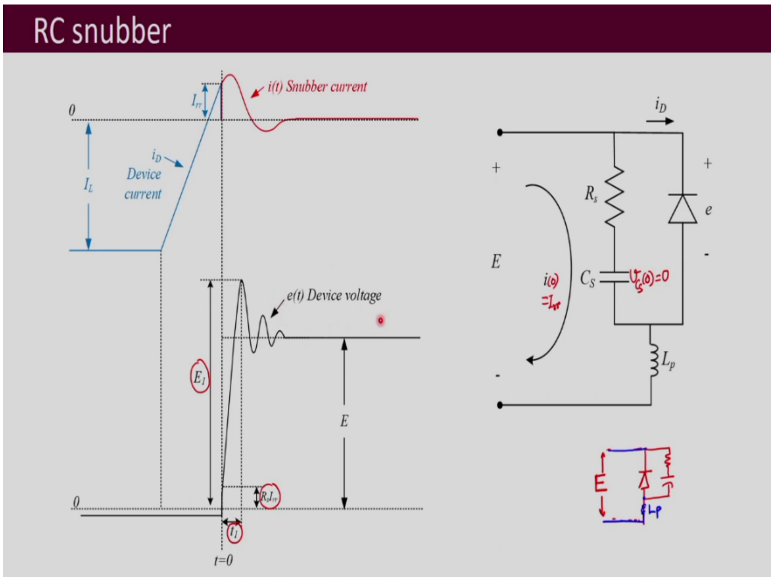

To analyze RC's snubbers I have taken this circuit. So, what it basically is that that we using this snubber design for this diode. So, in a circuit you have will have the diode connected and it may be connected to any part and there whatever the diode the voltage it is supposed to block that is your E and across the diode you will be connecting this RC and then it is close enough so, that we do not have to take into account any parasitic inductance here.

But over here for this connection, you will have this parasitic inductance LP which is what we are taking this LP parasitic inductance in between the connection of the diode and the rest of the circuit and here this is your rest of the circuit connection E, E that is getting formed over here. So, what we have is this RS and CS are those snubber resistances and capacitances and LP is the parasitic inductance and over here this diode whatever current it is going to carry where you representing it by iD.

Now, note down the direction of the current if the positive direction of current is taken as opposite to the direction in which the diode conducts. And then you have this voltage across the device which is your represented denoted here by small e and the current that flows through this snubber and to through this loop is this current i and then this is the voltage capital E is what the diode is supposed to block and we are discussing the turn of process. So, the waveforms that will be associated over here is that when the turn of process begins it is over here your first of all, there is no change in the current and device current for some time and the device voltage also.

So, this is your turn on voltage which is going to be negative because we the positive polarity that we have taken is opposite to the direction in which the diode conducts. Then after that the device current starts to reduce and it crosses and it reaches to the reverse recovery current value Irr and during this process the or the voltage does not build up and then what happens is that while this current has reached and build to certain extent of the reverse recovery current that is when you can assume the device to be blocking that means it has turned off because now is when the device voltage will start to build up.

So, this is the point which we are considering as the time 0. And then further what happens is that over here this snubber takes over and the current then starts to flow through this snubber. So, at this point your Irr current which was flowing through this diode. And this is of course in the opposite direction, because this is the reverse recovery current. Now, the reverse recovery current starts to flow through this RS and CS through this snubber. And so, here you can say this is the starting current and there is no voltage across the capacitor at the time.

So, the initial voltage across the capacitor is 0, because this is the equal to 0 what we are considering when we assumed the device to be almost off the diode to be almost off and the snubber to be taking over. And then what happens is that so, as your voltage tends to build up, but over here the initial voltage that will be appearing across the device and that time will be equal to RS multiplied by Irr, because this is the initial current.

And then it builds up in you have this RLC circuit, so, you may have this kind of a transient when this is the transient in your snubber current. So, this is an RLC circuit series RLC circuit. So, this will be the nature of the current you may have some bringing in the current or depending on what is the nature it is over damped critically damped or under damped this shape may be somewhat different.

So, finally this snubber current is supposed to go down to 0 and during the time the voltage the ringing maybe there it may increase to certain extent and then it will further reduce and go to the blocking voltage what the device is supposed to block that is your capital denoted by capital E over here and whatever the peak that it reaches this voltage e(t) the device voltage that we have denoted here by E1. So, this is the waveform that you have to keep in mind while we do the analysis and we go through the derivations associated with this RLC circuit first snubber design.

And also, one thing that I forgot to mention here is this time t1, so, time t1 is the time that the device voltage takes to reach to this peak value of E1. So, these different terms which are important for you to remember is this E1 the peak voltage in this time t1 and then that this initial voltages RS, Irr and the voltage across this VCS 0 at time 0 is equal to 0 and further what is the initial current and this initial current is 0 equal to Irr and we do the snubber analysis by analyzing this RLC circuit. And so, this I a solution we can get the curve this it this snubber current and from there we can obtain this device voltage Et.

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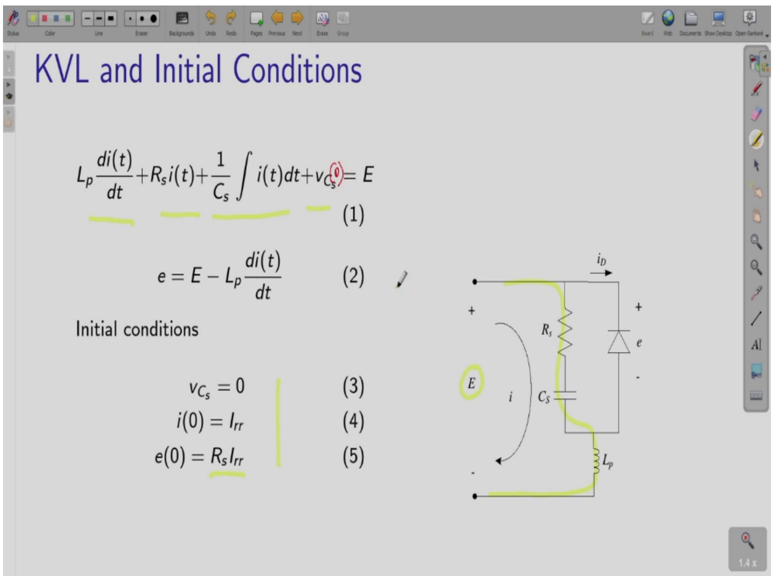

To analyze this RC circuit, we will apply KVL. So, here if you apply KVL in this part.

$$L_p \frac{di(t)}{dt} + R_s i(t) + \frac{1}{C_s}\int i(t)dt = V_{cs}(0) = E \qquad (1)$$

$$e = E - L_p \frac{di(t)}{dt} \quad (2)$$

Initial conditions

$$V_{Cs}(0) = 0 \quad (3)$$

$$i(0) = I_{rr} \quad (4)$$

$$e(0) = R_s I_{rr} \quad (5)$$

So, now, we had to further solve these equations.

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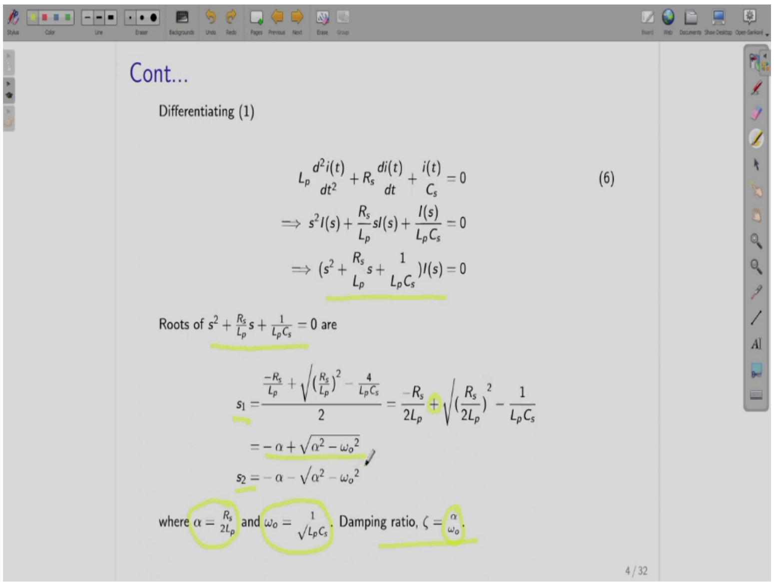

So, what you can do is you can differentiate it differentiate the first equation so, you will be obtaining like this

$$L_p \frac{d^2 i(t)}{dt^2} + R_s \frac{di(t)}{dt} + \frac{i(t)}{C_s} = 0 \quad (6)$$

And then you take the Laplace transform of it.

$$s^2 I(s) + \frac{R_s}{L_p} sI(s) + \frac{I(s)}{L_p C_s} = 0$$

And then so, we can rearrange and this is what we will be getting.

$$\left(s^2 + \frac{R_s}{L_p}s + \frac{1}{L_pC_s}\right)I(s) = 0$$

Roots of

$$\left(s^2 + \frac{R_s}{L_p}s + \frac{1}{L_pC_s}\right)I(s) = 0$$

are

$$S_1 = \frac{-R_S}{2L_P} + \sqrt{\left(\frac{R_S}{2L_P}\right)^2 - \frac{1}{L_PC_S}} = -\alpha + \sqrt{\alpha^2 - \omega_0{}^2}$$

$$S_2 = \frac{-R_S}{2L_P} - \sqrt{\left(\frac{R_S}{2L_P}\right)^2 - \frac{1}{L_PC_S}} = -\alpha - \sqrt{\alpha^2 - \omega_0{}^2}$$

Where $\alpha = \frac{R_s}{2L_p}$ and $\omega_0 = \frac{1}{\sqrt{L_PC_S}}$. Damping ratio, $\zeta = \frac{\alpha}{\omega_0}$

And you know that this is having 2 roots this is a quadratic equation and those 2 roots are your s1 and s2, One will be your plus and another will be your minus root.

So, now depending on the relative values of alpha square and w_o squared your zeta can be less than 1 greater than 1 or equal to 1 and depending on this the you know that these roots can be real, complex or they can be equal.

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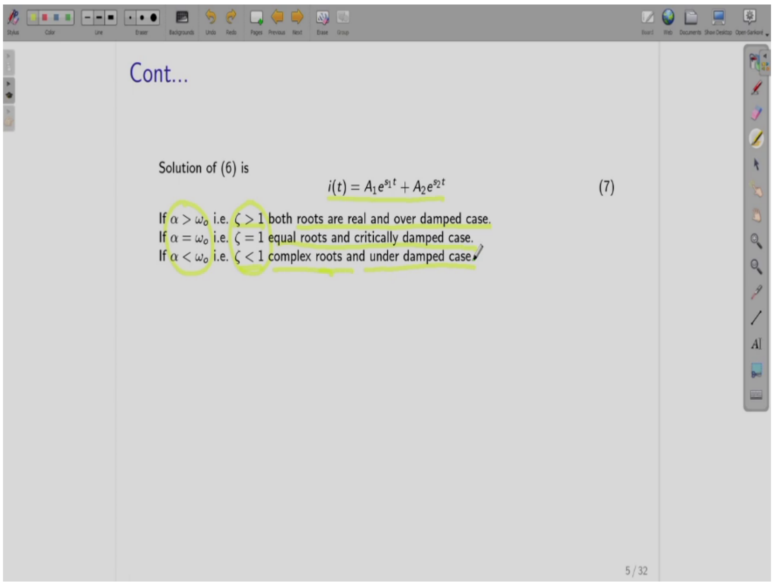

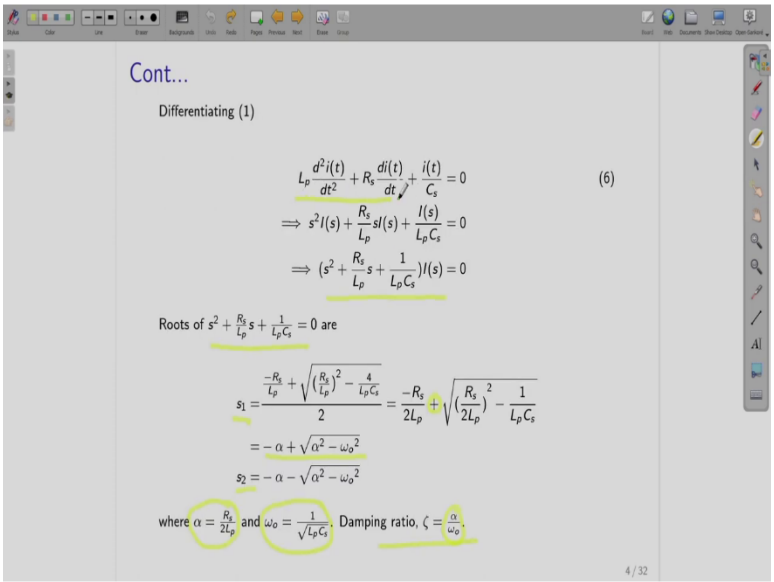

And so, the solution of this differential equation you might be knowing the solution is given as

$$i(t) = A_1 e^{s_1 t} + A_2 e^{s_2 t} \qquad (7)$$

If $\alpha > \omega_0$ i.e. $\zeta > 1$ both roots are real and over damped case.

If $\alpha = \omega_0$ i.e. $\zeta = 1$ equal roots and critically damped case.

If $\alpha < \omega_0$ i.e. $\zeta < 1$ complex roots and under damped case.

So, depending on these values as I told you alpha greater than ω_0 equal to ω_0 or less than ω_0, you have these 3, theta greater than 1, zeta greater than 1 means what this is real both of these 2 roots are real and so, you have both roots real and over damped case. Next is when both the roots will be equal that means alpha equal to ω_0.

So, if we have alpha equal to ω_0 so, this square root part gets eliminated and both the roots are equal and so, we will be having equal roots and critically damped case. And then, third one is when you will be having this alpha less than ω_0 that means zeta damping ratio is less than 1 and in that case you will be getting complex roots and complex roots because the square root part is going to become negative. So, complex roots and that is your under damped case in RLC circuit. So, these are the 3 cases which we have to analyze one by one to analyze the RC circuit and this is what we will be looking next the 3 different cases for RC snubber analysis. Thank you.