Design of Power Electronic Converters
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Module Snubber Design
Lecture: 35
RC Snubber Design- II

Welcome to the course in Design of Power Electronic Converters, we had started discussing RC snubber. And we did the derivations for the three cases of overdamped, underdamped and critically damped. And then whatever results we had obtained using that we had seen how to do RC snubber design with the perspective of limiting the spike voltage or limiting the dv by dt. Now, let us see further on this RC snubber design.

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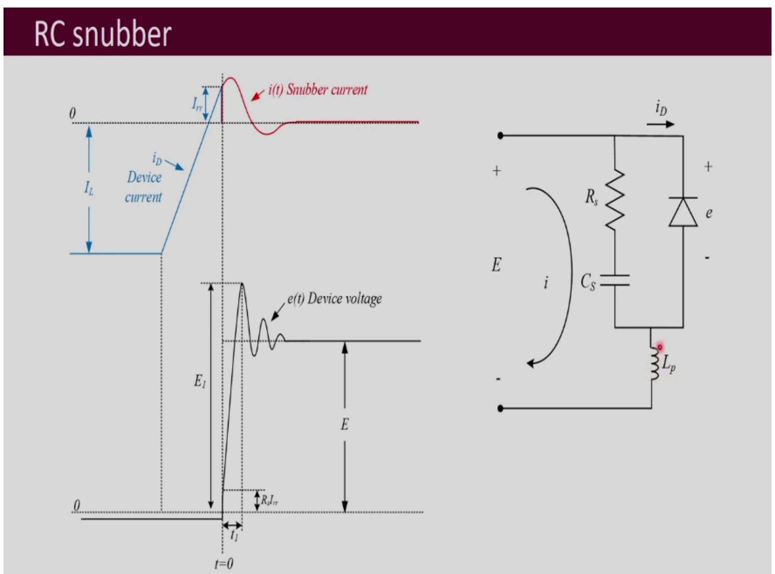

So, to refresh your memory again on this, this is the base circuit and the basic waveforms using which we were we had done the analysis and we are doing the design. So, this peak voltage E1 can be limited by RC snubber design and this rate of change of this voltage dv by dt that also we, there is one of the objectives of limiting it. So, then this parasitic Lp is assumed to be known, you will have an idea of it that is what we are assuming in this reverse recovery current is also something you will be having an idea and that is what is assume for this RC snubber design.

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Results of analysis

ζ	$\frac{E_1}{E}$	$\left(\frac{dv}{dt}\right)_{av} = \frac{E_1}{t_1}$
<1	$p(\zeta,\chi) = 1 + e^{\left(-\frac{\zeta}{\sqrt{1-\zeta^2}}\tan^{-1} f(\zeta,\chi)\right)}\sqrt{1-2\zeta\chi+\chi^2}$	$\omega_o E \frac{p(\zeta,\chi)\sqrt{1-\zeta^2}}{\tan^{-1} f(\zeta,\chi)}$
>1	$q(\zeta,\chi) = 1 + e^{\left(-\frac{\zeta}{\sqrt{\zeta^2-1}}\tanh^{-1} g(\zeta,\chi)\right)}\sqrt{1-2\zeta\chi+\chi^2}$	$\omega_o E \frac{q(\zeta,\chi)\sqrt{\zeta^2-1}}{\tanh^{-1} g(\zeta,\chi)}$
=1	$1 + (1-\chi)e^{-\frac{2-3\chi}{1-\chi}}$	$\omega_o E \left\{\frac{1-\chi}{2-3\chi}\right\}\left[1+(1-\chi)e^{-\frac{2-3\chi}{1-\chi}}\right]$

$$f(\zeta,\chi) = -\frac{(2\zeta - 4\zeta^2\chi + \chi)\sqrt{1-\zeta^2}}{(1 - 3\zeta\chi - 2\zeta^2 + 4\zeta^3\chi)} \qquad g(\zeta,\chi) = -\frac{(2\zeta - 4\zeta^2\chi + \chi)\sqrt{\zeta^2-1}}{(1 - 3\zeta\chi - 2\zeta^2 + 4\zeta^3\chi)}$$

Now, this was a summary of the results that we had obtained and we used these to do this snubber design.

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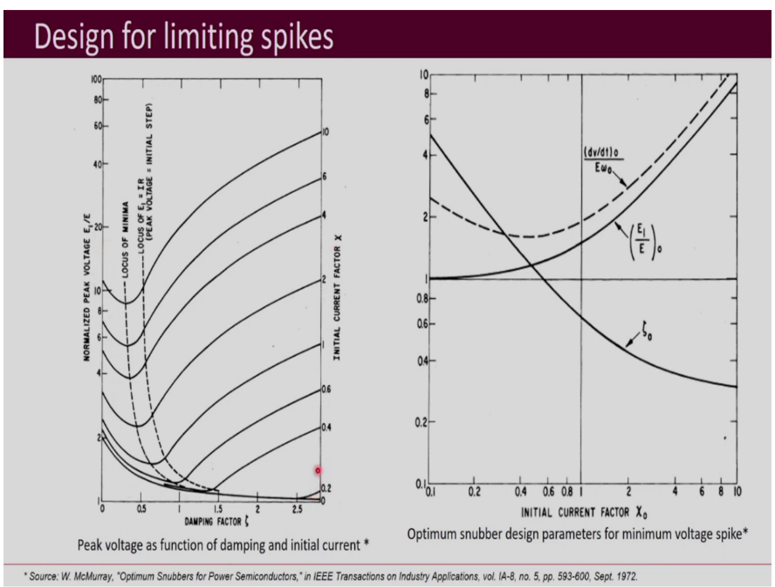

And then now, we had used first this set of equations to obtain these plots, where we had this normalized peak voltage your versus your zeta, with chi as a parameter and we saw that that we obtain a minima at certain points and then those are the points which were noted down to obtain this plot, which is your all these zeta 0 versus chi 0 and E1 by E 0 versus chi 0 and this dv by dt 0 by E omega 0, these three plots were obtained. And then using it, we saw how we can do the RC snubber design.

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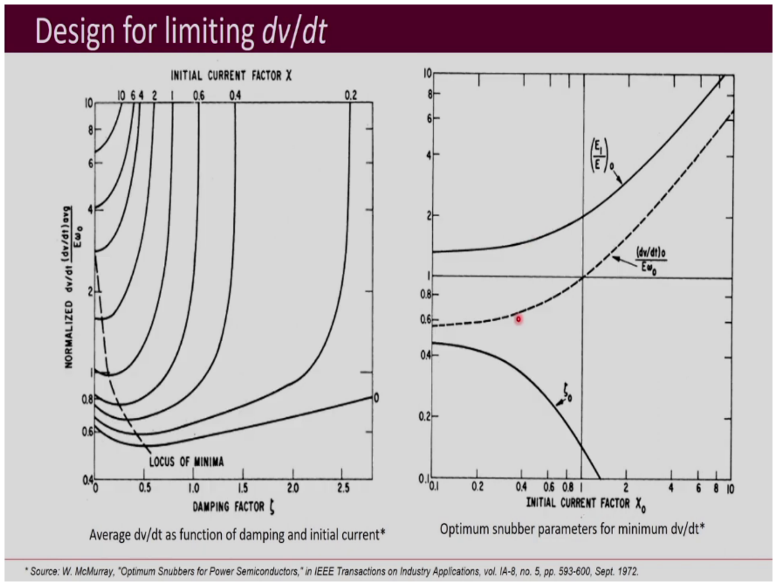

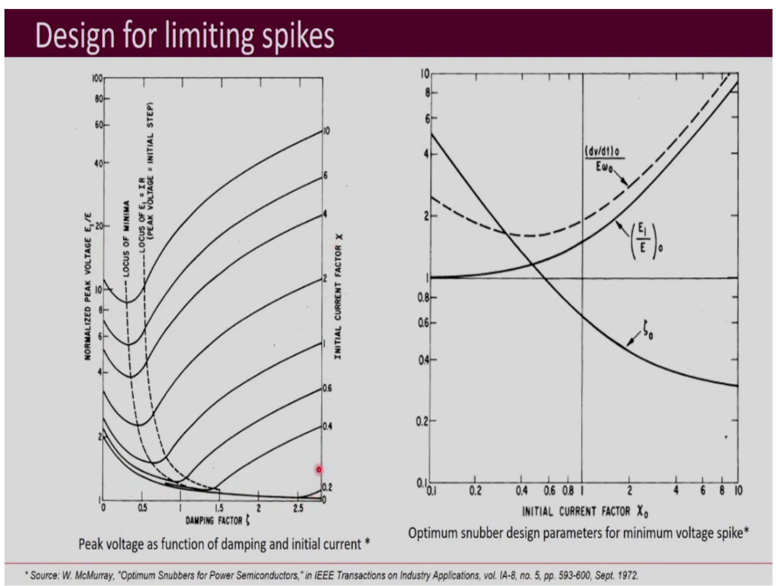

And similarly, we obtained another set of plots by using this set of functions for dv by dt. And similarly, we saw that how we can do RC snubber design for limiting dv by dt. Now, in most of the cases, we would like to do both we would like to limit dv by dt and we would also like to limit the spike. So, how can we achieve both of them together? If you observe this graph, and this graph, what you can see here is that they are here your this is going to give your higher damping ratio as compared to when you want to limit your dv by dt.

So, they the zeta 0 that you obtain in the two cases for minimum E1 by E as compared to minimizing your dv by dt they are different. So, then if you want to limit both of them, we have to do compromise like kind of trying to reduce both somewhere in between the two where both of them are reduced to some extent, to satisfactory extent we can say that rather than trying to obtain the minimum of both.

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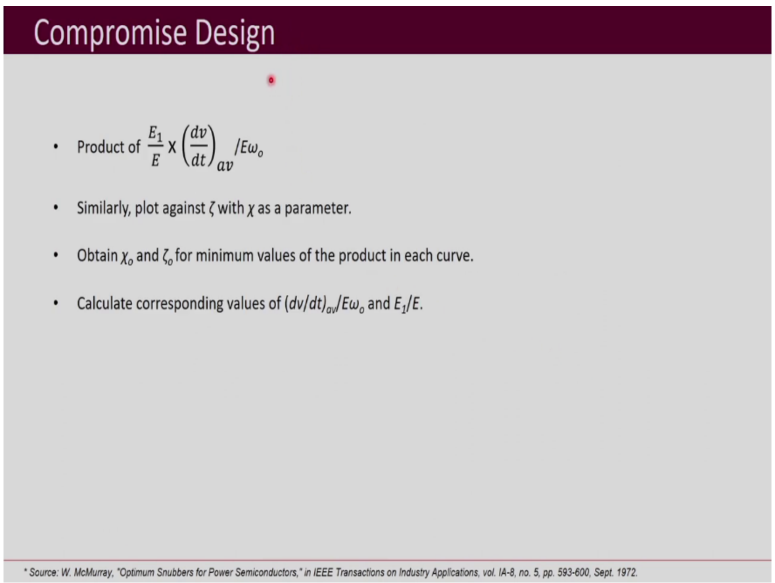

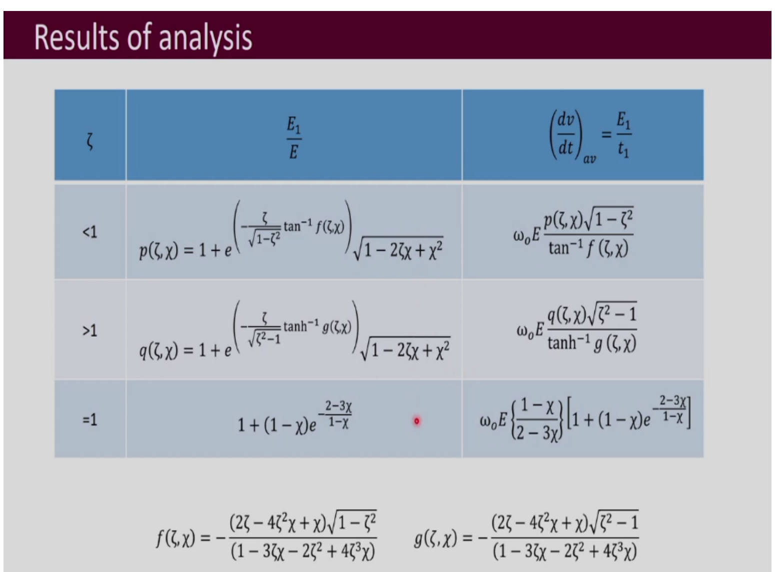

So, that is called as the compromise design. So, in the compromised design, what we do is that we use this product

$$\frac{E_1}{E} \text{ x } \left(\frac{dv}{dt}\right)_{av} / E\omega_o$$

we multiply $\frac{E_1}{E}$ and $\left(\frac{dv}{dt}\right)_{av}$ and based on it, we do the compromise design. So here what is done is that we multiply these (see the table) so you can multiply these two functions. And after that the process is similar to do the plotting.

You take chi as a parameter and you vary zeta and then obtain the values by substituting those zeta and corresponding chi, in your these different different functions, and then whatever values you are going to obtain, you do the plotting and then there are also at a certain point at a certain point of zeta 0, you will be obtaining the minimum. So, you know down those corresponding value of the product and also note down the corresponding value of zeta 0 and Chi 0.

As we did the plots for these curve and this curve is similarly, is the plotting done for this product also and the corresponding values of zeta 0 and Chi 0 where the product becomes minimum are noted down. And then once we have noted down those set of values, we substitute that in these expressions (given in table), and we obtain the corresponding values of E1 by E and dv by dt average you by E omega 0 the normalized one. So, that is noted down as the dv by dt average by omega 0 and E1 by E. Both you can denote it by this letter is 0 as we are doing at the minimum point.

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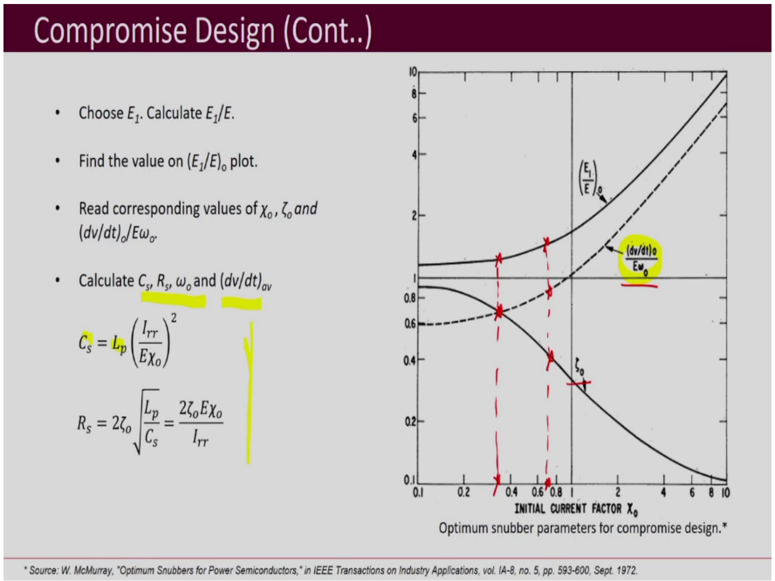

And then so, those set of values are then plotted. So, we get this nature of the plot where you have this similarly, initial current factor chi 0 with respect to that we plot this zeta 0 and we plot this E1 by E0 and we also plot this dv by dt 0 by E omega 0. So, we using these set of plots which are obtained by minimizing the product means we plotted the product curves, the product of E1 by E and dv by dt average by omega 0 and the points at which the minima occurred those are the points your corresponding zeta 0 and chi 0 were noted down and then that when plotted this is what we obtained.

So, when we use these values for our design, so, that means, we are kind of doing a compromise we are trying to reduce both E1 by E and the dv by dt. So, how you will design? You choose E1. So, you calculate E1 by E whatever is the peak that you can allow that based on it you obtain this normalized ratio and that you find out on the plot and further you find out the corresponding values of dv by dt by E omega 0 and corresponding values of zeta 0 and chi 0.

So, what we are telling is that let us say this is the point that you obtained and corresponding values of this dv by dt by E omega 0 you obtain also corresponding values of chi 0 here the point where I have chosen these two are almost very close enough and the corresponding value of chi 0 let us say you choose this point. So, here this is that corresponding point and this is the corresponding point for zeta 0 and this is the corresponding value of chi 0.

And once you have noted down those values, then you calculate the CS,RS, omega 0 and this dv by dt average. So, how you do it is that you use these two equations which we have already used for your, when we did the design for E1 by E. And then once you know CS then you can calculate omega 0 as well because Lp is known to you and then you multiply this with your this one dv by dt 0 by omega 0. So, then you obtain this dv by dt average.

Now, using this method of compromise design, what may happen is that you may get in the very first attempt you may get satisfactory dv by dt whatever dv by dt that you may be getting, that is good enough for your device. But it may also happen that it may not be sufficient enough it may be exceeding your dv by dt limit for the device.

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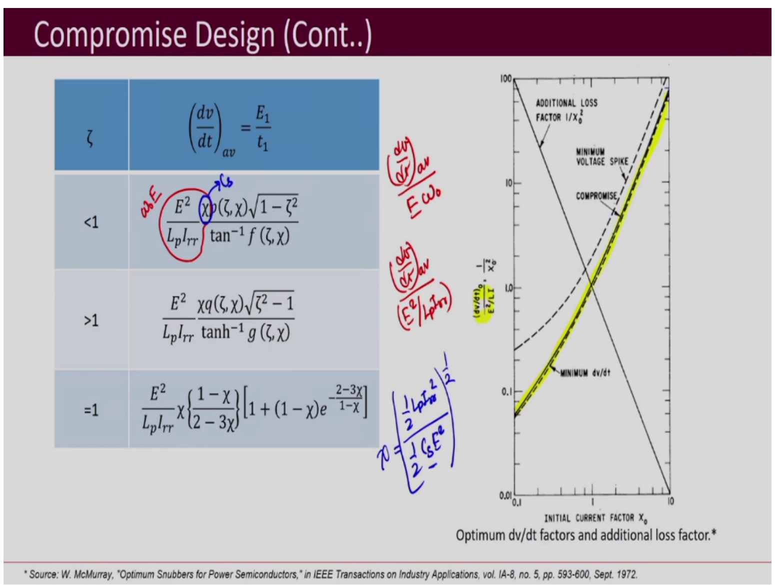

Results of analysis

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Then, what you can do is that for that further what is done is this dv by dt expression which we had written in terms of E omega 0. So, if you note down here this these expressions we had written is in terms of omega 0 E and if you recall the derivation at that time I had shown you that this omega 0 E can be replaced as your this multiplied by chi and another ratio which is in terms of your Irr CS. So, that is what is done this one is that part your E square by Lp Irr in Chi. So, that was written as just omega 0 E in the previously when we did the plotting for normalized plot, we normalized this dv by dt average by dividing it by E omega 0. $\frac{\left(\frac{dv}{dt}\right)_{av}}{E\omega_0}$

Now, we normalize it by doing this dv by dt average divided by E square by Lp Irr, $\frac{\left(\frac{dv}{dt}\right)_{av}}{\left(\frac{E^2}{L_p I_{rr}}\right)}$

what is happening here is that you may be wondering what is the difference between the two? The difference here is in terms of this part chi, this chi actually contains the CS inside it, if you remember it, it has that part CS in it it is the ratio of your initial inductor energy by your final capacitor energy. So, half Lp Irr square by half CSE squared this is the square root of it is what is your chi. So, it has this part CS in it and so, it affects the choice of the capacitor when you use involve that in your expression of dv by dt average.

So, one part of CS was removed when we were normalizing it with respect to E omega 0. Whereas, when we are including it this chi in that remove it from the normalization, then that is further going to impact the choice of CS. So, with these functions with a different type of normalization, you obtain this curve which is noted down here is the compromise curve. This compromise curve and this is that dv by dt 0 E square by Li that is what is written here. So, that is what we can plot.

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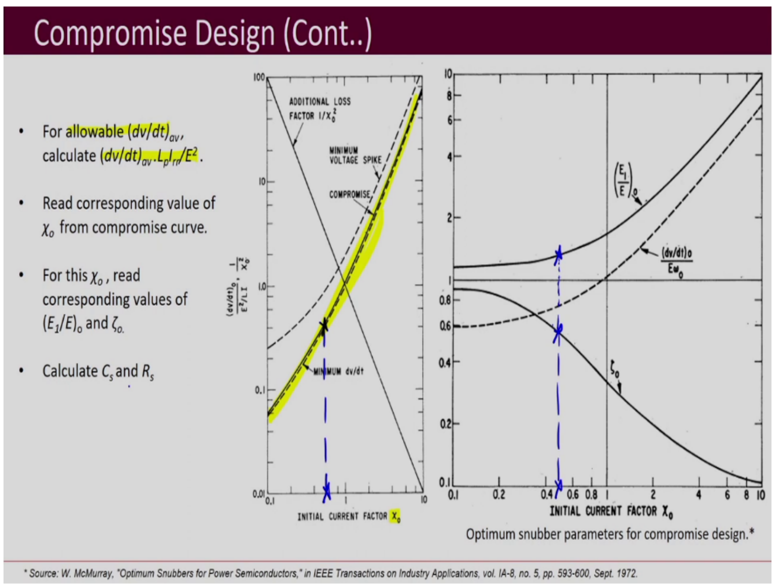

And then with that we use basically this graph, that I, this is the same graph that I had shown in the last slide and this is plotted with respect to this chi 0. And then you also this graph, this is the same graph as is shown here, with these two set of graphs, we do the design. So, here what we do is first you decide what is your allowable dv by dt average for your device, then you normalize it. So, basically you divided it by square by P Irr that means you multiplied with Lp Irr by E square and then what you do is you find out the corresponding value. So, let us say this is the value that you calculated and you calculate this corresponding value of chi 0.

And once you have done that, you note down that particular value over here. So, let us say this is the value that you obtained for chi 0 and then corresponding to it you note down the value of zeta 0 and note down the corresponding value of E1 by E0. And further, we know zeta 0, you also know chi 0. So, then you know using those two how you can calculate CS and RS, the required capacitance and required resistance for this snubber design. So, this is what is called as the compromise design you do try to compromise between basically you try to achieve both you try to limit both the spike as well as the dv by dt.

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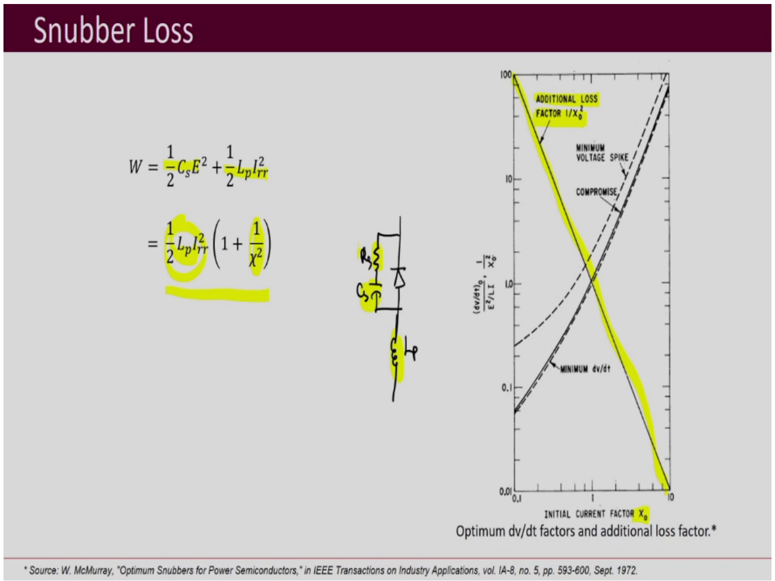

Now, it sounds very good that we can limit your peak voltage, that is the spike and we can also limit the dv by dt by using this snubber design, so, that is something very attractive, but is there any cost that we are paying for limiting these? And the cost is in terms of the snubber loss. So, what happens is that if when we recall the circuit, so, this is your diode that we have taken here for design snubber design and this is RC and this is your Lp, the parasitic inductance So, your this whatever is the energy that is here in this Lp, even if this snubber was not present this would have got dissipated somewhere.

So, that energy loss was anyway happening, but further when you added this snubber you also have this CS energy associated with it and that of course, in both of these two then as the way this snubber is designed and snubber operation takes place, it is basically your LPs and CS energy that is finally going to get dissipated in this RS, this resistor because this is the lossy element the resistor. So, this energy associated with your snubber which is

$$W = \frac{1}{2}C_s E^2 + \frac{1}{2}L_p I_{rr}^2$$

is your snubber loss RS and that could be written is terms of 1 plus 1 by chi square, if we want to rearrange it and write it in terms of chi the initial current factor.

$$W = \frac{1}{2} L_p I_{rr}^2 \left(1 + \frac{1}{\chi^2}\right)$$

So, as I told you this($\frac{1}{2} L_p I_{rr}^2$) was anyway happening even if this snubber was not present, but because of this CS this$\left(1 + \frac{1}{\chi^2}\right)$ is this additional term that came into picture. So, this is called as the additional loss factor 1 by chi 0 and this is the additional loss that is going to happen in the snubber resistor RS. So, that is plotted here with respect to this chi and as chi increases, we see that this is your decreasing, but this is the additional loss that is going to take place so, your loss in the converter is going to increase.

So, we do not want to reduce the efficiency of the converter by putting too high values of RS. So, that is what when you do the design, you also have to see how much is the extra loss that is happening by your snubber design, if it is becoming too lossy, then you can readjust the values and then again say how much additional losses are going to take place there.

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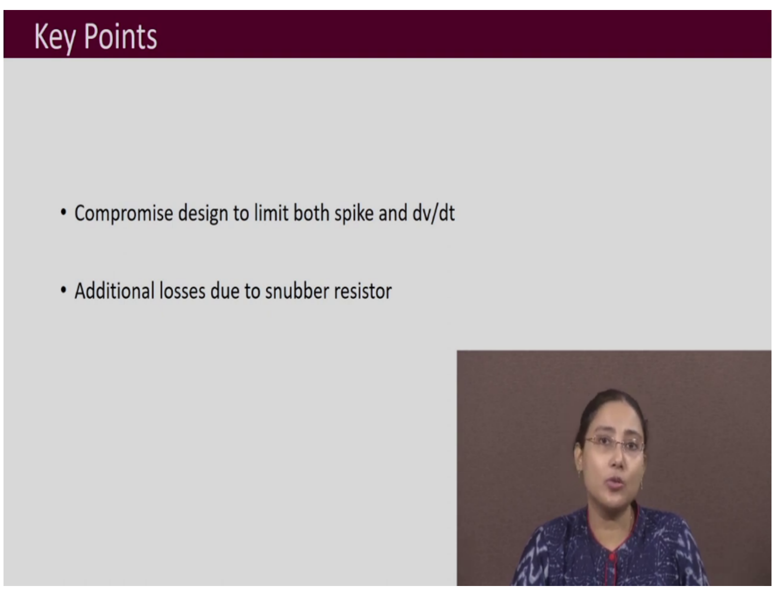

So, the key points of this lecture is that we can do compromise design which try to limit both dv by dt and your spike voltage. And again, the procedure is same you basically obtain graphs, different plots and using those plots, you can do the compromised design. And we also have to be aware that there are additional losses due to addition of this snubber and those losses, we should be looking into it that the losses are not too high to reduce the efficiency of the converter so we can redo this snubber design to adjust the losses. Thank you