Design of Power Electronic Converters
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Lecture 58
Design Solutions of EMI

Welcome back to the course on Design of Power Electronic Converters. We were discussing electromagnetic interference in power electronics. In the last lecture we saw the common mode noise and differential mode noise. So, now let us see some of the solutions that can be used to solve the problem of EMI in power electronic converters. To solve the problem of EMI or to make power electronic converters electromagnetically compatible that is to meet the EMC standard, which is required for a particular application there are two main methods: one is design of filter EMI filters and second is enclosure.

Now, enclosure means the converter will be kept inside some box. Usually it is a metallic box and the shape of the metallic box, how you design that metallic box, that whether there are holes in it or not or whether how many holes you put inside it for ventilation, those enclosures this sort of form become like an antenna or also are able to prevent the problem of radiated emissions. So, enclosures are used for mainly to solve the problem of radiated EMI and your EMI filters are used to solve the problem of a conducted EMI.

Now, these are generally more expensive solutions, because they are done towards the end of the design, after you have done the basic design of the converter, you have designed the PCBs, you have tested it, verified the operation and then finally you go for EMI testing, you see the levels or you determine what could be your EMI levels. And then you try to design the filter and then you try to meet the EMC standard. And further after that you also do the enclosure design.

Now, if we do not handle the problem of EMI from beginning at the design stage, then what will happen in the towards the end is that more amount of interference disturbance may be present and then we have to use expensive filters and more expensive enclosures to reduce the problem of interference. So, it is important that from the very beginning of the design we should be aware of the problem of interference and we should take measures so that the EMI is less.

From the measures that can be taken, first one is a proper PCB layout. Now, I have shown you before that the PCB itself is a very big source of parasitics and leads to lot of noise and disturbances in the circuit. So, then you have to ensure that when you design the PCB that means first step that you are going to place the different components in different positions, then you give a thought to the likely interference that may be taking place. So, the positioning of the or the placement of different components is very important.

And then when you further do the tracking, you place the traces at that time also you have to be careful and thoughtful about what is the signal that is going to be carried by that particular trace, what is its frequency, the nature of the waveform, how much voltage, how much current it is going to carry and whether the trace which is adjacent to it, whether there will be interference between the two adjacent traces or not or between a trace of one plane of the PCB one side of the PCB or another side of the PCB. So, these kind of different I mean things have to be looked upon while your PCB layout is being done.

And today there are software also present, which can help you in checking the signal integrity while doing the PCB design, if you wish you can use them also for your PCB layout design. Note that in power electronics, when you design the PCB, a lot of times on the same board you may be having the power electronic circuit, the control circuit, and the sensing circuit.

So, usually then you will be having one side which may be a mixed signal PCB, which may have both Analog and digital signals and the other side you have the power electronic circuit, which is a huge source of disturbance. So, then you have to do the proper placement and ensure that the tracks are not causing interference with each other.

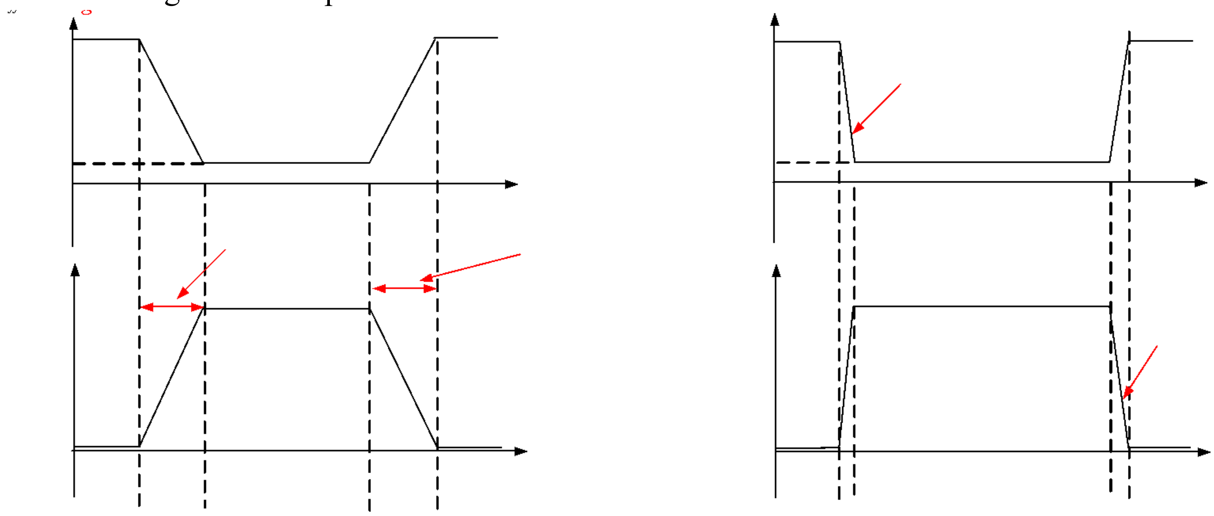
Then next you can use shielded cables. Now cables or wires are used for any converter. Now, if it is a bare wire it itself acts like an antenna, so now you can use the shielded wires and by shielding I am not talking about just putting an insulation, because that is not a very effective shield, you have to do proper shielding from the perspective of electromagnetic interference. So, shielded cables they also help in reducing the electromagnetic interference problem and the cable lens should be as small as possible, because the bigger the cable is you know that the more the parasitics that you are introducing.

Then, further your twisting of wires, now this kind of a twist can be done between two wires, so this is let us say wire 1 conductor 1 and this is conductor 2. So, when you twist them like this what will happen is that the fields will cancel out and that helps in the reduction of these electromagnetic disturbances. You can twist multiple wires also and this is called the leads connection and is also very much used in power electronic converters to reduce the electromagnetic disturbances.

Then, proper grounding, now when I discussed common mode noise and differential mode noise, I showed you how much is the ground involved in the issue of common mode noise. So, proper grounding, proper positioning of the grounding is very, very important, a single point grounding is better than grounding being done at multiple places. So, how you do the ground that also plays a very important role in reducing the electromagnetic disturbances. So, these are some of the common things, which are done very much to reduce the problem of interference.

Apart from this also at design stage some of the steps can be taken, some strategies can be used by which you can reduce the problem of electromagnetic interference. So, if you recall, I had told you that gate resistor, it plays a very important role in deciding the turn on and turn off times.

Let us say this is one waveform for a switch and the current through that switch, so this is for one particular value of gate resistor, where you see that this much is the time it is taking to turn on, that means the voltage to come down and the current to build up. And similarly this much is, what is the time it takes for that particular value of gate resistor, for the current to go down and the voltage to build up.



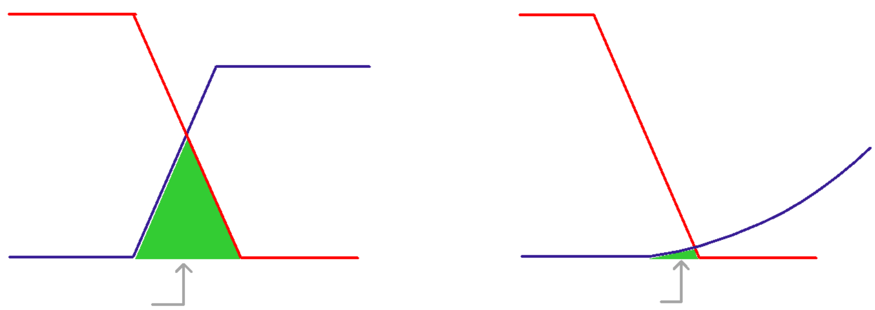
Now, for another different value of gate resistor, if let us say if you reduce the value of Rg the gate resistor, what will happen is that it will increase faster the current will increase faster and the voltage will reduce faster. And similarly your turn off time can also be reduced to certain extent by the use of Rg value.

So, Rg affects the turn on and turn off times and so it also affect the problem of electromagnetic interference. Well, I am not saying that using Rg, you will be able to meet the EMC standards, your problem of whatever you may be getting for electromagnetic interference can be completely resolved by it, but it helps to certain extent in reducing the disturbances, because you are shaping the trajectory of turn on and turn off using the gate resistor, it plays a very important role.

But, at the same time note that this is in contradiction to your thermal design, because if you increase the gate resistor value, then your turn on and turn off times are going to increase and increasing turn on a turn of times means slower turn and turn off helps in reducing electromagnetic interferences, but on the other hand that leads to more losses your more switching losses.

So, you have to do a compromise between the two, but still one should be aware that using Rg value a little bit to playing around with the Rg values can affect the performance of your I mean how much electromagnetic interference is being developed in a particular converter. Apart from that your snubbers also play important role. Again it is not that snubbers can solve the problem of EMI, but since snubbers they also shape the trajectory of turn on and turn off, they affect the turn on and turn off times, they also to certain extent play role in reducing EMI.

Then another thing which you should be knowing is the phenomena of a soft switching. So, your hard switching is what we have been discussing a lot, so that the voltage when the voltage comes down, it is at the same time the current also builds up, so during this if you multiply this voltage and current you will see that more amount of losses are taking place at that time. So, that is your hard switching.



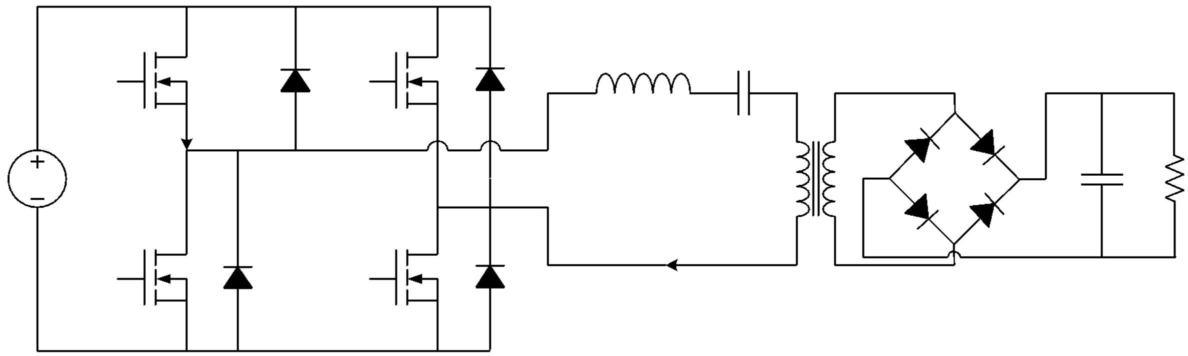
Now, there are strategies by which it can be so done that when the voltage is coming down, voltage is reducing at that time the current a can be made almost equal to 0 and the current may build up later on. So, this what will happen, because of it the loss that will be taking place will be much lesser.

So, first of all you get benefit in terms of switching losses, further if you are smoothening out your, the sharp turn on and turn offs that can also affect or reduce to certain extent the electromagnetic disturbance problem. Again this may not be able to solve the problem, but it does affect to a certain extent they may reduce the EMI, it is possible, although it is not ensured, but they can affect it.

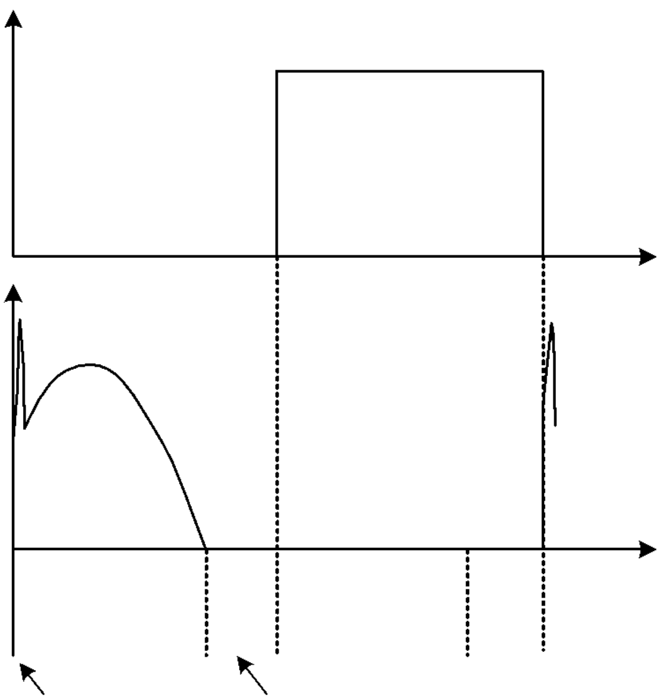
So, soft switching that is called as so this is if you make the current 0, when the voltage is changing that is called as 0 current switching and if you make the voltage 0 while the current is changing that is called as 0 voltage switching.

And then there are resonant converters also, where actually you sort of create some resonating waveforms and with that the converter operates and there you are hard switching or this sharp transitions of voltages and currents are avoided.

So, this is one example of soft switch converter, this is your familiar H bridge converter, now with this edge bridge this part this LC is added instead of directly connecting this output to this transformer and then rectifying it to obtain s DC. So, when this LC is there, so there is a part of sort of a resonating effect that comes up, of course it depends on what value of L and C you are choosing. So, depending on that the shape of these voltages in current waveforms more goes towards a sinusoidal nature, a resonating nature.



And then this type of waveforms may be obtained, so this is voltage waveform across one switch, V t A plus. So, here this is the current through the switch, so what you see is during turn on it is hard turn on that means your current is abruptly changing and the voltage will also be abruptly changing at that time, but while turn off what you observe is that the current has become 0, before the voltage is going to build up.



So, that is a soft switching that is taking place. So, half time soft switching can also be done either a turn on or a turn off or there may be converters, where both that turn on and turn off the soft switching may be happening that is your resonant converter. So, there are different types of such converters are there, of course they are more difficult to analyse, but they are there, they reduce losses and their electromagnetic performance will be different than your hard switched converters.

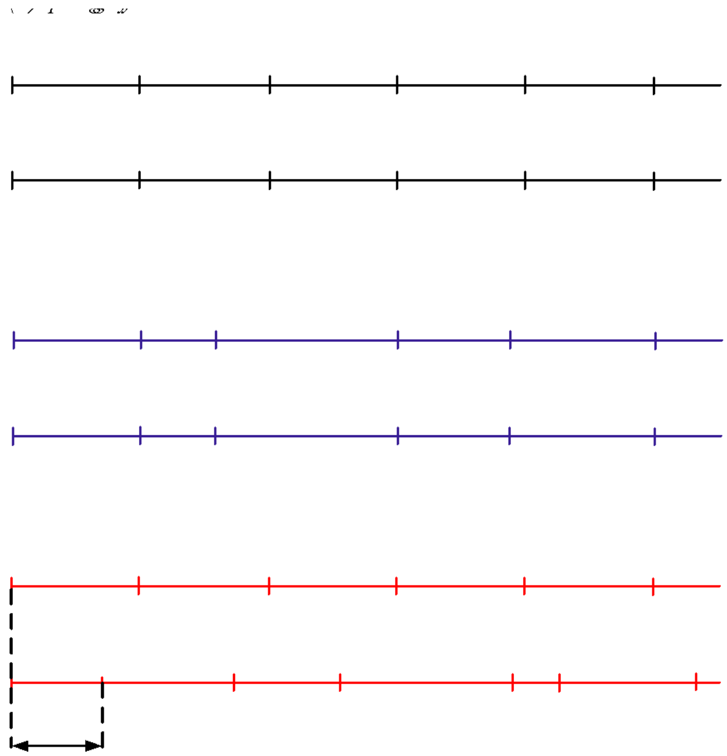
Then next what we have been telling is that, that your this entire problem of all these different frequency components in the range of your electromagnetic interference comes from the shape of the waveform, because it is a switched voltage waveform and that is giving rise to those high frequency components.

Now, then it also if it is depending on the shape of the waveforms, it also depends on the PWM method that you are using, now there are various different types of PWM methods that are available. And each PWM method may have a slightly different spectrum than any other PWM method. So, by using PWM method also to certain extent the levels of your interference generated can be reduced.

So, then one of those PWM methods is called as the random PWM. So, what it is, is that when we do the sampling of in power electronic converters, so then the sampling frequency and switching frequencies are most of the times the same. So, you sample your whatever signals you are sampling that means you are sensing the voltages and currents, you are sampling it.

So, they are at the same frequency, the same intervals as your switching cycles that means when you are turning on and off the devices, so that is what is being shown here, the different samples and the different, the different sampling cycles in the different switching cycles.

Now, then your this cycle you can say that is equal to your switching time period ts, 1 switching time period will be equal to 1 by f as the switching frequency. Now, what is observed is that, that if we randomize these sampling cycles and switching cycles, then your, the spectrum of which had the power at discrete points and which were led to more EMI levels that could be I mean transferred into converted into continuous spectra and that reduces the level of electromagnetic interference.



So, what we want to say there is that, this is your random PWM, that here you have these sampling cycles are randomized, you can see that there this is n is how much is this cycle is different than this n plus 1 cycle and then n plus 2 cycle is different than your n plus 1 and similarly n plus 3 is different than n plus 4. So, you are randomizing the sampling cycles.

And then accordingly you can also randomize the switching cycles also, so you can see here the switching cycles also here are randomized. This is called as the random PWM and it affects in reducing the EMI to certain extent, it is basically it changes the frequency spectrum.

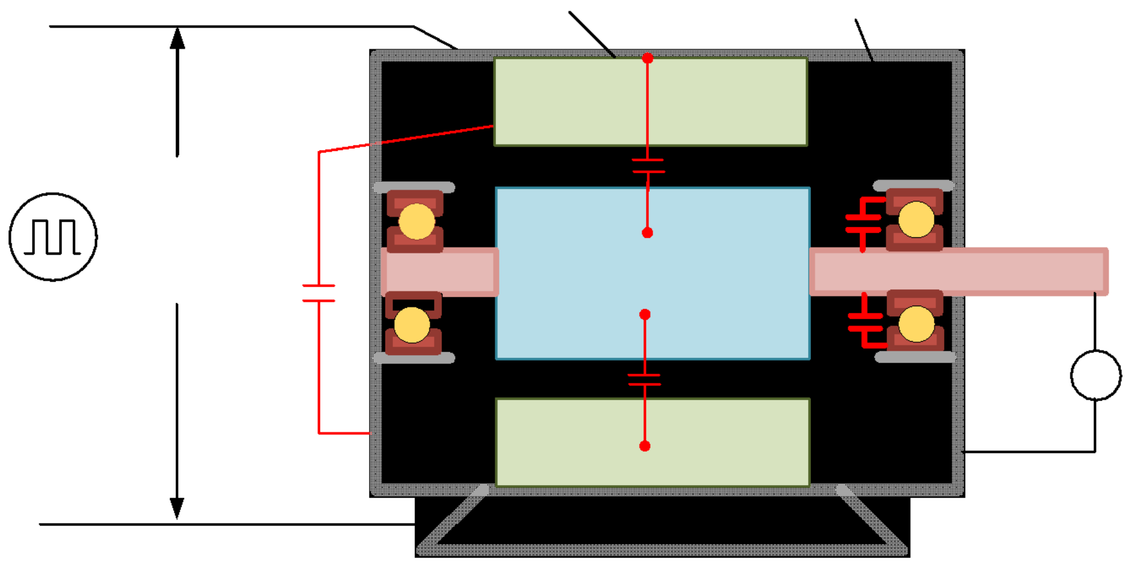
Now, this sometimes may not be doable, because if you are making the sampling cycle random, then that affects may affect your controller's performance, because your controller's bandwidth is many times decided by your sampling frequency. And so we would like to have it fixed, so in that case then what is done is that, that a delay is given to the switching cycle. So, here your sampling cycles are same are fixed, but your switching cycles they are randomized, so there is a random delay that is provided. So, here you can see that this n cycle nth switching cycle, it is delayed from the nth sampling cycle.

Similarly, here also to the n plus 1 switching cycle, there is a delay which is given, although n plus 1 of sampling cycle, n plus 2, n plus 3, all of them are equal, but the switching cycles you can see that they are unequal that means unequal delays are provided to them. So, they are the switching cycles are randomized. So, that is called as the variable delay random PWM.

Now, these can also be used for your power electronic converter design. So, in this random PWM method is actually can be used with any side triangle PWM or space vector PWM, any other PWM method that you may be using and by that you have to certain extent you can reduce the EMI levels.

Now, what happens in EMI filters is that if you have to attenuate the lower or relatively lower order harmonics of frequencies using EMI filters, then they become bigger and their cost increases. So, if some of the relatively lower order frequencies in the spectrum can be eliminated by some of these methods, so then you can reduce the size of your EMI filters and so you can reduce the cost of the converter also.

Then next the common mode voltages that are present in your motor drives, your electric drives. So, your this is the diagram of the different capacitances that may be present in the motor, so you use your stator and your rotor and this is again the stator and then this is the frame of the stator and this rotor is mounted on this shaft and this shaft will be having these bearings and which is then further connected to the frame of the of the motor.



So, now again you will be having capacitance between any two of these points, so like that between the frame and the rotor between the stator and the rotor, anywhere you have the potential difference, even slight they will be formation of a capacitance. Similarly, you will have the capacitance between stator and the frame and between your shaft and the bearings. So, whatever the common mode voltage that is there, so let us say if we have a three-phase motor, so the common mode voltage will be

So, if the sum of the three output voltages of your inverter is not your constant, then this Vcm will be changing, common mode voltage will be changing and then you have all these capacitances and they actually are connected to the JC ground and then that will lead to C dv/dt the capacitive current, so the common mode currents and then that will lead to problems of interferences.

So, now there are different methods by which this common mode problem can be reduced, some strategies, different switching strategies are used such that, that your this common mode voltage Vcm is made constant for your motor applications.

And many people also use different types of converters, like this is an example where an additional leg is used, additional leg is added and such a switching strategy is used such that, that your these common mode voltage becomes 0.

So, we can make common mode voltage 0 or common mode voltage constant, then your capacitive current associated with your common mode noise different, different places in the electric drive, there you would not be having currents, because of it and so you can resolve the problem because of common mode voltage. So, these are also some of the ways by which you can reduce the problem of electromagnetic disturbance.

So, the key points of this lecture are that, that from the very beginning of design you should be careful about the electromagnetic interference problems. And whatever are the different measures that can be taken to reduce it at design stage that should be ensured. There are various, various different things that can be done and that you can use that, if you do it at the design stage at an early stage, then later on towards the end, the cost of your EMI filter and enclosure may reduce. Thank you.