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Design of Power Electronic Converters

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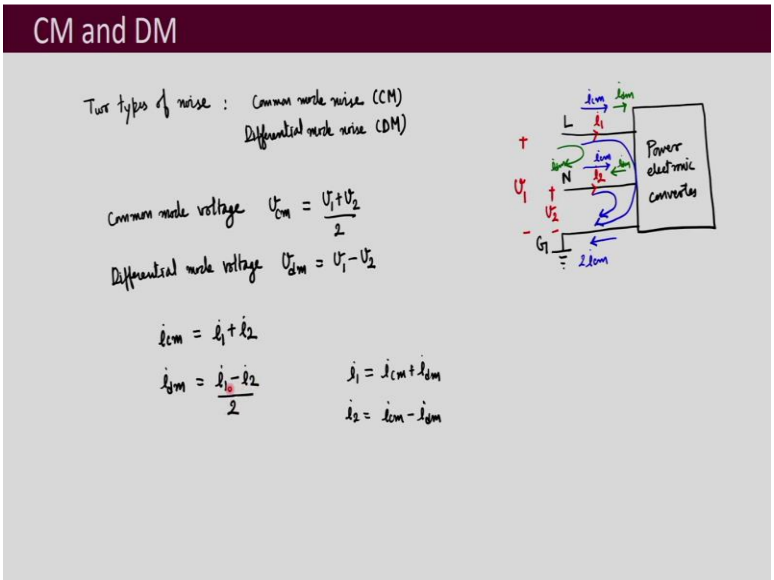
Lecture 57

CM and DM Noise

Welcome to the course on design of power electronic converters. We were discussing the module of electro magnetic interference and first I gave you an introduction to electromagnetic interference, the standards of electromagnetic compatibility, the different types of EMI. Further we also saw how to measure it and then I also explained you the reasons behind power electronic converters being taken as a big source of electromagnetic interference.



Now, let us continue with our discussion and in this lecture let us see the different types of noise that are present in the conducted EMI. There are two types of noise which are mainly present in power electronic converters. One is called as the common mode noise; in short it is also written as CM and another is differential mode noise and in short it is written as DM.

So, let us say that there is a power electronic converter. The line and the neutral both are given to the power electronic converter or the power supply and then there is another terminal, which is also coming out called as the ground. Now, with respect to the ground this first wire is having a voltage v_1 and the second wire is having the voltage v_2. Further the current flowing through the line is i_1 and the current flowing through the neutral or the return path is i_2.

So, common mode voltage is represented by

$$v_{cm} = \frac{v_1 + v_2}{2}.$$

Differential voltage is represented

$$v_{dm} = v_1 - v_2$$

Similarly, common mode current is represented by

$$i_{cm} = i_1 + i_2.$$

and differential mode current is given as

$$i_{dm} = \frac{i_1 - i_2}{2}.$$

Now, these are the definitions. But, what do we understand from this? So, differential mode voltage and currents are very easy for you to understand because we have been using this for analysis and we deal with various circuits normally.

So, that is basically the difference between the line and the neutral. The current is going to flow through the line and the same will be returning back through the neutral. But, common mode is the voltage or the current which is common to both of them with respect to this common reference, which you can call it as the ground.

So, then this i_1 is having one component, that is called i_{cm} and this i_2 is also having one component which is also called i_{cm}. The sum of these two are

$$i_1 = i_{cm} + i_{dm}$$

which is going to be coming out through these ground. This i_1 has this differential mode current i_{dm} and this is also having i_{dm} which is going to be flowing through this in the opposite direction.

So, we want to say that this i_{dm} flows through the line and returns to the neutral where i_{cm}, this common mode current flows to the line, returns to the ground and it flows to the neutral and also returns to the ground. So, common mode is common to both the line and neutral with respect to your ground. Whereas, differential mode is between the line and neutral.

So, how do you get this?It is given

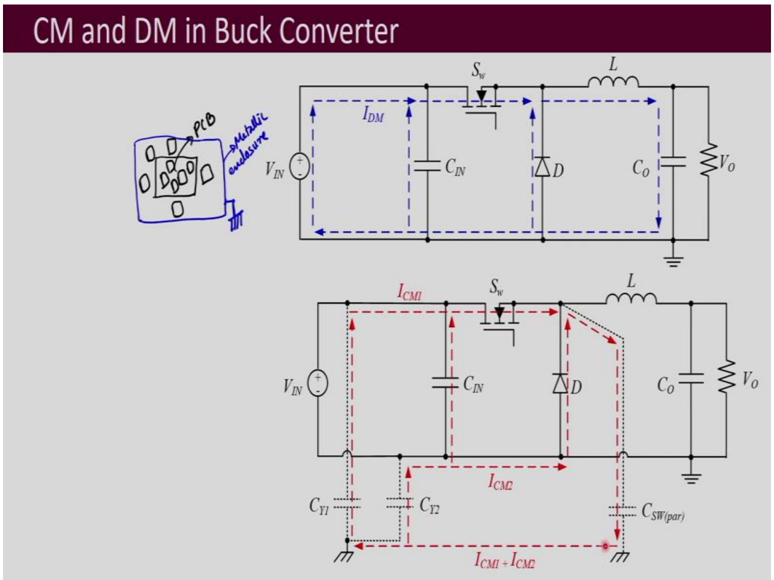
$$\frac{i_1 - i_2}{2}$$

So, that is actually because i_1 is having two parts, those are i_{cm} and i_{dm}. The sum of common mode and differential mode and i_2 is

$$i_2 = i_{cm} - i_{dm}$$

So, that’s why you will be getting the differential mode current as

$$\frac{i_1 - i_2}{2}$$



Now, what is this common mode and differential mode? How is it actually taking place inside of an electronic converter? So, let us take an example of buck converter. So, this is the buck converter circuit that you are familiar with and then this is the reference. This symbol right now over here is the reference. Do not assume that this is earth, this is a reference.

So, now this differential mode currents will be flowing. You are normally familiar with this current which will flow if the switch is on and then it will be coming back through this capacitor and return from here and this is the capacitors at the input. You can call it as the input filter capacitor.

So, then that will also lead to some currents which can flow and then again these currents will be flowing and the diode will also will be conducting. If it is conducting in this direction, the current will be flowing through this and then it will be returning like this. So, this is the normal operation. You are familiar with how the currents will be flowing and because of all the different parasitics may be present, there may be noise in these differential mode currents and so in the differential mode voltages differential mode noise will be presenting in the circuit.

Now, let us come to the common mode problem. How is this common mode currents and voltages arising? Now, this is the reference. Now, there is another ground which is called as the chassis ground. This chassis is basically the one point in the metallic enclosure where all the other is connected with that reference and this can be many times connected to Earth for safety.

So, now, you have the converter and then that is going to be kept inside an enclosure. Now you are finding it difficult to imagine that this is the PCB of the converter and it may be having different components placed inside it. Further you may be having some components which may be off the board or some different components on the board and this whole thing can be placed inside a box or a metallic enclosure.

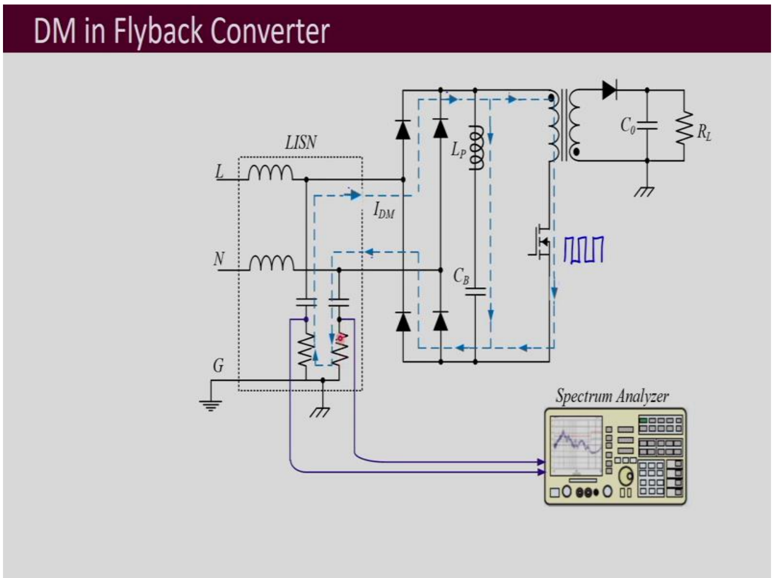
So, then over here this reference or the ground is chassis ground. So, now this converter is this circuit and this is the chassis which is the ground of the reference of the metallic enclosure. Now, with respect to this chassis ground these two may be having some voltages. That may be some small voltage, but that voltage may be there.

This of course is going to be V_{IN}. But, this other reference is the return or the neutral what you can call it as the negative DC bus. There may be a little different potential than chassis ground. So, then there may not be physically a capacitor which may be connected. But, there is potential difference between two points and there are different materials present in between including air and that will lead to some capacitance.

So, there is a formation of a capacitance here. Similarly, there may be formation of another capacitance here between this the negative bus and this ground. Further you know that these devices like the switch and the diode will be mounted to heat sinks and we have seen before that this also is a source of parasitic capacitance between the device and the ground. Of course, that heatsink maybe connected to the chassis.

So, you have a path then. So, these currents will be flowing like this through the switch to the heat sinks and then they can return through the ground. Similarly, here also there may be these currents which may be flowing like this through the capacitor. Then again here in this diode the small current may be there and then they also can combine here and come back.

So, like this these types of capacitors which are unintentionally getting formed between any point and the ground, are the source of common mode noise. It is the main source of common mode noise or the common mode current. They lead to small common mode currents and then of course, because of the current it will have the common mode voltage as well.

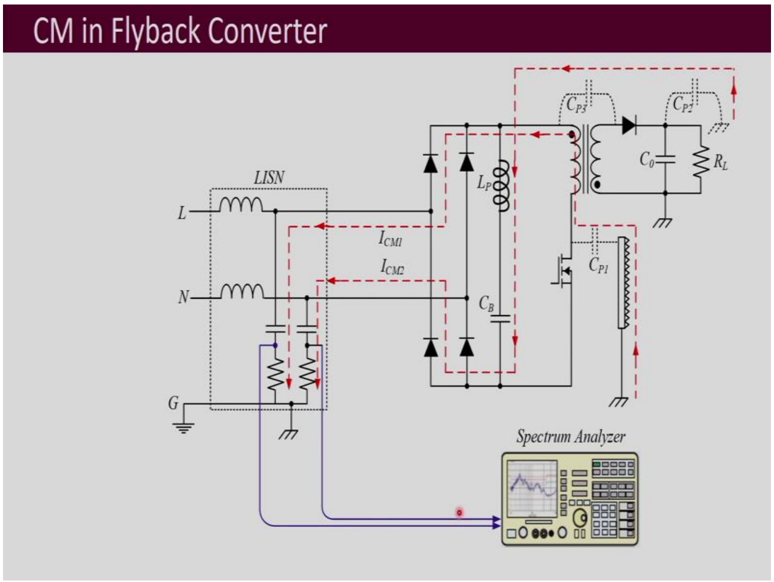


So, let us see that this is some other converter also. So, this is example of a flyback converter. Here, this part is flyback converter. So, here you have a simple rectifier. Now, here this LISN is drawn. We have seen LISN before. It is the equipment which is used for measurement of conducted EMI and this is somewhat like a filter circuit.

So, the impedance that we will be seeing over here at this point is *50* Ω, because all these probes are generally terminated by *50* Ω. So, where supply is coming, this LISN will just let the supply go in and not let the noise of the supply come here or the noise of this converter go to the supply.

So, this is a good way to measure the noise. These are both the differential mode and the common mode noise. Of course, it is distinction between common mode and differential mode currents. It may not be made during the testing of conducted EMI. So, you see here that you may be having these kind of differential mode currents which may be flowing. Whenever this switch is turned on, that means you give these kind of gate pulses to this device it to turn on and off, at that time this primary side voltage is equal to the DC bus voltage that is created.

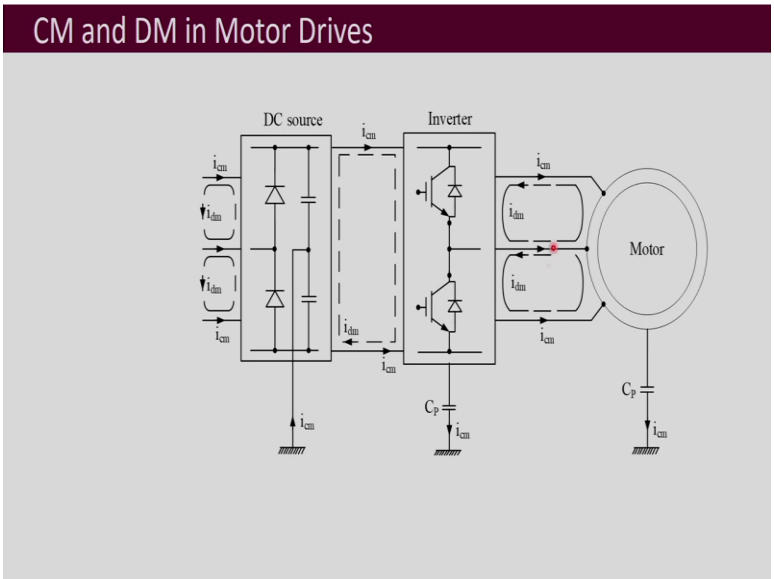
This is the parasitic inductance of this DC bus and then the currents flow through it. When this device is switched off, at that time the current flows through this diode. So, because of all the parasitics you will be having these differential mode currents that will be flowing and then you have here these LISN terminals, where you can put the probe and you will be able to see these corresponding voltages which will be formed because of the noise that is present.



If we see how is the common mode current arising, for that we have to see the different points where capacitors is getting formed between any point and the ground. So, we observe here that this point definitely will have some capacitance with respect to the chassis ground. In between these two primary and secondary also there will be some parasitic capacitance and further these devices will also have the parasitic capacitance with respect to the chassis ground because of the heat sink.

So, now, all these are the nature of the current. We observe here that the current can flow like this from here and to this and then if we follow this path through these capacitances, we observe that there is another path and both of these are in the same direction and it further comes here and through this ground it returns. It is the return path that means, it completes its circuit through the ground. There is no wire which is connecting the two. But, because the ground is common for all of them, these common mode currents can flow.

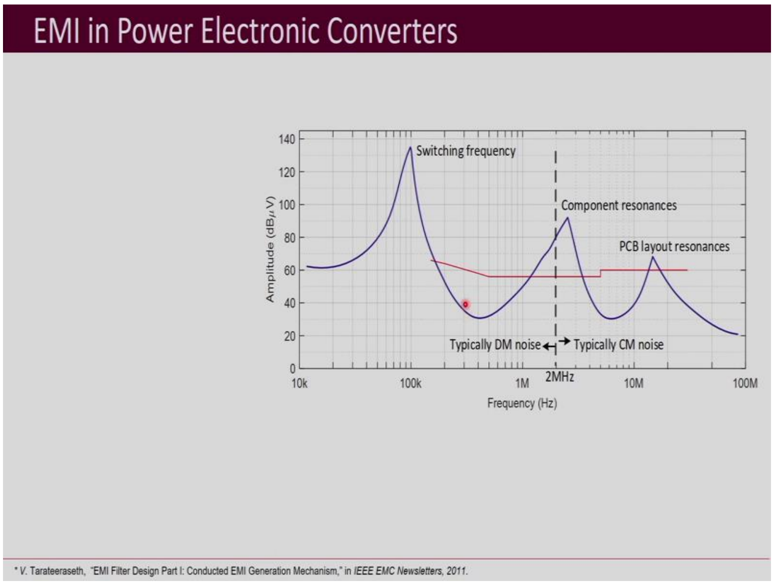
So, again when you put the probe, then you will get to see the noise. But, as I said you cannot really distinguish between common mode and differential mode by putting the probes of the spectrum analyser. Because when you operate the circuit, both of the noises will be present together.



Then CM and DM noise are present in all power electronic converters and in motor drives also. So, I showed you how it is present in converters, the motors that we use in the electric drives. When you are having motors, they further add up to some of the sources of common mode noise because you might have heard about bearing currents and all that. So, that is like common mode voltage which gets formed and that affects the motor performance.

So, here between the motor there are different things which contribute to some parasitic capacitance with respect to the ground and then they further lead to this common mode currents. If this is the positive bus and negative bus, in between you are connecting it to the ground then further you will be having this path for this common mode current (i_{cm}) to flow here and there this is not going to be grounded and so there will be a parasitic capacitance between this inverter and the chassis. There will be common mode current flowing through this.

Further this common mode currents will be flowing through all these output wires which connect to the motor and then motor itself will have several parasitic capacitances with respect to the chassis ground and the currents will be then the common mode currents which will be then completing their path through the ground. Differential mode currents are of course, getting affected. It will be flowing in one direction and then returning through the other wire. So, differential mode currents will be obviously flowing in different parts of the circuit.



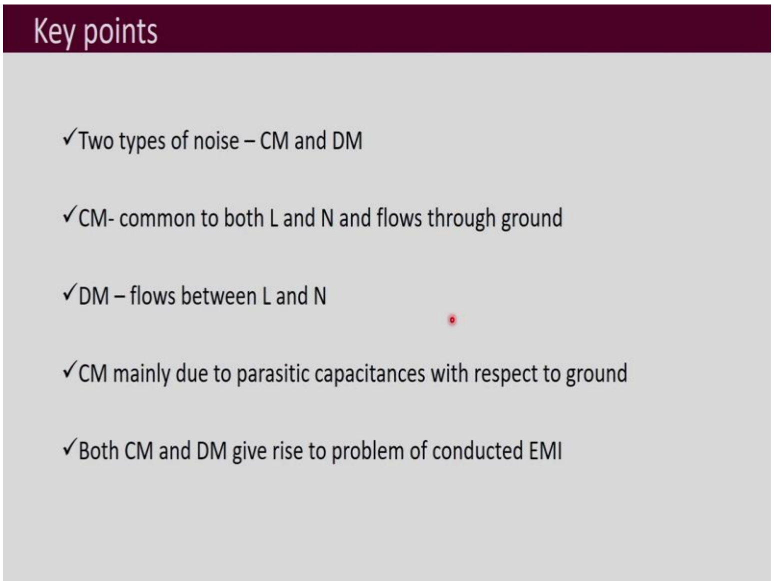
So, now this common mode noise and differential mode noise have different frequency range. Usually common mode noise is obtained above *2 MHz* of frequency and the frequency components in common mode noise is observed. This common mode noise is more because of the component resonance. That means the parasitic capacitances and other parasitics are present in the devices. We saw that MOSFET's and diodes have got their capacitances. So, some of these capacitances are with respect to the ground.

So, they will have their own resonance and they will be leading to the problem of common mode noise. These are the PCB layout resonances because the PCB itself is a big source of parasitic and there will be resonating effect because of them as well and that also lead to the problem of common mode noise.

So, this is typically usually in this range above *2 MHz* common mode noise probe. Differential mode noise is normally observed below *2 MHz* because of the switching frequency. So, 70 kHz, *10 kHz* to *100 kHz* or *300 kHz* is the range in which normally the power electronic devices are presently being switched. Then because of the switching there will be harmonics and the different differential mode noise may be generated by that. Then the frequency range of those differential mode noise is generally in this below *2 MHz* region.

Further you saw here that common mode noise is mainly occurring because of the different parasitic capacitances. So, it is more of a noise which is generated by the *Cdv/dt* effect. So, that means *dv/dt* plays a very important role in common mode noise. Whereas, in differential mode noise here it is the *di/dt*. Because of parasitic inductances differential mode noise are generated more.

So, *di/dt* effect more significantly impacts differential mode noise and *dv/dt* more significantly impacts the common mode noise. These are very crude generalization. Do not think that this is exact analytical point of view. I am telling and in general you can take it.



So, the key points of this lecture are that there are two types of noise. Those are common mode and differential mode and the common mode is one which is common to both line and neutral and it returns its path to the ground. Differential mode is the difference between the line and the neutral and different parasitic elements are present in the circuit and they are responsible for this common mode noise and differential mode noise problems. Both of them give rise to the problem of conducted EMI and so they have to be taken care of while designing the power electronic converter. Thank you.