Design of Power Electronic Converters
Professor Doctor Shabari Nath
Department of Electronics and Electrical Engineering
Indian Institute of Technology Guwahati
Lecture: EMI Filters-1

Welcome back to the course on design of electronic converters. We will be discussing electromagnetic interference. We saw what is electromagnetic interference, and what are the reasons that power electronic converters are considered a big source of electromagnetics problems.

Then we also saw the various standards that have to be followed to make power electronic converters electromagnetically compatible, and then we also further saw some of the solutions which can be used at the design stage, so that the problem of EMI can be reduced from the very beginning.

So, now, let us see EMI filters. EMI filters are the ones which are used to reduce the conducted emissions. Now, irrespective of whatever solutions at the level of power electronics design are taken to reduce the level of EMI, almost all converters require an EMI filter to be able to meet the EMC standards. So, let us have a brief introduction to EMI filters.

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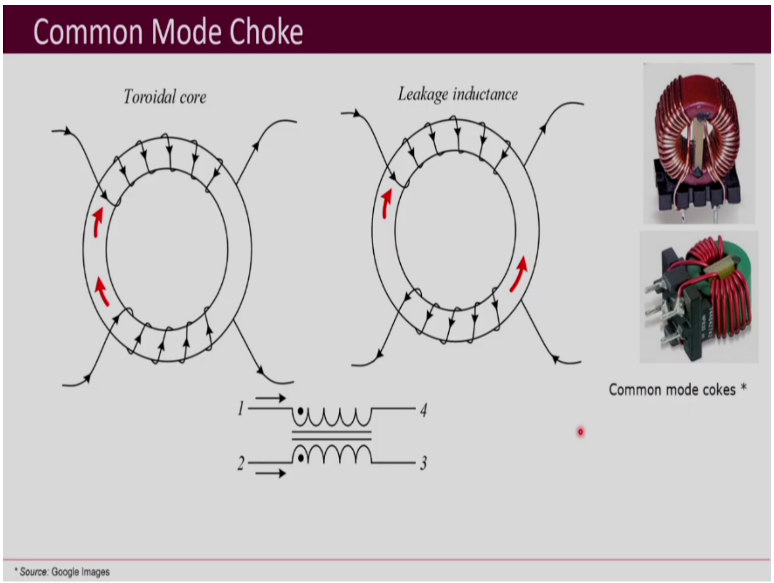

So, to understand EMI filters, we have to first get familiarized with common mode chokes. These are pictures of common-mode chokes. Now, this is actually an inductor. So, you may be wondering what is the difference between an inductor and what is being called a common mode choke.

So, as you see here there is a toroidal core and then on that, there are two coils. So, if on this you are not able to understand whether they are two coils or not in this picture, this picture is very clear, because you can see these four terminals coming out.

And if we have to represent it symbolically, so, this is how it is represented: two coils which are coupled to each other and the winding is such that the dots are over here are both at this point where the current enters the dot in both of these coils. So, if we have to understand that what happens inside this we look at the flux picture.

So, now, when we talk about the common-mode currents, then we saw that for common-mode currents, the current direction is the same for both the line as well as the neutral and it returns through the ground, whereas for differential mode currents the direction is opposite for line and neutral, that means if it is in the forward direction for the line, then for the neutral it will be in the reverse the opposite direction.

So, now, if the same common mode and differential mode currents have to pass through this kind of choke, a common mode choke, then let us see what happens in the flux. So, if the current directions are the same, so here in this one if you see that the current directions are the same the way these are wound, this is the flux produced by one winding and this is the flux produced by another winding. And what you observe is that they both aid each other.

So, if they are going to aid each other, that means the currents are going to be in the same direction, and then those currents will see an inductance because of this toroidal core. Now, let us see what happens for the differential current. So, differential currents are going to be the opposite.

So, over here this is the forward direction of the current. So, the flux produced by it is in this direction which is the clockwise direction and here the current is opposite, so, the flux that is produced by it is in the opposite direction which is the anti-clockwise direction. So, now, what do you see is that these two fluxes are opposed to each other which means they tend to cancel out each other?

So, therefore, if the differential mode currents are passed through these common mode chokes, they would not see any inductance So, effectively I mean ideally 0 inductance but any practical inductor will have some leakage. So, the differential mode currents will definitely be reduced by the leakage inductance but it will otherwise be unaffected by the main inductance of the common mode choke.

Whereas, if we see for the common mode currents, they are going to be attenuated or reduced significantly because of the common mode chokes. So, therefore, what we observe is that these common mode chokes will be able to reduce the level and to a certain extent can be used for filtering common-mode currents, but to a great extent, they are almost invisible to the differential mode current. So, they do not affect the differential mode currents, so, much.

So, common mode chokes can be used for filtering of common-mode currents. And also, one thing when you actually particularly buy a common mode choke or you when you make one, you will see that relatively much larger values of inductances can be made for as a common mode choke with a much smaller size as compared to a normal inductor. If you have to make let us say one mili Henry, 30 ampere common mode choke, the size of that will be much smaller as compared to 30 amperes one mili Henry normal inductor. And the reason is that the rating 30 A and the inductance is associated with the common-mode currents would be much lesser. The 30 A differential current would be cancelling out.

So, mistakenly when you actually practically design it , some time those who are absolutely new, they buy those common mode chokes and then they think that that can be used as your normal inductance also, but that is not true. So, please be careful, common mode chokes are meant for your common mode for reducing the common-mode currents and not for giving an inductance to the normal current or what you can call the differential mode currents.

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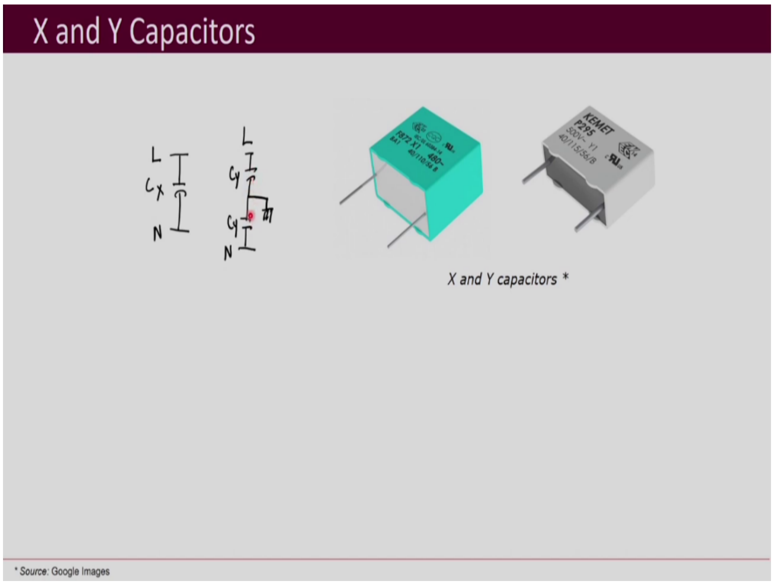

Then, another component which is very much used for your EMI filters is your X and Y capacitor. So, now, what is this X capacitor Y capacitor? You know about capacitors and you also might be knowing that there are different types of capacitors: electrolytic film capacitors, ceramic capacitors and so forth. Now, what are these X and Y capacitors?

Now, X capacitors are the ones which are used for filtering differential mode current. So, that is your X, which means it will be put between the line and the neutral. Whereas Y capacitors are placed between your ground and the line or the neutral. So, these are your Y capacitors whereas, this is your X capacitor.

Now X capacitor could be like a normal film capacitor or it may be having some special features related to it's design. But Y capacitors when they are manufactured or designed then special precautions have to be taken because you are those are meant to be put between the line and the ground or the neutral the ground.

And this is the point where we are any operator can touch it, because as I told you this is the chassis ground and it is like the ground which is connected to the metallic enclosure of the converter and so you may happen to touch it or the operator may touch it and so, safety is very important there and these will be carrying those common mode currents. And so, therefore, this cannot exceed a certain value. There are restrictions on how much could be the Y capacitor values and also special precautions are taken to manufacture or design these Y capacitors.

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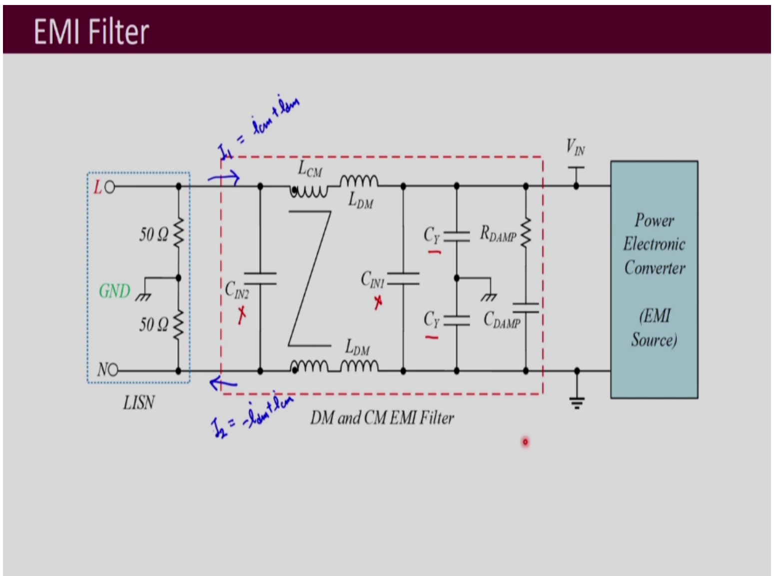

So, let us see an EMI filter, how does it look inside? So, this is an example of a Pi type EMI filter, Pi because you can see that a C, L, and C, topology which is used for the filter. Now, this is your power electronic converter which is the source of the EMI and this is the supply. And then this is the equivalent circuit of the LISN, the line impedance stabilization network.

So, I mean when you practically use it then you would not be using a LISN, but when you will be measuring EMI, conducted EMI, then you will be using a LISN, so that is why this equivalent circuit is shown here. Now, over here uptil this and the filter side these 50 Ohm impedances will be observed because as I have explained before that usually the terminations are for 50 Ohm from the spectrum analyzer and then the way the LISN is made, the impedance is chosen as such that the equivalent impedance when you see from the filter side, it turns out to be 50 ohms.

So, you can see that this is a 50 Ohm impedances resistance between line and ground, the neutral and ground. So, now, this is your C_{IN2}, C_{IN1}. So, these X capacitors are used for filtering the differential mode noise. And then these you can see here these are the Y capacitors and these are put between here the ground and the line and the neutral and the ground.

And this is the common mode choke LCM, these are coupled to each other. So, they will not be filtering the differential mode currents, but they will be filtering out the common-mode noise. And then we also have to put some filter on the differential mode noise and so, therefore, L also has to be there for differential mode noise. So, that is L_{DM} which is kept for both of them, the line and neutral.

Now, it is always better to put it on both the lines rather than just putting it on the line and not on the neutral. So, this practice is used in many places where you will see that the inductance can be divided and put on both the forward path and on the return path. So, what will happen here is when your currents enter

$I_1= I_{CM}+I_{DM}$

And the return current:

$I_2= -I_{CM}+I_{DM}$

And so, this capacitor will first filter out some of these currents, this differential mode noise and then this L_{CM} will be filtering the common mode noise and this L_{DM} will be filtering your differential mode noise and then further the Y capacitors are for filtering the common-mode noise. And to the differential mode, it appears that these two C_Y can be as a series connection of two capacitors, which is what the differential mode noise will be observing.

And further, we have these damping resistors and capacitors because we want to avoid the problem of resonance. Obviously, whenever you are using a filter it will have resonating frequencies and then that can make the entire system unstable because whatever the controller that is going to be designed for this power electronic converter, usually the time at which the controller is designed at that time this filter is not selected.

So, then many times the design of the controller of the converter is carried out without considering the filter, and then when you add the filter, you do not want to make the system unstable because both of these two are part of the same system and affect the dynamics of the power electronic converter. So, that is why damping is required and these two are for damping: R_{DAMP} and C_{DAMP}. So, now, let us look into the equivalent circuit separately for your differential mode and common mode noise.

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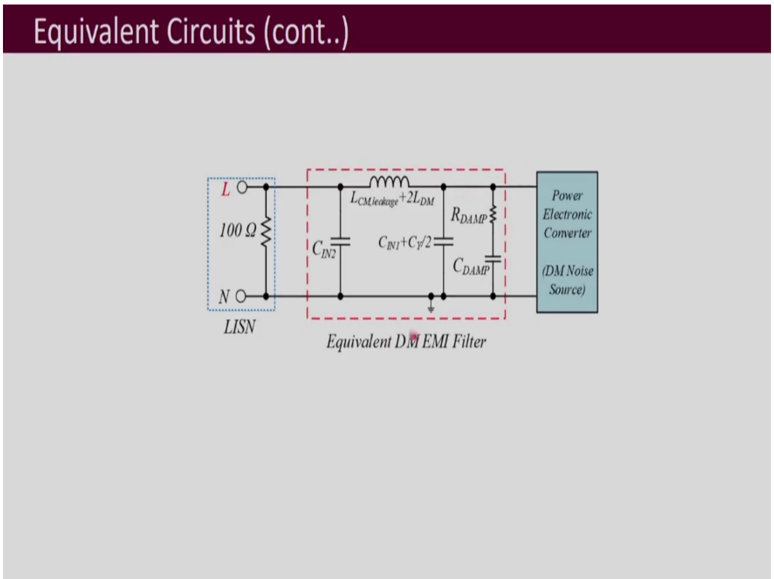

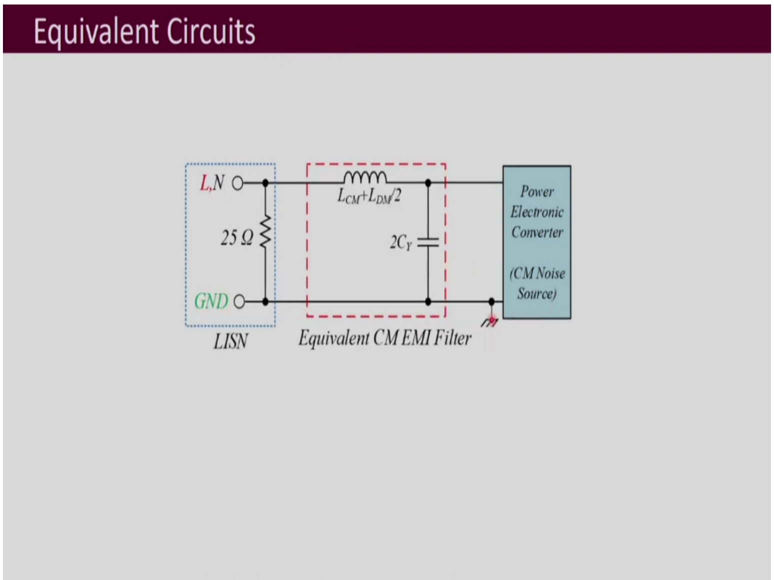

So, if you see for the differential mode, what will happen between the line and neutral? Those two 50 Ohm resistors will add up and you will see a 100 Ohm resistor. And what you will observe here is this C_{IN2} which consists of the X capacitor and the sum of the X plus the two Y capacitors which will be in series. So that is where it will become $C_Y/2$, and the damping circuit remains the same.

And then the inductance that will be seen by the differential mode noise will be the sum of the leakage of the common mode choke plus twice the differential mode inductance that is put. So, this is what the equivalent circuit will be and this end is going to be the reference for analysis of the differential mode noise and the filter, and how much the filter is affecting or attenuating the differential mode noise.

Then we see the equivalent circuit for common-mode noise. So, what we will observe is that since this is going to be the ground or the chassis ground, so, therefore, the two resistances will appear in parallel and so we will have the resistances as 25 ohms. And it will be like an LC filter instead of a Pi filter for your differential mode noise.

In differential mode noise, we saw that this is like a Pi filter, but for common-mode noise, we see that this is like an LC filter. So, here you it will be the sum of two $L_{CM} + L_{DM}/ 2$. So, L_{DM} appears as half because now the same current is flowing to both line and neutrals it is like a parallel connection. And then you have two capacitances, 2 C_Y that you will be able to see if you make the equivalent circuit.

So, now, using these equivalent circuits your filters can be analyzed and also it can be observed how effective the filter is in attenuating the common mode noise and the differential mode noise. And then accordingly the filter can be designed. To design the filter would mean, choosing the values of C_X, , L_{CM}, and L_{DM}. These values can be chosen by analyzing these equivalent circuits.

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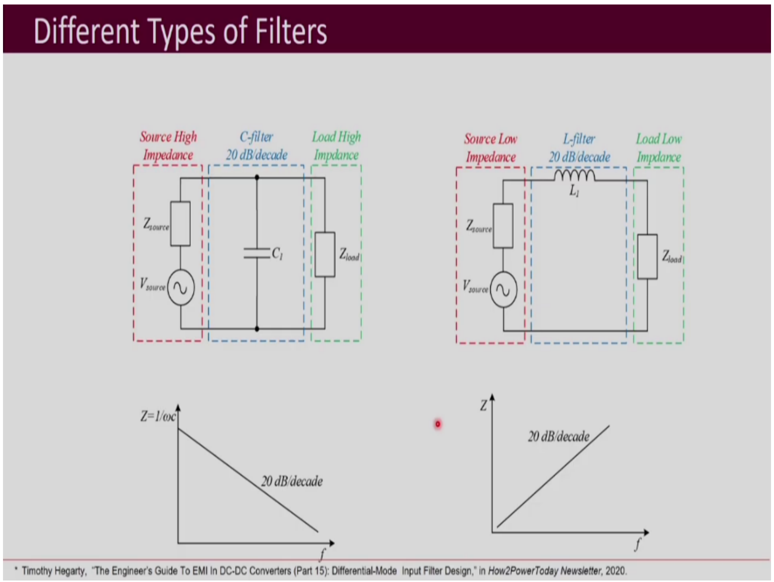

Now, let us see what could be the different types of filters that can be used as EMI filters. One could be just a simple C, because C itself also acts like a filter. Now, if you see the impedance plot of it, means impedance versus the frequency, then you know that the impedance of a capacitor reduces as frequency increases. So, with a high source impedance, it will be better to use a C capacitor.

Similarly, your L filters can be used. Filter which is just using an inductor and if you plot the impedance versus frequency, it will be increasing at 20 dB per decade because the impedance of an inductance increases with frequency. Then as an EMI filter, a CL type of filter can also be used. Then your LC filters can also be used for EMI purposes. We also saw this LC filter gets formed in the equivalent circuit when the same filter is being analyzed, I mean when the equivalent circuit is drawn for your common-mode noise. So, LC filters can also be used.

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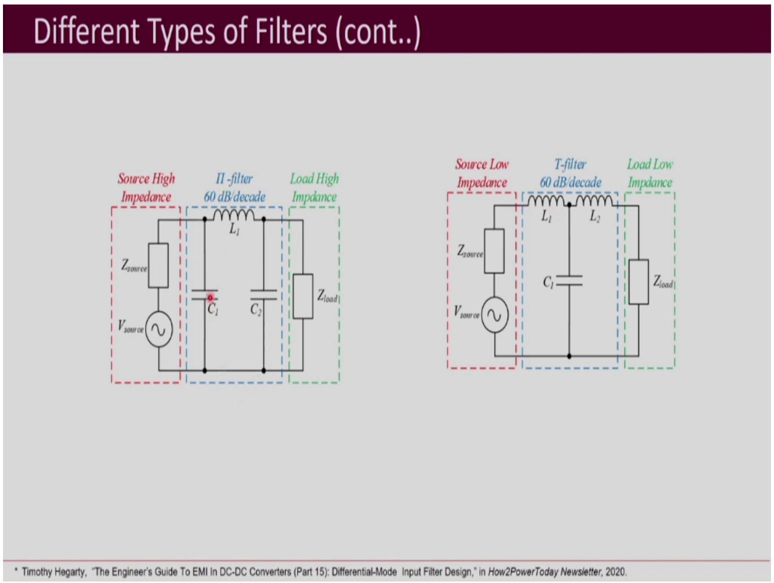

Then this Pi filter structure , C, L and C, that can also be used for EMI filters. And of course, these types of T filters where you have L, C and L, are also used for your EMI applications. So, there are different types of filter topologies and depending on the need one filter circuit can be chosen and then the values of L and C can be decided based on the analysis of the filters.

When we say the analysis of the filter you have to write down the equations and you have to plot what is called the insertion loss or the attenuation plot can be done and from there the filters can be designed. Now, how to design a filter will not be covered in this course here. I will just look into the basic terms which are important for you to choose one filter that may be already existing.

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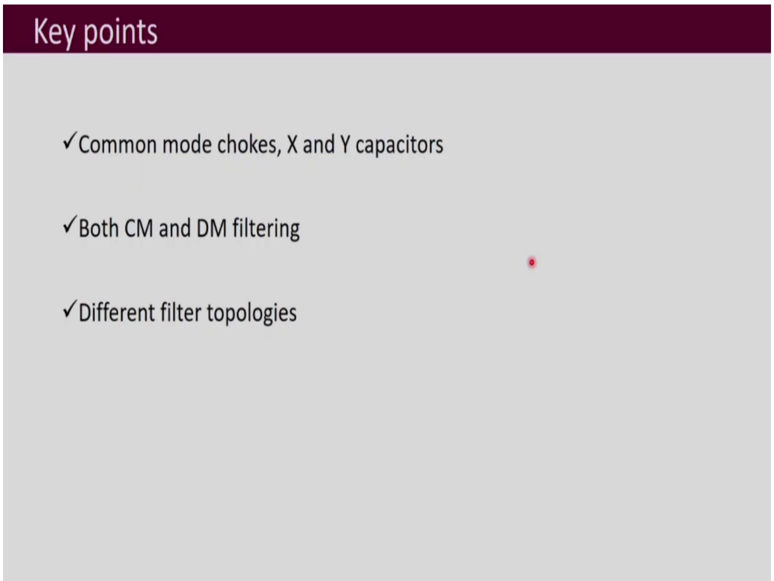

So, the key points of this lecture are that your common mode chokes and X and Y capacitors are used to make EMI filters to filter out both common mode and differential mode noise. And there are different filter topologies and based on the requirement, a particular filter topology can be selected. Thank you.