Design of Power Electronics Converters
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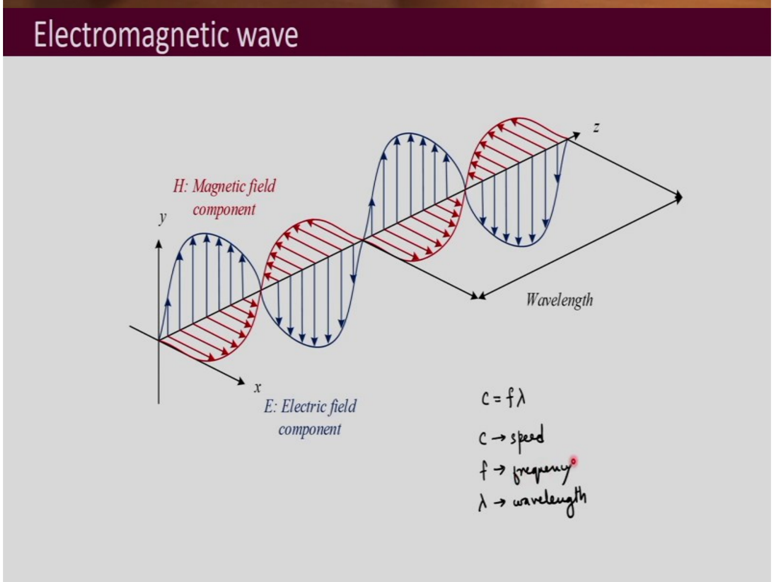
Lecture 54
Introduction to Electromagnetic Interference

Welcome to the course on Design of Power Electronic Converters. Today we will begin the next module that is Introduction to Electromagnetic Interference. Electromagnetic Interference is a very important problem to be solved in power electronic converters. To understand electromagnetic interference, let us see an example.



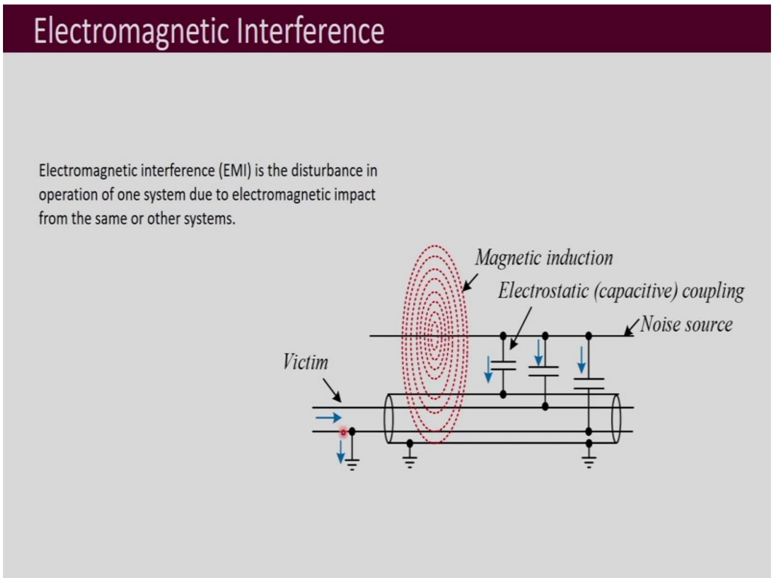
The basis of electromagnetic interference is electromagnetic wave. You might be already familiar with electromagnetic wave. So, electromagnetic wave has got electric field and magnetic fields perpendicular to each other.

So, if we have one x axis that means, you have got the electric field varying in this plane and if you have the magnetic field varying over parallel to the y axis plane, they are perpendicular to each other. This direction that means perpendicular to both of them is the direction in which the wave propagates and some of the important terms related with it are the wavelength and the speed of the wave and also the frequency. So, you might be already familiar that

$$c = f\lambda$$

where *c* is the speed, *f* is the frequency and λ is the wavelength.

Now, we observe that frequency and wavelength are inversely proportional. So, as the frequency increases, the wavelength reduces. So, if the frequency is low, the wavelengths are going to be very long. So, for electromagnetic interference the range of frequency to be concerned, are high frequencies in the range of *kHz*, *100 kHz* and above that. Especially the range of MHz are the frequency range in the electromagnetic spectrum which are of concern and that create electromagnetic interference.



So, let us understand phenomena of electromagnetic interference. Let us say we have two conductors close to each other. This is one conductor, which is carrying some current and is having some noise in it. So, you can say that this is the source of noise. Then there is another conductor. Let us say it is a shielded conductor and it has got two wires inside it. One carries the current and another is the return path and that let us say it is grounded and the shield is also grounded.

So, the current is flowing through this conductor. If it is varying, then it will produce a magnetic field which will be also varying and this varying magnetic field will induce voltages in these conductors and as the circuit is going to be closed, they will have their own currents because of those induced voltages.

So, if you have a current carrying conductor in the vicinity, you will be having voltages induced because of them. Further I mean between these two conductors or in any of these two conductors there will be a capacitance.

Now, you may say that I am not able to see any physical capacitance over there because you might have seen that a capacitor looks like a cylinder, if it is electrolytic or you might have seen ceramic capacitors. Whatever you might have seen the capacitor in the labs, your imagination may be that about the capacitor. But actually capacitance is formed whenever there is potential difference between any two points.

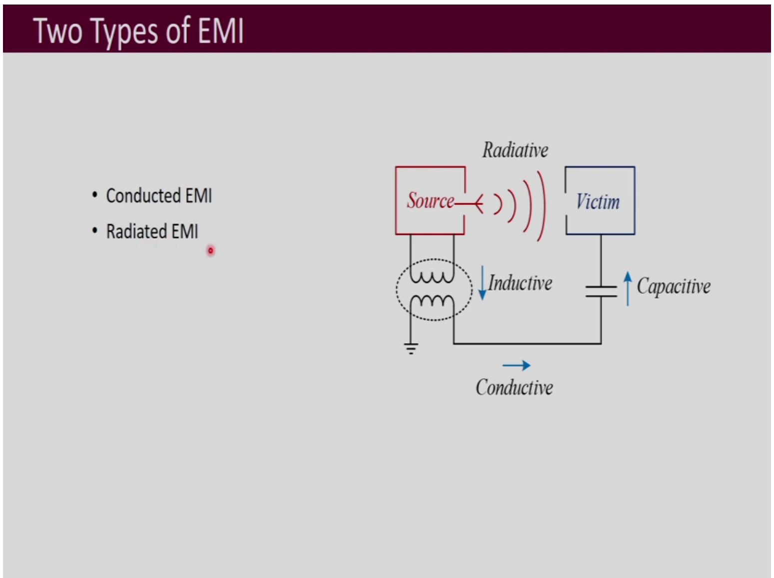
Obviously, there will be a dielectric medium which is air in this case. So, you have two points where there is potential difference and there is a dielectric medium that is air in between them. So, there will be a formation of a capacitor. Although, you may not be able to see that capacitor physically but there is capacitance between them.

So, that is the capacitance which we are talking about here. You will have capacitance between these two conductors and this shield and also between these two conductors and further between these as well. So, we will have capacitances over here in between and since, there is a potential difference in the capacitor. So, there will be a capacitive current which also will be flowing through it and this also is going to create a disturbance.

So, we observe that, because of this noise source, there is disturbance in the operation of the second conductor which you can call it as the victim. So, there is a source and then there is a victim.

So, we can say that electromagnetic interference is the disturbance in the operation of one system due to electromagnetic impact from another system or electromagnetic impact of the same system. When we say that electromagnetic impact of the same system, that means if you have a big system or if you have power electronic converter, it may be having different sections and different parts in it. One part may be generating noise and that noise may be affecting the functioning of another part.

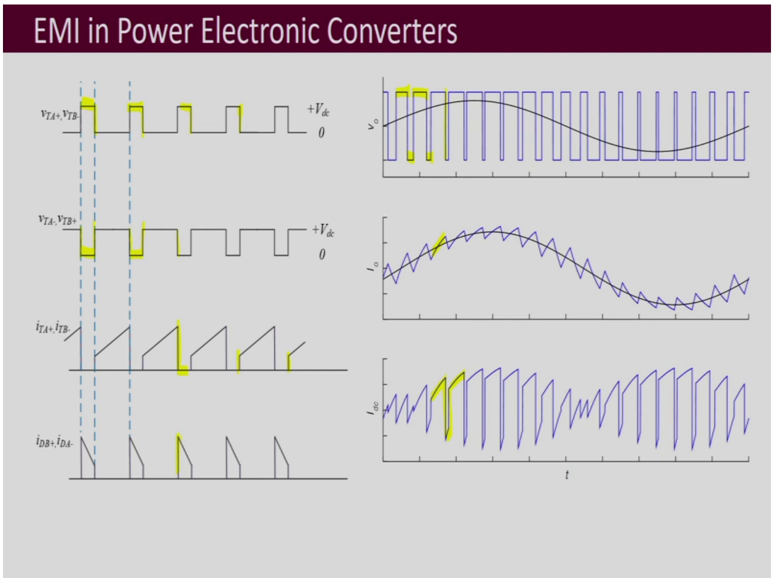
So, the system is creating disturbance with itself due to the same system and it is happening. So that is also interference, or this is called as electromagnetic interference. Now, electromagnetic interference in short is called as EMI.



So, in this example, we saw the inductive coupling and capacitive coupling and through wires the disturbance or the interference is going to travel from the source to the victim. But the disturbance can also travel through air via electromagnetic waves.

Now, you may again say that for waves to travel first of all we need antennas which will be transmitting the waves and then there should be a receiver antenna which should be able to receive the electromagnetic wave. We intentionally want a wave to be transmitted and travel and then to be received. But unintentionally also when we have metallic conductors, they all form an inefficient antennas. They are also antennas, but they are not efficient. They are not intentional, and they also have the ability to transmit electromagnetic waves to some extent.

So, then they will be radiating those electromagnetic waves. They will travel through space or air and then they can be received by the metallic structures that may be present in adjacent. So, adjacent systems may be there and when they are received, they can cause disturbance in them as well. So, that is the interference, which is happening via radiation. So, therefore, there are two types of EMI. One is the conducted EMI and second is radiated EMI.

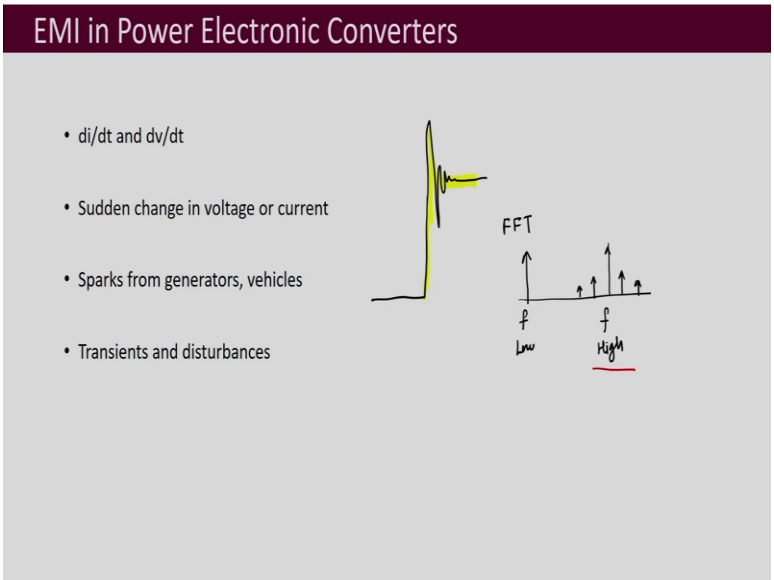


Now, you may be wondering that why in power electronic it is so important to pay attention to EMI problem. So, for that let us recall the waveforms which we have studied for H-bridge converters. Now, this is the waveform that we saw as the output voltage waveform for bipolar PWM in H-bridge. So, we see that the voltage changes from $+V_{dc}$ to $-V_{dc}$. It keeps on changing and here in between there is a fast transition from $+V_{dc}$ to $-V_{dc}$.

Then further we see that here are the dc bus currents. Here also we see that the current changes from output current $+i_o$ to $-i_o$ and that transition also takes place in a very short interval of time. These are basically decided by the rise times and fall times of those switches which are in the order of ns or μs.

Further, we had seen the switch voltages here. So, here again we see that the voltage changes from $+V_{dc}$ to 0 and in a very short interval of time these transitions take place. Again, these are also another set of switch voltages. Again we see the same thing. So, if we observe the switch current again, there is a huge transition in the current that means, it is going from $+i_o$ to 0 in a very short interval of time.

We see the same for the diode currents as well. So, from this we understand that in power electronic converters there are transitions in the voltage. The changes in the voltages and currents are by huge level in very short period of time.

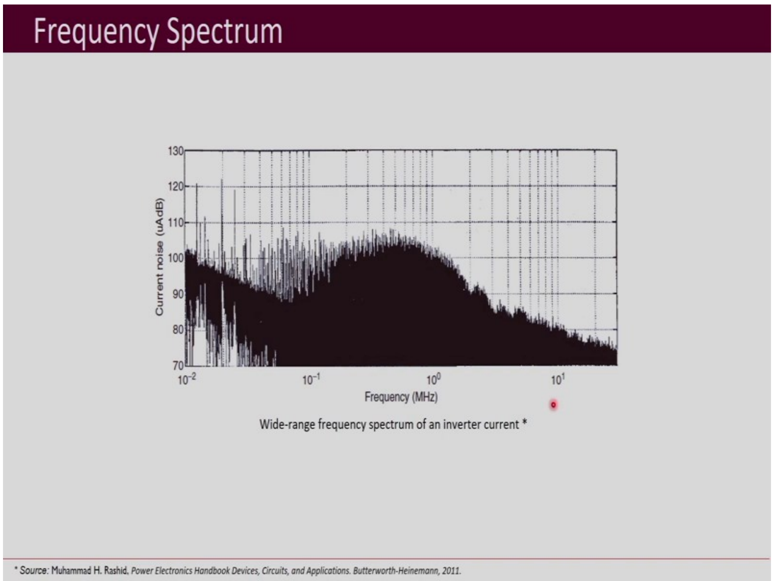


So, there are huge *di/dt* and *dv/dt*. The rate of change of current and rate of change of voltages are very high in power electronic converters. So, that is because of the sudden change in voltage or current plus there may be running generators or motors or the vehicles. There may be sparks also in them. So, that also is a source where suddenly voltages are changing very quickly.

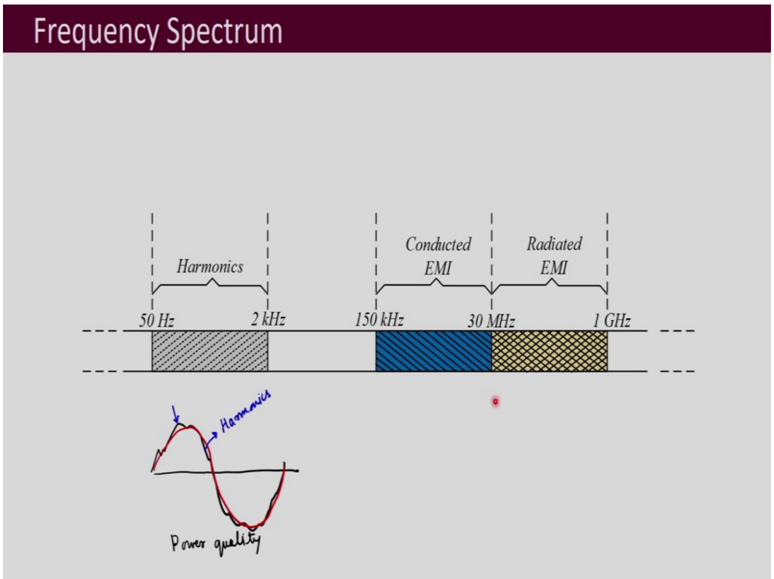
So, that also will lead to lot of transient voltages and currents. Of course, there may be other transients and disturbances that may be associated with the power electronic converters. Now, if we have a huge transient like this, then that may be because of a sudden change in voltage.

So, if you do a fast fourier transform of it, you will be observing that there are certain frequency components which may be of very high frequency range. So, this may be very high. This *f* may be high. It may be having some low frequency components as well. So, this is the fast fourier transform nature, what I am showing.

So, if we have these high frequencies present due to these kinds of transitions, that may be due to sudden change in voltages and currents which is taking place. So, they will be a source of electromagnetic interference and that's why in power electronics we pay so much attention to the problem of EMI because power electronic converters act as a big source of interference.



This picture shows the frequency spectrum obtained from the current of an inverter. So, this is expressed in *μAdB* and here you can see that the some parts of the frequencies are shown for this current noise, or this is given for the corresponding frequencies. Here you can see that this lie in the *MHz* range. So, here this is *0.1 MHz*, *1 MHz*, *10 MHz* and so forth. So, these are very high frequencies that means very high frequency noise is present due to power electronic converters. It may be in the current as well as in the voltages.



Now, we should be paying attention to the frequency ranges which are of concern and those frequencies presented in power electronic converters are sort of filtered out. We can divide them in three parts. The three spectrum parts are important for us to understand.

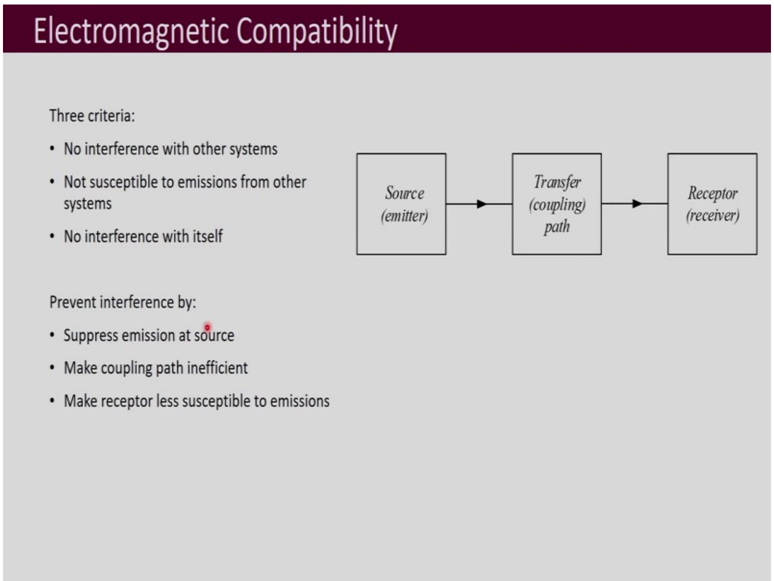
One is this frequency range which is *50 Hz* to *2 kHz*. This can be told as the harmonics range. So, if you observe the voltage that may be coming to your home, you may be observing something like this. That means, you would like to have a very nice sinusoid. But it may not be a proper sinusoid that may be the supplied. That may be coming to your home but this is slightly distorted from it.

So, what does that mean? So, those distortions which you are seeing, these are because of the low frequency harmonics or relatively the higher frequency harmonics in this range of up till *2 kHz*. The harmonics present in those waveforms may be there in the voltage. They may also be present in the current. So, this reduces the power quality.

So, this is associated with power quality and there are ways to improve power quality, which we are not going to discuss here. So, here is for you to understand that *50 Hz* to *2 kHz* is the frequency range. If we have those frequencies present in the converter waveforms, then they will lead to power quality issues. So, those harmonics should be removed to improve the power quality.

Then the other frequency range of great importance is from *150 kHz* to *1 GHz* and *150 kHz* to *30 MHz* is the range, where we have conducted EMI. This is the frequency range where we have noise present in the waveforms. So, then through cables, those disturbances can transfer to other parts of the same system or between two different systems and cause interference.

So, they will lead to conducted EMI and if we have noise or disturbances present above that, in the range of *30 MHz* to *1 GHz* they can radiate or they can transmit electromagnetic waves and then that will lead to radiated interference in this range *30 MHz* to *1 GHz*. So, for EMI perspective, this *150 kHz* to *30 MHz* and *30 MHz* to *1 GHz* is of importance.



Now, when we say that interference can happen, so then we have to make converters compatible for electromagnetic interference. That means, they should have electromagnetic compatibility, which in short is also called as EMC. So, there are three things. One is source which is going to emit or create the problem of EMI.

There will be a coupling path or transfer path via which the interference or the disturbance is going to travel and then there will be a receptor or receiver which is going to be affected by the problem of interference. So, we can say that this is the problem or I mean, there can be three criterias by which we can say that the system is electromagnetically compatible with its environment.

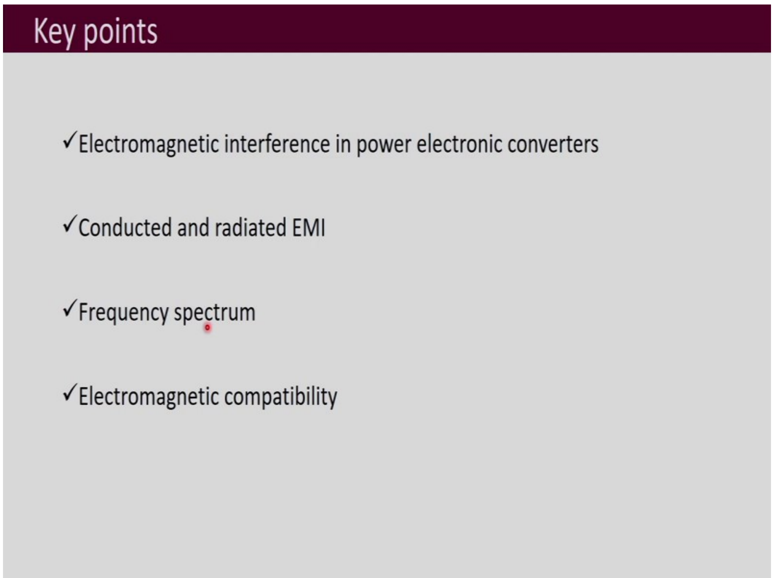
One is that it is not creating interference with other systems. Second, it is not susceptible to emissions from other systems. At the first place it should not create emissions or create disturbance and second is that, if disturbances are coming from other places, it should not get affected by that. Thirdly, it should not create interference with itself. One part of the same system should not create interference with another part of that system.

How do we do that? One is that we suppress the emission at the source. So, we ensure that we take such measures by which the problem of interference is not created by the converter which we are designing. Second is that we make the coupling path inefficient that means the transfer path is very inefficient. So, it won't be able to transmit.

Third is that the receptor is less susceptible to emissions that means, it is receiving the receiver such that it does not receive the outside interference or disturbances. So, mostly in this course, I will give you ideas to suppress the emission at the source. You design the power electronic converter such that it is not creating the problem of electromagnetic interference.

However, the other two measures are also very important. But, it is beyond the scope of this course. This is not a dedicated course on electromagnetic compatibility. Electromagnetic compatibility is a very huge topic and is a course in itself. We are not going into those steps.

Here, I will introduce you electromagnetic interference, the measurement of it and then further we will be looking into some of those design concepts which you can apply in power electronic converters to reduce the emission from them.



So, the key points of this lecture are that there is problem of electromagnetic interference in power electronic converters and it is mainly because of the nature of waveforms which have very high *di/dt* and *dv/dt* present in them. Basically switched voltages and switched currents are the main source of EMI in power electronic converters.

We have two types of them. Those are conducted and radiated. Conducted means it travelled through wires and conductors and radiated means it travels through air and cause disturbance. There is a particular frequency spectrum, or range of frequencies which are of importance for assessing the electromagnetic compatibility with respect to this problem of interference. This electromagnetic compatibility means how much the system is not affected by interference of any sort. Thank you.