High Power Multilevel Converters - Analysis, Design and Operational Issues
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Lecture - 04
Basic Understanding of Converter - (Harmonics in sinusoidal PWM)

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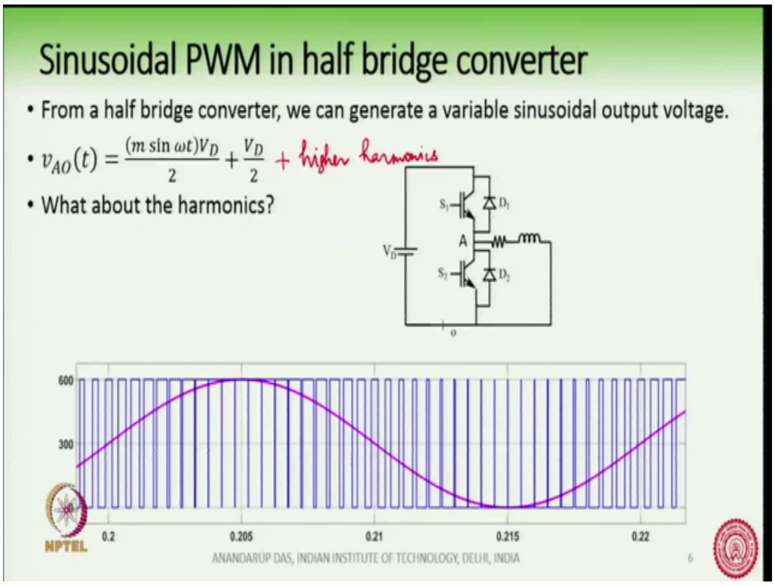

So, far we have only talked about the fundamental voltage that is available from the converter. Now in addition to the fundamental voltage, the switching action in the converter also produces higher harmonics ok. So, in this expression if you see, the v AO t that is the voltage produced, the pole voltage produced is m sin omega t into V D by 2 plus V D by 2.

This is the voltage produced from the half bridge, but there are some higher harmonics here. Apart from this happens due to switching action and these higher harmonics, we will try to see what are these harmonics where are they present like that ok.

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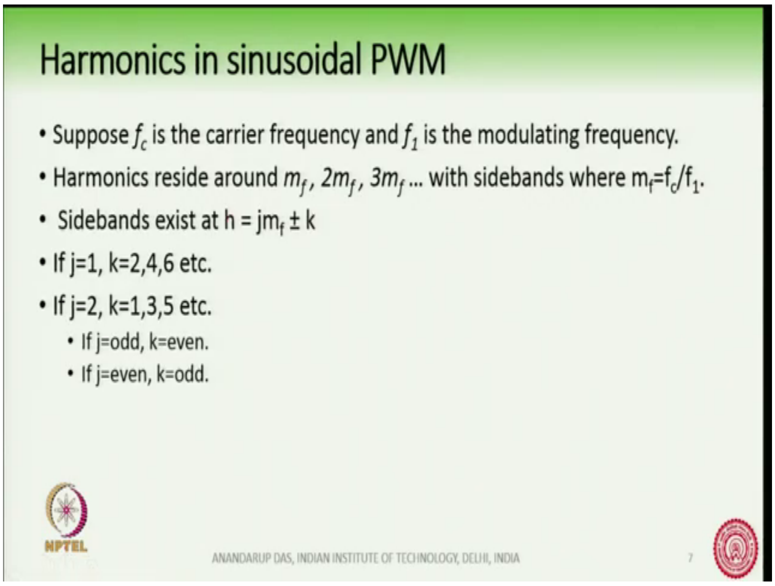

So, suppose in f c is the carrier frequency that is the triangular frequency is f c and f 1 is the modulating frequency or the reference waveform frequency. Say for example, the modulating frequency can be a 50 Hertz reference waveform and the carrier frequency for example, can be a 10 kilo Hertz triangular waveform. So, we define a term m f where m f is equal to f c divided by f 1. So, it is the ratio of the frequency of the carrier to the modulating waveform.

So, m f the harmonics in sinusoidal PWM they reside around m f 2 m f 3 m f like that. So, this is the position of the harmonics in the harmonic spectrum. So, the harmonics will reside. So, suppose if you if your f c is equal to 10 kilo Hertz and your f 1 is equal to 50 Hertz then the m f value is equal to 200 and so, the harmonics will reside at 200, at four 400, at 600 times the fundamental in the harmonic spectrum.

Now apart from so, this is the main harmonic that exists, but we also have side bands that exists at j m f plus minus k, this positions. What are the values of j and k? If j equal to 1, k equal to 2, 4, 6 and if j equal to 2, then k equal to 1, 3, 5 etcetera which means in general if j equal to odd, k equal to even and if j equal to even, k equal to odd.

How does this come in if you want to do the really mathematical analysis? It comes from the analysis of the Bessel function. We are not going to deal that in this course and interested students are if you can see some other books and can find out how exactly this formula is derived.

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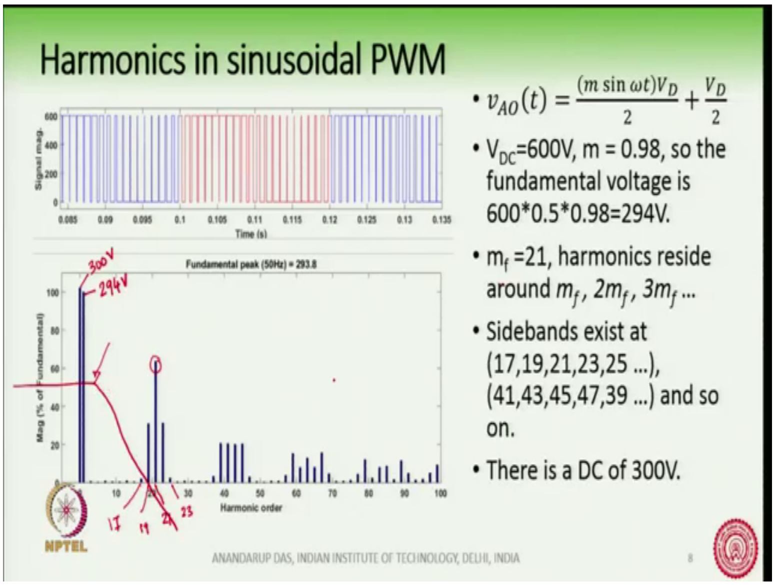

What is important here is to see the position of the harmonics because we will come to that because this is how if you are designing a filter it is important where is the corner frequency of the filter at the output of the converter ok. So, this waveform here the shows the position of the harmonics in the harmonic spectrum.

So, suppose this is the on the top here this is the, this is the v AO voltage waveform and you can see this varying between 0 to 600. And in this case, we have taken m f equal to 21 ok. So, we expect that the harmonics will reside around m f, 2 m f, 3 m f etcetera. Even before we going to the harmonics, let us first see that what is the fundamental voltage inside this. So, we know that v AO t is m sin omega t V D by 2 plus V D by 2.

So, here we have taken V D as 600 volt, m is equal to 0.98. So, the fundamental voltage is 600 into 0.5 into 0.98. I am putting here, the peak fundamental voltage is equal to m m times V D by 2 that is 600 into 0.5 into 0.98 which is equal to 294 volts that is the peak fundamental voltage out of the half bridge converter. On the lower on this curve, this is the harmonic spectrum ok.

This curve here shows the harmonic spectrum and the 0 th harmonic that is the DC as expected the DC is equal to V D by 2, we have seen it here the DC is equal to V D by 2 and so, it must be equal to 600 by 2 that is 300 volts which is here this is 300 volt. It is a shown as a percentage of fundamental.

So, the fundamental voltage here is taken as 100 percent which is equal to 294 volt and which is obtained also from simulation, 294 volts here 293.8 which is almost equal to 294 volts. So, this one this bar here this bar is corresponding to 294 volt which is at harmonic order 1. There is a fundamental is taken as 100 percent and its magnitude is 294 and therefore, the DC is slightly because the DC is 300 volt.

So, this value is 300 volt here and this value is here 294 volt ok. So, this is the DC is 300 and the fun peak fundamental is 294. Now what about the harmonics? The harmonics reside there will be side bands from the previous formula we have seen that it is if j equal to 1 k equal to

2, 4, 6. So, therefore, side bands will exist as 17, 19, 23, 25 like that. So, this is the 19 th harmonic and this is the seventeenth harmonic like that.

So, this is the place where the first band of harmonics exist and then there is also harmonics and its sidebands around 2 m f, around 3 m f, around 4 m f and like that. We are not very much concerned about the peak of the harmonics because in any case, we are going to filter out to this harmonics using the for example, a filter at the output of the converter. So, in order to determine the corner frequency of the filter, it is important to know the position of the harmonics ok.

So, that is why we are more concerned about the position of the harmonics rather than its amplitude because in any case the filter will filter out these harmonics. So, for example, if we see if we try to plot the plot the gain the gain plot of the filter, we can have a filter of like this; this is the gain plot of the filter where this is the corner frequency of the filter.

So, if we choose the corner frequency in clever way, then we can make the gain plot in such a way that the for all the harmonics here, the filter the gain is 0 at the harmonic frequency and all the higher harmonic frequency the gain is 0 or less than 0 or the gain is 0.

So, therefore, the filter will get rid of all the harmonics present. So, if we choose a higher and higher m f value, then the filter frequency can be pushed further right hand side. For example, we can push the filter if the m f if the first band of harmonics.

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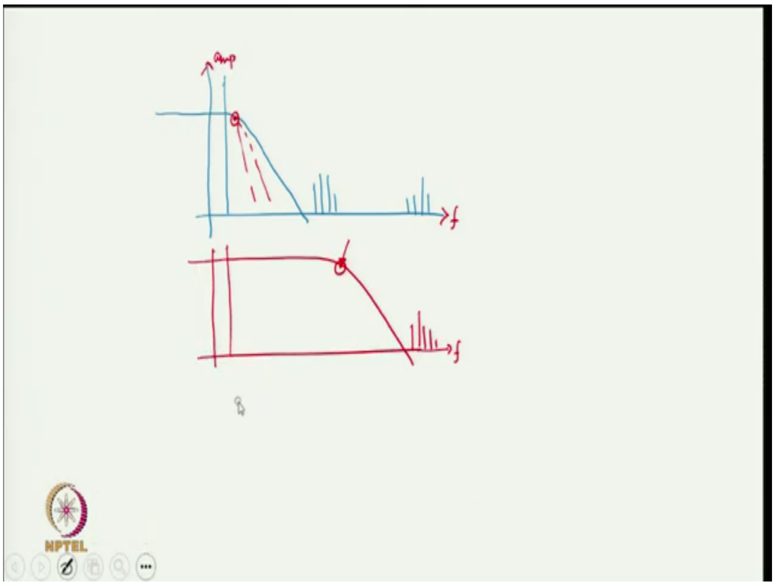

So, let us take an example that this is the fundamental and there are harmonics which are present here and then there are second harmonics like this. So, we can design our filter such that the corner frequency is well ahead of the first band of harmonics. In another case, if we have a converter where the fundamental is here, but the harmonics are here; then the filter corner frequency can be set here.

Earlier the filter corner frequency was here now, it is here. So, where this is the harmonic axis frequency axis and this is the amplitude. So, the filter corner frequency can be shifted if the harmonic if the switching frequency of the converter is increased. And if we do this the size of the filter because the corner frequency if you shift towards the right, the size of the filter will go down and we can also choose if this is for example, for a second order filter we can also choose third order filter or more.

So, that the slope here will change that is also another option. Anyway what I want to say here is that the position of the harmonics is important because the filters will take care of the all the harmonics. So, from the harmonic point of view and from the filter point of view, the value of m f should be very large.

Larger is the value of mf, smaller will be the size of the filter because you are pushing the harmonics right more and more right in the harmonic spectrum. On the other hand, the increased value of f m f causes more losses in the converter because the switching frequency is increasing in the converter. Why does the switching frequency increases? Because now the triangle period will go down and there will be more number of switching happening in the converter.

So, usually we say that for low power rating, a value of for low power rating for example, within 5 kilo Watt power rating the switch a switching frequency of 20 kilo Hertz 40 or even 50 kilo Hertz is quite acceptable whereas, for high power applications say in the mega Watt level or in the gig Watt level, the switching frequency of the converter has to be sufficiently low.

So, you can have converters where the switching frequency is less than 300 Hertz, 200 Hertz etcetera, but that will impose a lot of restriction on the filter design because the filter will then become very bulky. So, we go with other possibilities, other technological possibilities one of them being the introduction of multi level converters, we will see that later in the course.

Apart from that what are the values of m f that we should maintain. It should be an integer m f should be an integer because otherwise sub harmonics will be produced. So, synchronization should is needed synchronization between the sine wave and the carrier wave ok. So, m f must be an integer and it should be an odd value.

So, that no even harmonics are produced and it should be an odd multiple of 3 to maintain the three phase symmetry. These criteria for m f is actually valid when m f is quite low. For example, like m f up to 21 these criteria here which I have mentioned here its valid. For large values of m f these we can relax this criteria ok. It is not necessary that m f must be an odd value because suppose if the value of m f is 400 or 500, then this criteria can be relaxed a little bit.

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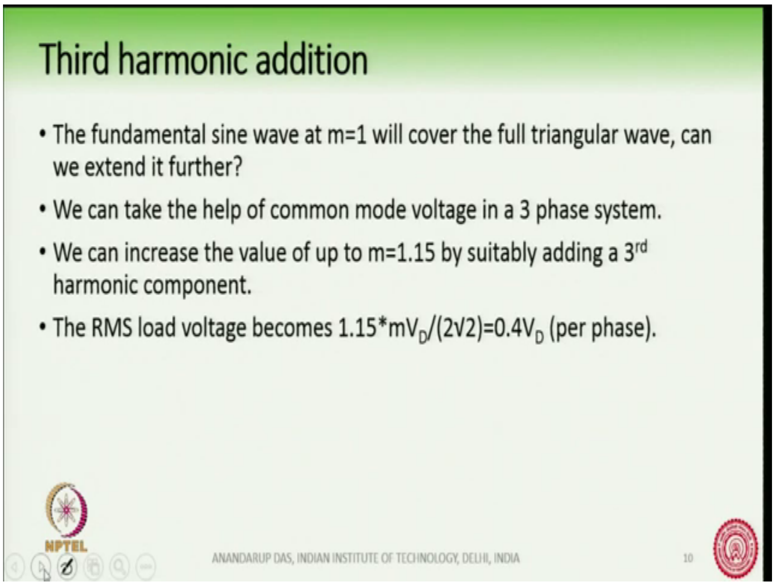

Now, we go into something which is the third harmonic addition.