High Power Multilevel Converters - Analysis, Design and Operational Issues
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Lecture – 11
Introduction to Multilevel Converters

Hello everyone. We are going to start the discussion about Multilevel Converters. More specifically we are going to start with one of the multilevel converters which is the Cascaded H Bridge converter, in short CHB.

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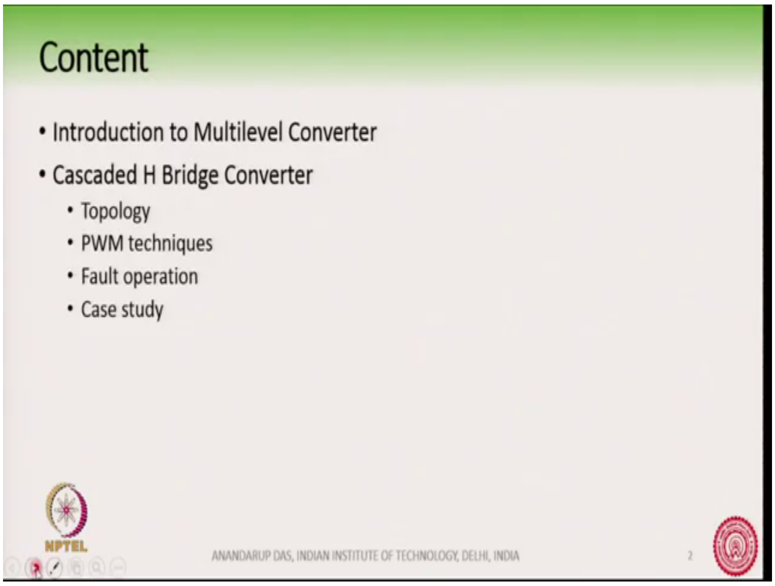

And before we go into the multilevel converters let us see what we are going to talk about today. We are going to talk about an introduction to the multilevel converters, why they are used, what are the advantages, and then we will talk about the first multilevel converter that is the cascaded H bridge. We will talk about the topology and the PWM techniques, fault operation and one case study. Subsequently, we will talk about other multilevel converters like modular multilevel converters and then neutral point clamped converters in details.

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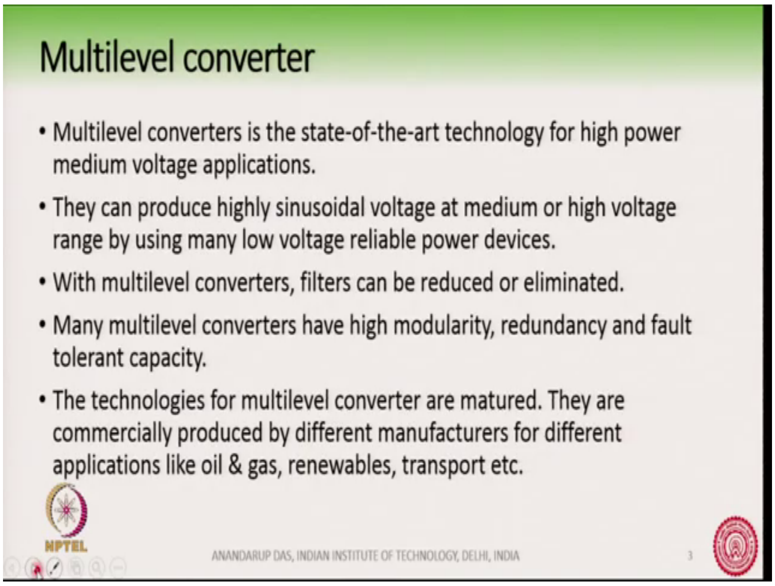

So, let us start with the multilevel converter. The multilevel converter is the state-of-the-art technology for high power medium voltage applications. It was introduced somewhere around the 80s, 1980s and slowly it became popular and the initially there were two types of multilevel converters, one was called the cascaded H bridge converter which we are going to discuss today and the other was the neutral point clamped converter.

More recently, another multilevel converter has become very popular which is the modular multilevel converter. Multilevel converters are used mainly in medium voltage or high voltage, high power applications. For example, neutral point clamped and cascaded H bridge both are used at the medium voltage level. Cascaded H Bridge is also used at the high voltage level, for example, in STATCOM in transmission systems. Modular Multilevel Converters MMCs are more used for HVDC applications, but they are also getting or they are being introduced in the market for motor drives application at lower voltage also.

Now, why do we use these multilevel converters? So, for example, if we see the motor drive application, one of the application areas of multilevel converter is motor drives and the multilevel converter can produce highly sinusoidal voltage at medium or high voltage range and they do that by using a large number of low voltage reliable power devices. So, by using low voltage devices and having many of them working together we produce this multilevel converter.

Now, why do we do that? If we see the development of any power converter or if you see the development of any power device for example, IGBT, we will see that initially it starts with the introduction of a low voltage device, low voltage IGBT. For example, it starts with say 600 volt IGBT. When you, when it was introduced in the market first one was the 600 volt and then subsequently the voltage capability of the device was increased.

Now, we have IGBTs coming around 6500 volt also. So, if you see the development we see that the low voltage device is more mature. People have used that often it has more years of experience or years of operation in the field, so people have gathered a lot of experience, seeing the performance of the device over long periods of time in the actual environment or in the field. So, the low voltage devices people have better understanding researchers or engineers or design engineers, they have better understanding of the properties of this low voltage device rather than a very high voltage device.

So, 600 volt for example, 600 volt IGBTs are very popular compared to 6500 volt IGBTs which are less popular, this these are used for more specific application. So, when we use low voltage power devices we have more expertise in for example, the operation of the operation of the device or for example, for designing the gate driver circuit etcetera. So, if you want to make mass production of any converter, if you want to make a lot of such devices probably a low voltage device is a better choice because we have more expertise on it.

So, the present generation multilevel converters can reach a very high voltage by using many of these low voltage devices, but many of them working together. So, this is the one of the primary reason why multilevel converters are getting popular. Additionally, we see that multilevel converters, with multilevel converters filters can be drastically the size of the filters can be drastically reduced or in some cases it is completely eliminated, ok.

Now, by the way when we see, when we say that medium voltage or high voltage, medium voltage generally starts from about 2.3 kilo volt and it go up to like 33 kilo volt beyond which we say that it goes into the high voltage region. So, multilevel converters are very popular in this voltage range and power range can be several mega Watts to several 100s of mega Watts.

Now, one type of multilevel converter which is MMC or Modular Multilevel Converter has become very for HVDC application, where the voltage level can be plus minus several 100 kilo volts. Say, plus minus 200 or plus minus 400 kilo volt and power can go up to giga Watt range of power. So, these multilevel, so this MMC multilevel converter is very popular at the very high voltage level also.

Apart from the using low voltage devices and use the elimination or reduction of filter size, the other advantage of a multilevel converter are like they are highly modular. So, you can use several of identical rated devices. We will see some of these as we go on in the lecture. So, they have high modularity, they have inbuilt redundancy and fault tolerant capacity, ok. So, with use of multilevel converters you can bypass some modules and can still run the converter. So, this is a very advantageous feature because since we are using a large number of devices of course, the probability of failure increases.

And if you have one device failing and then you see say that we have to shut down the converter then it is not a very advantageous, it is not a good design because your many you have many devices working together and because of one particular device failing you if you have to shut down the converter then it is not advantageous. So, the fault tolerant capacity, so that you can bypass this faulty module and can still run the converter probably at a reduced rating. This feature is also quite useful.

The technologies for multilevel converters are quite matured and many many such converters for the past 20-30 years have been commercially deployed and running, and you have produced by different manufacturers for various applications like oil and gas industry, for renewable for integrating renewable energies and also for traction applications like that.

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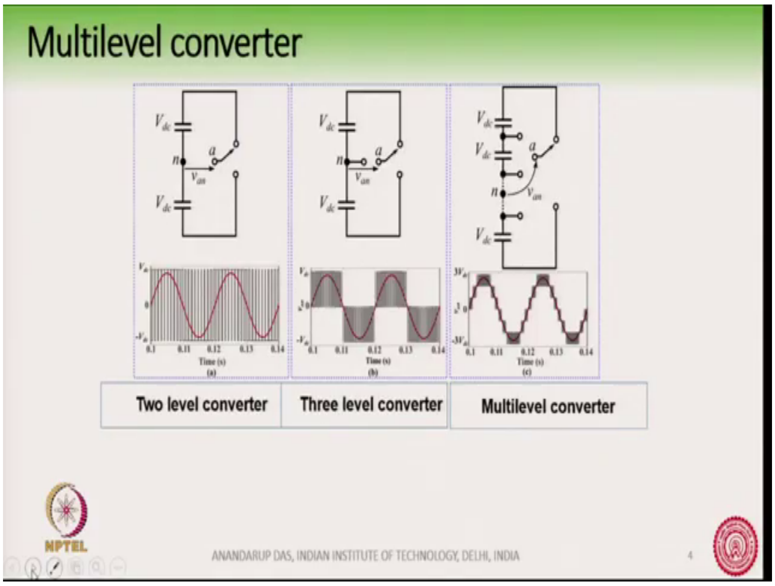

So, what is the basic idea of a multilevel converter? How does it produce sinusoidal wave form? This can be understood by this 3 diagrams here. Here on the left we have this two-level converter, then we have something called as a three-level converter and then we have a something like a multilevel converter.

Now, we will later define what is a three-level and what is a multilevel, but we have already covered this two-level converter where we had seen that the pole voltage that is the voltage a for example, with respect to n or with respect to the negative of the dc bus it can assume two voltage levels. It can be 0 or V d, and if you take the midpoint as the reference then you it will be plus V d and minus V d or plus V dc and minus V dc. These are the two voltages possible at point a. So, it is represented by a single pole double flow switch here.

So, here if the switch is on the upper side we get plus V dc with respect to point n, if the switch if the throw is on the negative side or the lower side here then we get a minus V dc. So, the instantaneous voltage which is available at the pole is represented by this series of pulses, series of PWM pulses and it looks like this black curve. Now, we have seen that when we do sinusoidal PWM, then the voltage which is produced because of sinusoidal PWM is kind of like embedded inside this waveform, ok.

It is not apparent. Just by seeing this black waveform you will not be able to conclude that there is a sine wave inside it, but if you do the Fourier analysis then we find that yes there is a fundamental sine wave which is shown by the red curve here. It is kind of like embedded or hidden inside this PWM instantaneous waveform. Now, if you observe this sine wave carefully, we see that there is always an instantaneous error between the red curve and the black curve.

The red curve is the curve, for example, if we are using this to level convertor for a motor drive application, we are connected to other motor drive, then we are trying to produce a sine wave out of the converter, this is a dc to ac converter or a inverter. We would like to produce a sine wave out of the converter, but and so this sine wave is this red curve here, red waveform. This is the sine wave fundamental sine wave which we would like to which we would like to feed it to the load.

But what is available in my hand is this black waveform because we have only two switching states, I can either I can put the switch either on the top or at the bottom. So, the waveform that I wish to produce is the red waveform, but the waveform that I can produce is the black waveform and there is an instantaneous error between the two. There is always an instantaneous error between the red waveform and the black waveform. The red waveform is the one I wish to produce and the black waveform is what is available in my hand and there is an instantaneous error.

Now, let us see a different convertor which is called a three-level converter, where suppose this switch can be either put here, it can be put here or it can be put here. I mean we if we can get three-levels of voltage, earlier in the two-level converter we were getting two-levels of voltage. Now, suppose we have a switch through which we can connect to this point, this point or this point, ok, so if we have such a switch then I can get either plus V dc or 0 or minus V dc I can get 3 voltages at the pole.

So, then it is possible for me to produce this kind of a waveform which is shown by the black curve here this is the pole voltage waveform. Here you can see there are three-levels it can be 0, it can be plus V dc or it can be minus V dc. So, there are three-levels of voltage because the switch can take or switch can connect to the 3 points, either it can connect here, here or here, these 3 points.

So, therefore, now the sine wave which we wish to produce which is shown by this red curve here, if we compare that sine wave with the black waveform which is the instantaneous pole voltage and we compare it with this waveform of the two-level converter, we see that the instantaneous error in this waveform is less as compared to the instantaneous error obtained here.

It is quite obvious by observing the waveform that now when the sine wave is positive we are switching between 0 and V dc whereas, when the sine wave is negative we are switching between 0 and minus V dc. It was not happening here. So, the instantaneous error is less for this waveform here. Now, what is the significance of this instantaneous error? The significance of the instantaneous error is that the harmonics which are getting produced from the converter, the harmonics are getting reduced. If the instantaneous error is reducing then the harmonics are also reducing.

Here the harmonics produced because at the pole voltage waveform the harmonics produced here is more as compared to here. So, this waveform has a better harmonic performance. So, the three-level converter waveform has a better harmonic performance than a two-level converter waveform simply because of the reason that you evident from the waveform that the instantaneous error is less.

Now, let us go to another converter which we call as a multilevel converter. Three-level converter is also a multilevel converter, but three-level is sometimes specifically reserved word anything more than two-level is a multilevel converter, but usually we keep this three-level word separate. So, anything more than three-level we sometimes call it as multilevel converter. In this multilevel converter, in this circuit we see that the pole voltage; the pole voltage can have it can take many many voltages. For example, the pole voltage can be here, here, here, can be connected here, here, here like that.

So, if this pole voltage can assume many levels then we see that for example, the pole voltage can be connected either to this point on the top, it can be connected here, it can be connected here. So, there are several sources, so the pole voltage can take small steps and we can produce a pole voltage waveform like this, the black one here, ok.

Now, when we superimpose the sine wave, the red sine wave here we see that the black waveform is now very close to the sine wave, the instantaneous error is has reduced considerably and therefore, the multilevel converter has better harmonic performance as compared to this three-level waveform or the two-level waveform. So, this is one of the reasons or one of the primary reasons why multilevel converters are used. We can get we can get a voltage waveform which is very close to a sine wave. It is very useful for say motor drive applications because if we get to a waveform which is very close to sine wave then we do not need any filters, ok.

The motor and the cable inductance is sufficient to attenuate any high frequency currents. So, we do not need any filters and this is why this is the reason why multilevel converters are popular. But apart from that there are other reasons we will see this, we will see that when we try to produce such a waveform, we will use a large number of low voltage devices in order to produce a high voltage and that is one of the advantages of a multilevel converter.

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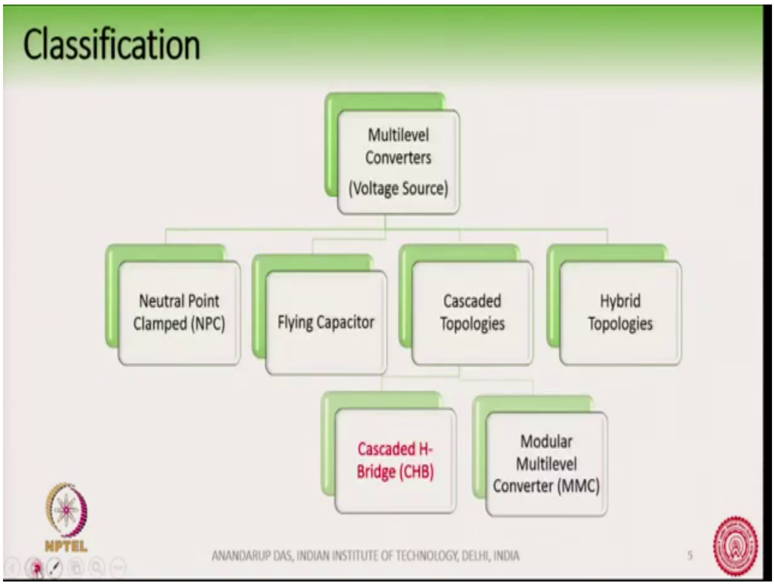

So, if we see the family of multilevel converters, basically this is multilevel converters are usually voltage source converters, we have this neutral point clamp converter in PC. We will study this in details sometime later. There is also this flying capacitor. Flying capacitor is, although it was commercially produced by one manufacturer, but it has not gained much success. So, we will briefly talk about this.

And then you have the cascaded topologies under which we have the cascaded H bridge which we will discuss now this topology and later we will talk about MMC, Modular Multilevel Converters, this we will talk. And then we also have a hybrid topology which is basically a combination of either the neutral point clamp and CHB or several such combination, these hybrid topologies are sometimes implemented, also have been implemented commercially.