High Power Multilevel Converters - Analysis, Design and Operational Issues
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Lecture – 35
Multipulse Transformer - Part I

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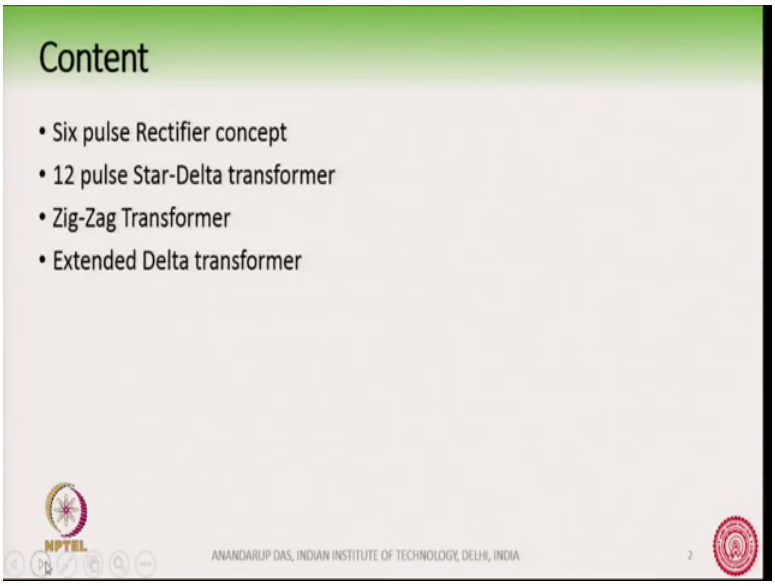

Hello everyone, today we will start a new session on Multipulse Transformers ok. So, this multipulse transformer, we will have these contents like six pulse rectifier concepts from which we will develop the 12 pulse star delta transformer and then zigzag transformers and extended delta transformers. which can be used for the feeding the rectifiers of converters. So, why we need to study multipulse transformers?

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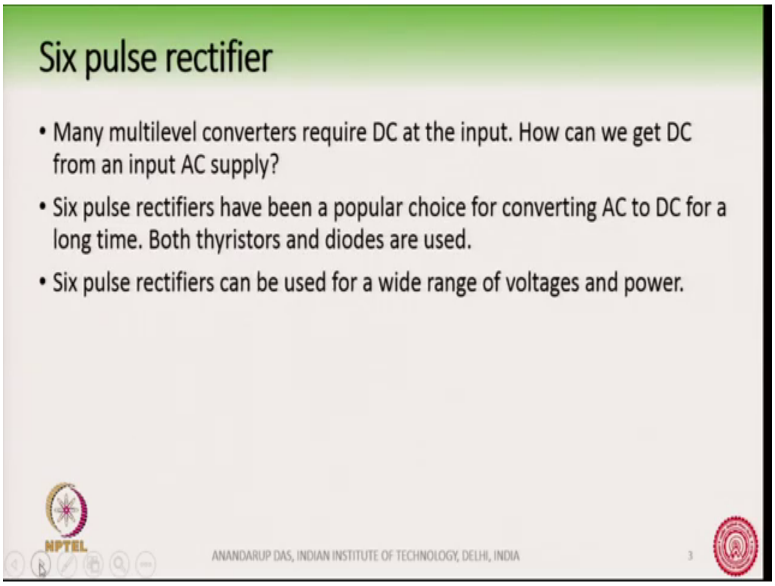

Now, many multi level converters, not only multi level converters, but many normal conventional two level VSI or VSC, they have the DC at the input ok. So, the DC bus is present on in such voltage source converters. Now the question is how do we get that DC? We get that DC from an input AC supply right. Of course, we can also get the DC from a battery or from other steep DC sources. But in many of the multi level converters, we get the DC by rectifying the input AC supply.

Now, these kind of multi level converters for example can be used for motor drives application for example. And then we have an input fixed AC which is converted into a DC and from the DC and using a voltage source inverter, we can get a variable AC output which can be fed to the motor.

So, AC to DC and then DC to variable AC. This is how the structure looks like. Now in this part of the course, we are focusing on the rectification part that is AC to DC, that part. So, what has been popularly used for converting AC to DC is a 6 pulse rectifier, bridge rectifier, three phase which has been like a very popular choice for a long time now ok. And, in this both thyristors and diodes can be used for converting the AC to DC.

We can also have front end converters or PWM rectifiers at the AC to DC, but those are controllable switches, they require controllable switches. In many applications where we do not need the use of like variable DC supply, we simply use a diode bridge rectifier, three phase diode bridge rectifier, because diodes are much easy to construct and they do not require any control it is a uncontrolled devices.

So, in many cases for the sake of simplicity, we simply convert the AC into DC through a 6 pulse diode bridge rectifier. So, such 6 pulse diode bridge rectifiers have been in use for a long time and for a wide range of voltage and power ok. Starting from like converting from 230 volt single phase AC to 15 volt DC for low power electronics for some less than a watt or maybe tens of watts and going up to like in the megawatt power range also ok.

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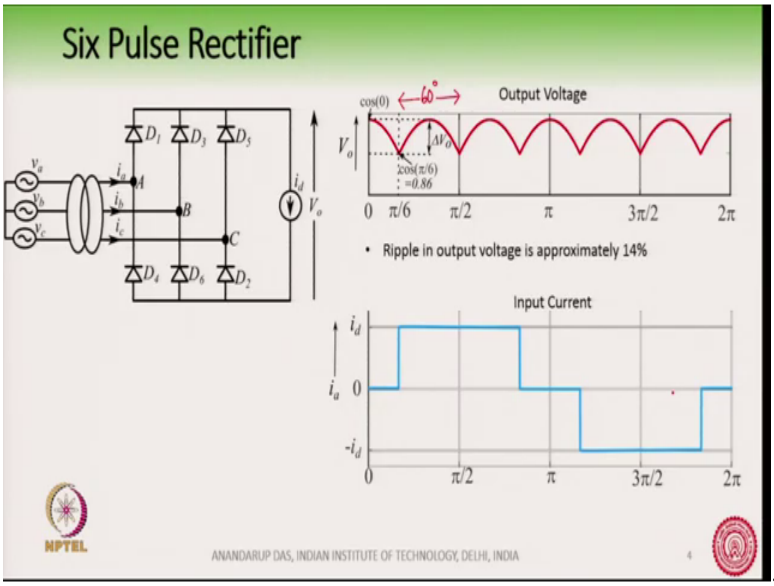

Now, if you see so, this is the six pulse rectifier ok. So, here you can see we have a input AC and we have a transformer and then, the transformer is fed through a 6 diode bridge rectifier, three phase diode bridge rectifier and on this side we have a current source which is acting or which is representing the load ok. Now usually, we have the transformer here.

The transformer is needed mainly for two purposes; number 1 is that it isolates the AC sites from this side of the load. So, there is an electrical isolation because of the transformer that is the number 1. And number 2 is that in case of a fault on the DC side for example, if there is a dead short circuit fault here ok, on the DC side then the leakage inductance of the transformer helps us to limit the rate of rise of the short circuit current ok.

So, the transformer leakage impedance should be fine means a certain value. For example, people typically choose transformers having leakage impedance say 5 to 6 percent ok.

Typically, 4 to say 4 to 6 percent in that range and it cannot be made very small because during the time of short circuit on the DC side the transformer impedance is the element that limits the rate of rise of current.

So, it plays an important role apart from isolation. Now, on the DC side we see that we have a very large inductive load which is represented by a current source here. So, we will continue with this because in most of the high power converter applications this may be a good representation of the actual circuit used. In some cases, we also have capacitors here on the DC side.

So, the analysis is slightly different, but on a similar strategy; we can do the analysis with a similar strategy if we have a capacitor on the DC side. But in this course we will consider current source at the load side ok. Now this analysis is already very well covered in basic power electronics courses, I will not go into the details of operation of the diodes here. For example, you can see that diodes have a numbering here D 1, D 3, D 5 and D 2, D 6, D 4. So, there is a sequence of conduction of these diodes.

So, D 1 and D 2 will first conduct and then D 2 and D 3 will conduct depending on the instantaneous line voltage magnitudes ok, whoever is at the peak that pair of diodes will conduct. So, I will not cover that, what we will see more in this part is what happens to the output voltage and the input current. More specifically, the input current is something which we are going to study and which is our concern for this course and for multi level converters. Now why it is a concern we will come to that. Now let us first understand how is the output voltage waveform and the input current.

So, the output voltage waveform is because of the sequence of conduction of the diodes it typically looks like this. So, it is called a 6 pulse rectifier because there are 6 loops in this fundamental cycle. And so, if this is 360 degree then, each loop is kind of like spanning one sixth of 360 degree, that is 60 degrees. So, the peak to peak ripple here so, if this is 1 here, if this value is one that is cos 0. So, this value will be 30 degree because this total length is 60 degree.

So, this is 60 degree here and so, half of it is 30 degree and cos 30 degree or cos pi by 6 is equal to 0.866. So, therefore, the peak to peak ripple is close to 14 percent, there are 6 loops ok. That is why this is called a 6 pulse rectifier. Now what is the input current waveform? So, if you take any phase suppose you take i a the input current waveform typically looks like this ok, this is a quasi square wave waveform. And where for some time this is 0 and sometimes this is equal to the load current magnitude when the diodes are conducting. So, when D 1 is conducting, this is a positive value, when D 4 is conducting, it is a negative value ok.

So, this is how so, this blue waveform here is how the input current looks like and this input current as you can understand from the waveform is highly non sinusoidal it is far away from sinusoidal ok.

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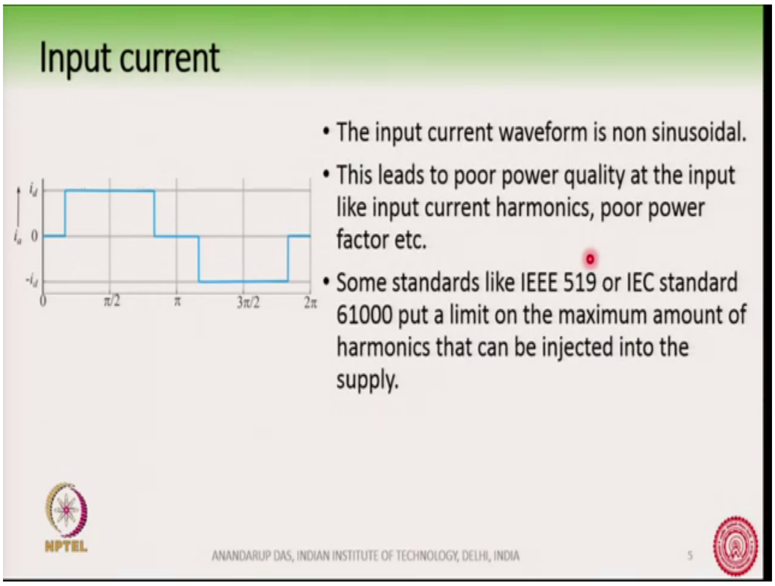

It has a lot of harmonics present in it. Now, the input supply voltage is sinusoidal. Typically, we can assume that the input supply voltage is almost close to a perfect sine wave. Now the input current drawn by this 6 pulse rectifier as you can see here is not at all sinusoidal ok, it is a quasi squared wave. Now this leads to poor power quality at the input. So, we are basically injecting a lot of harmonics into the supply ok.

Now as long as the magnitude of this current is less the harmonics that we are injecting and which leads to the overall deterioration of the input current is reasonable or it is under control if the magnitude of the load is small. But for many high power application the magnitude of the load is quite significant ok.

So, in that case, the amount of harmonics or the degree of pollution that we are injecting into the supply that can be quite high, that can be substantial. And this will lead to a lot of input current harmonics and consequently poor power factor. So, which will lead to an overall deterioration of the input supply voltage quality which has been which can be supplied to other loads ok.

So, it can cause flicker, it can cause unwanted disturbances or to other loads etcetera. So, there are some standards like IEEE 519 or IEC 61000 where the standard say that if you build a converter, then the maximum amount of harmonic that this converter can inject into the supply there is a limit to that maximum value ok. So, typically like IEEE 519 says that the something called as THD is there we will explain that THD that should be less than 5 percent of the input current.

So, we need to device some strategy to improve the input current quality or reduce the harmonics in the input current. So, this is what we will study here ok. So, we can use multipulse rectifiers to improve the quality of the input current right.

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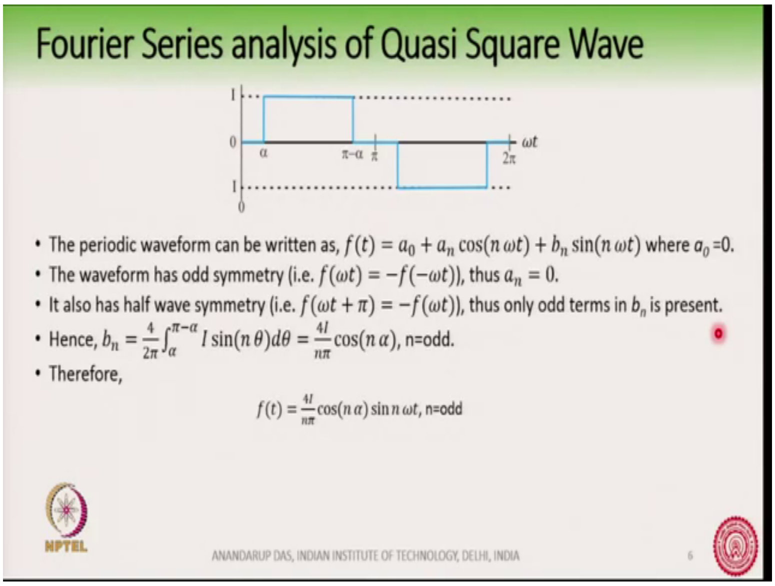

So, before going that, so let us analyse quickly, what are the harmonics present in this waveform ok. So, that we can at least know what are the harmonics that are getting injected into the supply. So, this is the periodic waveform and so, if you write the Fourier series, this is very standard notations.

So, this is a 0, a n cos n omega t and b n sin omega t and from observation we see that a 0 is 0. This waveform has odd symmetry because f of omega t is minus of f of minus omega t. So, this means here whatever is happening f of omega t a minus of omega t here the negative is happening. So, therefore, we can say that n terms are 0. And also it has half wave symmetry. You can see that f of omega t plus pi that is whatever is there is minus of f of omega t or what is happening here. So, therefore, only odd terms in b n are present.

So, therefore, we can now find out what is b n because a n is 0 and a 0 is equal to 0. And so, b n is equal to we can do this integration and then you find four I by n pi cos n l alpha. Where alpha is the angle at which the squared wave be below alpha the squared wave value is 0, quasi square wave value is 0. After alpha the quasi squared wave value is I. So, the magnitude of harmonic so, we can write f t as 4 I by n pi cos n alpha sin n omega t. So, this is the Fourier series expansion of this quasi squared wave where n is equal to odd.

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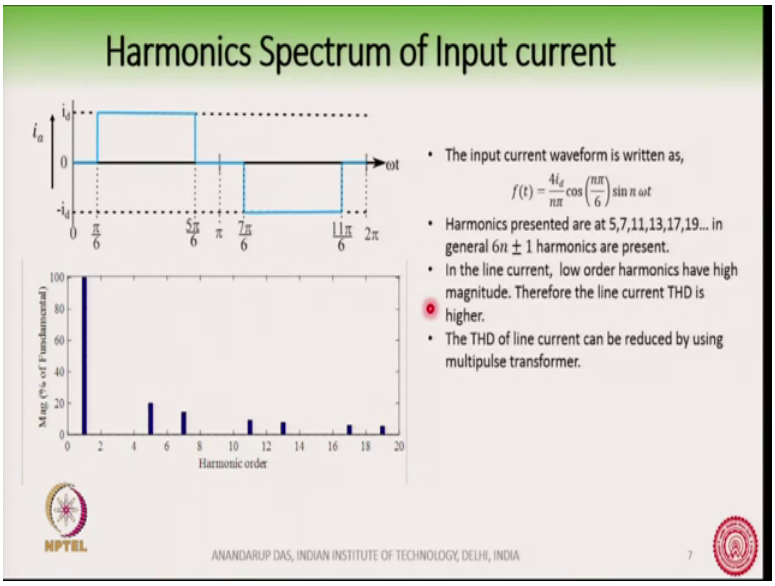

So, we see that we have all the odd harmonics present here ok. So, in this case, in the case of a, in the case of the input current drawn from the 6 pulse rectifier; the value of alpha is equal to pi by 6 as you can see here. So, if you put f t there cos n alpha so, you put n pi by 6 and then if you put the values of n as 3, 5, 7, 11 like that we find that all these fifth seventh eleventh thirteen seventeen nineteenth in general 6 n plus minus one harmonics are present in the input current waveform here.

So, these are all these all these harmonics will be injected into the supply ok. So, this is the like the Fourier spectrum fifth seventh and the magnitude of the n th harmonic as you can see is proportional to 1 by n ok. So, the harmonic, the contribution of the harmonic of course, is more if we have like fifth and 7, their contribution is predominant rather than if you go to the higher spectrum their contribution goes down.

Now as I said for low power application this may be sometimes acceptable because the total contribution of this harmonic is not so great, but when you go for say megawatt applications, the harmonics the contribution of the harmonic is quite substantial and we have to take care of this harmonic.

So, one way of taking care of this is like using multipulse transformer; that is more than 6 pulse transformer ok. So, we will study one of this multiple strands multiple trans [vocalised-noise] multipulse transformer that is the 12 pulse transformer and then subsequently higher pulse transformers also ok.

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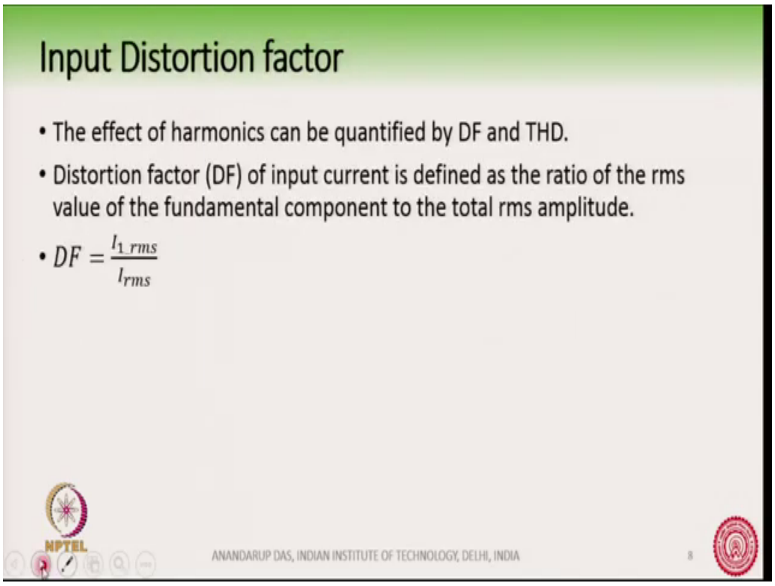

So, before I go into that, let me also say that certain [vocalised-noise] let me also quantify a certain we will put some definitions like distortion factor. So, distortion factor is kind of like a measure of harmonics ok. So, distortion factor of input current is defined as the ratio of the rms value of the fundamental component to the total rms amplitude. So, distortion factor is the fundamental rms divided by the total rms ok. In the presence of harmonics ok. So, this is one definition distortion factor.

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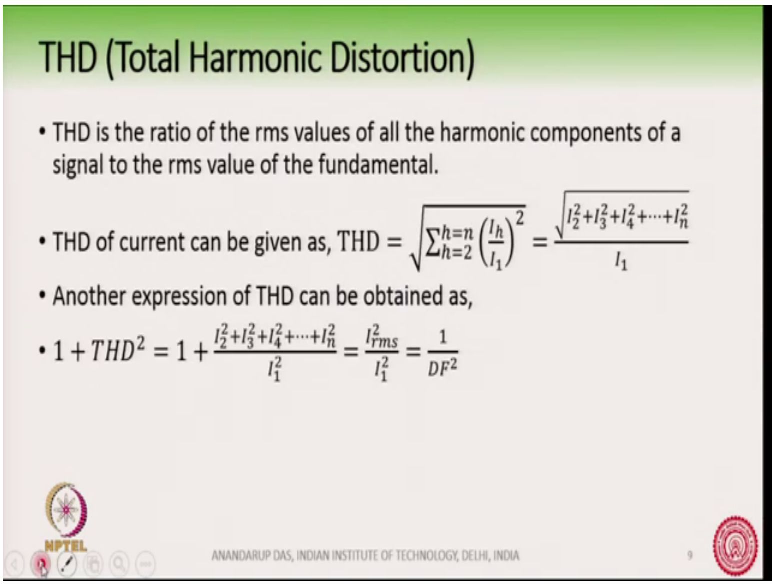

Then another definition which is frequently used total harmonic distortion. So, what is total harmonic distortion? It is, so, it is defined as like this. So, basically it is the contribution of all the harmonics as a percentage of I 1. That is as a percentage of the fundamental ok. So, it is the contribution of all the harmonics that you can see here I 2 square plus I 3 square plus up to I n square divided by I 1 ok. So, this is another quantification of harmonics which is present in the input current.

So, THD and distortion factor they are related to each other. So, you can just put the value. So, 1 plus THD square is 1 by DF square ok. You can see this relationship.

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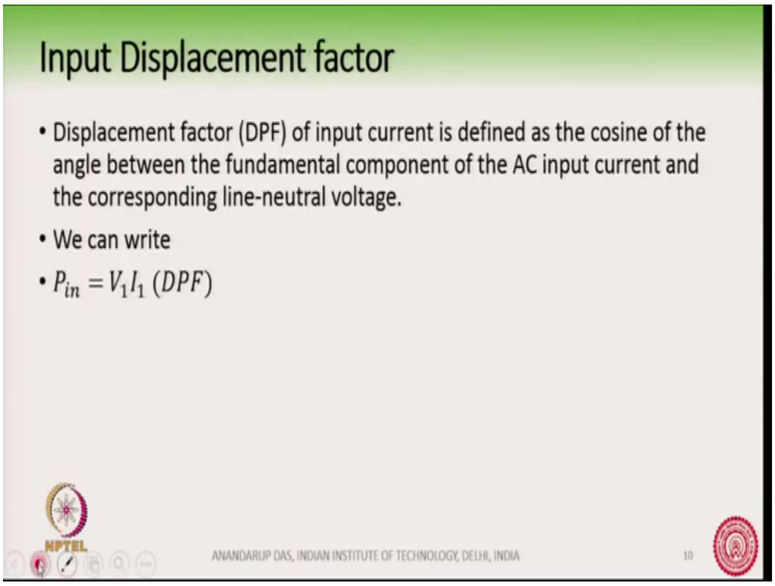

And, there is also one more definition that is called the input displacement factor. So, the displacement factor of the input current is defined as the cosine of the angle between the fundamental component of AC current and the fundamental AC voltage ok. So, fundamental AC voltage and fundamental current the angle between them cosine of that angle is called DPF or Distortion Power Factor ok. So, the power input is V 1 I 1 into distortion power factor.

Note that this voltage we are assuming to be almost very close to a sine wave. So, the harmonics in the voltage are not so significant. So, we can assume that the input voltage is a perfect sine wave without any harmonics. So, the power flow from the supply is because of the fundamental component of current and the DPF ok. Other higher harmonics of current will interact with the fundamental voltage, but the net average power will be 0 for the higher harmonic current components ok.

If we had a voltage which also has harmonics, then the voltage harmonics and the current harmonics will also cause a power flow. But most of the cases we see that the voltage is almost like a pure sine wave the supply voltage. So, it will. So, the power delivered to the load will be the interaction between the fundamental voltage and the fundamental current and the DPF. So, that is what is written here P in is V 1 I 1 into DPF.

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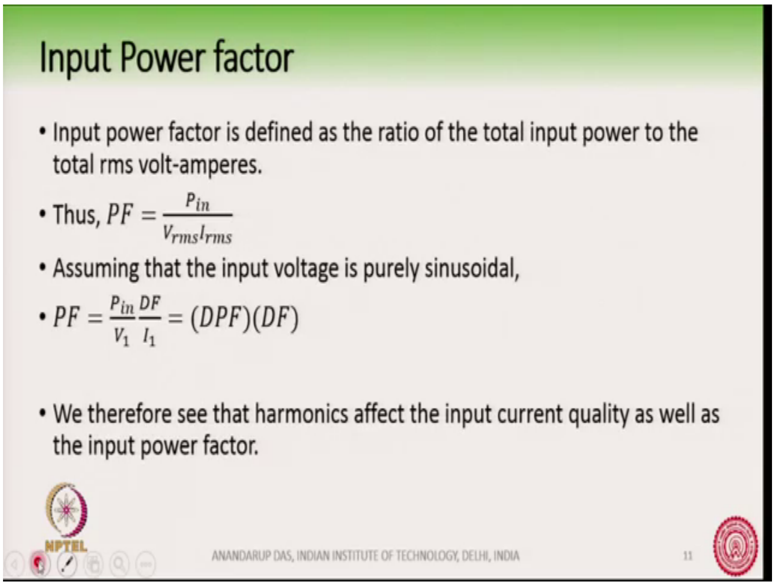

So, the input power factor is defined as the ratio of the total input power to the total rms volt ampere ok. So, the power factor is P in divided by V rms into I rms. Now, v rms is same as V in v 1, so P in by V 1. So, I can substitute P in by V 1 and what is I rms is distortion factor divided by I 1 from the definition of distortion factor.

So, therefore, power factor is equal to DPF into DF, that is power factor, input power factor is distortion power factor into distortion factor ok. And this is this relationship is noted because you see the effect of harmonics is not only to inject means the effect of harmonics also deteriorates the power factor ok. So, harmonics affect the input current quality as well as the input power factor. So, therefore, we need some methods to address this issue.

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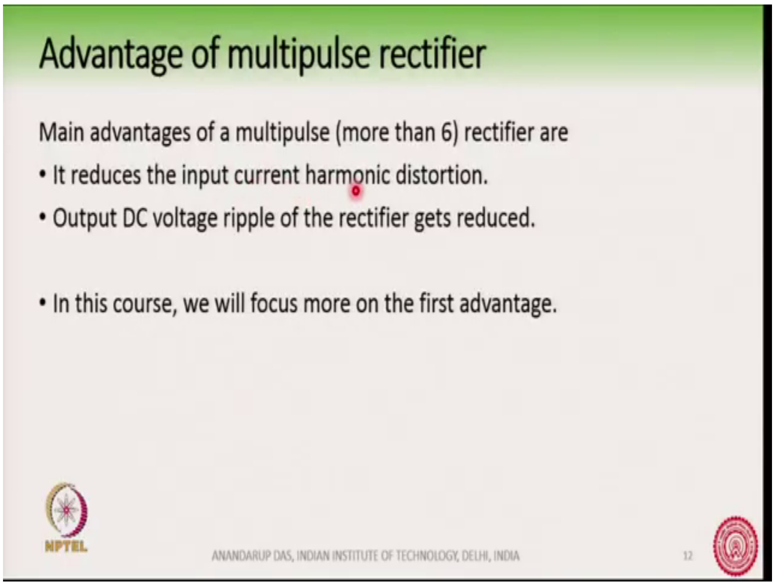

Now, there are several strategies. So, we will talk about the multipulse rectifier that is more than 6 rectifier in reducing the harmonics ok. Now, there are several types other types of strategies other types of techniques to mitigate harmonics ok. Like, you can also have active filters and others, but they are essentially a component which is outside the converter ok.

So, means that if you build a converter, it is desirable that the converter is kind of like self sufficient on it is own in terms of the input side current which is drawing from the supply ok. What I mean to say is that the input current drawn by a converter ideally should be such that it meets all these standards like IEEE 519 or IEC 61000 standards. So, therefore, the converter must have some technique inside it. So, that the input current which is drawn from the supply is more or less free from harmonics or very less in harmonics.

So, that is why for large power converters we go for a multipulse rectifiers ok. The concept of 6 pulse or the concept of multipulse rectifier, 12 pulse rectifier or 18 pulse or 36 pulse rectifier; these concepts have been taken from AC to DC rectification ok. 12 pulse rectifiers have been in use to have better quality of DC voltage ok. Wherever we used to convert from AC to DC, 12 pulse rectifiers have been quite very well established. For example, the DC bus of an NPC the NPC has a you if you recollect the NPC as a DC bus that DC bus can be fed from a 12 pulse rectifier the twelve pulse rectifier has a substantially improved harmonic performance as compared to the 6 pulse rectifier ok.

So, the advantage of multipulse rectifier is that there are two advantages mainly. So, it reduces the input current harmonic distortion and it also improves the DC voltage ripple. So, that means; it minimizes the DC voltage ripple of the rectifier in case of a 12 pulse rectifier. So, in this course we will focus more on this factor the input current harmonic distortion ok. So, this is the one which is more of concern in this course.