**Power Quality Improvement Technique**
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**Lecture – 16**
**Three Phase Converters**

Welcome to our NPTEL course on Power Quality Improvement. First of all, today we will discuss about the problem of the power quality due to this three-phase converter. Thereafter we shall talk about the multi pulse converter. First, we will talk about a 6-pulse converter for different kind of load and its THD and its solutions with the multi-pules converter.

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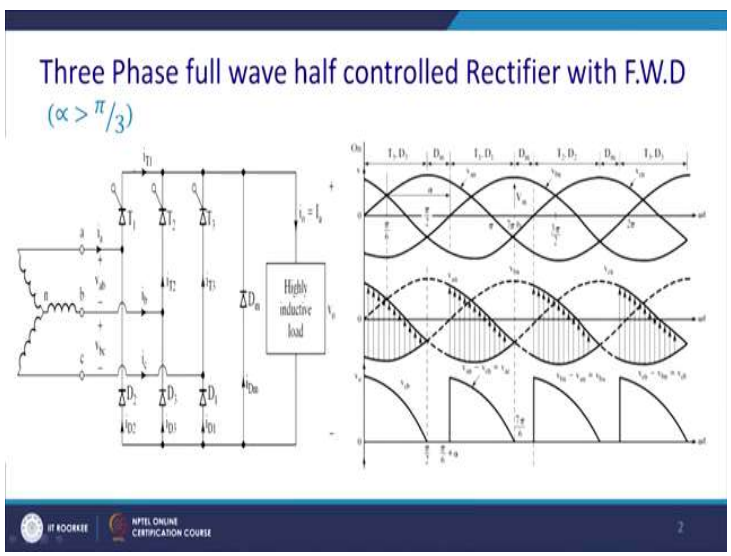


So, it is quite elementary. We have chosen that, till now in many industrial drives predominantly we had a DC motor for traction for railways. Let us say. These are the quite heavy machines in terms its rating. For this reason, still they are using this kind of control rectifier. We will just revisit the control, half control rectifier with the freewheel and you know this wave forms quite well in your power electronics courses. What I wanted to say here that we assume that a load current is highly inductive thus you have a square wave and that will be transmitted into the AC side also as a square wave.

So, these are the line voltages because this is the duration alpha, where alpha is more than pi by 360 degree. That means it will start from this point and for this reason at this duration

$T_1$ and $D_1$ will conduct and you will get a voltage that is equivalent to the Vac. Similarly, there will be a duration where freewheel will occur and you would not get any voltage.

It is better to the have a freewheel into the system otherwise you will have a negative portion of it and then due to that you will get a poor power factor. So, that is not advisable and for this reason we want that freewheel to be placed. Free wheel improves the power factor. And what about the power quality? We will discuss consecutive 2 to 3 classes on how it can be further be enhanced. So, this will be your output voltage profile.

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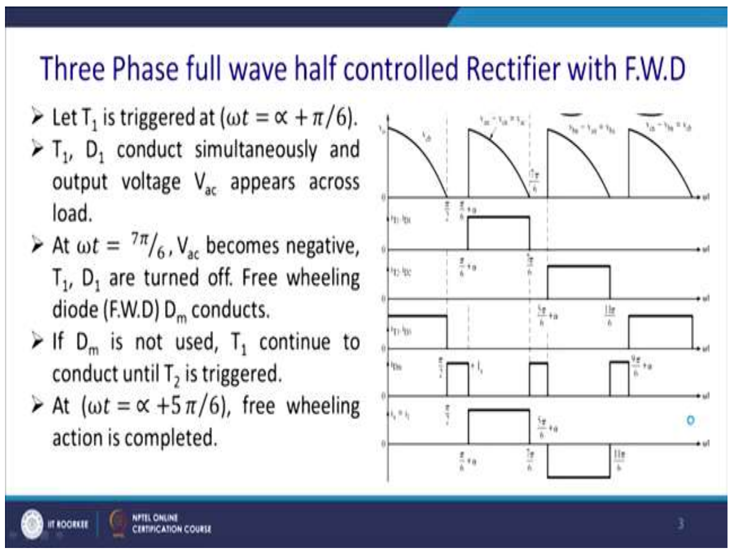


Hence, this is your output voltage profile when $T_1$ and $D_1$ conducts. So, this will be the current for phase 'a' and similarly this will be the current in phase 'b'. This will be the current for a phase 'c' and of course, if you see that the current $I_1$ then this current will be in a positive and this kind will be negative same way you will have a phase 'b' and phase 'c' or 1 2 3.

So, thus it is quite elementary. Just for the sake of recap, I am just telling. Let us take $T_1$ is been triggered at an angle $\left(\alpha + \frac{\pi}{6}\right)$. So, $T_1$ and $D_1$ conducts simultaneously and output voltage Vac will appear across load. At $\omega t = \frac{7\pi}{6}$, Vac becomes negative, $T_1$ and $D_1$ are turned off and freewheel actions takes place. If Dm is not used, $T_1$ continues to conduct until $T_2$ is triggered and thus you will have a negative portion of it into the load voltage.

This is essentially what will happen. You will degrade the power factor. And at $\omega t = \left(\alpha + \frac{5\pi}{6}\right)$ freewheel again be completed for the $T_2$ $D_2$.

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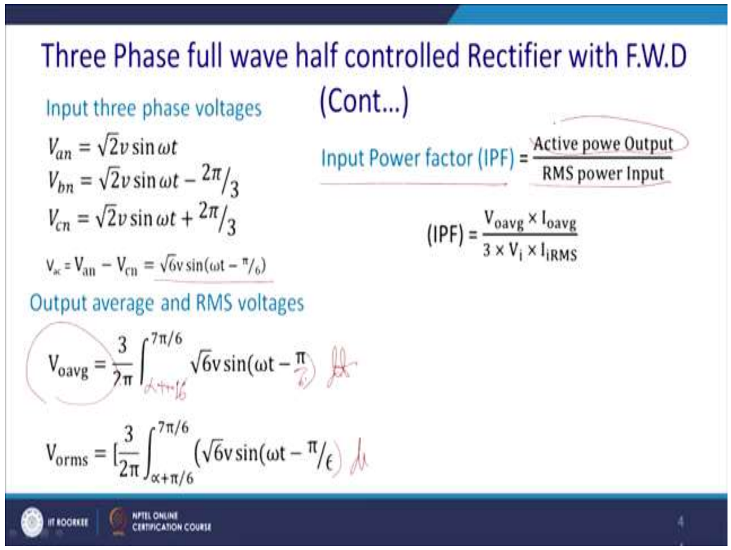


Now, we have some parameter to be analyzed. So, They are 20 degree phase shifted wave form and Vac equal to Van minus Vcn. So, ultimately you get $\sqrt{6}v\sin\left(\omega t - \frac{5\pi}{6}\right)$ and if you integrate over it, they will get 3 cycles. You will get the average power and you get the RMS value of it. Of course, you have to integrate over dt. Thus, the input power factor is a important quantity and this important quantity is the active power by the RMS input power. Once you have a negative portion of it the active power essentially will be subtraction.

So, if you have this portion of it in without freewheel. Then what will happen? Effective average value will come down and thus input power factor will be lowered. This is the expression of it $IPF = \frac{V_{oavg} \times I_{oavg}}{3V_i \times I_{iRMS}}$.

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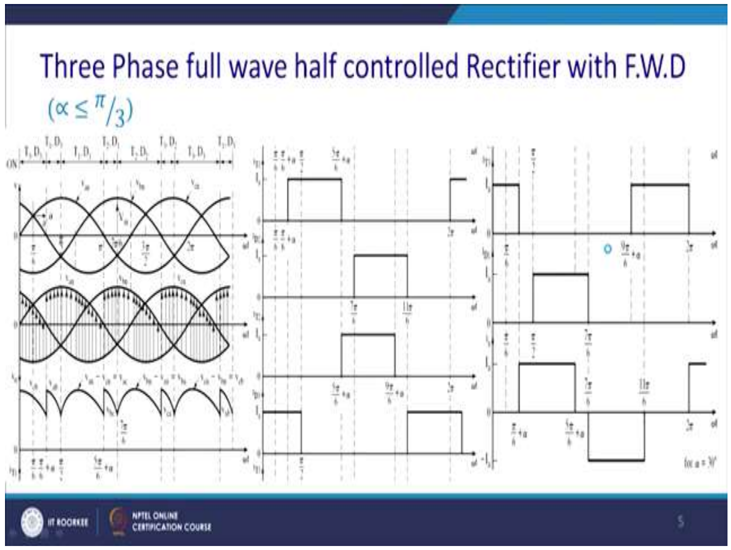


Now, for the three-phase full wave half control rectifier these are the wave forms you have studied in the power electronics. So, you start from this point for continuous and for alpha less than 30 degree. So, ultimately you triggered alpha here $T_1$ $D_3$ will conduct. So, you get the voltage first ‘cv’ that thereafter ‘ab’, thereafter ‘an’ thereafter ‘cn’, ‘ac’, like that you will get the waveform. So, this will be the current through the thyristor $T_1$. This will be the current through the diode $D_2$. Similarly, you can have the current. This is the thyristor $T_1$ if you combine, this will be the phase current and you can see that the symmetry is lost previously we had a symmetry.

So, ultimately you got this kind of input current. That is our contention now. So, you get this kind of square wave and you know here this point is little more. This is $\left(\alpha + \frac{\pi}{6}\right)$ and this point is quite less. So, you have an asymmetry, but if you go back to this circuit generally there was no asymmetry. Ok?

So, we have to do the Fourier analysis of this waveform and ultimately come up with what should be the harmonic content of it and what is the THD of it and how we can mitigate. Of course, we cannot use thyristors. If we use thyristor, we have to go for different solutions. But apart from that we required to visit the fact that how to mitigate this problem.

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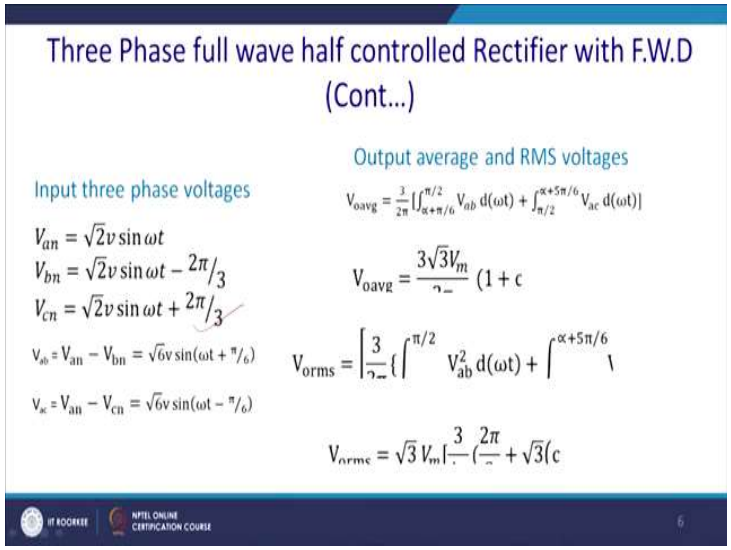


So, this is the 3-phase, phase shifted voltage and ultimately $V_{ab} = V_{an} - V_{bn} = \sqrt{6}v \sin\left(\omega t + \frac{\pi}{6}\right)$ and $V_{ac} = \sqrt{6}v \sin\left(\omega t - \frac{\pi}{6}\right)$. So, you can get the average value.

So, you have to have a 3 such pulses. So, 3/2π, from π+π/6 to π/2 where you will have that voltage Vab there after you will have a voltage Vac and you subtract it and ultimately you have the average voltage and the RMS voltage.

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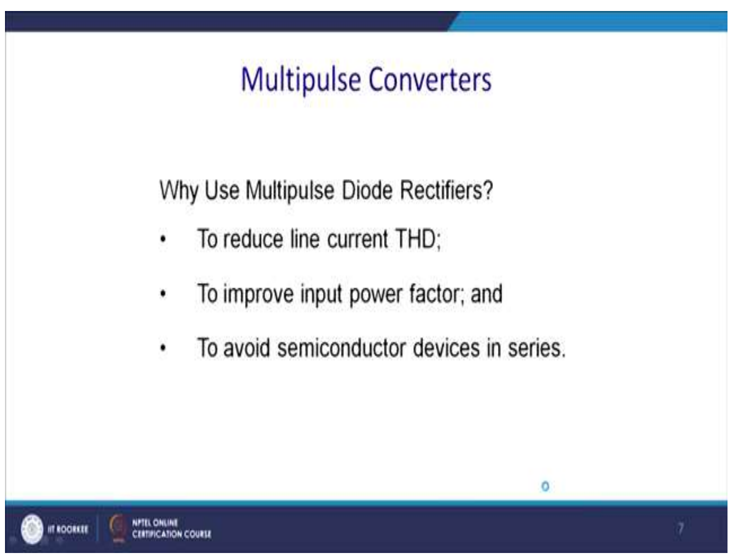

Now, this is the problem of the converter. So, why to use the multi pulse diode rectifier? I will show little later that current THD will be around 30 percent and to improve the input power factor you will have a voltage. You required to have also close to 0.95 and to avoid the semiconductor devices in series. So, that it may get damaged severely because if you have so much devices in series then turning on and if there is a delay, whole stress will be on other devices and thus device may be damaged.

But that is not the case of the multilevel inverter. We shall separately discuss about the multilevel inverter and its applications of the power quality. So, we will come later to that. But let us talk about this 6-pluse diode bridge rectifier and ultimately what you get is Vab and that is a simplest circuits we can have in the three phase and this one is your $\sqrt{2}v_{LL}\sin\left(\omega t-\frac{\pi}{6}\right)$.

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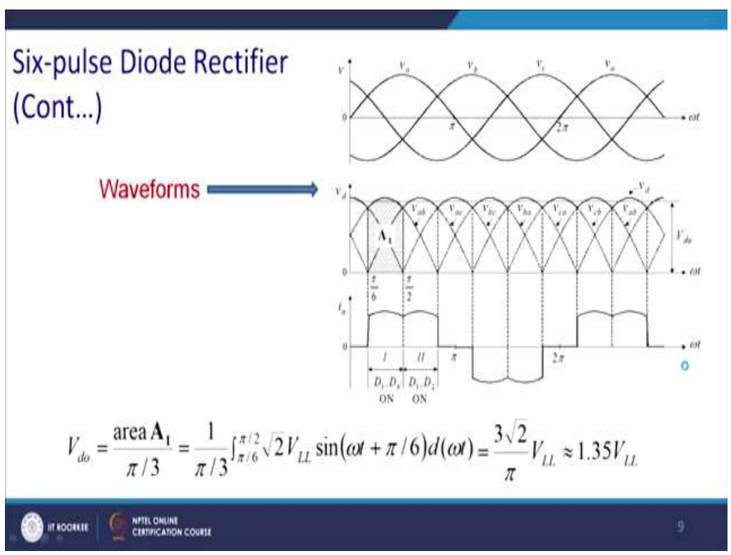


Similarly, we can calculate and ultimately you can see that current pattern instead of the square wave we will have this kind of waveform for resistive kind of load. But if you make this current RL, you can get a straight line also for the inductive kind of load. So, ultimately as you have seen that for this duration it will start in conduction mode because it is equivalent to alpha equal to '0'.

So, it will start in the conduction mode when $D_1$ and $D_6$ starts conducting and thus you get the $\frac{areaA_1}{\pi/3} = \frac{1}{\pi/3}\int_{\pi/6}^{\pi/2} \sqrt{2}\, V_{LL} \sin\left(\omega t + \frac{\pi}{6}\right) d(\omega t) = \frac{3\sqrt{2}}{\pi} V_{LL} \simeq 1.35 V_{LL}$,that will appear as a DC voltage in case of the diode bridge rectifier.

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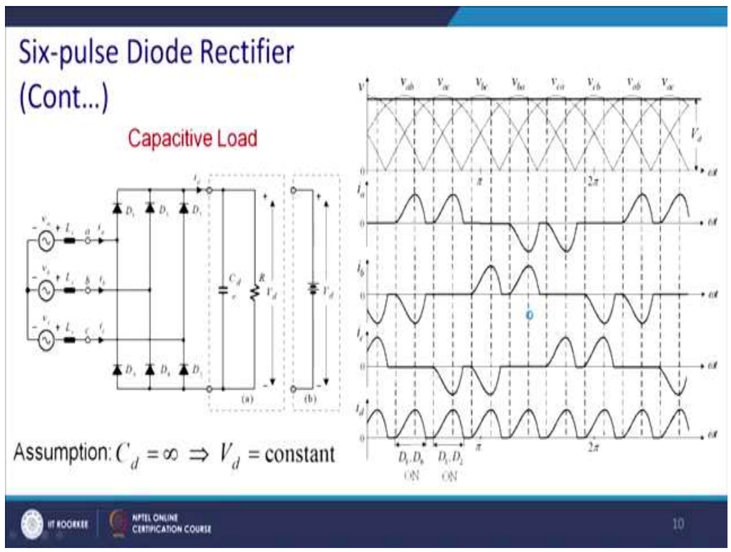


So, we can calculate what is a line to line voltage in RMS. Let us multiply with 1.35 that will be your DC average voltage. Now, this is the case. Once you want a constant DC pulse voltage and due to that you required to put a huge capacitor and once you put the huge capacitor then it becomes constant. In that case that is the quite detrimental because current will flow once this Vab crosses this value of the Vdc only, for that much of duration.

So, current will be only for this much of duration. Again, it will be flowing for AC once it goes high for this duration, similarly for 'ba' and the 'ca' and so on. Thus, you got a problem of the shifted power factor for displacement power factor. For this reason you can see that this is $i_a$, $i_b$, $i_c$ and it will have a rather more nasty THD for the capacitor and it can go as high as 70 percent for the light load. So, this will be the diode current $i_d$ and that will be like this where $D_1$ $D_6$ conduct, $D_1$ $D_2$ conduct and so on.

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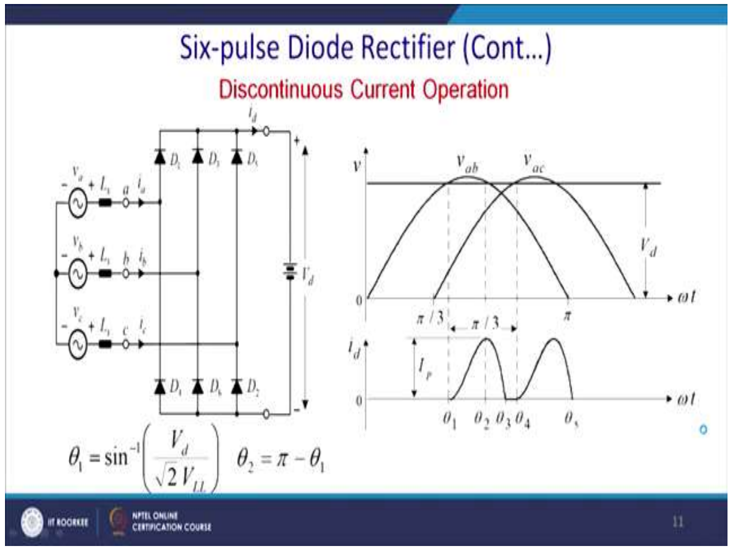


Now, how you will calculate the conduction angle? So, this is a $\Theta_1 = \sin^{-1}\left(\frac{V_d}{\sqrt{2}V_{LL}}\right)$ where it is $\Theta_2 = \pi - \Theta_1$ because you cross over here then this D 1 will be forward biased and current will flow. Again, at this point it will be reverse biased and current will not flow. But what happened? For the Vac again this phenomenon will occur. So, ultimately this will conduct, till this time. That is for the $\Theta_2$ to $\Theta_3$ there will no conduction for this time. Again, it will pick up in this duration. When AC again crosses the capacitor value and due to that this will be the nature of the current.

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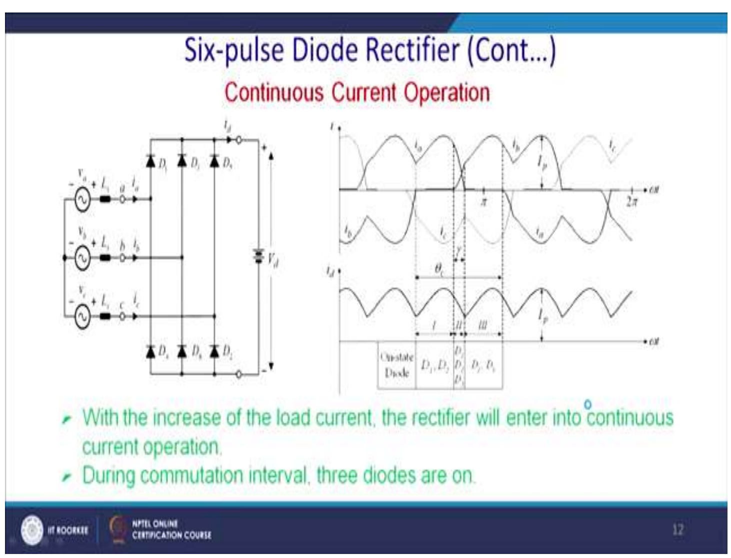

And this is a worst condition rather you might be the charging the battery and that is a quite common applications that we will be doing. And there what happens? You can see that this is the different current has been shown. This is $i_a$. This portion L is $i_a$ and I have just taken a different color pen. May be blue. So, this is $i_c$ and this one is ib. So, ultimately this will be the current profile and its TSD is equally bad.

This is the overlapping region, where 3 devices conduct. So, $D_1$, $D_2$, $D_3$. So, $D_1$ and $D_3$ for the upper leg and $D_3$ from the lower leg. So, what happened? Then with the increase in the load current, the rectifier will enter into the discontinuous current operation. During the commutation interval that 3 diodes are on. That is the one of the issues. So, you have a more conduction loss also. Please understand that all diodes are of power diode. It is not the simple signal level diode that you have a 0.7 volt drop, you may have more voltage drop because of the more epitaxial layer of the plus 'n' region.

So, you can have these drop may be 1 volt or 1.2 volt, if it is carrying 50ampere of current. So, 3 diode it is current 30, 3 volt each plus 50. So, 150watt will be lost due to that. So, this system is also quite inefficient apart from that is a problem of the power qualities.

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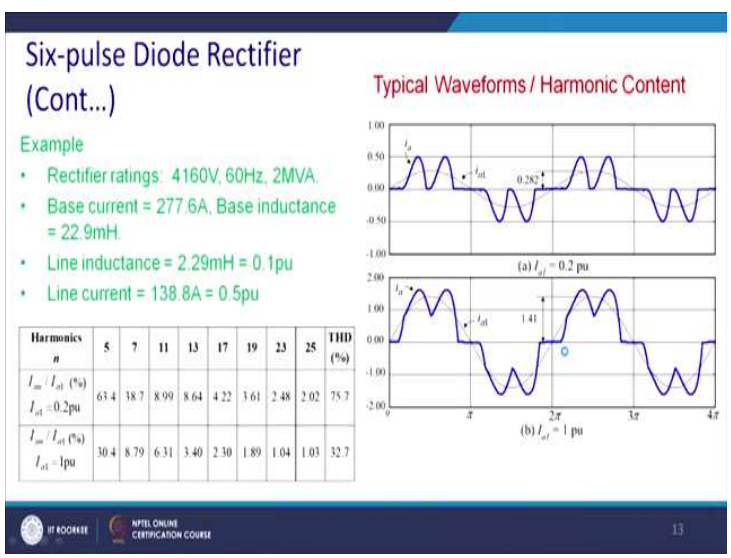


So, this is something like that waveform. We can see that is the example of the 6-pulse diode bridge rectifier and the rectifier rating is of this much volt, 60 Hertz and 2 MVA. So, base current is this much ampere and the base inductance is 22.9 milli Henry and line inductance is this much per unit. So, this is the profile of this and ultimately this is the fundamental of this current and you can see that this is the $I_1$ when per unit loading is less. So, you have that 63 percent of this harmonic, 5th harmonic and it is also negative sequence component to some extent. Why? Because if you sit on the sixth harmonic with respect to it, it is a negative sequence.

So, this is the 7th harmonic, these are 11, 13 and so on. We consider the 3 phase 3 wire system. So, multiple of 3 is absent. So, you can see that the THD as high as 75 percent for the light load and once you upload it little bit. So, it will come down to the level of 32.7 percent. We have discussed about the power quality. We have seen that restricted power quality is 5 to 3 THD. So, here you got a THD well above that the standard requirements. So, what can be the solution?

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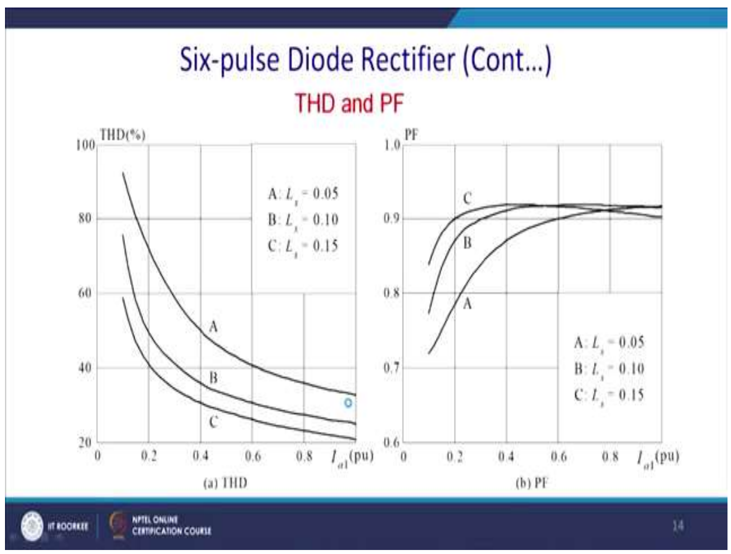


Also, we wanted to check few aspects of this. This is the effect of the THD. Source inductance. You know that effect of the source inductance. So, as an effect of the source inductance you will have an overlapping region into the line current and thus no power will be supplied during that region. That is that angle $\cos\mu$. Due to that what happened? Power factor degrades with higher source inductance, but it is better for the THD point of view. It will try to reduce the displacement power factor and for this reason you can see that this is the graph for very low source inductance.

So, this is the curve while increasing the load and this is a curve for Ls equal to 0.1 for increasing this load and for having a quite considerable amount of the source inductance you can see that even that THD is comes out to be close to the 5 percent here which is quite acceptable.

On the other hand, you can find that at the low frequency, lower source inductance will give you better power factor, but gradually once it is close to the load it increases. So, that gives you better power factor. So, we can add the source inductance which will considered to be a detrimental. It is not that detrimental considering the power quality problem.

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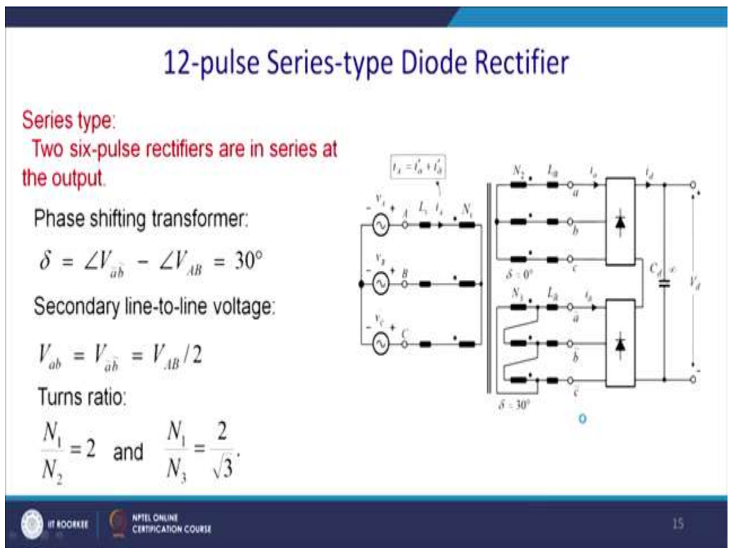


So, for this reason you know we can think of a 12-pulse converter. So, this is a concept of the 12-pulse converter. We can have 18-pulse converter, we can have a 24-pulse converter as well as the 48-pulse converter. For sake of time again, we required to restrict our discussions on the 12-pulse converter and you are required to go through the other method. It is the same extension of the 12-pulse converter.

So, I just take the example where this angle is 30-degree phase shifted and the secondary line to line voltage $V_{ab} = V_{\widetilde{ab}} = {}^{V_{AB}}/_{2}$ because one is star, another is delta. This primary is star and you can see that this one is star and this one is delta. So, there will be a phase shift of 30 degree between these two lines and ultimately, they can be connected in series and the required ratio generally is required to be $\frac{N_1}{N_1} = 2$. So, $N_1$ is a primary side and generally it is in the distribution side.

So, we expect that it would be required to be stepped down but you require the same level of voltage and for this reason you know it got more line voltage for this reason the ratio required to be 2. Here ratio required to be .1 by 0.866 rather. $\frac{N_1}{N_1}$ is required be 2 by 1.732. So, it will be little higher than 1. So, in that way you required to fix up the winding and you see what happened then.

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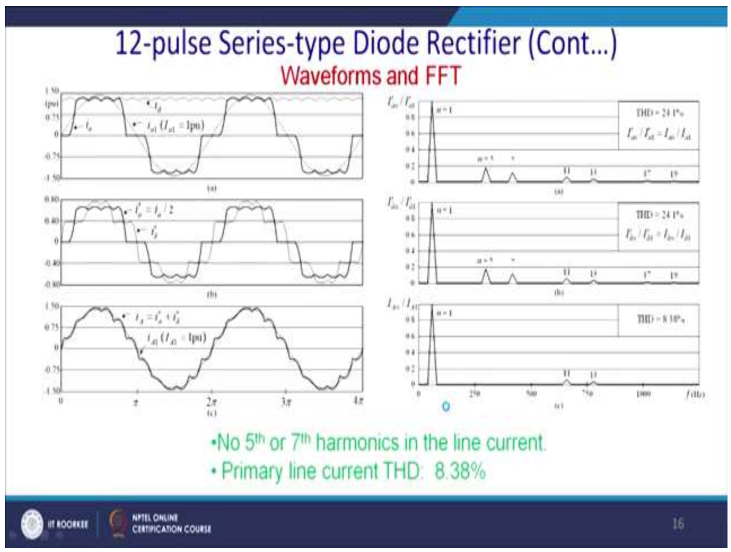


So, this is the first. This one is the waveform for the first converter that is $i_a$ and for the primary. And this one will be essentially for the $i_a$ prime and ultimately this has to be added up. So, this wave form and this wave form required to be added up and ultimately if you add up you get this wave form. That is as your input. So, as you know that there will be a fundamental as well as 5th 7th and there will be a fundamental and the 5th and 7th, but they will cancel out since they are 30-degree phase shifted.

So, thus what happens? Fifth and seventh are of equal magnitude, but in opposite direction hence will cancel out and ultimately you will have 11 and 13. So, what happened? In the star side of it are the primary, you will not have any 11 and 13. So, you can see that due to the absence of 11 and 5th and 7th harmonic that THD has been increased to 8.38 percent. That is close to your 5 percent standard. Some way it is acceptable.

So, if you want to have more, then we required to go for the 18-pulse converter. Hence, you require a typical design and there after you can have your 15-degree phase shift for this 24-pulse converter and also you can go for the 48-pulse converted. Let us see that what are the changes of the loading, of the THD.

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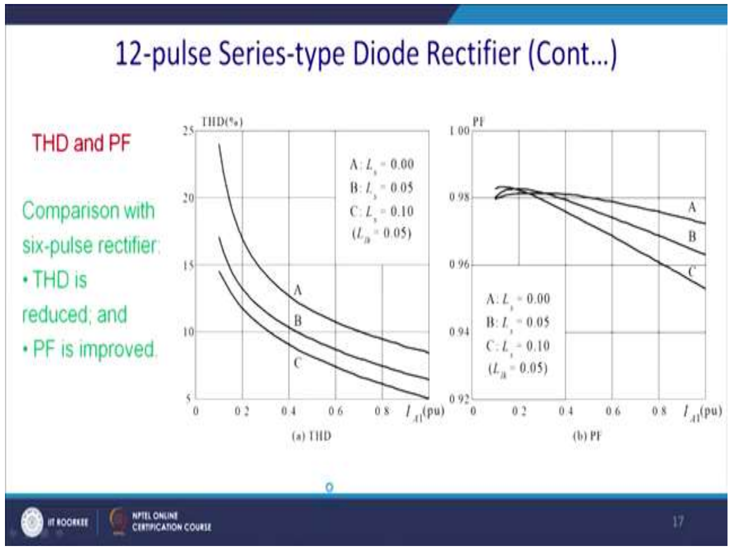


You know while source inductance being ‘0’ that is ‘A’ most unlikely, but there we can consider a heavy inductance. But it is quite low inductance. So, this will be the THD. Ultimately if you load it, it comes close to the 8 percent. That is what has been mentioned with the previous slide. So, if you have little more source inductance of 0.5, it will come to around 0.6 and generally it is present and thus you almost get into the 5 percent standard and if you have added around 5 percent inductance. So, you can see that you can well above the requirements and with the leakage reactance of 0.5 percent because that is generally present here because of this transformer.

So, similarly you can have ‘A’ that is the THD is being fed to ‘0’. So, if you load it there will be a little drop because of the leakage reactance which is present. That is quite normal. Little drop in the overall power factor, but we do not bother about power factor, if it is closed to 0.9. But it is well above 0.9. So, for this reason this solution is acceptable to us. So, at ‘B’ gives you little close to 0.95 and ‘C’ gives you little bit less than 0.95.

Thank you for your attention. I shall continue our discussions about the different topologies. Thereafter we shall visit that solutions because this is one of the solutions of for this 12-pulse. We can have solution with the 18 pulse as well as 24 pulse, 48 pulse whereas designing constraint is quite complicated and you required to have this solution which is quite bulky. Instead of that we may look for power electronic solutions based on the three phase PWM rectifier. That we can see and we can also find its applications.

So, we shall continue our discussions. First the problem of the three-phase power converter and from there diode bridge rectifier which we prefer because it is also quite simple, but it is a 12-pulse rectifier. So, same way we required to change the transformer pattern and we can have an 18-pulse converter. Same way we can have a 24-pulse converter and so on. So, these are some observations and some portion of the mitigations of the power quality by multi pulse converter.

Thank you.