Advance Power Electronics and Control
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Lecture – 13
Three Phase Converters - II

Welcome to our NPTEL lectures on advance power electronics and control today we shall continue to discuss with the 3 phase converter. Now we are discussing about in previous class when the firing angle alpha.

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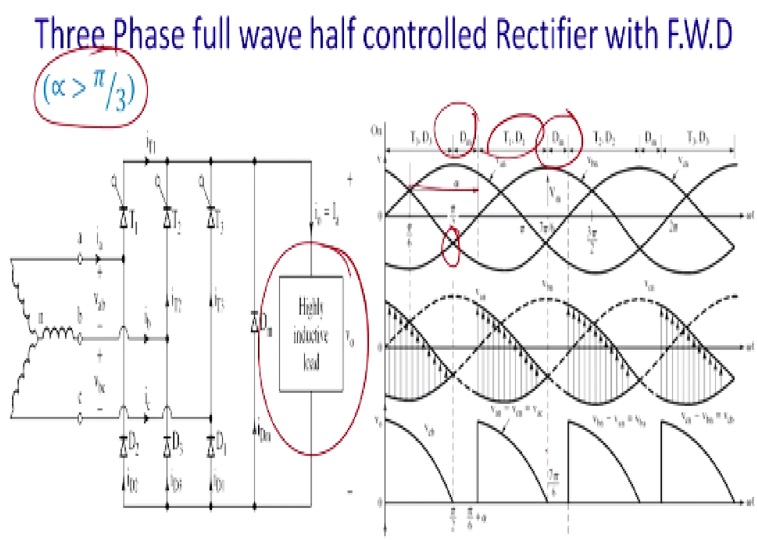

More than 60 degree so let us see that how the wave form will work for the half controlled converter for alpha > 60 degree and this is a mode where discontinuous operation start and we assumed that this it is highly inductive load. So, we always start from the crossing up a and c from this point. So, it is been delayed by an angle more than Pi/3 so till this point actually you can see that you know when actually this crossover takes place at Pi/2.

Then T3 and till T3 and D3 conducts after that since this crossover takes place B is no longer most negative phase and it will be naturally this D3 will be stop conducting. And thus then free wheel action will takes place through this to till the time the T1 is not triggered. And this will be the sequence T3 D3 thereafter will be an interval of the time where free wheel action will take place followed by T1D1.

Then it will continue so in every actually crossing in negative of cycle will there will be a fresh shipped and the lower diet will actually naturally will put off and this actually free wheel diet will comes into the picture. Similarly, it will sequence and you will get a voltage like first CV then after ac and then after ba and cb so instead of the 6 wave form in this case you are going to get a 4 wave form.

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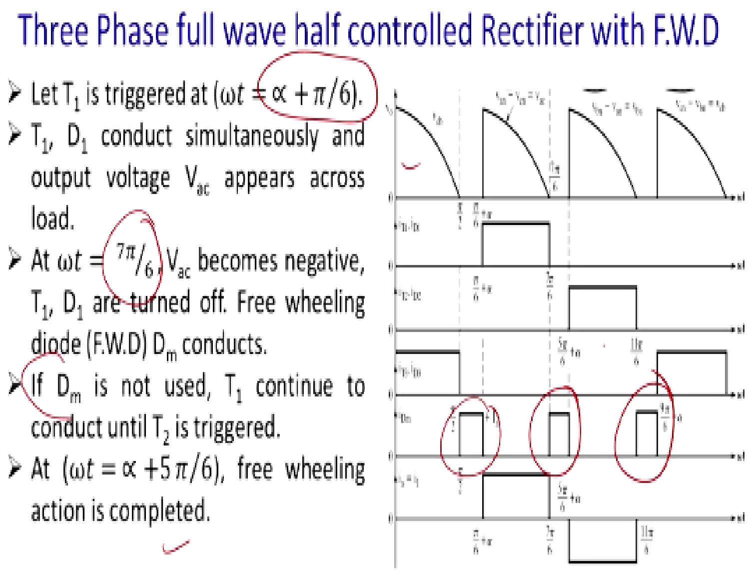

Now 3 phase full wave half controlled converter same thing will continue so discussion is let us triggered T1 at an angle Pi/6+ alpha. So, T1 and D1 will conduct and output voltage will appear across this AC thereafter at Omega t =7Pi/6 V ac becomes most negative actually D1 will turn off and free wheel action will take place. And if Dm is not used T1 will continue to conduct until T2 is triggered since float is highly inductive.

At omega t = alpha +5Pi/6 again free wheel action is completed so this is the output voltage this is cb and this is actually sc that fba and cb and this is the current Thyristor T1 and square wave kind of thing and thereafter this is the current through Thyristor T2 and D2. Similarly, it is a current through the Thyristor T3 and D3 and this is the inverter interval where actually free wheel act will conduct and input current. You will have this kind of sequence how 120 degree conduction.

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Three Phase full wave half controlled Rectifier with F.W.D (Cont...)

Input three phase voltages

$$V_{an} = \sqrt{2}v \sin \omega t$$
$$V_{bn} = \sqrt{2}v \sin \omega t - {2\pi}/{3}$$
$$V_{cn} = \sqrt{2}v \sin \omega t + {2\pi}/{3}$$
$$V_{ac} = V_{an} - V_{cn} = \sqrt{6}v \sin(\omega t - {\pi}/{6})$$

Input Power factor (IPF) $= \frac{\text{Active powe Output}}{\text{RMS power Input}}$

$$(IPF) = \frac{V_{oavg} \times I_{oavg}}{3 \times V_{l} \times I_{IRMS}}$$

Output average and RMS voltages

$$V_{oavg} = \frac{3}{2\pi}\int_{\alpha+\pi/6}^{7\pi/6} \sqrt{6}v \sin(\omega t - {\pi}/{6})\, d(\omega t)$$

$$V_{orms} = [\frac{3}{2\pi}\int_{\alpha+\pi/6}^{7\pi/6} (\sqrt{6}v \sin(\omega t - {\pi}/{6}))^2\, d(\omega t)]^{\frac{1}{2}}$$

So, we required to understand now we can see that the Van and Vbn and Vcn will have a same sequence 120 degree – phase shift Vac will be Van –Vcn that will be under root 6 v sin omega T – Pi/6 thus this output voltage hour h voltage we calculate. So we have 3 such cycles in 120 degree fresh shifted. So, it is alpha+ Pi/6 to 7 Pi/6 1/Pi so this is 3 interval, so it is multiplied by 3 and ultimately it is under root 6v sin omega t –Pi/6 d omega t and similarly output arrives at voltage calculated by the same method of integrating over the trait alpha + Pi/6 to 7Pi/6.

Similarly, the input power factor will be actually active power output / RMS power input this IPF average voltage / RMS voltage.

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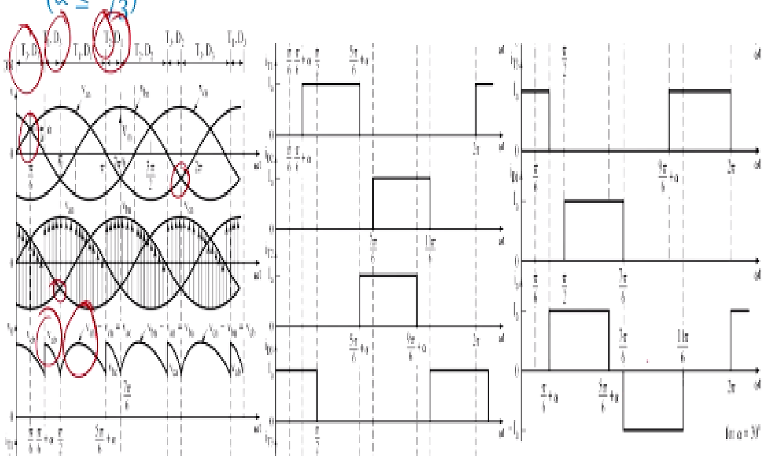
Three Phase full wave half controlled Rectifier with F.W.D

$(\alpha \leq {\pi}/{3})$



Now this is the 3 phase full wave half controlled rectifier with the free wheel action where the triggering angle is <= Pi/3 60 degree now in this configuration you know 1st as the instant of this triggering is physically the crossing over of the a and c so from this point actually we measure alpha till that time actually T3 D3 was conducting now T1 is triggered and from the negative half the direct D3 is conducting.

And it will be actually commutated at this point when the cross over b and c takes place and thus from this point on T1D1 will conduct and you know it will conduct till the commutation takes place. National commutation takes place of T1 because of the firing of T2 and till this point actually T2D1 will conduct and there after T2D2 will conduct and after that again when it is again at 0 crossing of this point.

So, there will be a fresh change and here T3D2 will conduct and same sequence we will continue. So, here instead of the 4 pulses previously we will have a voltage and it will be a continuous and will get six pulses so the time actually alpha Pi/6 to 2 + Pi/2 you will get for CV. Thereafter, you get ab there after you get an and thereafter you get an - cn = VC and there after ba in between you get ca again you get cb you get ab and such a way it will continue.

And the current flow Thyristor you will find that actually it will be delayed by some angle alpha from the actually Pi/6 so it will continue to 5 Pi/6 + alpha and thereafter again it will continue after Pi/2 so similarly D 2 will conduct all at time 7 Pi/6 to 11Pi/6 and so on and effectively you will see that actually the infest current IA will be actually conduct from Pi/6+ alpha to 5 Pi/6 alpha. Similarly, begin to conduct for 7Pi/6 alpha to 11Pi/6 + alpha and so on.

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Three Phase full wave half controlled Rectifier with F.W.D (Cont...)

Input three phase voltages

$$V_{an} = \sqrt{2}v \sin \omega t$$
$$V_{bn} = \sqrt{2}v \sin \omega t - {}^{2\pi}/_{3}$$
$$V_{cn} = \sqrt{2}v \sin \omega t + {}^{2\pi}/_{3}$$
$$V_{ab} = V_{an} - V_{bn} = \sqrt{6}v \sin(\omega t + {}^{\pi}/_{6})$$
$$V_{ac} = V_{an} - V_{cn} = \sqrt{6}v \sin(\omega t - {}^{\pi}/_{6})$$

Output average and RMS voltages

$$V_{oavg} = \frac{3}{2\pi}\left[\int_{\alpha+\pi/6}^{\pi/2} V_{ab}\, d(\omega t) + \int_{\pi/2}^{\alpha+5\pi/6} V_{ac}\, d(\omega t)\right]$$

$$V_{oavg} = \frac{3\sqrt{3}V_m}{2\pi}(1+\cos\alpha)$$

$$V_{orms} = \left[\frac{3}{2\pi}\left\{\int_{\alpha+\pi/6}^{\pi/2} V_{ab}^2\, d(\omega t) + \int_{\pi/2}^{\alpha+5\pi/6} V_{ac}^2\, d(\omega t)\right\}\right]^{\frac{1}{2}}$$

$$V_{orms} = \sqrt{3}\, V_m \left[\frac{3}{4\pi}\left(\frac{2\pi}{3} + \sqrt{3}(\cos\alpha)^2\right)\right]^{\frac{1}{2}}$$

Now we require to again calculate what we have done in case of the alpha more than 60 degree we required to done also alpha <= 60 degree 90 so value of the RMS voltage and the value of the average voltage given by same thing it is alpha +Pi/6 Pi/2 Vab + they will be a limit change it will be 0 otherwise in the previous condition. So, Pi/2 alpha + 5Pi/6 Vac d omega t so from there the value will be come out to be 3 root 3Vm/2Pi 1 + cos alpha for this alpha< 60 degree.

So, what will be the value for this condition similarly for RMS value we can also calculate so this value to be comes out to be that 3 root Vm 3/4Pi 2Pi/3+ root 3 cos alpha square the whole under root of 2 so this will be the average RMS value for alpha <= 60 degree. So, the expressions of the voltages half control converter will be changing depending on the triggering angle.

Now let us introduce because you have seen that you know that we shall discuss a little later about the power quality issues since we have a more number of pulses within a cycle is more. It is easier to rectify and moreover so the distortion of the current in input the (()) (09:53) side will be less considering that can we use a multiple diode based rectifier that is the simplest because you do not require triggering circuit.

And thus we can reduce the THD and other parameter which is actually conflicting while DC to DC conversion.

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Multipulse Converters

Why Use Multipulse Diode Rectifiers?

- To reduce line current THD;
- To improve input power factor; and
- To avoid semiconductor devices in series.

So, for this you know we have to keep in mind to reduce the line THD and to improve the input power factor and avoid the semiconductor devices in cities to have a higher rating. So, for these things let us come back again us natural 6% water we have discussed initially and we assume that 6 pulse feeding resistive load.

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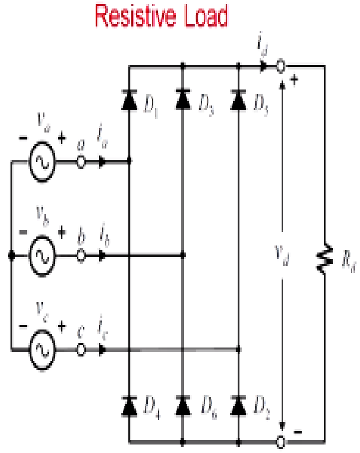
Six-pulse Diode Rectifier

Resistive Load



Supply Voltages

$$v_a = \sqrt{2}V_{PH}\sin(\omega t)$$

$$v_b = \sqrt{2}V_{PH}\sin(\omega t - 2\pi/3)$$

$$v_c = \sqrt{2}V_{PH}\sin(\omega t - 4\pi/3)$$

$$v_{ab} = v_a - v_b = \sqrt{2}V_{LL}\sin(\omega t + \pi/6)$$

And you know actually VAB= Va – Vb, it is actually root to V LL sin omega t + pi/6.

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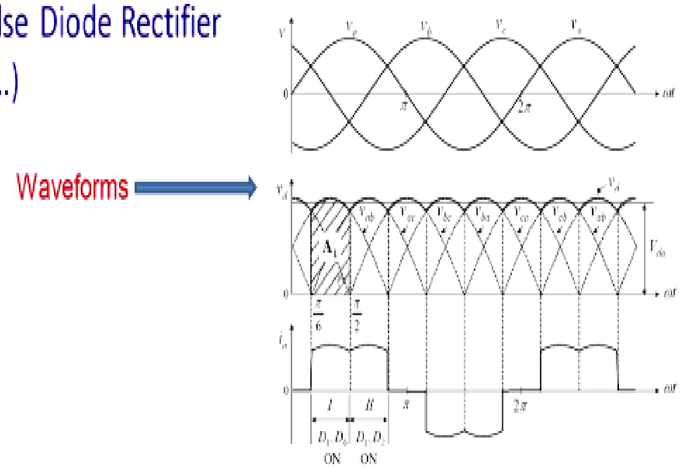
Six-pulse Diode Rectifier (Cont...)



$$V_{do} = \frac{\text{area } \mathbf{A}_1}{\pi/3} = \frac{1}{\pi/3}\int_{\pi/6}^{\pi/2}\sqrt{2}V_{LL}\sin(\omega t + \pi/6)\,d(\omega t) = \frac{3\sqrt{2}}{\pi}V_{LL} \approx 1.35V_{LL}$$

And so six-pulse you can find it out what is actually the wave form. Wave form will be like this so this is the for the area A1 same kind of area will be available for other so you can get due to that you know what happen the current will have this kind of actually the profile so for here D1 D6 conduct and here D1 and D2 conduct so actually the output voltage due to this diode can be actually you have 3 such area so area A1/ Pi/3.

So,1/Pi/3 you have to integrate actually since this area is basically sin AB. You can see here basically sin AB voltage so Pi/6 Pi/2 root 2 VLL sin omega t +Pi/6 d omega t =3 root 2/Pi VLL that is basically receive voltage comes out to be 1.3 times of line to line voltage so that is something you require to keep in mind while you use for a six-pulse converter 3 phase six-pulse converter and what happen you know this things become drastically changes. You know and when we have a RC load the current will conduct assume that this value is ready.

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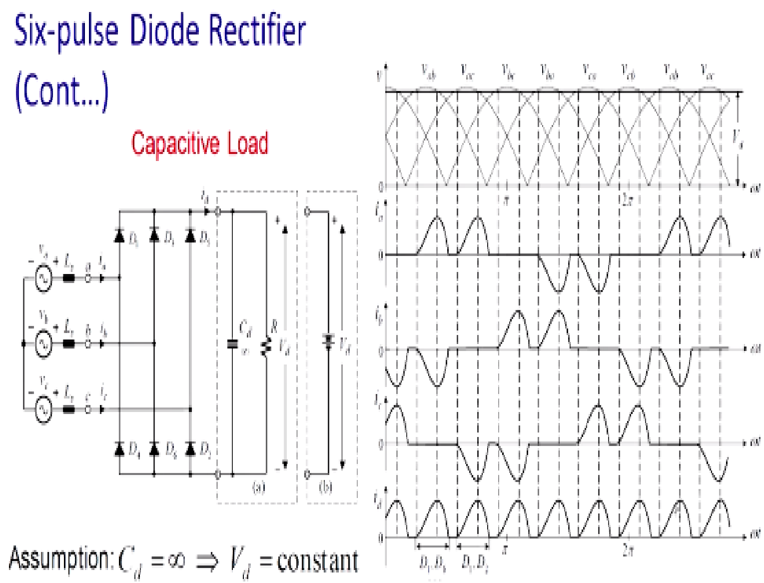

Current will conduct you know once this is actually the most positive phase is more than this actually the Vdc or Vd. So for this small interval where actually phase AV is more than this is the output of Vd so current will conduct similarly it will conduct for a very small interval of pain. So, accordingly you will have that and this is the input current and which is very much contaminated with the harmonics.

And this is a critical case when we basically use we basically we want almost a huge dizzy capacity to make it triple free. And due to that you pay the penalty in the input side having very degraded value of the disbursement power factor THD and all those issues and the current through the diode id will have this kind of pulses so it is not a constant current.

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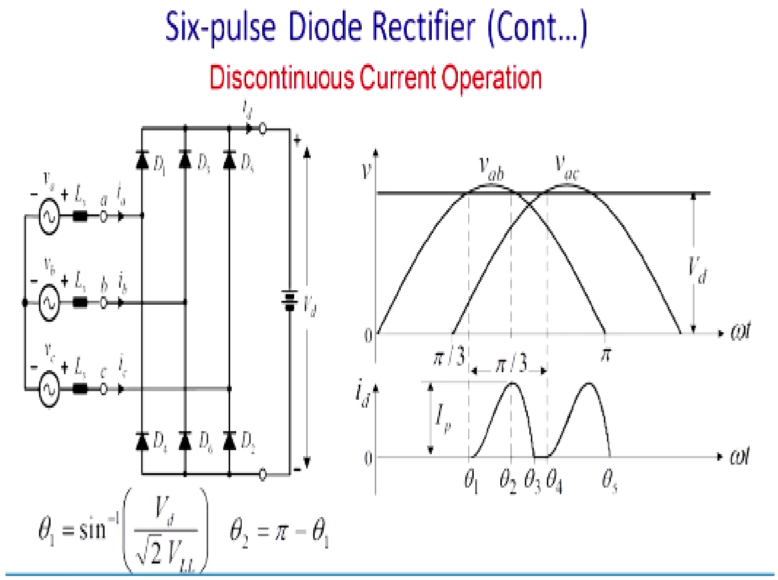

So, let us take a six-pulse converter discontinuous current mode what happened here till this value Vav is actually more than this rectified voltage till that time current will not flow. So, it will current will start picking up at a point let us say theta 1 so when actually Vab crosses and Vac will have phase lag of pi/6 so once actually at this point once again it will 0 crossing takes place so then what happen capacitors current continue to flow due to that reasons.

Actually you will have the current will come back like this since till this value voltage line voltage ac will again cross this actually the VDC. There is no current will flow into the system and thus you will have this kind of current and the theta 1 can we calculated that is actually sin inverse of Vd / theta 2 definitely is willing to be Pi – Theta 1.

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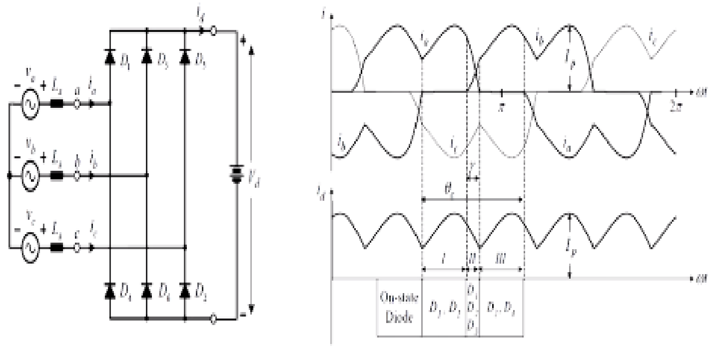
Six-pulse Diode Rectifier (Cont...)

Continuous Current Operation



- With the increase of the load current, the rectifier will enter into continuous current operation.
- During commutation interval, three diodes are on.

So, we can have a continuous current operation if we increase the load and thus the value of the VDD will come down. And what we will find that you know this is basically the ia and this is basically ib and this is basically ic so when we increase the load current then actually the current becomes inverse so we have to increase the load so ultimately you know the ia becomes this and ib becomes this and ic becomes this.

This passing of cycle and this current through the diode will be a continuous one and then what happens in some interval of the time went on state of the diode. For example, when ias is conducting when current is showing like this. So, automatically you know written part will be by the sub diode so what happens ia will be conducting once actually current is increasing. So, D1 and D2 will conduct then after that you know this interval region 3 what happened.

So, you can see that in this region ia falls and ib picks up so for this reason you will find that since ia falls D1 still conducting as well as the D3 comes into that picture for forward part b of this circuit so D1 D2 D3 will conduct gradually after some gradually ia will become 0 and the D1 will be off then D2 D3 will conduct. So, there will be overlapping zone where ia and ib both are conducting in this mode of operation.

So, with the increasing load current rectifier will enter into the continuous current operation and during commutation interval there are actually 3 diodes that would be into the operation.

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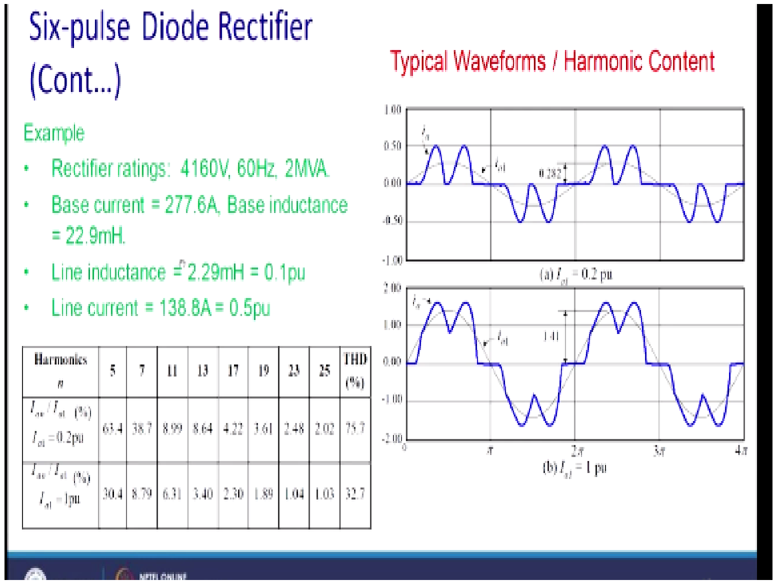

Harmonics n	5	7	11	13	17	19	23	25	THD (%)
I_{sn}/I_{s1} (%) $I_{s1}=0.2$pu	63.4	38.7	8.99	8.64	4.22	3.61	2.48	2.02	75.7
I_{sn}/I_{s1} (%) $I_{s1}=1$pu	30.4	8.79	6.31	3.40	2.30	1.89	1.04	1.03	32.7

Now there is an example we can sight the rating required high value rectifier. It is a USA system for this and it is a 60 hertz so we have 4160volt 2MVA rectifier and base current as high as you know 277.6 A and base inductance of this value and line inductance will have let us say 2.29 that is point 1 per unit and line current is assumed to be actually half of the rated current 227 will be this one.

So, we can find then what is that harmonic containing in it so this is the basically the blue one is essentially the load input current is feeding to the axis diode rectified feeding axis circuit and this black line current is the fundamental one so we can see that you know in case of the second power unit value is 0.2 and this is a second case where power unit value is one. So, our current rating is one.

And thus these things become continuous and this is physically discontinuous almost so you can see one thing here if load current is low. So, it is discontinuous in nature and mostly and the harmonic content will drastically increase at low load current so you can see that 5th hour warning is 63% and 7th hour warning is 38% and so on. And that is what our THD is coming out to be a 75% in case of the diode 6 and diode with rectifier feeding a RC load.

But when we come out why do you need it is actually rotate current but hitting effect will we there and other issues will be there and as far as THD is concerned this will be reduced because of the continuous conduction mode so THD will come down actually 32% basically this current is 30% and 8% and other values you can check almost half.

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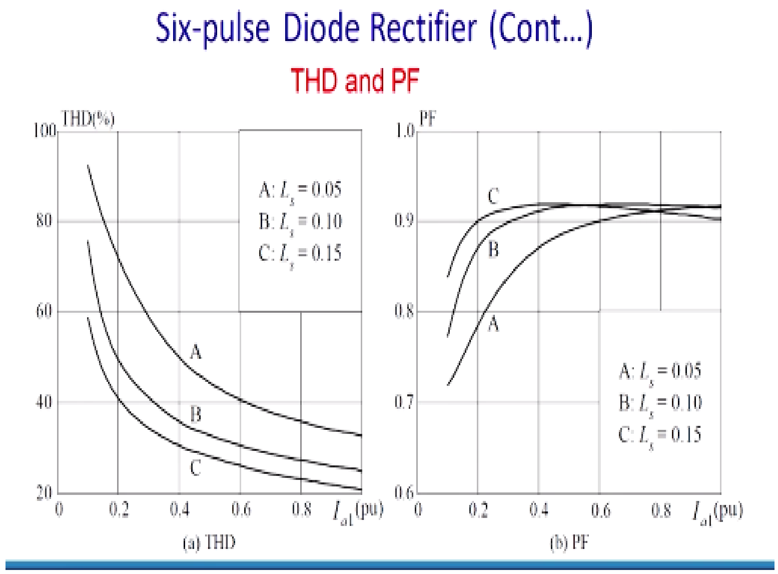

Now what happened this is a case of showing how THD decreases with the load and with different values of the source inductance. There is a effect of the source induction first case as you can see the induction is low you will find that THD will be actual higher and once you actually increase the load current of course THD will come down same thing for different values of the source inductance.

And what happened the power factor you will find that actually increasing the load power factor will improve because this discontinuous power factor has actually reduced you can of course assume that apart from that you know due to the source inductance you will find that power factor is least in case of the aid gradually and whichever is maximum value when it actually reaches its peak value and B is actually the middle point in the row.

So, actually it will be in the half point and after some time let us say 0.5 unity power factor 0.5 uploading you will find that source inductance affects almost mitigated as far as power factor is consent power quality mostly consists of THD and the power factor. So, you can find that source inductance increase the source inductance basically decreases the THD. But here after few 50% of the load current source inductance does not have much effect on the power factor.

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12-pulse Series-type Diode Rectifier

Series type:
Two six-pulse rectifiers are in series at the output.

Phase shifting transformer:

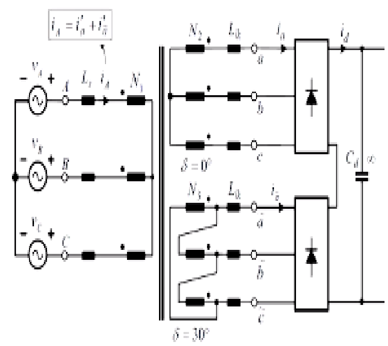
$$\delta = \angle V_{\bar{a}\bar{b}} - \angle V_{AB} = 30^\circ$$

Secondary line-to-line voltage:

$$V_{ab} = V_{\bar{a}\bar{b}} = V_{AB}/2$$

Turns ratio:

$$\frac{N_1}{N_2} = 2 \text{ and } \frac{N_1}{N_3} = \frac{2}{\sqrt{3}}.$$



Now let us analyse 12 pulse converter but to have that 12 pulse converter we required to have some configuration changes and we require to have a transformer in the system and who is actually you should have a different kind of transformer you can and here generally this part is delta and you have also the deltas star transformer and it has a different kind of vector group to operate. So in this case what happened you have a phase shift between this line current.

And this line current by 30 degree and since Ia is basically primary current is Ia if it is a I is to 1 transform, we will have spitted between the star and delta part. The phase shift between the transformer is basically 30 degree.

And secondary line to line voltage it is ab= Vab delta =v AB/2 and let us assume that actually N1/N2=2 and N1/N3=2 /root 3 so this is the Turns ratio. So you require a special configuration of a transformer to have 12 pulse converter or 12 pulse rectifier to the system.

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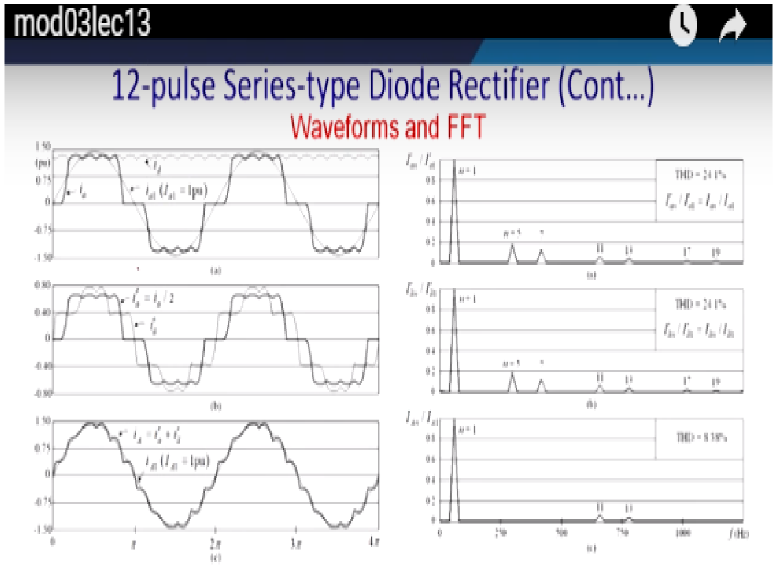

So what happened here you know you will find that why it is 12 pulse because there will be a two current basically you know this is the current for delta and this is the current for star and thus actually it makes out to be the star and delta and ultimately you will have total 12 pulse into the system, and you can find out that Vam/a1 that is the fundamental 5th that 7th and overall THD has drastically reduced to 24% from the 35% in case of the (()) (24:04) feeding cycle.

We can we have take same kind of load, but you know we are actually having a 12 pulse converter. And the current profile you can see it is closed to the sinusoidal and thus harmonic content is left and you know what you can find out that you know there is no harmonic content in the primary because this is basically the IN1/A1 it contains 5th and 7th but in case of the input current it does not have 5th and 7th harmonics.

So 6N+harmonics is totally eliminated you just have 11 and 13 harmonics and so on. Similarly, 17 and 19 harmonics is eliminated. So thus THD in case of this delta part was 21% and the star part was 24% but input side it just get reflected only 8% so it is drastically reduced from the previous one. So this is a great achievement from the power quality point of view, but you required to incorporate extra cost on the transformer.

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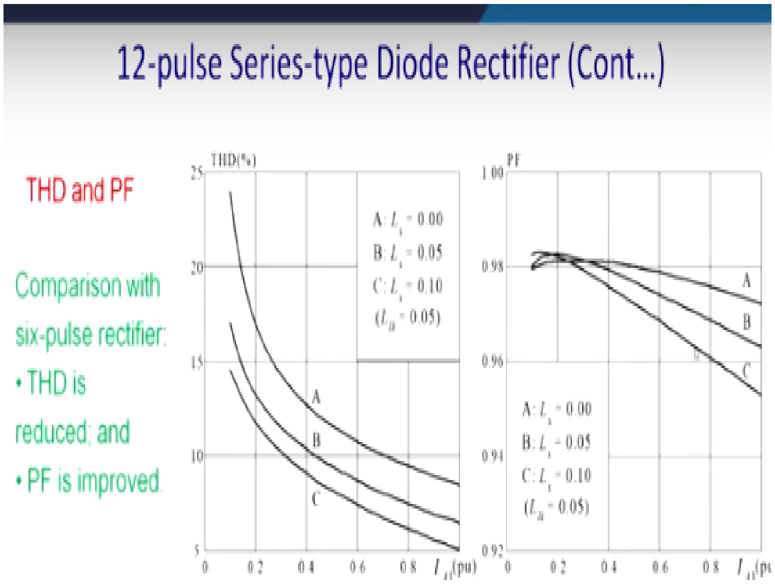

So let us have a performance analysis and you can have A that is source induction is 0and you can see that actually increasing the load with load current THD will be as high as actually near close to the 20% but it will come down close to actually 8% and thereafter if it is actually have a source inductance then actually it may come further. So this is the comparison between the 6 pulse and the 12 pulse converter. 12 pulse converter gives you quite low THD same.

What happened let us see the power factor. power factor you know actually in this case will have a little bit of detrimental effect. So you will start from the high power factor and this will not change much if there is a no source inductance. But with the effect of the source inductance you will find that power factor will decrease because we have put an extra inductance into the system. Thanks for your attention we shall continue to the part of the different kind of pulse converter in our next class.