Advance Power Electronics and Control
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Lecture -14
Multipulse Converters – II

Welcome to our Advanced Power Electronics and Control course in NPTEL. We shall continue with the Multipulse Converter – II. Now let us consider, we have already discussed 12-pulse converter.

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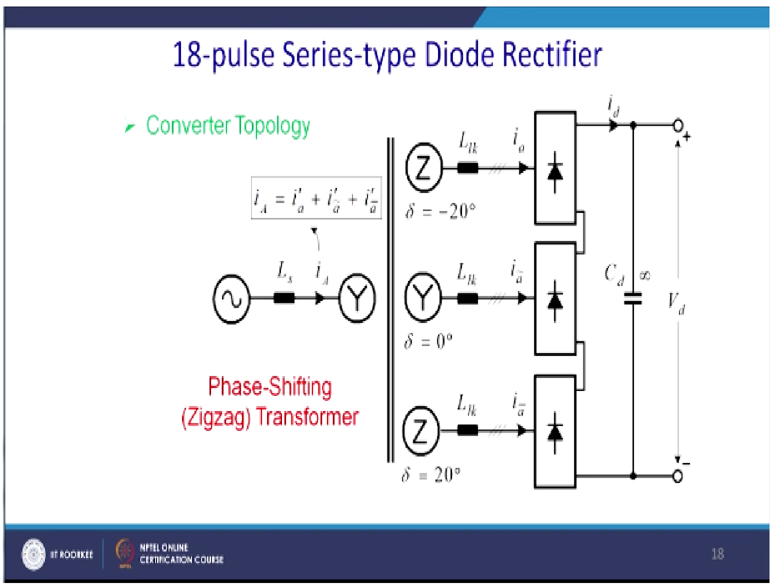

Now let us take the 18-pulse converter. Of course the complexity will increase so we will have one Zigzag transformer. Since we have 18-pulse so it require to a special design. So the phase difference between this transformer require to be actually 20 degree, so that is something a special arrangement, special kind of transformer is required to be built to fit into the system and this kind of transformer is called Zigzag transformer.

So we shall see that and ia is basically will have a this component ia prime ia prime + delta ia prime + bar. So this is the ia, this is ia delta and ia bar. This is the three current in secondary. So this consisting of the total current. And this side is basically primary side is ia and which is actually start connected.

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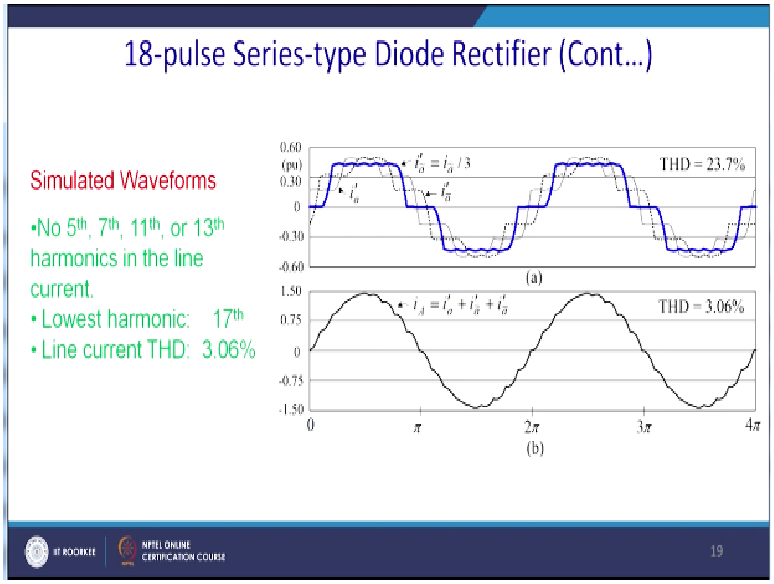

So what happen in case of the 18-pulse converter so if you; there are three current actually as soon into the one by blue other by dot and other by the front line. So these three current consisting of actually the current of the individual rectifier. And if you superimpose these three current ultimately we get the current which is available into the primary and individual THD of this current may be as high as 23%.

But when it is been reflected to the primary side so values are come to be less than 3% and generally we have for power quality issue we have iaaa9 standard so that says that THD is required to be 5%. So we can achieve it by this method. And thus what happen, so it does not have any 6n+-1 harmonic, 12n+-1 harmonic it starts from 18n+-1 harmonic, so worst harmonic failure after first harmonic will be 17 and thus 9 THD comes out to be only 3%.

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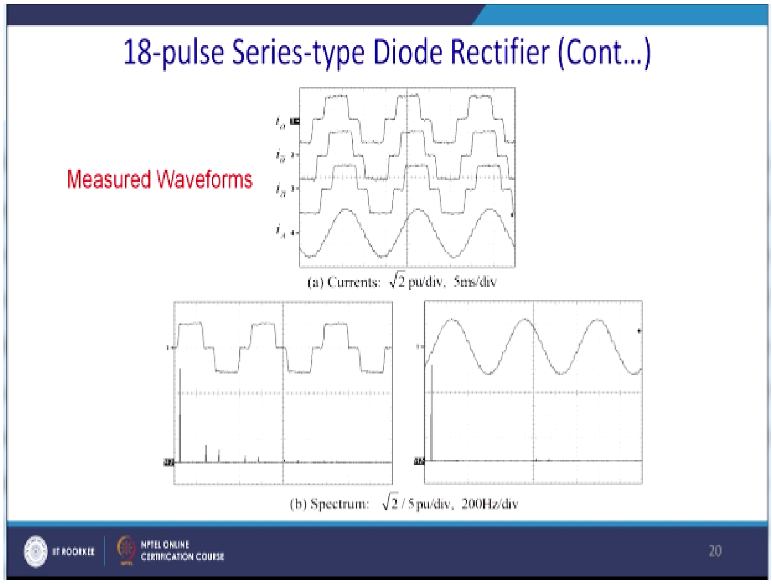

So this the waveform of the 16-pulse converter so; this is actually ia, ia bar delta and this is if you impose this three currents together and this becomes the basically essentially the value of this input current and this is the harmonic spectrum real data and you can sign that actually all the this is the harmonic spectrum of the primary of this 18-pulse converter.

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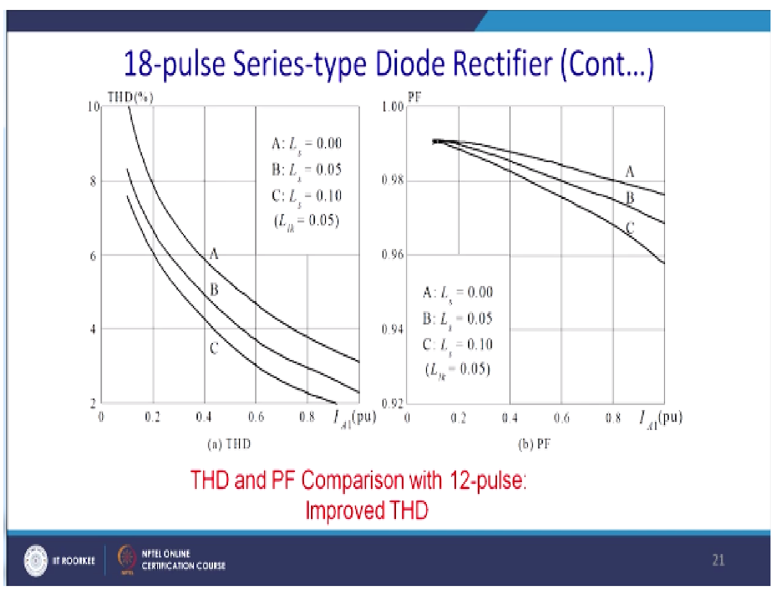

Similarly, same analysis can be continued as we have done in case of actually the 6 and 18 harmonic. So you can see that by increasing if it is a low load current of course THD is going to be higher. So once actually come down to the 3% for Geo-Source inductance it can be much below to the almost actually 0% for 0.1 per unit of the source inductance and similarly actually we may have a little high power factor at low input current and gradually it will decrease little bit.

But power factor you can see that the difference is not much, so we accept power factor, most of the power quality companies and the utility accept the power quality in and around 0.95. So there actually well in the range and if source inductance is 0 and they are well in the range of the 0.98, so thus this should actually switch all our purposes for practical utilities and concern for rectification operation.

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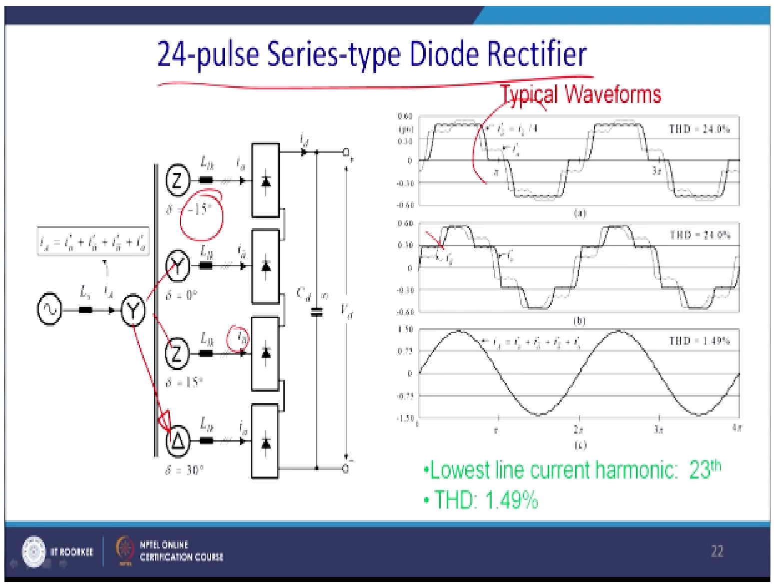

So now let us talk about the 24-pulse diode rectifier. So, even though it almost meets some application we require a very precise kind of actually power factor and other issues. So similarly, you know so we require 24-pulse converter there this is actually Zigzag transformer was phase shifted by 20 degree; here it will have a phase shift of 15 degree because it is a 24-pulse converter.

So we will have actually this will have a phase shifted by delta; this is a star, so this star and this star will have a same phase and from there we will have actually -15 degree phase shift. And this will have this Zigzag transformer will have a +15 degree phase shift. Thereafter, we will have a delta that definitely will give you a 30 degree phase shift. So you have actually let us draw this current because we cannot draw all the current in together.

Let us draw basically, this current and this current so if you can superimpose on it so will get actually this current and this current are having a 15 degree phase shift. Similarly, this current and this current will have a 15 degree phase shift they are put together. And all these two current are been put together into the third waveform and this is consisting of this basically the primary current and that is basically ia+ia delta+ia bar+ia prime.

So you can see that this individual THDs are 24% but once you come across while superimposing this fundamental current this load current become basically and will have a harmonic, it will be shifted at the level of the 23th harmonic. So the THD level will be very low as low as 1.49%. So this is the advantage of this actually the 24-pluse converter.

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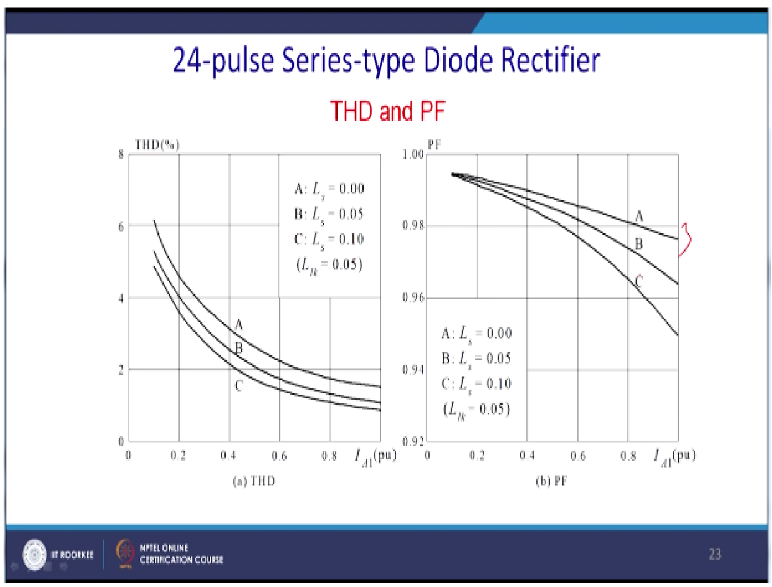

Now same thing, so if you have a low source inductance or Geo-Source inductance so a THD will gradually come down. But you can see that start from actually 6% and goes below 2% and similarly you know you can see that what happen to the power factor; power factor is quite good and for the A power factor is as close to the 98.98.

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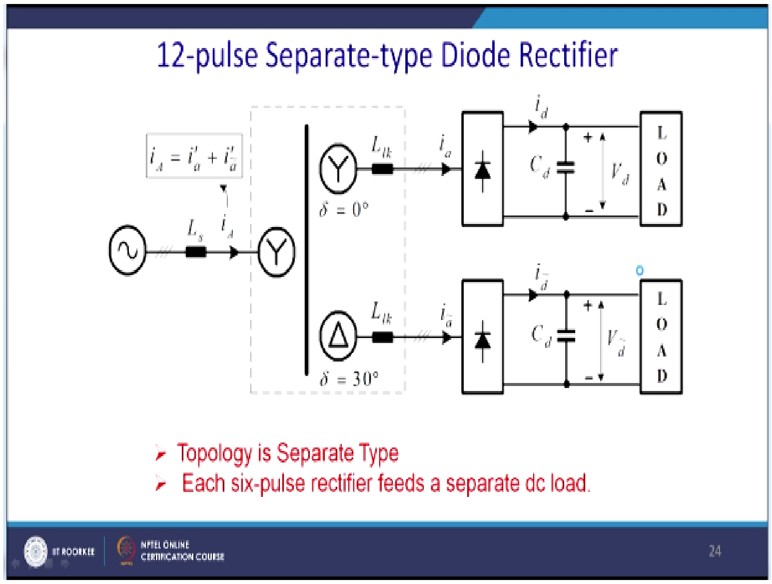

Now 12-pulse Separate-type Diode Rectifier, so if you have this kind of thing. So this is a separate you have a one start delta topology and 1-star test topology; it is maybe DY11 or DY1 at different kind of (()) (08:43) deferred primary current will be ia prime + ia delta prime and this is ia and we assume that it is ia delta and this id and this is id delta. And let us see what happen actually whether it gives much better waveform than any other. We can have this kind of segregation to run it because as far as receivers is concerned it is separately running so there is no problem at all.

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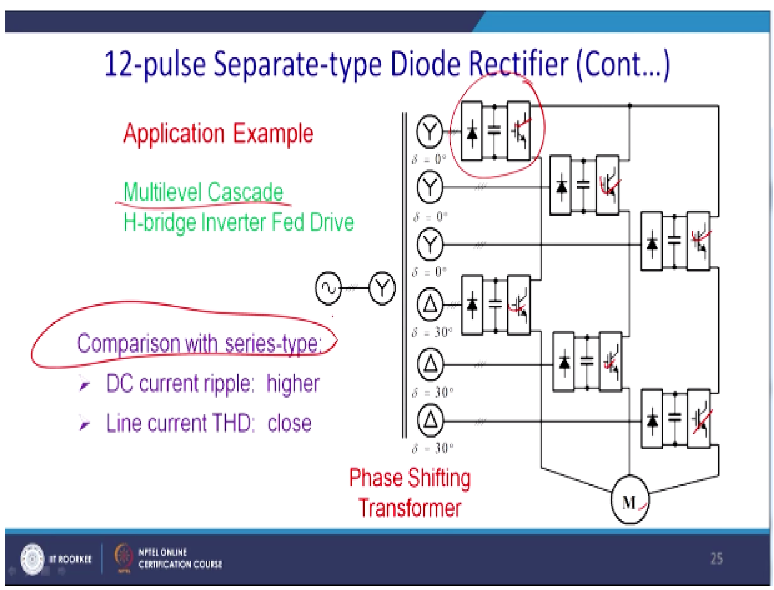

So what will happen in this case? We can use this devices for many purposes. So for example Multilevel Cascade, we can have actually different kind of cascade multilevel this actually drive was actually proposed by the Siemens and students are requested to find their whitepapers on it so you can have one dedicated drive.

Thereafter, you can see that you know it is coming like this and ultimately one this; one inverter this inverter as feeding. Similarly, this inverter and this inverter feeding and this inverter and this inverter is feeding. This is called multilevel cascade H-bridge Inverter Fed Drive. So it is applicable for the high voltage routine highly precisely drives were actually inverter is feeder to the motor drive. So this is as a great advantage of it, so comparison with the series-type.

So here what you will find that the DC current ripple is higher and the current THD is actually close to 0. So we require a phase shifting transformer like this to operate this highly sensitive drive like a 12-pulse separated-type diode rectifier.

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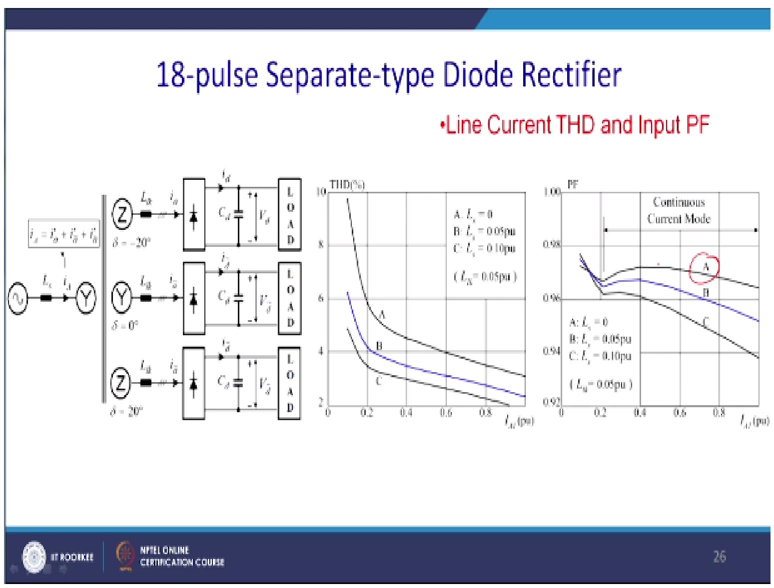

Now let us analyze the actually 18-pluse Separate-type Diode Rectifier. So now we can have actually 20 degree phase shifted and we have this kind of drives and we can find that actually value of the THD is quite low compare to this actually single 18-pluse type and it is come down to be actually below 4% and with a inductance it will be blue one and another inductance little more that will be C1 and but what we will find that power factor will actually degrade little bit little bit from actually till this point is the discontinuous conduction mode.

Once this actually conduction mode started you will find that this is the A and that will basically having a good power factor and ultimately all are accepted because power factor is quite close to 0.95 and this is quite acceptable for the utilities.

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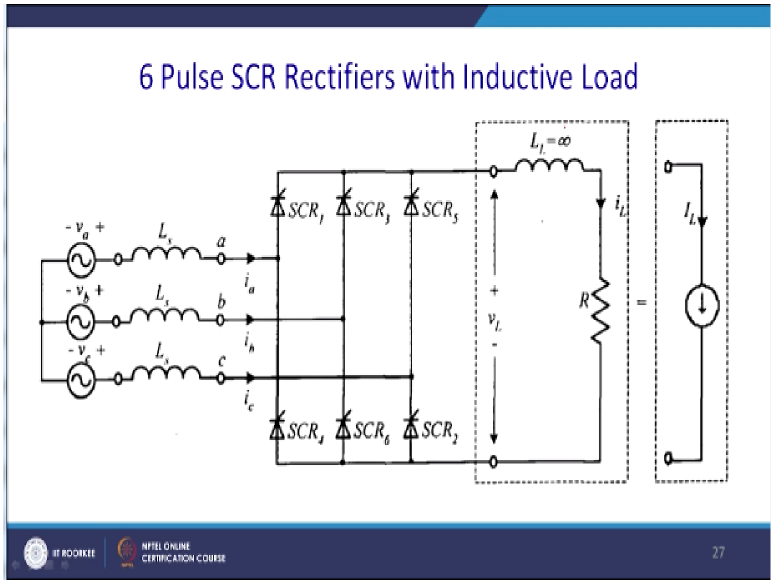

Let us talk about same thing with the controlled rectifier that mean with the converter. Let us go again the 6-pluse and see a rectifier with the inductive load and see that what happens its performance analysis.

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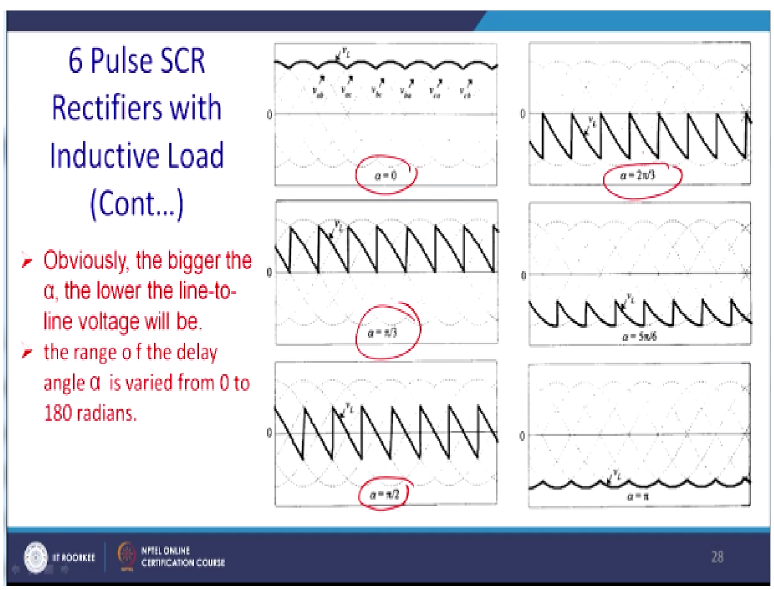

Now we have already discussed in the diode rectifier. So this is the case where alpha=0 you get this kind of load voltage. And this is the case for alpha=60 degree after that actually this is the pattern you will get till that point actually you will get a 6-pulse. And this is the pattern where actually alpha=pi/2. Since this is the full control refer to the waveform the full control converter, so average voltage will be 0. So you are not supplying any voltage to the load.

And once you increase this alpha adopt pi/2 so it will work as a inverter and you will get negative voltage. Similarly, at pi you get just reverse or mirror replica of 0 degree. Obviously, the bigger the alpha lower the line to line voltage and you can operate 0 to 180 degree in a full control mode for rectifier to the inversion or converter to the inversion operation.

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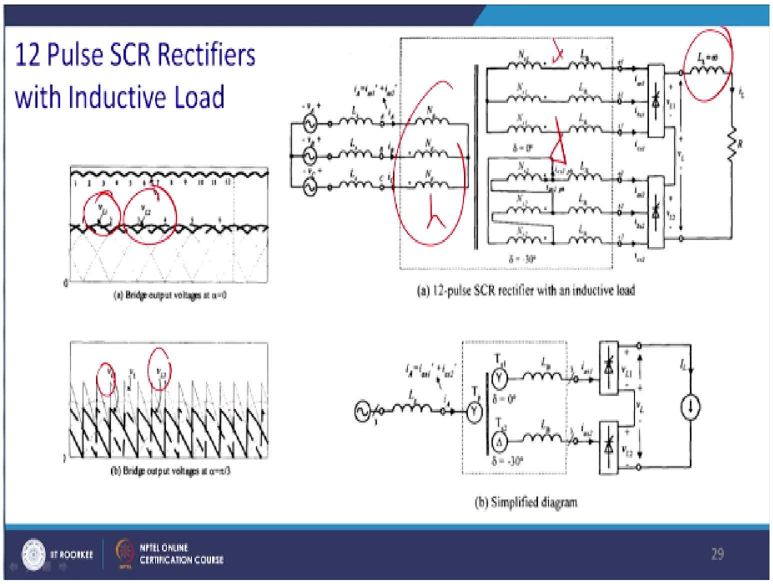

Now what happen you know actually in case of the 12-pulse with the inductive load. So what happen you know actually, so you have to impose the actually the star and this is the star and this is the delta, so this part is star and this part is also star but mind the dots and this part is delta. So ultimately you will have a 12-pulse in the cycle that consisting of VL1 and VL2 and thus what will happen.

So you will have a 12 (()) (14:37) into the load and we assume that this value of the inductive is quite high and iL is continuous and so you will have a different VL1 VL2 and ultimately you get the pattern VL here for alpha=pi/3. And essentially what will happen in the same case, so this is be consistent iA1 consisting of iS1 and iS2, so basically and you can add up this thing in series to boost the voltage level and ultimately it will be fitted to the highly inductive load.

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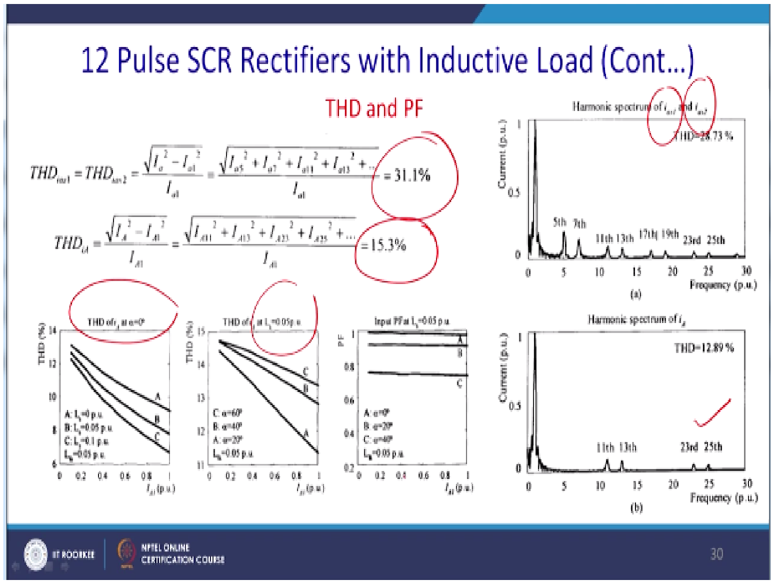

So in this case you can calculate so what will be the THD, so you will find that THD1=THD2 will be actually as high as 31% for the 12-pluse converter fitting; and for alpha=60 degree. But similarly you know these value you will be actually getting around 15%, this is for the iS1 and iS2 for both this but in the line harmonic spectrum of the input side it will be shifted to the 11 and 13 harmonic you will get this time spectrum.

Similarly, you can see that this is the effect of alpha=0; the THD will be actually starting from the 14%; once you actually increase the load current it will come down to be around 7 to 8% and if alpha is little more than that; this is the THD for source current and for the different values of the alpha, alpha=60 degree, 40 degree, 20 degree you can see that. More the value of the alpha this actually this will have a more THD, you have around 15% THD which you have calculated for alpha=60 degree.

And gradually it will come down for the load inductance this. And similarly for the power factor you can see that for alpha=0 it will have a quite high almost constant power factor for alpha=20 degree you can see that almost 20 degree constant power factor or 0.9 for alpha=40 degree you will have actually it will grouping characteristic it will be around 0.8 to 0.75 power factor. So this is the analysis, so while increasing alpha of course we expect that THD and power quality will degrade but you can have a control over the voltages.

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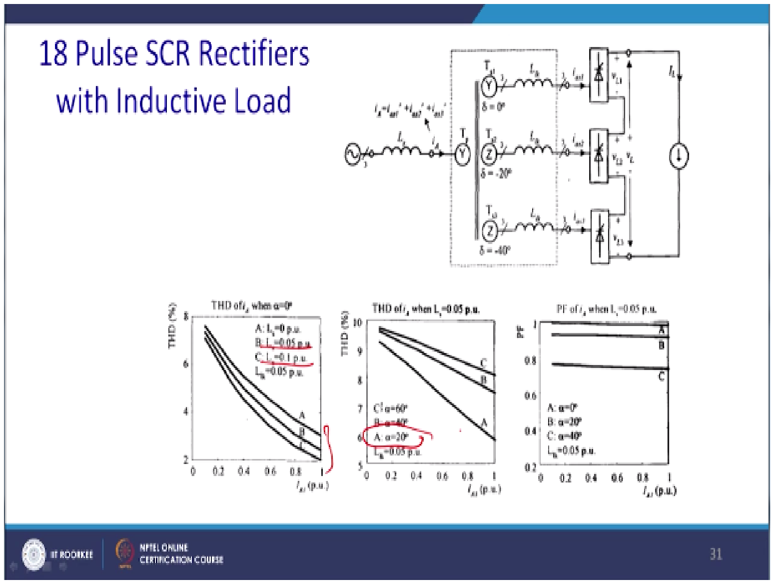

So similarly, what should be the corresponding parameters of 18-pulse converter? So of course they will be phase shifted by 20 degree. And for alpha=0 you can find it out that it actually the THD for the input current will be quite high as 18% but it will come down to around 2%. So and for the little high source inductance it comes down little below similarly, when THD for the different triggered angle will be also actually replicated here.

So with increasing input current THD is getting better, so at one per unit THD will be actually around 9% for 18-pulse converter but this will not change much actually around 10% or 9% and; but you can find there is a huge change when actually alpha=20 degree so it will come down to be around less than 5% to around 9%. Similarly, this is the waveform correspond to the power factor and a different values of the firing angle alpha=0, alpha=20 degree and alpha=0 degree and this is the corresponding load current in per unit.

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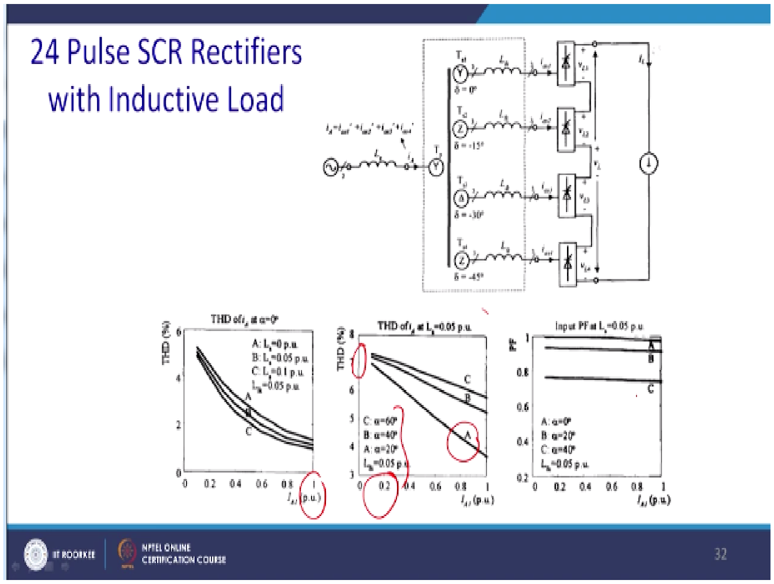

Similarly, we can do the same graph for the 24-pulse converter. So that will have a phase shift by 15 degree, so here actually the THD for alpha=0 start from 6% and while you are increasing the load current it comes below the 2% and different curve you will get for different values of the source inductance. Similarly, for same source inductance for difference values of the alpha it will start from around 7% for very low input current and a discontinuous conduction mode maybe; thereafter once it get into the conduction mode this part is not plotted because of the discontinuous conduction mode in nature.

So gradually you can see that the THD gradually reduces in case of the A, so basically it is alpha=20 degree it comes down as below as 4%. Similarly, this is the case for this firing angle alpha=0 to 20 and this, so you can see that power factor almost remains constant in case of the A and it is as close as 1 and for 20 degree it is around actually 0.95 and it is continue to be so and similarly same for the alpha=40 degree.

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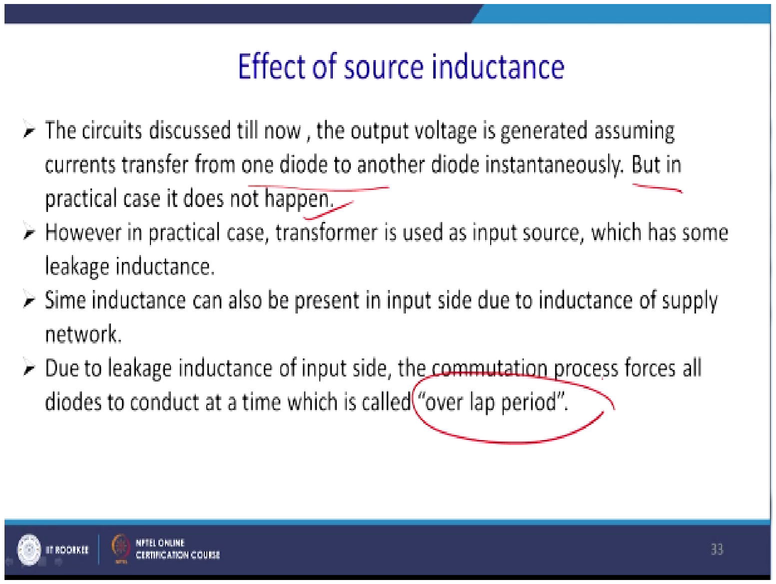

Now let us come to the; we have discussed in detail; we have tried to detail by the mapping that THD decreases due to the source inductance because it try to make the current continuous discontinuous conduction mode, try to diminish and thus it is been reflected in the THD. But you pay the penalty having a low power factor having high source inductance, so whether it is beneficial or detrimental. So let us see that.

The circuits discussed till now, the output voltage is generated assuming currents transfer from one diode to another diode instantaneously, but once there is a source (()) (21:11) it does not happen, so we have overlapping angle but in practical case it does not happen. However, in practical cases transformer is used as source and which has some leakage inductance, so we have to incorporate it into the system. Same inductance can also be present in the input side due to the inductance of the network.

Due to leakage inductance mostly you will find you know actually because you require a very special kind of transformer for 18-pulse as well as for 24-pluse leakage inductance of the input side of the commutation process all the diode to conduct at a time which is called overlapping angle.

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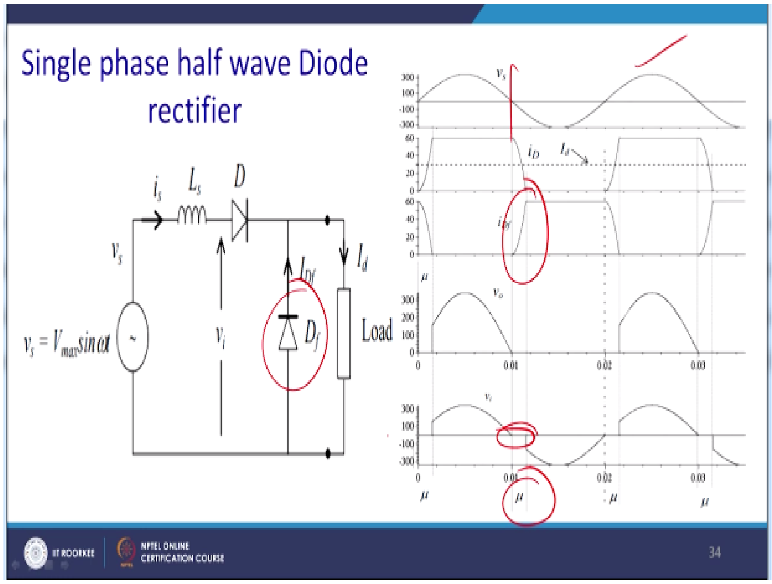

Now let us take a simple example of a source inductance with the free wave diode single phase half wave rectifier. So what happens you know this is a source voltage we have to; this is the current Id because it picks up once this current 0 because of the source inductance it will try to conduct. And you know this will actually fall but it is not instantaneous that the Df will pick up, so there will be time Df will pickup, for this is Df will pickup sometime it will continue to flow.

So for this reason till the time both the diode conducting actually this angle is called overlapping angle and this is called Mu and what happen you know here this input voltage become 0 and thus this is the affect of it the average voltage is reduced during this time.

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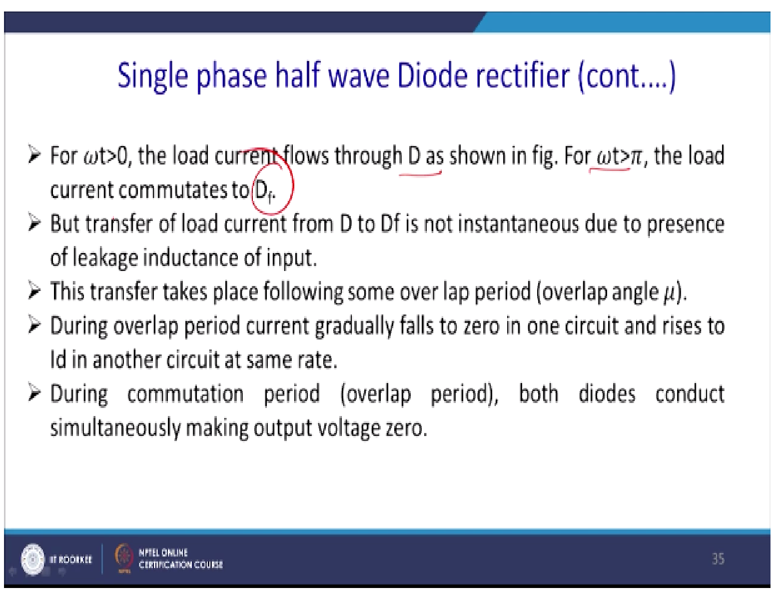

So for a single phase half wave diode rectifier, for omega t > 0, the load current flows the diode when diode D1 as shown in the figure for omega t>pi, the load current commutes to Df. But transfer of load current from D to Df is not instantaneous due to the presence of the inputs of the leakage inductance. This transfer takes place following some overlap period of which is actually marked by the angle Mu.

During the overlap period the current gradually falls to zero in one circuit and rises Id to the another circuit and during the commutation period the overlap period can both the diode conduct simultaneously making the output voltage zero at the load.

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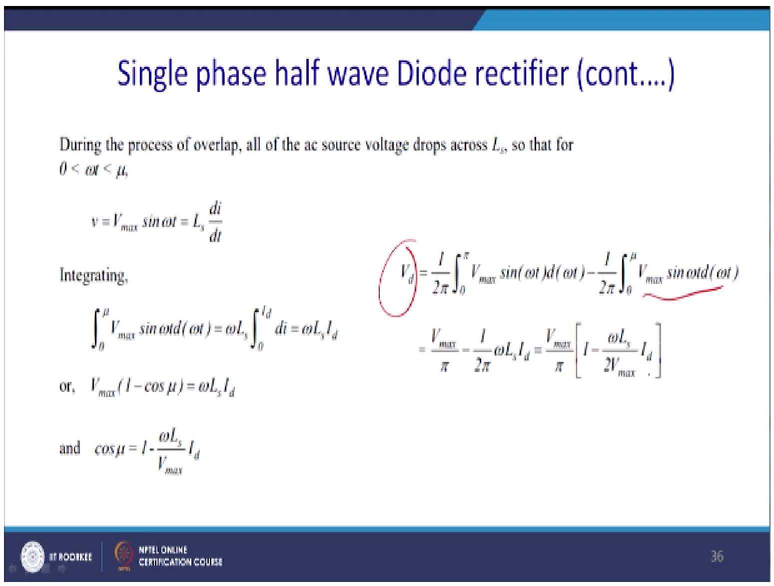

So we can calculate so in a simplest form, so Vm* sin omega t and it is feeding L di/dt. So while integrating over the time we essentially get the value of the cos Mu and the cos Mu basically called 1-omega Ls or Vmax into the Id. So similarly, we can calculate Vdd and since this zone 0 to Mu it does not get any voltage so output voltage comes down and we require to subtract that voltage.

So for this duration so Vmax/pi 1/2pi omega Ls*Id so effectively that value becomes Vmax/pi 1-omega Ls/2Vmax*Id. So this will be the average voltage while accompanying this source inductance into the system. Now let us go to the little complex circuit of the normal practical circuit that is single phase full bridge rectifier.

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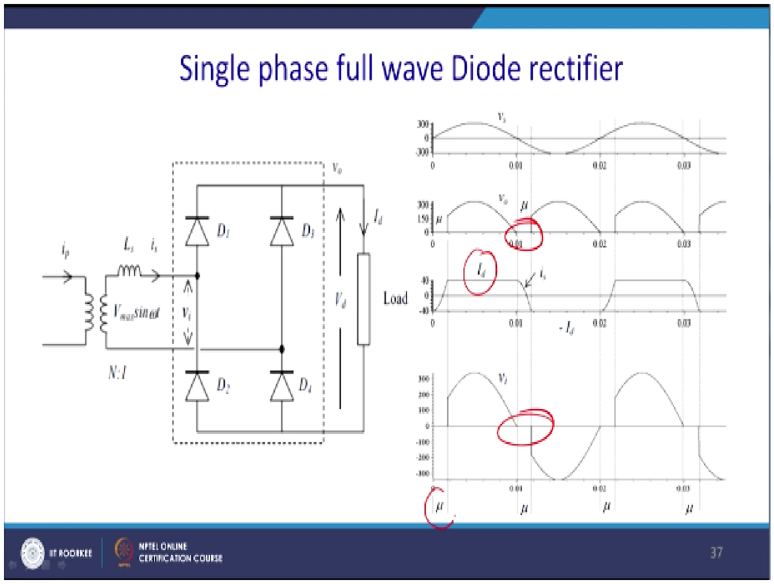

So her also same thing happens, till the point Mu both that actually due to the overlapping angle; here overlapping angle comes into the picture first D1 D4 conducts, D2 conducts and due to that what happen, actually so there will be a overlapping. Once this actually current through this D1 and D4 decades and current through the D2 D3 picks up. And this is the current Id1 across the load and also this is Vi and within this Mu region nothing is takes place.

But this times Mu this kind of operations comes 4th time in a operation in a 2pi. So we require to incorporate it and we require to calculate the value.

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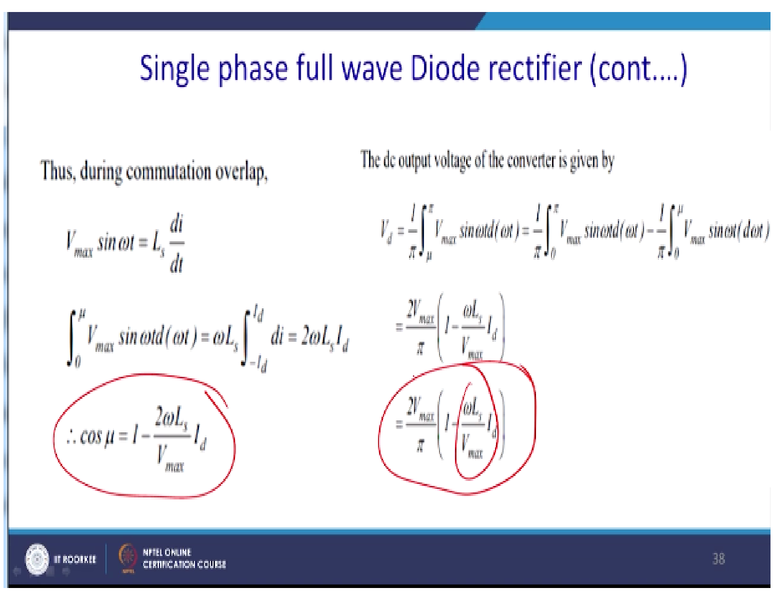

So the same calculation has to be repeated so Vmax sin omega t = Ls di/dt for the source inductance and this value what we have calculated same. So dc output voltage we require to calculate so it is 1/pi 0 to Vmax sin omega t– 1/pi 0 to Mu and ultimately you come across this expression of the output voltage decreased that is basically this part is been the decreased part due to the actually the overlapping angle.

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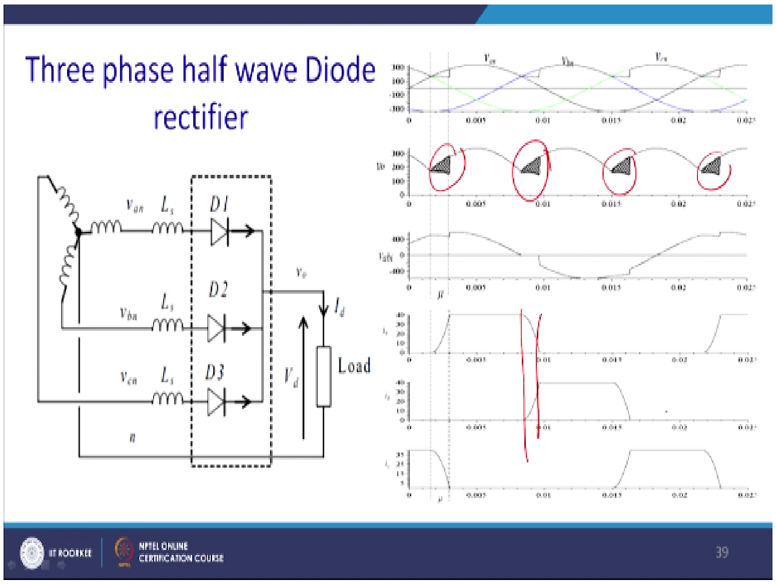

Similarly, same thing can be explored to the three phase half wave diode bridge rectifier. And this is the actually the overlapping time, so this is the actually ia, this is ib and overlapping time is basically the same and due to this overlapping time you will see that fall in voltages.

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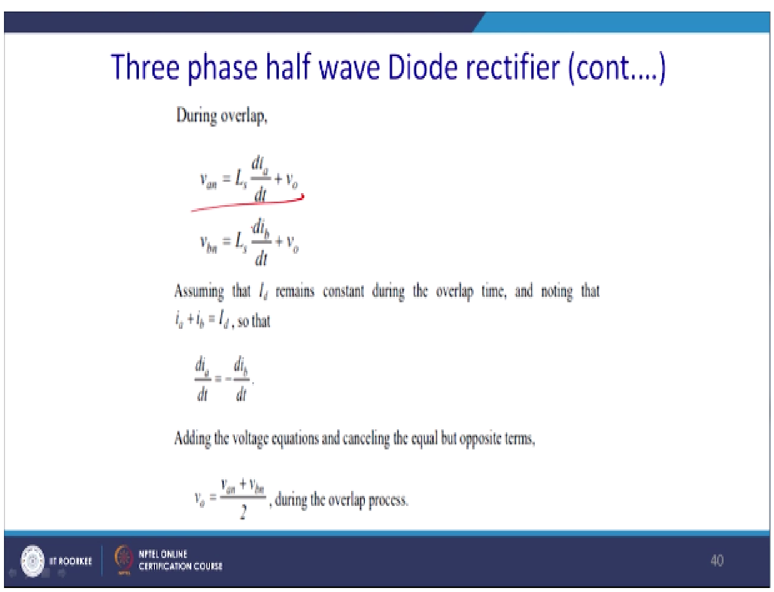

And similarly you can do the calculations, here actually since both the diode conducting we will have a two circuits into the picture that is given by Van = source inductance * di/dt + output voltage and same for the B phase. And from there actually you can add up since current is flowing to the phase A is coming out to the phase B if you assume then actually output voltage will be half of the An+Bn.

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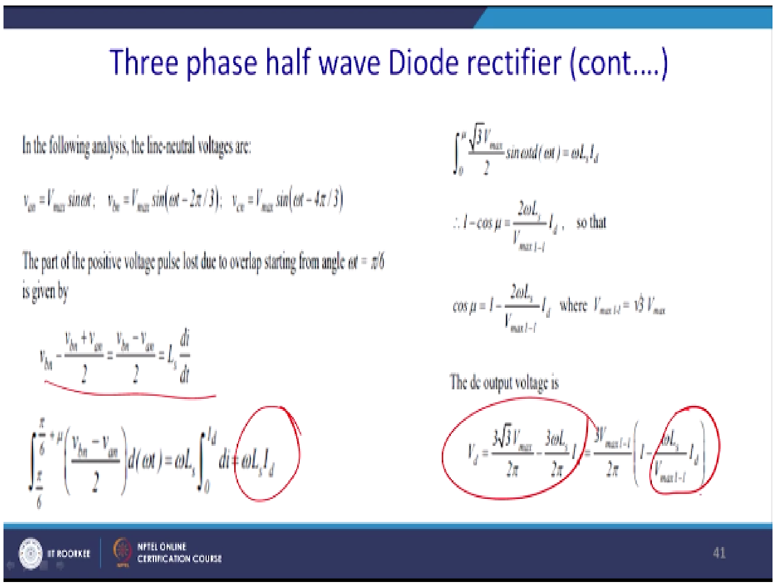

From there we can calculate so you can calculate basically the what should be the value of the Bn and what should be value of the An and thus what we can do, you can calculate the average value of it. So while calculating average value you can find it our; it is almost same 3Vmax/2pi 1- this part is basically coming for the source inductance and so this is actually the integration is pi/6 to pi/6+Mu.

If you assume that actually that diode d1 is conducting for the time period of Mu 1, so voltage you are actually getting is this two voltages and thus this is the current across the diode, so from there actually you can drive this expressions. So this is for the Three phase half wave Diode rectifier. And we can extend the affect of the source inductance for the other circuit and we shall continue to our discussions in our next class.