Power Quality
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Module - 04
Chapter - 13
Lecture - 36
Three Phase AC-DC Improved Power Quality Converters

Welcome to the course on Power Quality. We will cover three phase AC-DC improved power quality converters (IPQCs).

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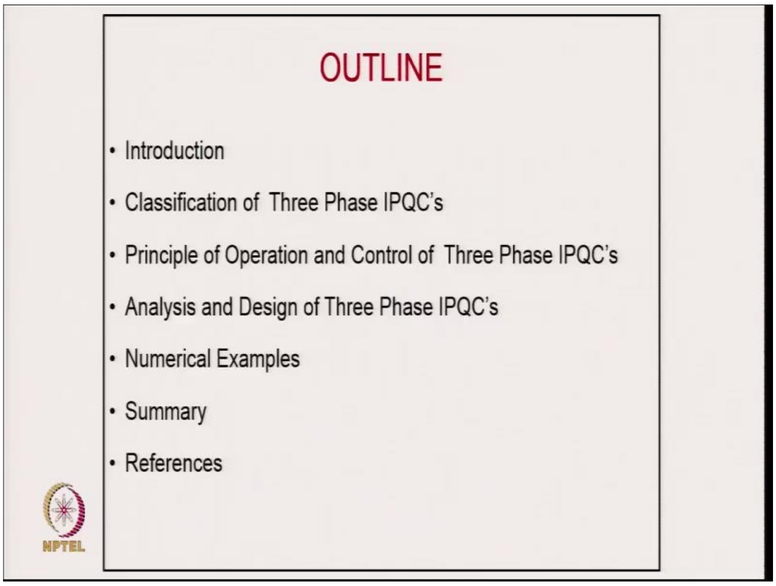

Coming to the outline, we would like to introduce three phase IPQCs; then we will talk about classification, operation, control, analysis, and design of three phase improved power quality converter (IPQCs). We will also have some numerical examples.

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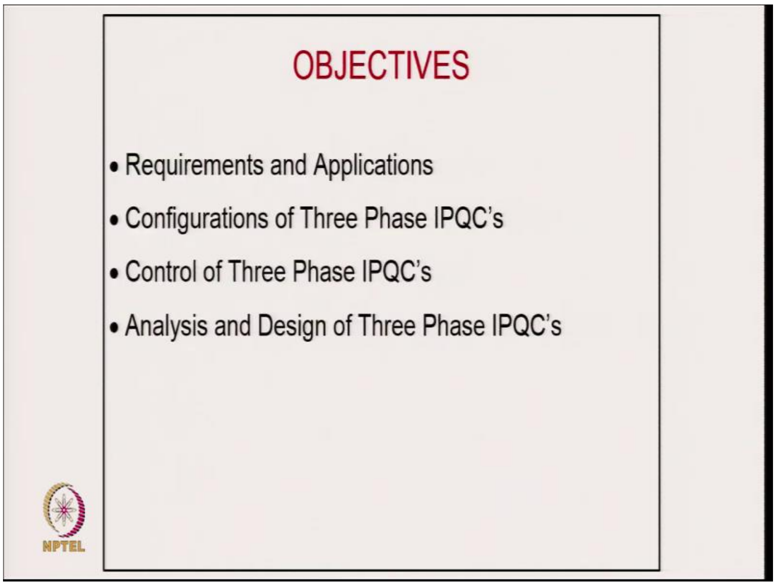

Now, coming to the objective, first we will like to discuss requirement and the application of these improved quality converters and then we will talk about configurations, control, design and analysis of the three phase IPQCs.

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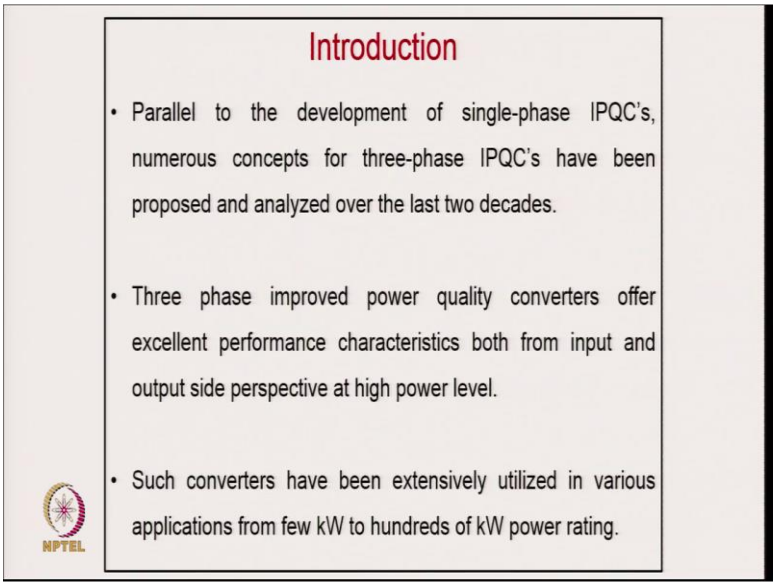

Now, coming to the introduction part. Parallel to the development of single-phase improved power quality converter, numerous concepts for three phase Improved power quality converters have been proposed and analyzed over the last two decades. The three-phase improved power quality converters offer excellent performance characteristic, both from input and output perspective at high power level. And such converters are extensively utilized in various application from few kW to hundreds of kW power rating.

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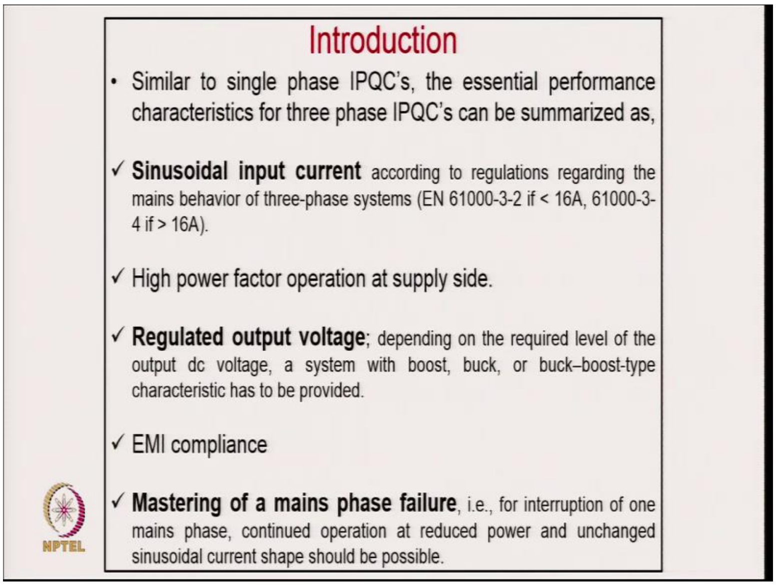

Similar to single phase improved power controller, the essential performance characteristic for three phase improved quality converters are also summarized as with the supply input current, sinusoidal supply input current according to the various regulation regarding the mains behavior of three phase system.

With EN 61000 and typically for less than 16 ampere 61000-3 for more than 16 ampere and a high power factor operation also AC mains, regulated output voltage depending upon the required level of output DC voltage at system with boost, buck and buck boost type characteristic and of course, with the EMI electromagnetic interference compliance and mastering of AC mains failure that is for interruption of one mains phase continued operation at reduce power or unchanged sinusoidal current shape should be possible.

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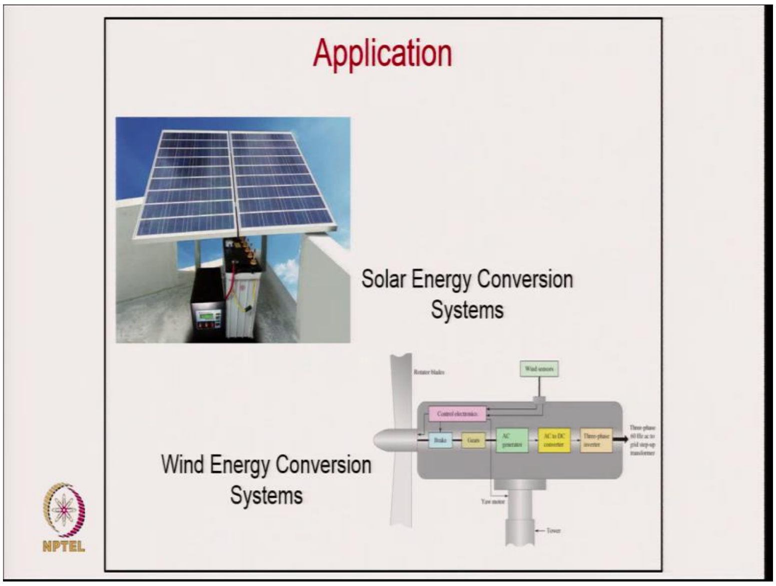

[FL] These are typical applications in of these converter like maybe solar grid interface system, Solar Energy Conversion System, Wind Energy Conversion Systems where these converters are taking really big application. [FL] We like to have a given latter the case studies of them.

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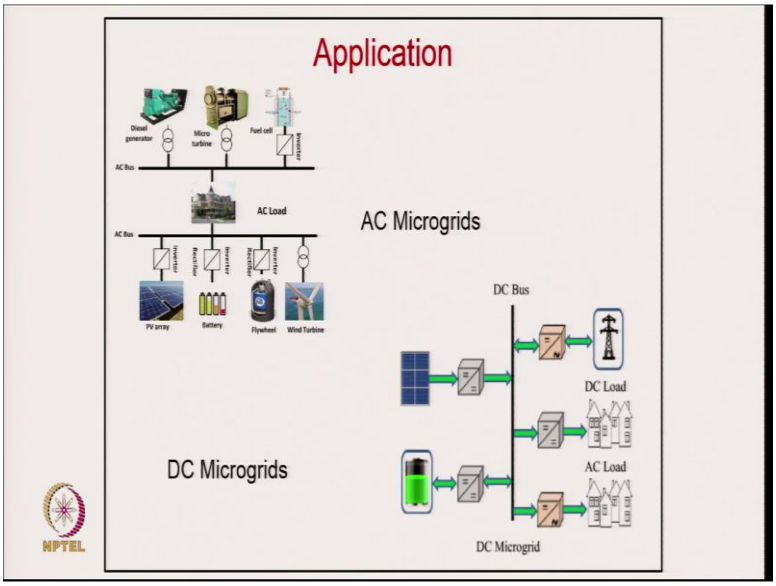

And then the other application like AC Microgrid where you are I mean connecting because you are including the DC sources also similar to like a fuel cell than solar PV generation variable, speed wind power generation and including the battery energy storage for making the microgrid. It means you are using several such converters which really does not test by power quality problems on the AC side.

I mean because you have a AC bus [FL] AC bus will not be affected by power quality problem either by these renewable power generation or conventional generation of DC set as well as the connected load on the this AC bus. Then other of course, they are also important for DC microgrid also where the you are connecting this with the AC grid for transferring the power [FL], power quality problems will not be either on DC side as well as AC side like.

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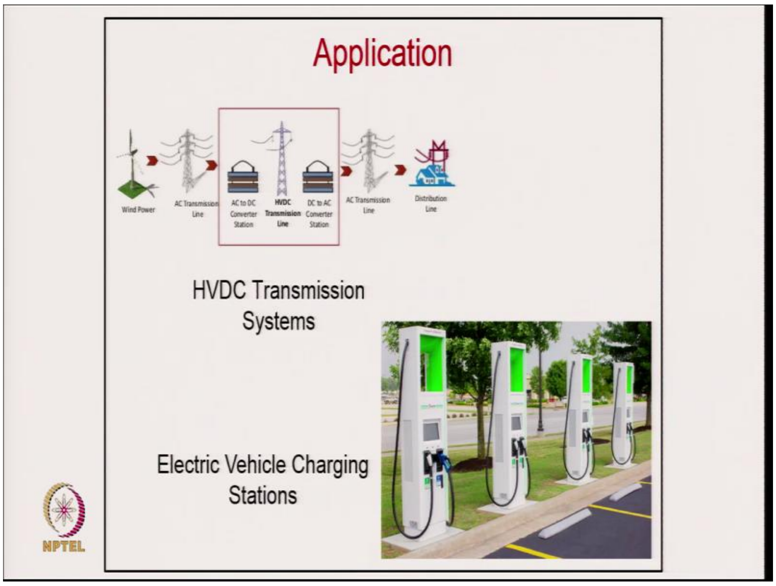

Then coming to applications like HVDC system, I mean as HVDC system is quite old applications even for since 1954 [FL] earlier we were using the thyristor converter typically with the passive filters, but nowadays we start using voltage source converters. I mean with the benefit of that you are able to eliminate, there is no need of reactive power virtually you are able to generate the reactive power by voltage source converter required on AC side during contingencies.

Or otherwise and moreover it does not draw harmonics and there is no need of bulky passive filters. You require very small ripple filter similar to what we discussed already voltage source converter [FL] new breed of HVDC system using the different names we call it as HVDC light or we call it as HVDC plus [FL] their concept by the industry had put by these converter which have a good power quality without filters like I mean.

With the bidirectional power flow in HVDC system they are developed for many applications for like a wind form and solar form also. Another major applications is coming electric vehicle charging station. I mean which even now for these converter. So, that the you are not having a power quality problem on the grid because you are drawing the power from the grid, I mean like and you make sure that neither the reactive power burden is on the supply as on AC mains as well as harmonics are also not injected by this electric reacting charging stations like or charges like.

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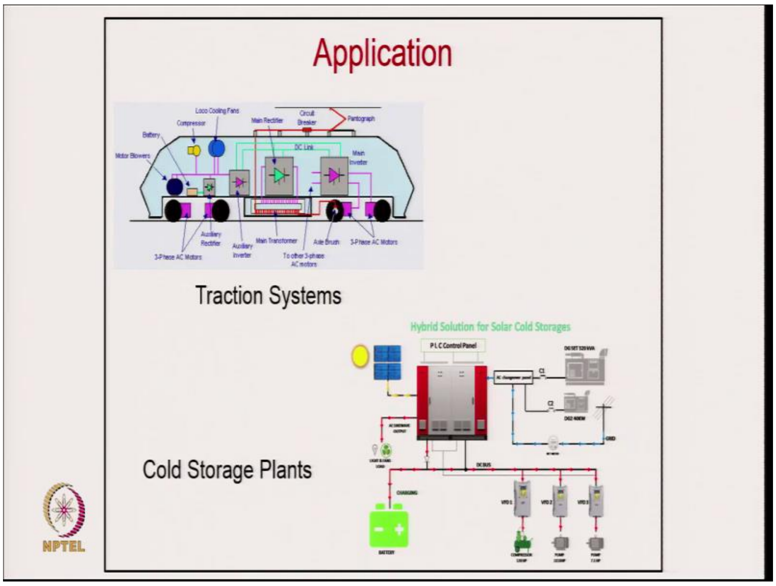

Well coming to another application to Traction System. I mean traction system also now we start putting like a typically traction not only include like electric traction, but it also include the metro [FL] we start putting now typically voltage source converters on the grid side, I mean typically so, that neither the harmonics nor the reactive power burden is put on the grid.

But actually you should be able to support the reactive power if required and then cold storage plant you are using large number of variably speed drive as well as DC set into typically in cold storage as well as energy storage [FL] So, that you should not have on AC grid the power quality problem [FL]. You are selecting the right converter in power quality converter for these applications like.

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[FL] High Power Electric Drive System for various applications where you would use the medium voltage drive with the power quality improvement like in cement industry, mining and minerals industry, metal industry, marine and chemical industry, oil gas industry and of course, water industry and many more applications.

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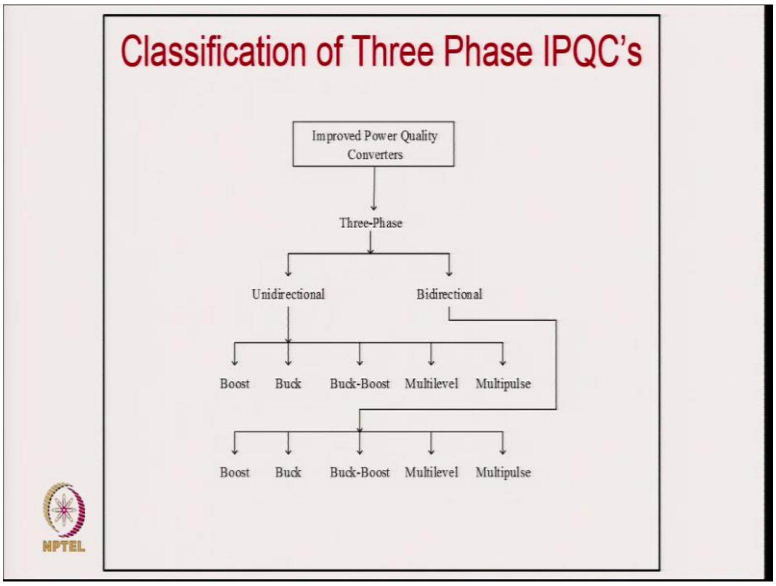

Now, coming to the classification these of three phase improved power quality converters, we classified into them into like a based on power flow like a unidirectional power flow and bidirectional power flow. Unidirectional power flow the example, I can talk about typically like a medium voltage drive for large air conditioning system or refrigeration system where the power flows into the one direction.

But typical example may be of bidirectional power flow of these converter are the typically like a traction the active load where we are connecting them and of course, we classify unidirectional further into like a category of boost where you are having a boost operation, buck operation, buck boost operation, multilevel operation as well as we have multipulse converters also.

That is also coming as a big way. We like to discuss in a typically in separate lecture like I mean similarly for bidirectional also we have a boost buck and buck boost and multilevel and multipulse like [FL] you have a typically these 10 category of these improved power quality converter in three phase connected supply system.

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[FL] Coming to like a typically three phase unidirectional boost converters so improved power quality converter, this is the first that we want unidirectional.

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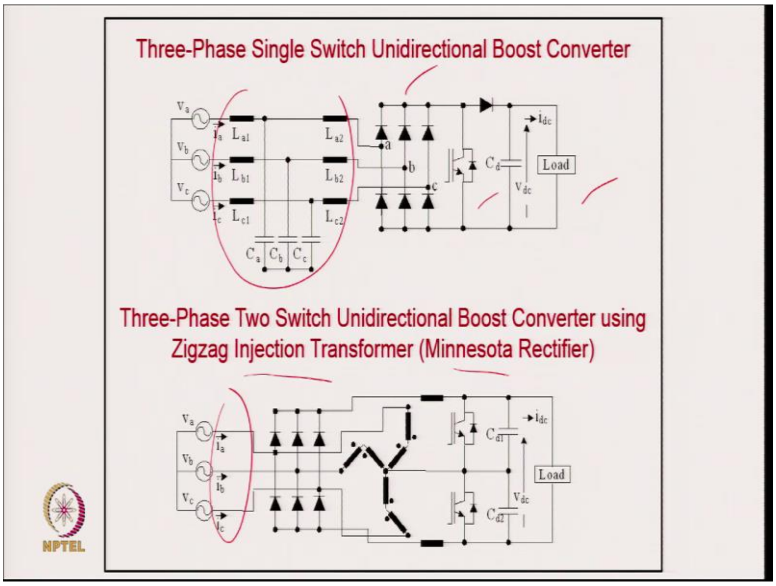

In the sense that we have here typically three phase diode rectifier with the boost converter of course, it cannot give a too good power quality on the supplies wide and that is the reason we connect typically a this you can call it T filters on input which are able to provide the harmonic reduction into this and you get almost like a closer to unity power factor on the supply system which is normally used in lower rating like I mean or.

So, then we have a typically another converter three phase, two switch unidirectional boost converter using zigzag injection transformer. This is also known as Minnesota Rectifier. I mean this was virtually invented in Minnesota University and that is the name they put like a Minnesota Rectifier [FL] you can see AC with the your you can call it like injection transformer here and you have a two boost converter to regulate the output voltage.

This is I mean you can have a harmonics quite here of course, and unity power factor on this side and of course, if load needs only DC, you can have this it provide the boosting feature because you are having a boost converter here. Apart from that, it has a very interesting feature that if you have a require a load like 2 equal voltage across the load DC load like similar to like a switched reluctance motor drive midpoint converter, you can provide this also from this converter like.

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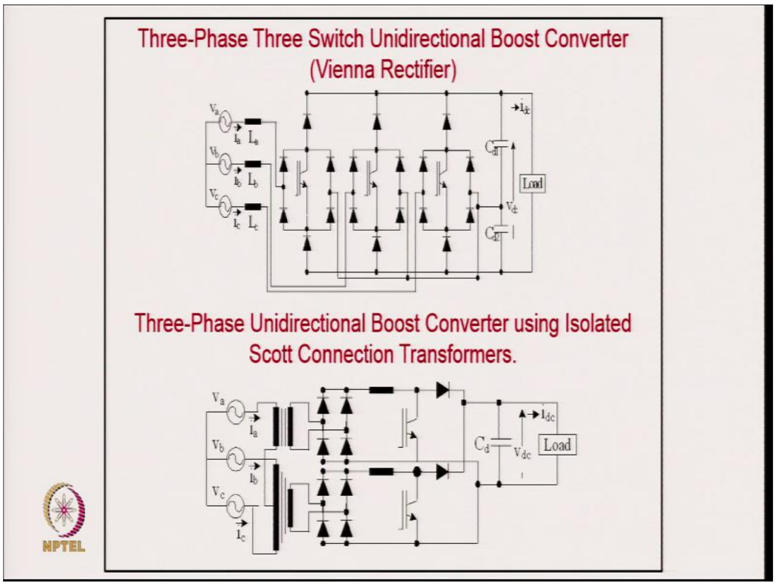

Then coming to like a Vienna Converter. This is again by invented by Professor Kolar who has been in the Vienna University [FL] in the Vienna capital of Austria. He put the name on the city [FL] called Vienna Rectifier and this is with the 3 switch PFC Converter.

It also boost converter and give a almost good power quality on the supply side. This converter has become very popular many versions are there we will discuss in detail and you can use of course, on load side if, but if you want 2 equal voltage across for load, which I will already mention that similar to like a midpoint point converter switched reluctance motor drive, you can use this converter of course, it is very much used in telecommunication industries like I mean or so.

[FL] Another your unidirectional is that you can take a Scott connection of three phase supply and then you can have a 2 converter PFC with the equal power sharing to get output voltage [FL] you have a of course, the isolation and if you have a balanced load on this Scott connection, you have a balance current in the supply system as well as you get of course, the power factor correction because of this PFC boost converter operating in this case like.

[FL] You are able to regulate the output voltage the good quality THD, but only the drawback is that you are using power frequency is Scott connected transformer which are not in other circuit like, but of course, you are getting isolation [FL] depends on a application requirement if you are using this like.

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Now, coming to three phase bidirectional boost improve power quality converter.

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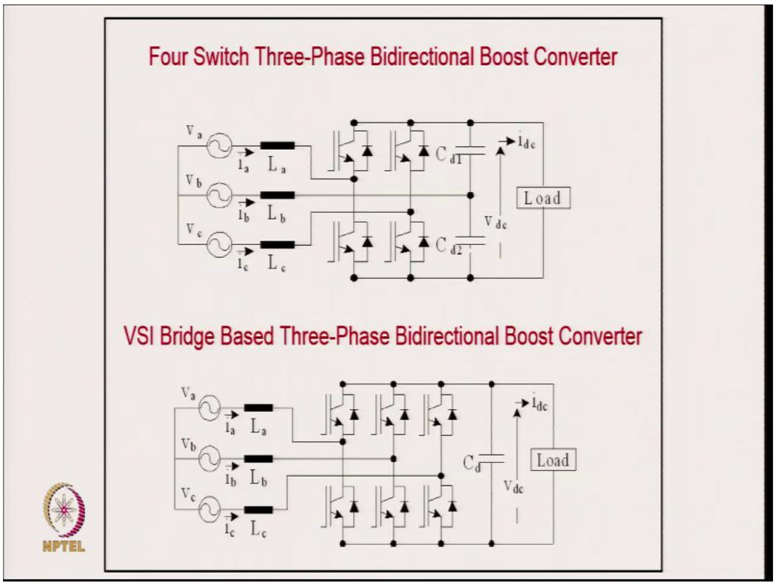

I mean this is three phase bidirectional boost converter. One leg each I mean replaced by midpoint capacitor [FL] because of whole current of this phase move through this capacitor, value of capacitor is very large [FL]. This is not considered quite good and voltage output have to be very high and of course, this is the very well justified converter which can have a bidirectional power flow and this is used of course, with a bidirectional power flow, in the sense I can say normally used for solar grid interface, I mean like and sometime we have a energy storage like a battery and solar grid interface on the DC side.

[FL] In the night we do not have a solar, you can charge the battery also from this at unity power factor and you can put the solar power injection to the grid on the unity power factor [FL]; such converters are also now becoming quite popular for renewable energy interface with the energy storage on the DC link itself [FL]. We will like to discuss that case study separately like I mean or so.

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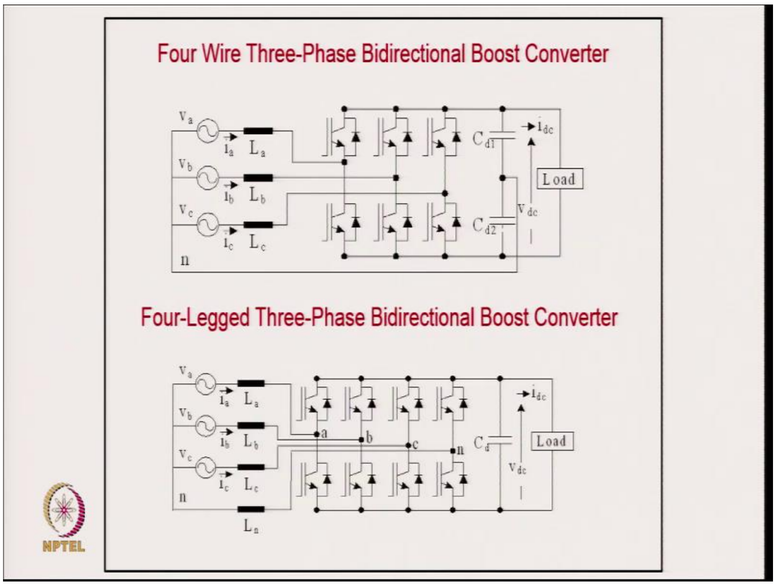

Then coming to of course, the fourth leg here, the midpoint I mean to improve the performance of this similarly fourth leg is taken here for the sometime for neutral current compensation kind of thing. We will discuss little later.

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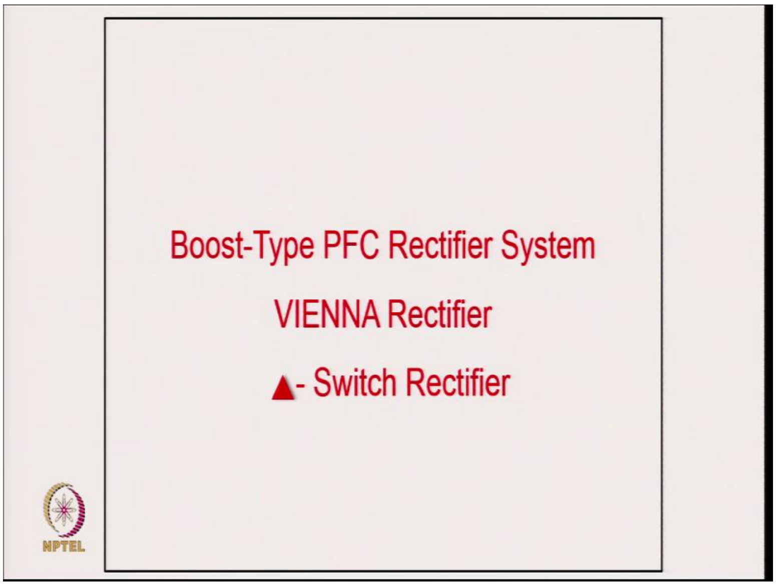

[FL] Now coming to typically Boost Type Power Factor Correction Rectifier, Vienna converter or it is also called Delta Switch Rectifier and this is the another version of typically of Vienna rectifier where the bidirectional switch are connected here and by modulating this you can make the three current sinusoidal.

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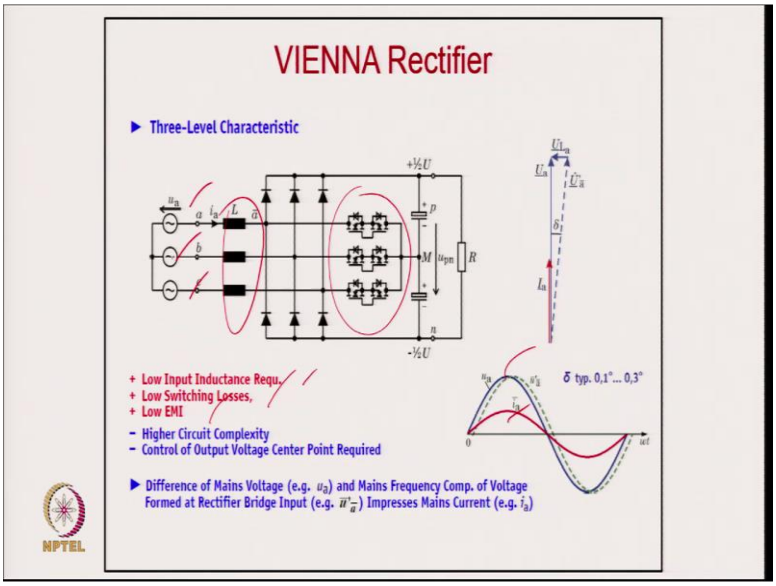

Of course, in this case you are able to reduce the number of the devices and you are able to get like a supply current in phase with the supply voltage with properly and of course, with proper design you are able to get low input inductance requirement of these with if you operate renewable switching frequency low switching losses and low EMI and higher circuit losses [FL].

These have become very popular for telecommunication industries like because you have to charge the battery virtually from the your either from DC set or from the grid, but maintaining the power good power quality means good power factor and reduce harmonics and no reactive power button on the supply system.

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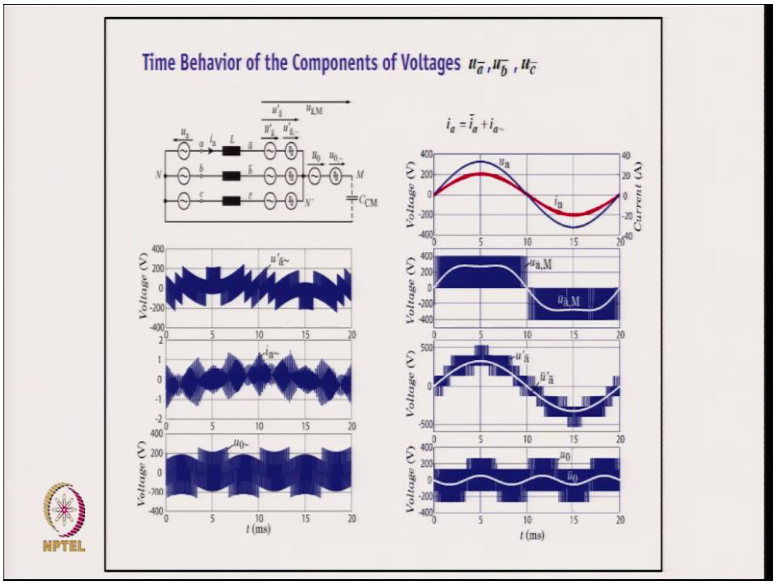

These are the typical of course, the waveform that how we are able to get supply voltage and supply current with the different kind of switching, I mean of the these device bidirectional switches and how the different voltage and here able to even use the typically sometime phase factor modulation for PWM switching. Of course these are the different modes of operation.

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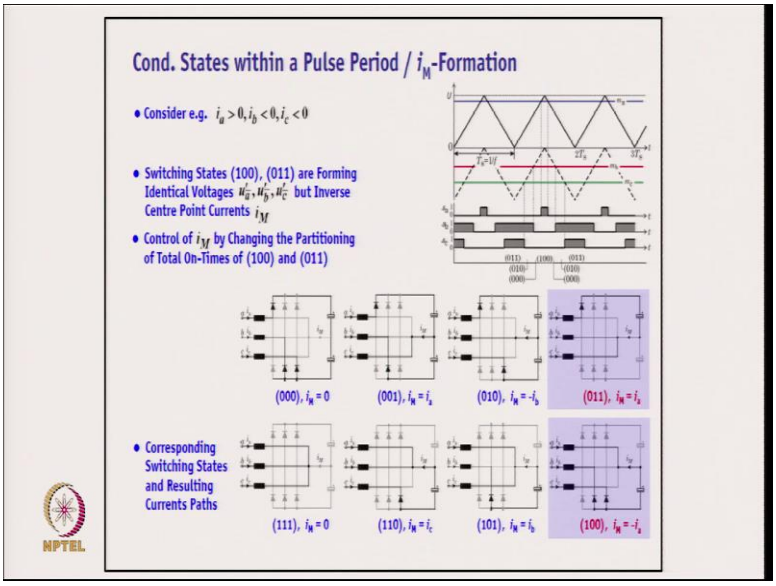

I mean like here you can have a typically 8 modes of operation of these converters for the purpose of switching how you really are able to get boost operation as well as maintain the power quality on the supply side like and these are typically the another version of this till we call it delta switch converter virtually for the actual power flow, I mean where this switch are not connected virtually they are connected in delta manner. They are not connected star with the midpoint.

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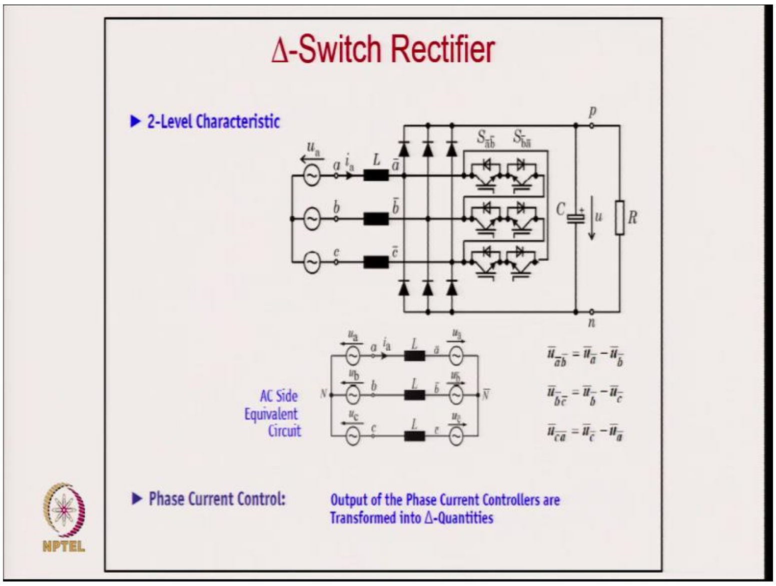

[FL] The benefit that you do not need the two capacitor here on the DC side and it is able to control the you can call it output to voltage regulator as well as you are able to get sinusoidal current on input side like.

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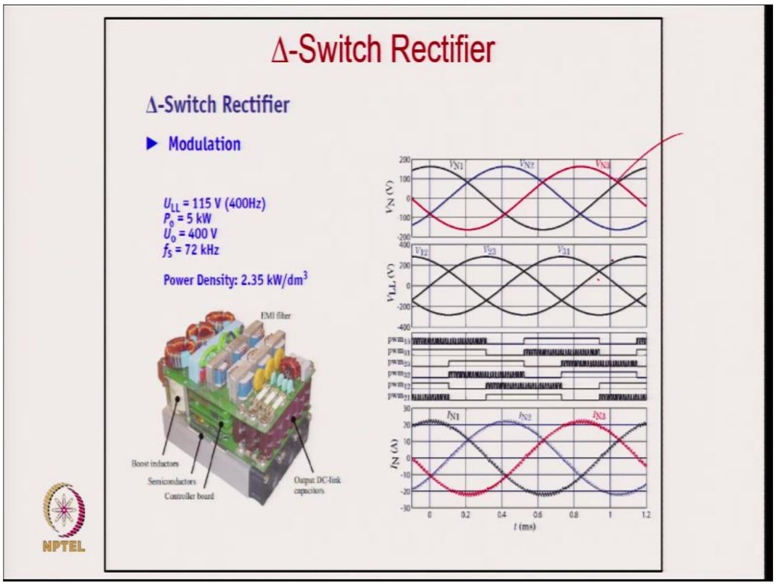

And you can see the three phase supply voltage with three phase typically the voltage and you have a three phase supply current from this converter. This is typically for 5 kilowatt converter, I mean how you look into the summarizes these. These are very popular with the high power density you can think about I mean like for used for again for telecommunication industry and many industry for with power factor correction on the supply side like and how the PWM switching pulses are generated for those bidirectional switches like.

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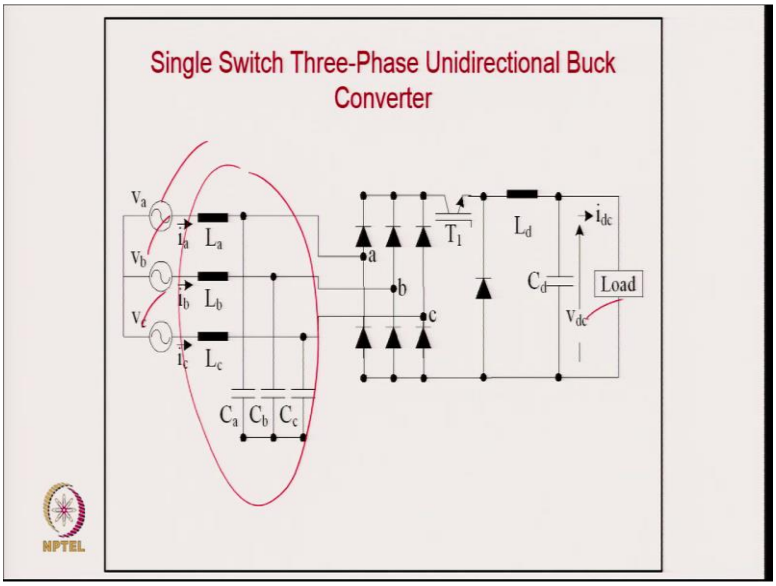

[FL] Now, coming to Three Phase Unidirectional Buck Converter and this is simple buck converter that you have a buck converter after diode rectifier and it is a replacement of you can call it typically like semi converter of thyristor converter type and you have a like of course, single switch cannot have a good power quality on input side, but you use the LC filter to save the current of course, on input side of this converter or to get renewable good power quality.

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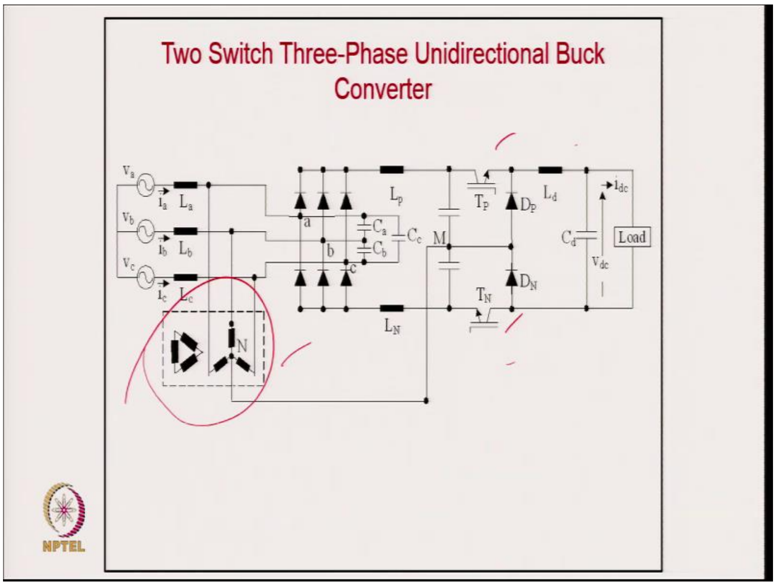

But of course, we use the typically we call it this is two switch derive converter, similar to like what we talk about another converter with the ripple injection similar to Minnesota Rectifier but this is for buck operation, two converter operating in buck mode for regulating output inductor.

And this ripple injection circuit you can of course, use the zigzag or you can use this star with the closed path of the for ripple injection with the delta circuit [FL] these all of course, provide the [FL] you can call it is a complementary of Minnesota rectifier for the buck operation.

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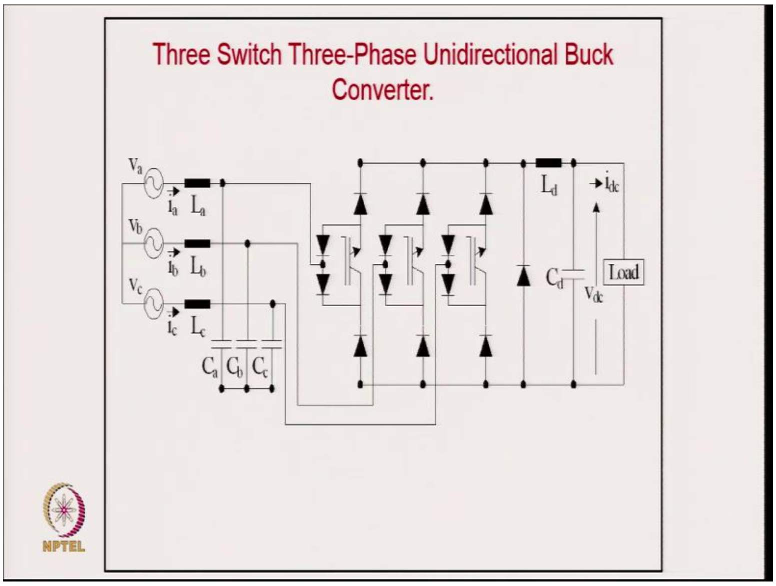

And you have again the buck converter corresponding to again complementary of your Vienna rectifier for buck operation with the 3 switches and with the EMI filter [FL] it also be buck operation at the output voltage.

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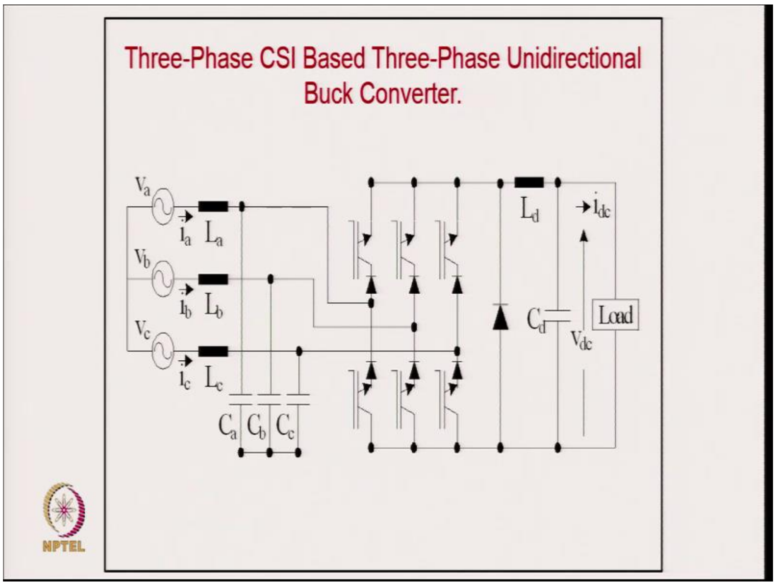

And similarly now this is what we call it the typically buck operation of the three phase current source converter with the only feeding diode at out with the filter and you are able to get of course, the well shaping of the current on the input like. [FL] These are the version of unidirectional buck converter.

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Now, coming to Three Phase Bidirectional Buck Converter.

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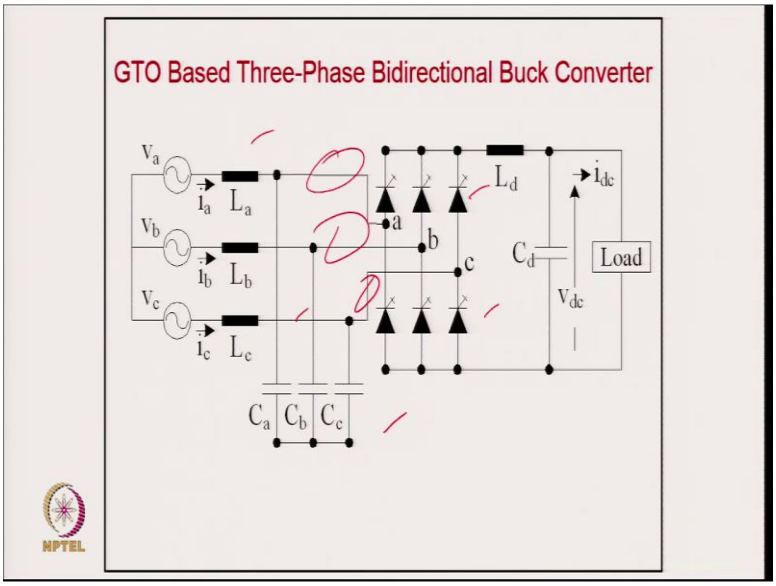

I mean this is typically you can think about is a we are using the GTO here the switches with the input LC filter because the reason being these currents are the PWM current here because you will be operating this converter in PWM mode and this is the replacement of thyristor converter.

The benefit compared to thyristor converter of this is that there is no reactive burden as well as no harmonics on the supply side and you are able to get a control voltage at the output of course, why you selecting a GTO? GTO have a gate turn off thyristor have a reverse voltage blocking capability which is this current source converter needs here.

And of course, the limitations of this is the GTO cannot operate the high switching frequency [FL] you cannot have the size of filter lower, but you can use the IGBT with series diode for this converter [FL] that allow higher switching frequency and you can reduce the size of this typically of the EMI filter for output inductor also for three phase respectively.

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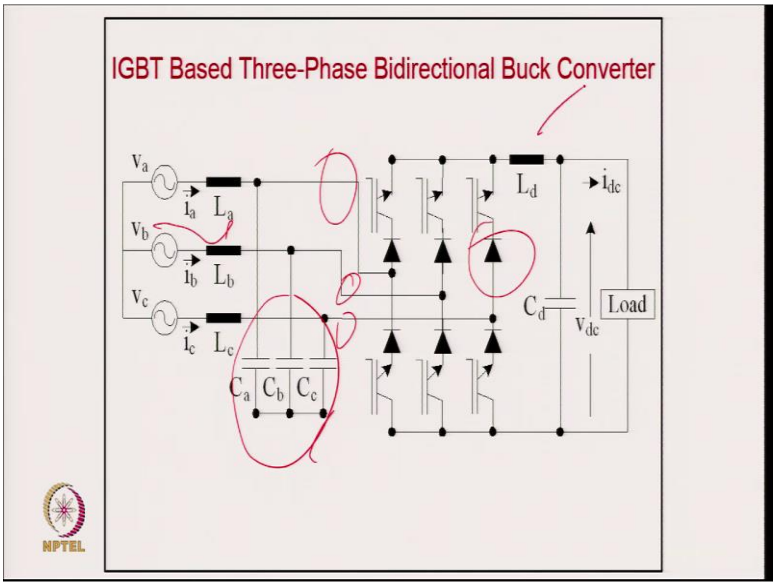

And this is the circuit with the IGBT with series diode. The reason being this is a current source converter and you have a PWM current here and it needs the reverse voltage blocking capability across the switch that is the reason IGBT or MOSFET, I mean your transistor phase bridge does not have a reverse voltage blocking capability. That is the reason for reverse voltage you are connecting diode.

[FL] One of the major drawback of this is, that the now losses of the 2 devices are there not one I mean like and you need of course, because it is a PWM current, you want here continuous current [FL] you need the this capacitor shunt capacitor and value of shunt capacitor certainly depends on the value of typically of your switching frequency like.

But of course, I mean here the drawback is that this is also mandatory and you need the inductor filter where the boost converter do not need this inductor filter only capacitor is enough like or they [FL] again this is again the you can say replacement of you can get a bidirectional voltage at the output, but current will be unidirectional.

Because inductor is there similar to like a thyristor bridge like, but compared to your thyristor converter, bridge converter the benefit here you have do not have a reactive power button and you do not have a harmonics, that have a harmonics as well as reactive power button I mean like or so.

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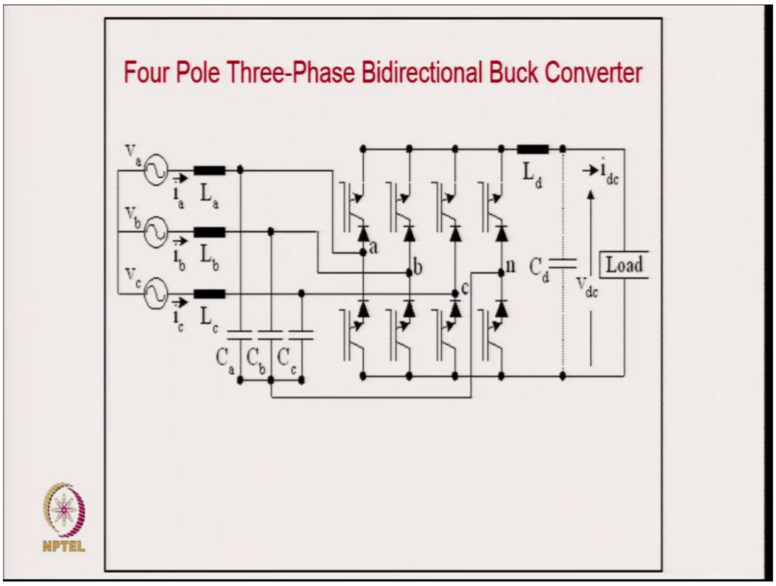

Now, this is typically again with the fourth leg corresponding to take care of the typically Improved characteristic corresponding to the with this fourth leg for corresponding to the neutral leg.

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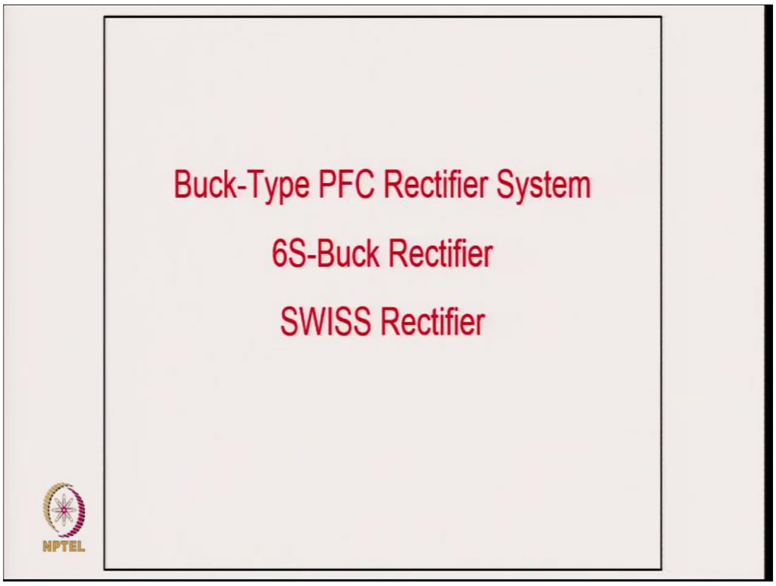

Now, coming to buck type power factor correction rectifier systems.

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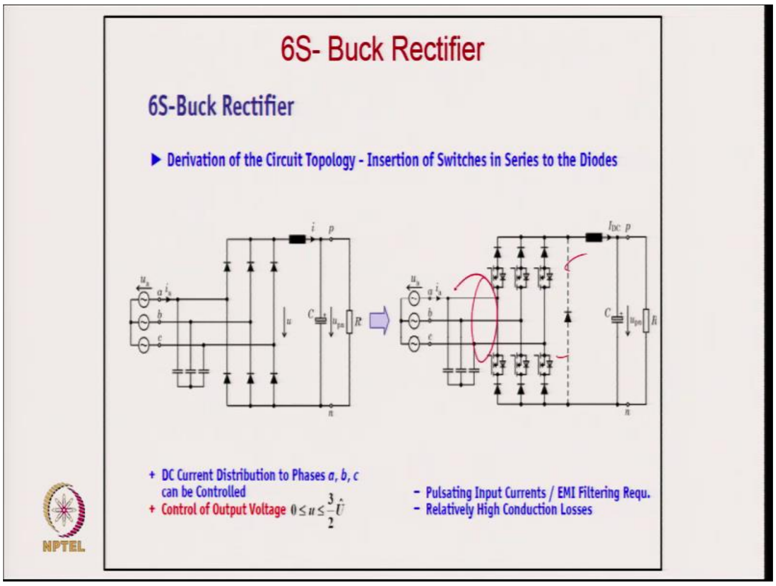

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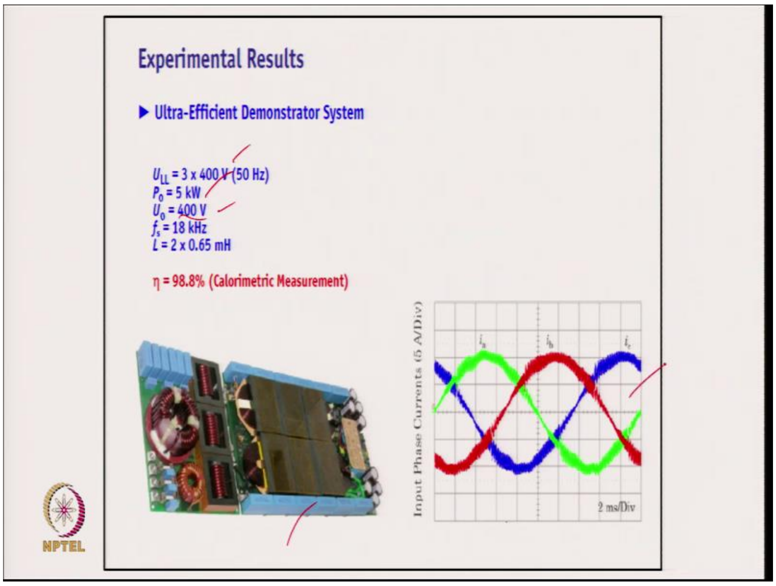

This is how the converter look like for 5 kHz, and these are the supply current which are balanced sinusoidal at the supply side.

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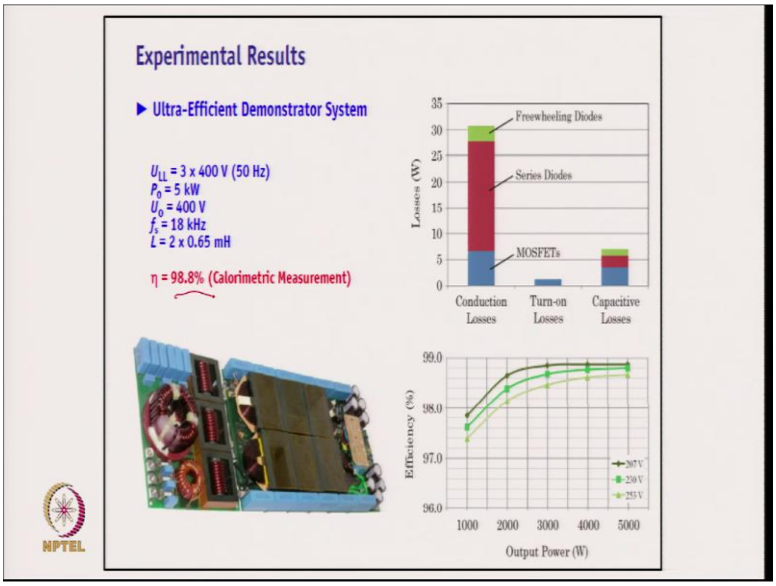

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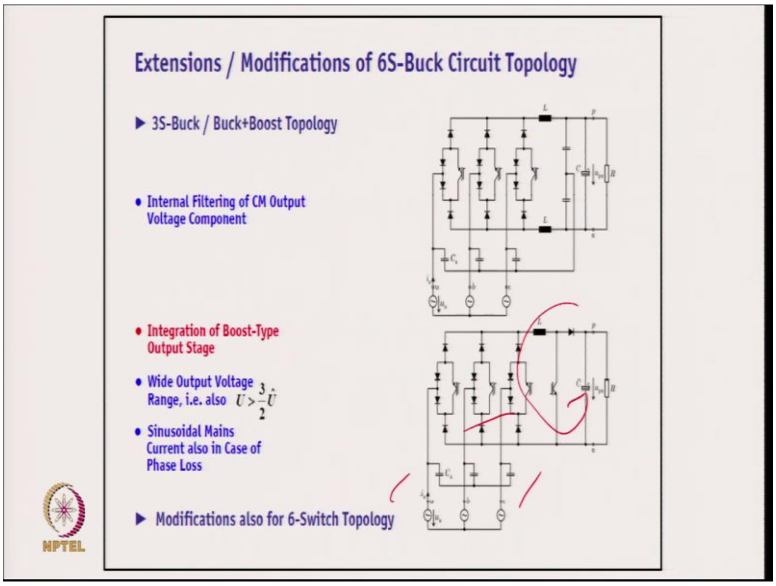

And this is the extension of 6S buck boost topology.

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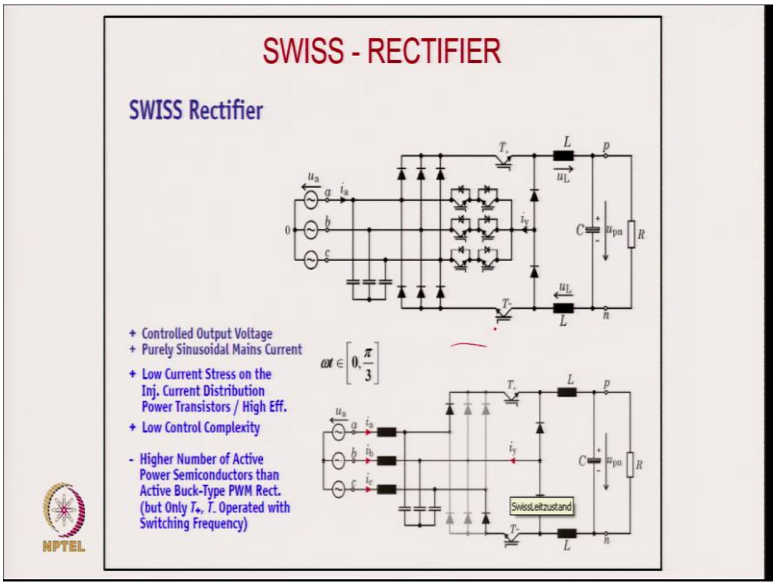

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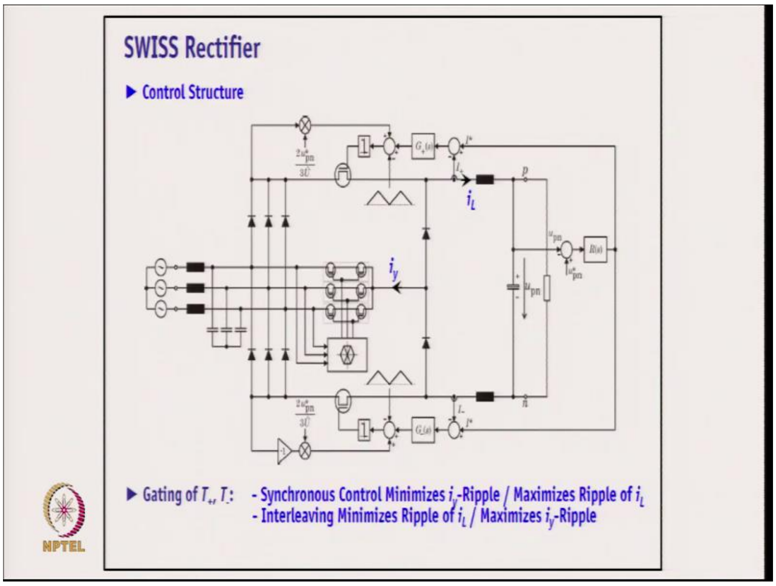

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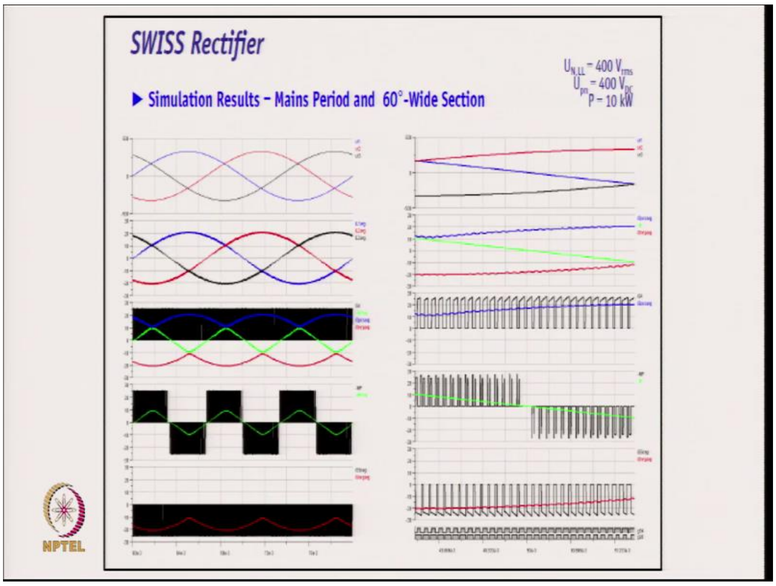

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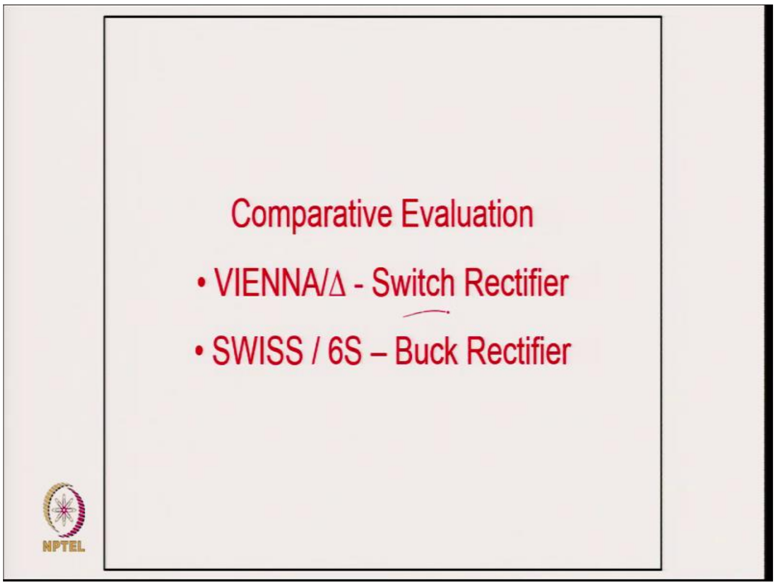

Now, a comparative evaluation is given here between the Vienna and delta as well as between the SWISS and 6S converter.

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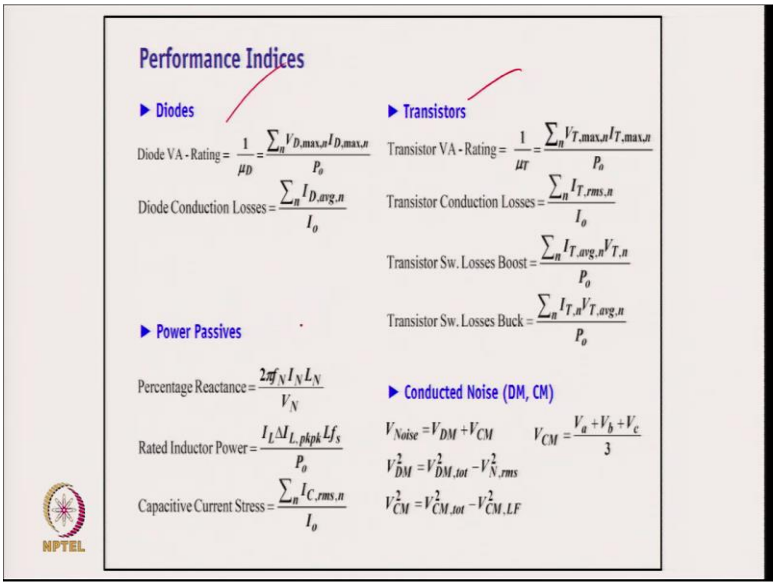

These are the typical performance indices corresponding to the VA ratings, losses for all components i.e., for the transistors, diodes and passive components and the conducted noise associated with each converter.

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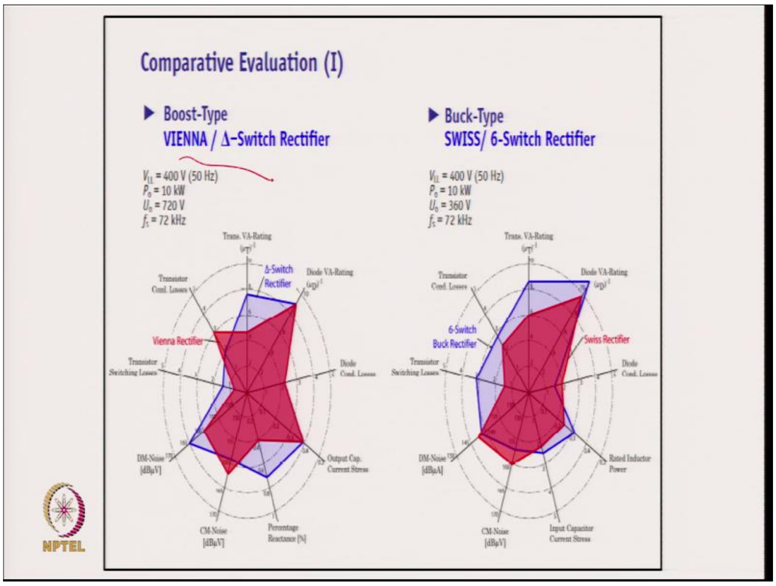

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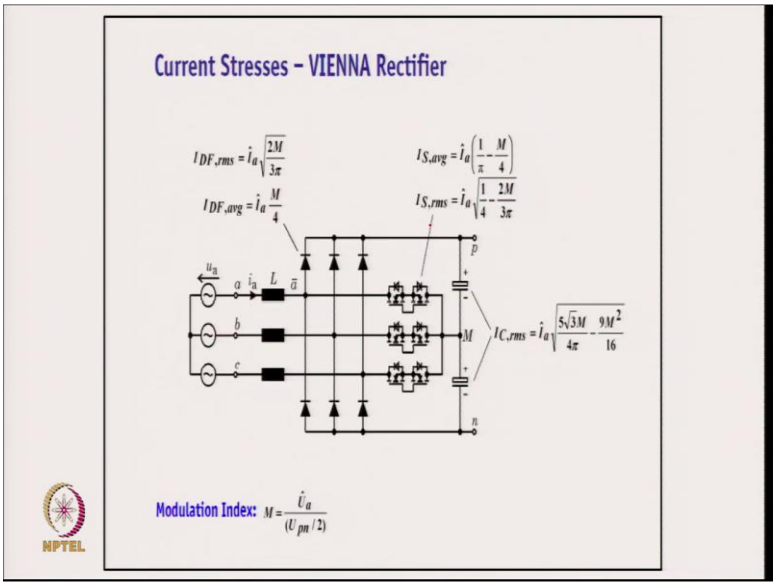

This is typically the current stresses calculations correspond to the Vienna rectifier.

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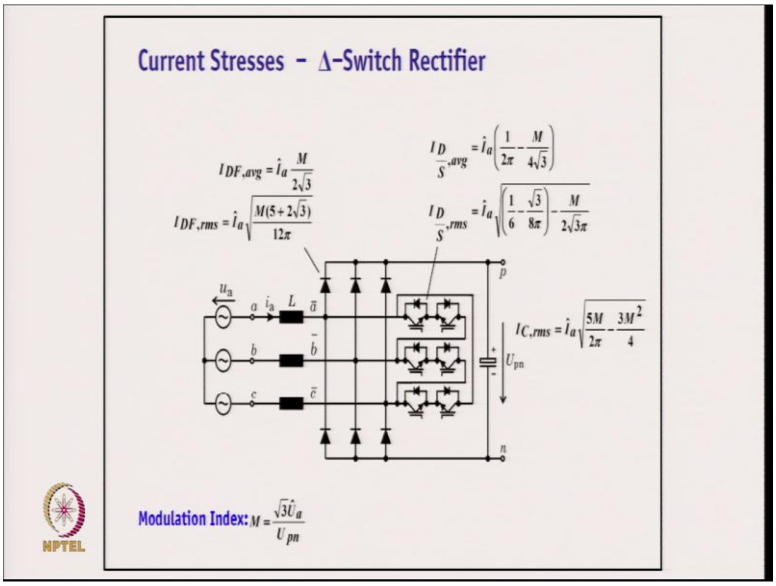

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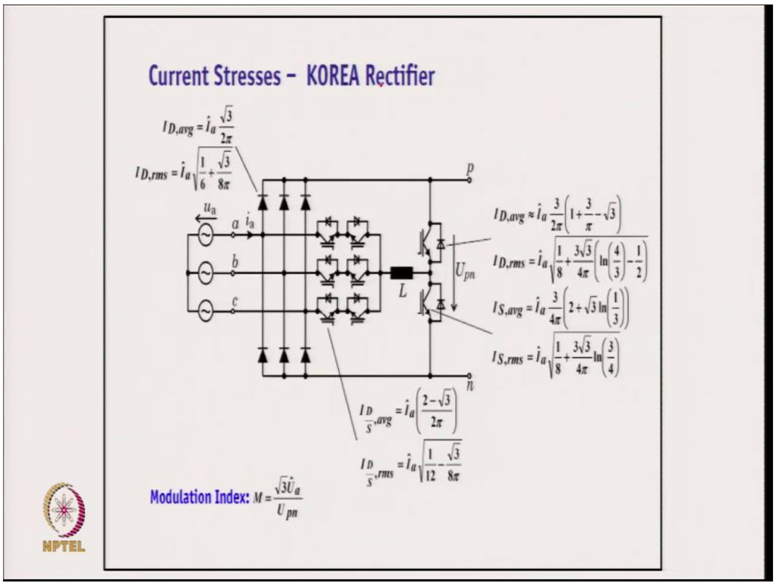

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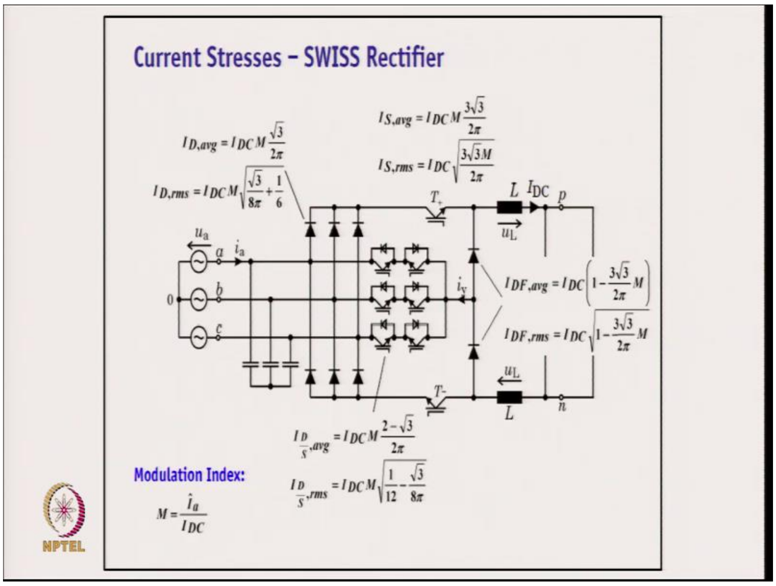

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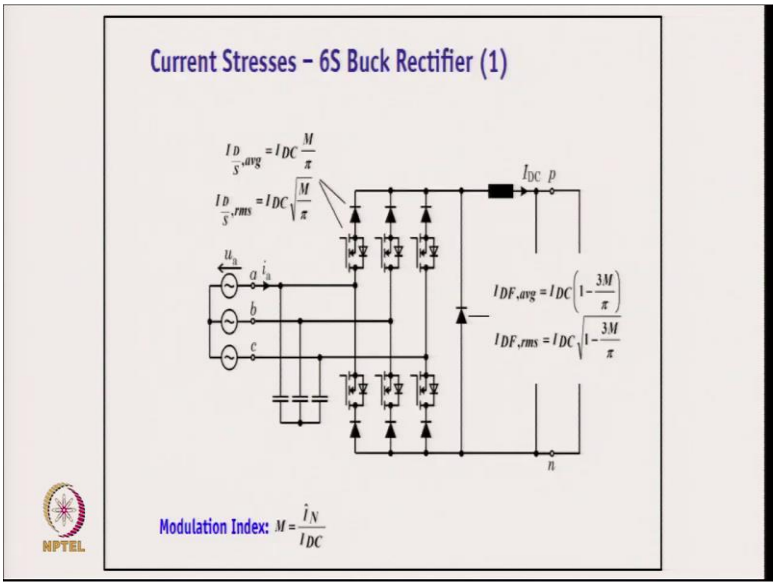

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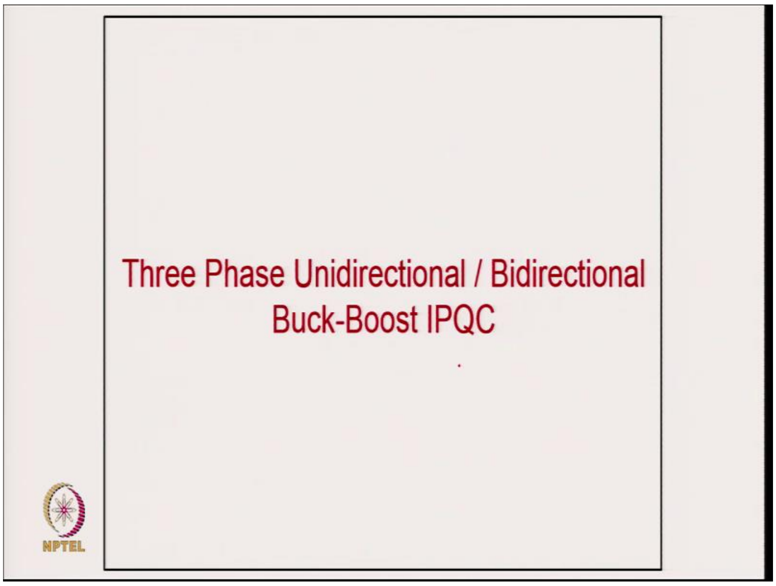
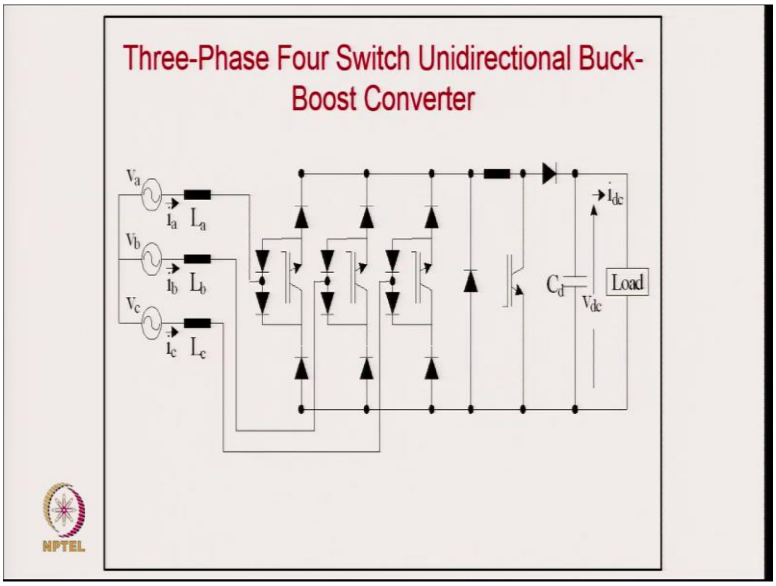


Now, coming to the three phase unidirectional/bidirectional buck-boost converter

(Refer Slide Time: 19:56)



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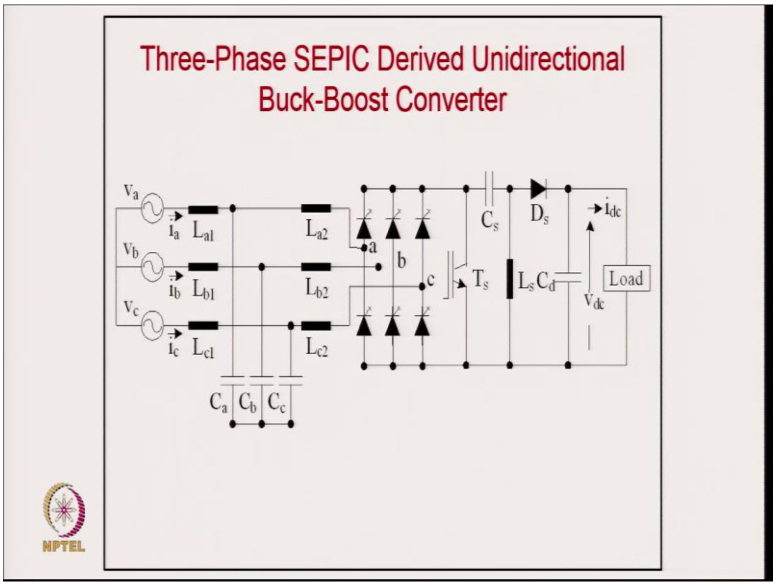

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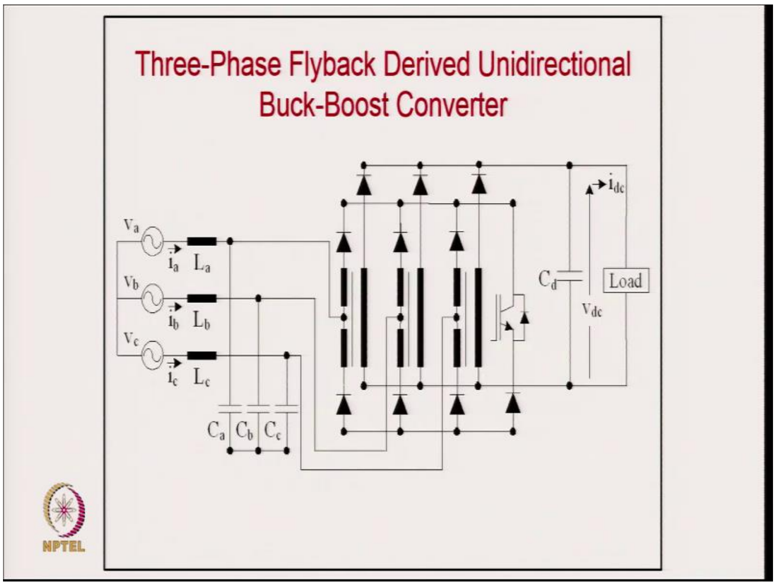

And this is typically a Vienna rectifier, where the buck boost feature is derived by a single switch. This is an interesting circuit as you will get a shaped current wave only by one switch.

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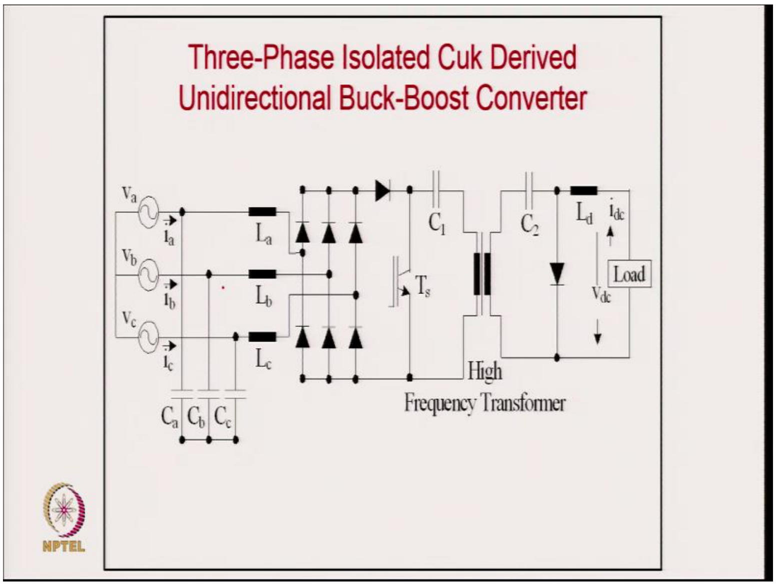

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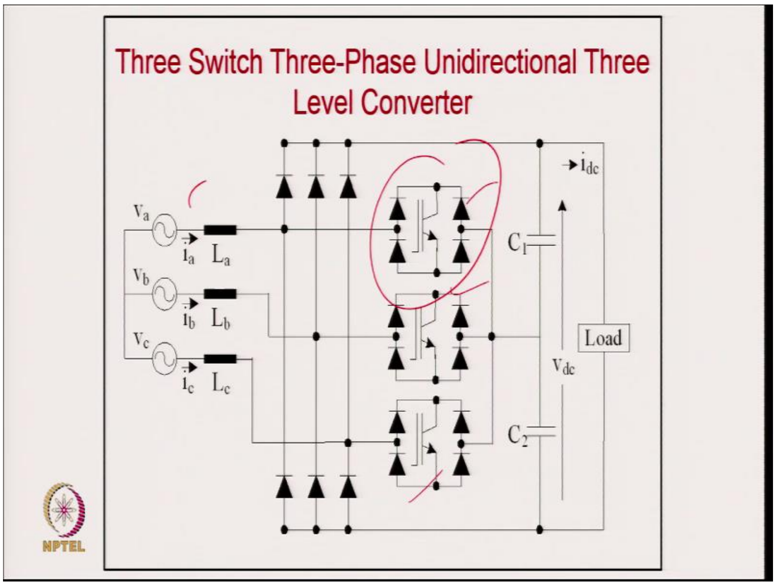

This is a 3 level unidirectional buck-boost AC-DC converter. In this, the multi-levels are created for improving the power quality on the supply side and having a boosting operation with the help of three bidirectional switch.

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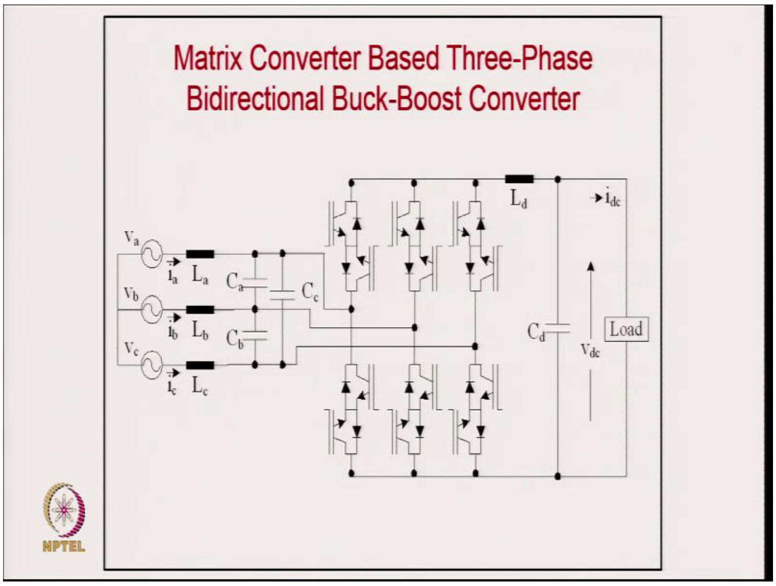
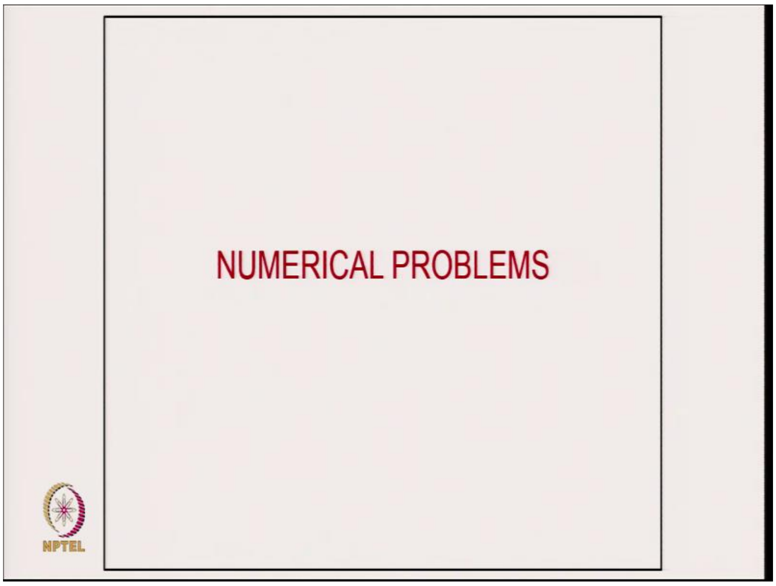


And this is a bidirectional Buck-Boost converter. This is derived from the matrix converter. The matrix converter is a very important converter which can do all 4 conversion AC to DC, DC to AC and AC to AC, but here it is derived for the AC to DC conversion with the bidirectional power flow.

Now, coming to the numerical examples.

(Refer Slide Time: 21:45)



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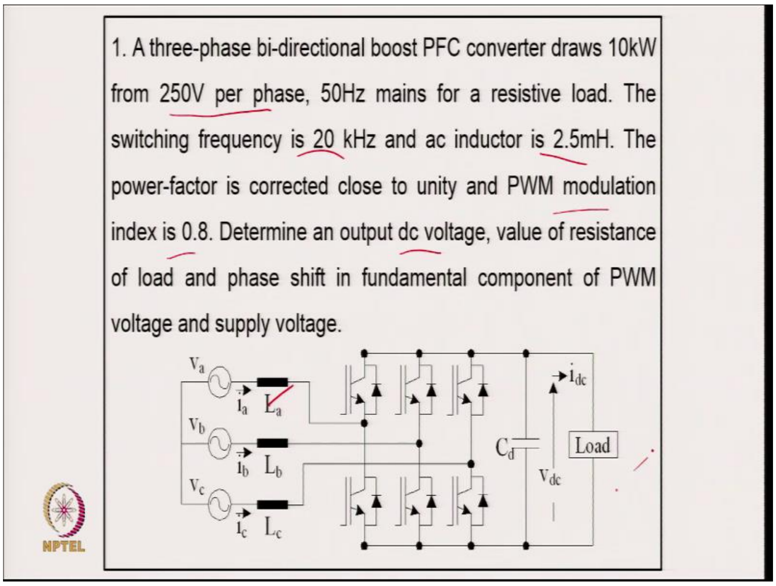
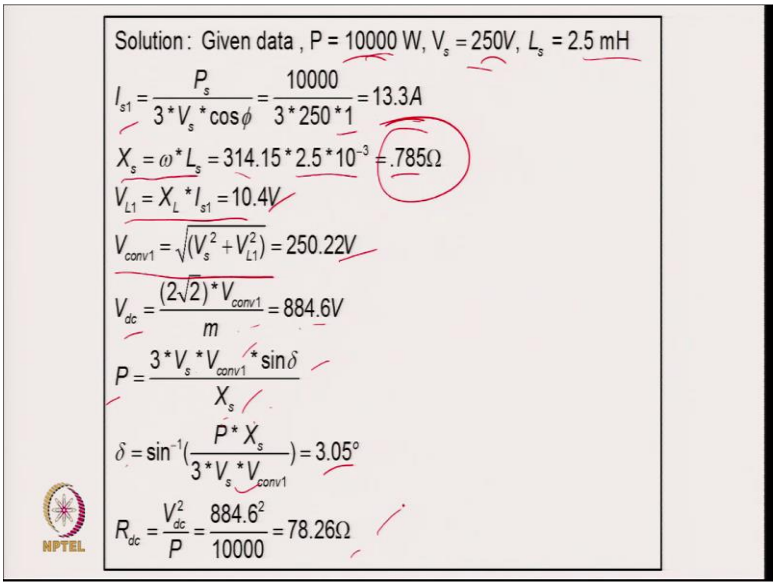


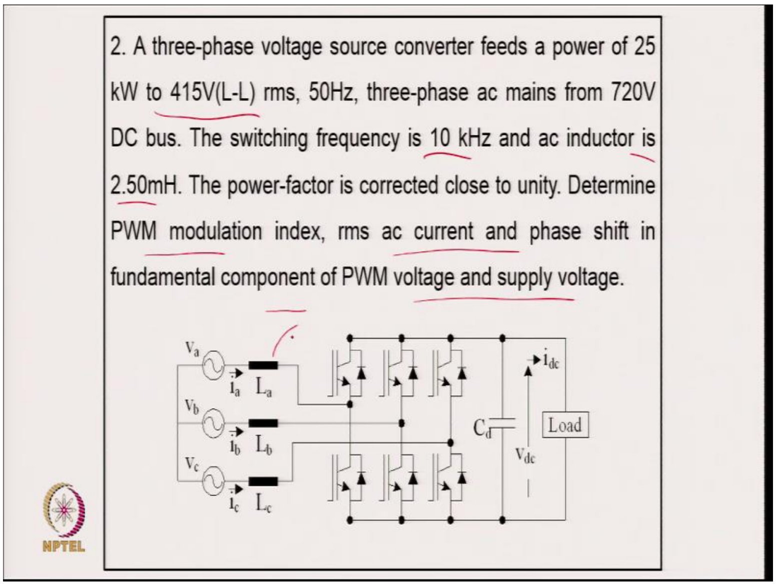
Coming to the first numerical example. A Three phase bidirectional boost PFC converter draws 10 kW from 250 V per phase, 50 hertz, 3 phase AC mains for a resistive load. The switching frequency 20 kHz and AC input inductor 2.5 mH. The power factor is corrected close to unity and PWM modulation index is 0.8. Determine the output DC link voltage, value of equivalent resistance of the load and phase shift between fundamental component of PWM.

(Refer Slide Time: 22:25)



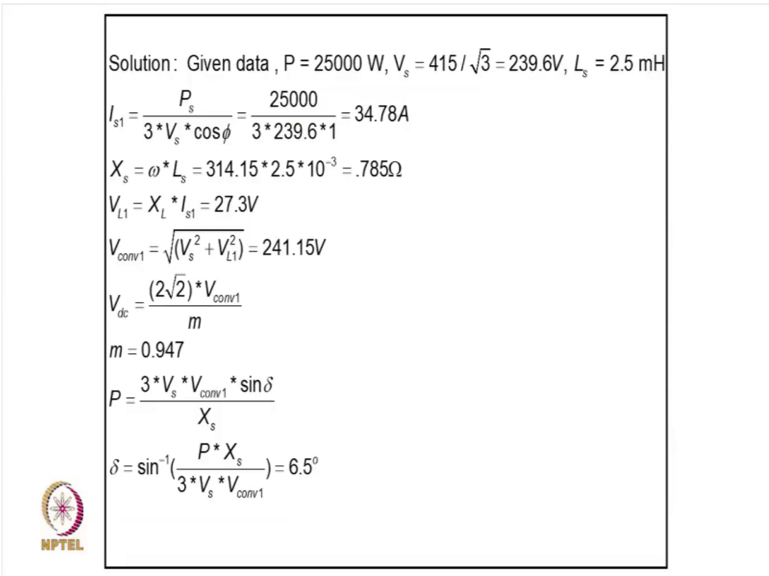
The solution of this problem is given in the abovemention slides.

(Refer Slide Time: 24:11)



Now, coming to second numerical, a three phase voltage source converter feeds a power of 25 kW to 415 V line to line RMS 50 hertz three phase ac mains from 720 V DC bus voltage. The switching frequency is 10 kHz and the AC inductor is 2.5 mH. The power factor is corrected close to unity. Determine the PWM modulation index, RMS supply ac current and phase shift between fundamental component and PWM voltage and supply voltage.

(Refer Slide Time: 24:51)



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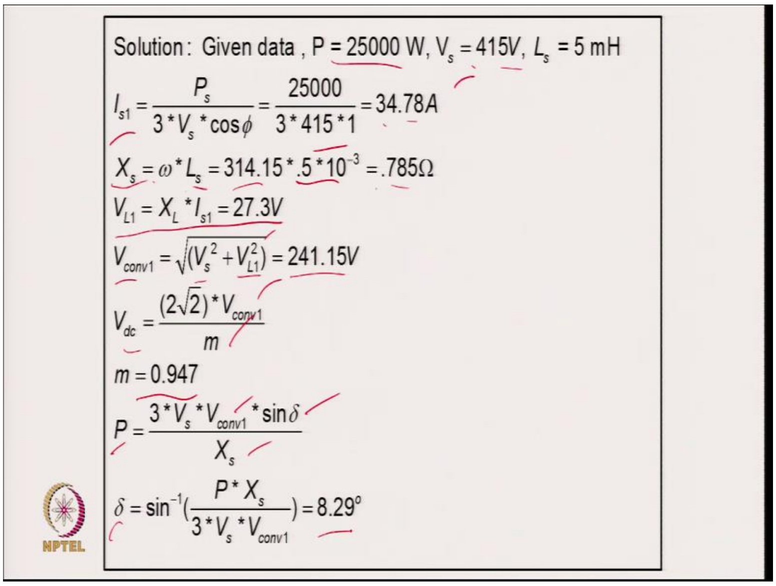

The solution of this problem is given in the abovemention slides.

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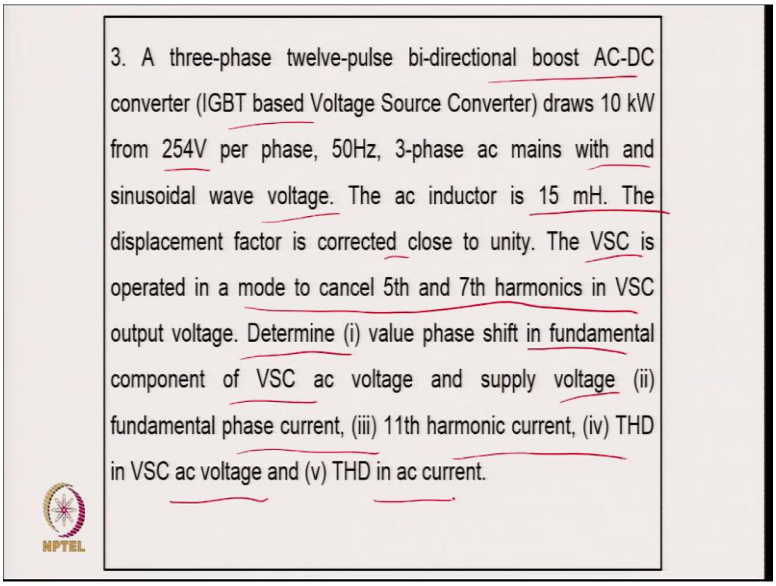


Now, coming to next numerical problem. A three phase twelve pulse bidirectional boost converter draws 10 kW from 250 V per phase, 50 Hz three phase AC mains. The AC inductor is 15 mH. The displacement factor is corrected close to unity. The VSC is operated in mode to cancel 5^{th} and 7^{th} harmonics in output voltage of VSC. Determine the value of phase shift in fundamental component of VSC AC voltage and supply voltage, fundamental phase current, 11^{th} harmonic current, total harmonic distortion in VSC AC voltage and THD in AC current.

(Refer Slide Time: 26:49)

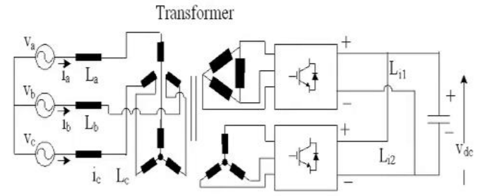
Solution: Given data, P = 10000 W, $V_s = 254V$, L_s = 15 mH

$$I_{s1} = \frac{P_s}{3 * V_s * \cos\phi} = \frac{10000}{3 * 254 * 1} = 13.123A$$

$$X_s = \omega * L_s = 314.15 * 15 * 10^{-3} = 4.71\Omega, \; V_{L1} = X_s * I_{s1} = 61.84V$$

$$V_{conv1} = \sqrt{(V_s^2 + V_{L1}^2)} = 261.41V$$

$$\delta = \sin^{-1}\left(\frac{P * X_s}{3 * V_s * V_{conv1}}\right) = 13.677^o$$



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$$V_n = \frac{V_1}{n}$$

$$V_{11} = \frac{V_1}{11} = 23.7645V$$

$$V_{13} = \frac{V_1}{13} = 20.10846V$$

$$V_{23} = \frac{V_1}{23} = 11.3656V$$

$$V_{25} = \frac{V_1}{25} = 10.4564V$$

$$V_{35} = \frac{V_1}{n} = 7.4688V$$

$$V_{37} = \frac{V_1}{37} = 7.0651V$$

$$V_{47} = \frac{V_1}{47} = 5.5619V$$

$$V_{49} = \frac{V_1}{49} = 5.3348V$$

$$I_n = \frac{V_1}{n^2 X_L}$$

$$I_{11} = \frac{V_1}{121 * 4.71} = 0.4586A$$

$$I_{13} = \frac{V_1}{169 * 4.71} = 0.32841A$$

$$I_{23} = 0.1049A$$

$$I_{25} = 0.0888A$$

$$I_{35} = 0.0453A$$

$$I_{37} = 0.0405A$$

$$I_{47} = 0.0251A$$

$$I_{49} = 0.0231A$$

(Refer Slide Time: 29:28)

$$THD_V = \sqrt{\frac{V_{rms}^2 - V_1^2}{V_1^2}}$$

$$THD_V \approx \sqrt{\frac{V_{11}^2 + V_{13}^2 + V_{23}^2 + V_{25}^2 + V_{35}^2 + V_{37}^2 + V_{47}^2 + V_{49}^2}{V_1^2}} = 0.1417$$

$$THD_V \approx 14.17\%$$

$$THD_I = \sqrt{\frac{I_{rms}^2 - I_1^2}{I_1^2}}$$

$$THD_I \approx \sqrt{\frac{I_{11}^2 + I_{13}^2 + I_{23}^2 + I_{25}^2 + I_{35}^2 + I_{37}^2 + I_{47}^2 + I_{49}^2}{I_1^2}} = 0.0456$$

$$THD_I \approx 4.456\%$$

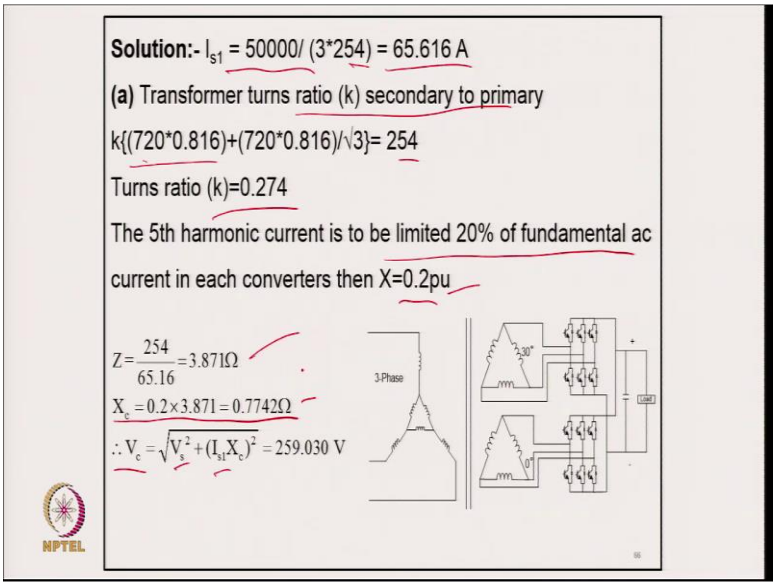
The solution of this problem is given in the abovemention slides.

(Refer Slide Time: 30:16)

4. A three-phase twelve-pulse quasi-square bi-directional boost AC-DC converter (IGBT based Voltage Source Converter coupled with transformers having primaries connected to ac mains star/delta and delta/delta with common dc bus) with fundamental frequency switching and feeding 50 kW from a dc battery of 720 V to a 254V per phase, 50Hz, 3-phase ac mains. The 5th harmonic current is to be limited 20% of fundamental ac current in each converters. The displacement factor is corrected close to unity. The VSCs are operated in a mode to cancel 5th and 7th harmonics in ac mains current. Determine (a) transformer turns ratios, (b) value phase shift in fundamental component of VSC ac voltage and supply voltage, (c) fundamental phase current, (d) THD in the ac current and (e) the value of leakage inductance of the transformer.

Now, coming to the 4th problem. A three phase 12 pulse quasi-square bi-directional AC DC converter with the fundamental frequency switching and feeding 50 kW from a DC battery of 720 V to a 254 V per phase, 50 hertz, 3 phase AC main. The 5th harmonic current is to be limited by 20 % of fundamental AC current to each converter. The displacement factor is corrected close to unity. The VSCs are operated in a mode to cancel 5th and 7th harmonics in AC mains current. Determine (a) transformer turns ratio (b) value of the phase shift in fundamental component of VSC AC voltage and supply voltage (c) the fundamental phase current (d) total harmonics distortion of AC mains current and then (e) the value of leakage inductance of the transformer.

(Refer Slide Time: 31:06)



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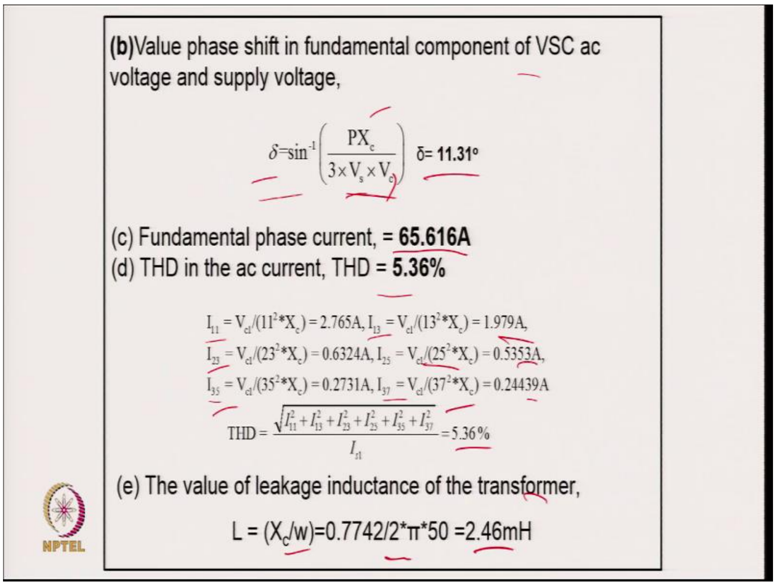

The solution of this problem is given in the abovemention slides.

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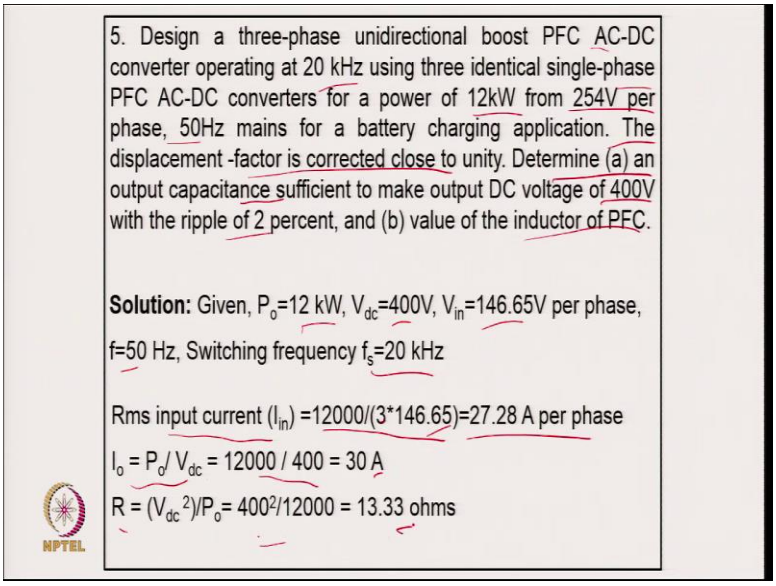
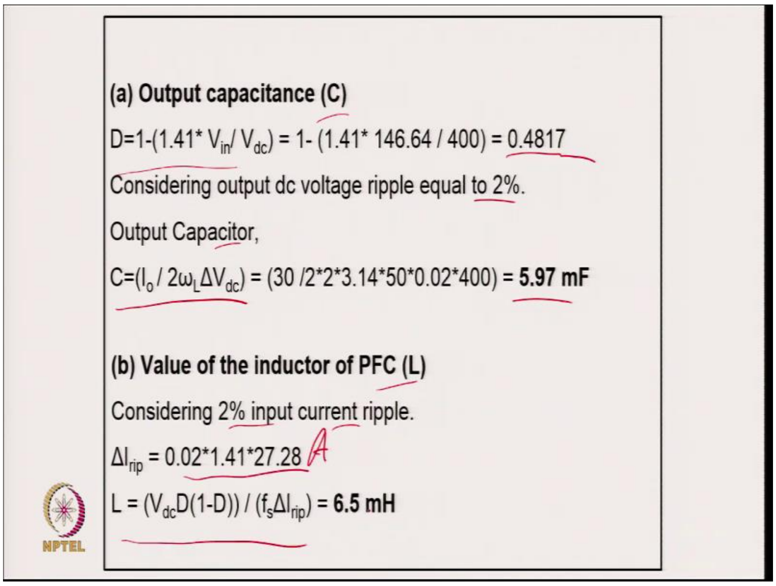


Coming to 5th example. Design a three phase unidirectional boost PFC AC DC converter operating at 20 kHz using 3 identical single phase PFC AC DC converter for a power rating of 12 kW from 254 V per phase and 50 hertz AC mains for a battery charging application. The displacement factor is corrected to unity. Determine (a) output capacitance sufficient to make output DC voltage of 400 V with the ripple of 2 %, and the value of inductor for PFC.

(Refer Slide Time: 34:02)



The solution of this problem is given in the abovemention slide.

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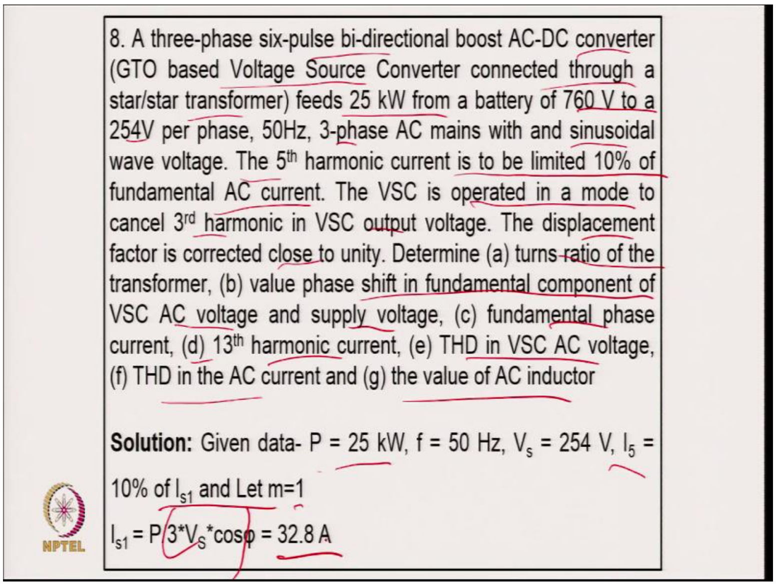
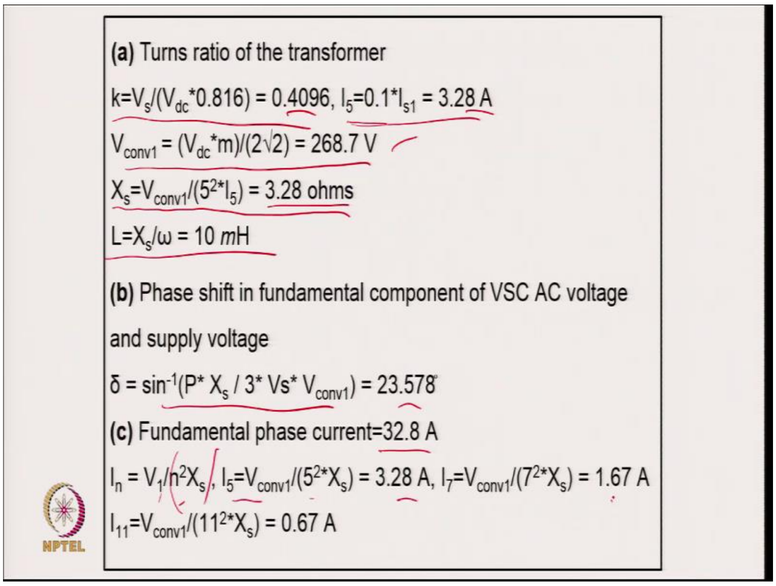


Coming to next example. A three phase 6 pulse bi-directional boost AC-DC converter feeds a 25 kW from a battery of 760 V to 254 V per phase, 50 hertz, 3 phase AC mains. The 5^{th} harmonics current is to be limited 10 % of the fundamental AC current. The VSC is operated in a mode to cancel 3^{rd} harmonic VSC output voltage. The displacement factor is close to unity. Determine, (a) turns ratio of the transformer, (b) value of phase shift in fundamental component of VSC AC voltage and supply voltage (c) the fundamental phase current, (d) 13^{th} harmonic current (e) THD in VSC AC voltage, (f) THD of AC mains current, and (g) value of AC inductor.

(Refer Slide Time: 35:32)



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(d) 13^{th} harmonic current

$I_{13}=V_{conv1}/(13^2*X_s) = 0.48$ A,

$I_{17}=V_{conv1}/(17^2*X_s) = 0.28$ A ,

$I_{19}=V_{conv1}/(19^2*X_s) = 0.22$ A,

$I_{23}= V_{conv1}/(23^2*X_s) = 0.15$ A,

$I_{25}= V_{conv1}/(25^2*X_s) = 0.13$ A,

$I_{29}=V_{conv1}/(29^2*X_s) = 0.097$A,

$I_{31}=V_{conv1}/(31^2*X_s) = 0.085$ A,

$I_{35}=V_{conv1}/(35^2*X_s) = 0.067$ A,

$I_{37}=V_{conv1}/(37^2*X_s) = 0.059$ A,

$I_{41}=V_{conv1}/(41^2*X_s) = 0.048$ A,

$I_{43}=V_{conv1}/(43^2*X_s) = 0.044$ A,

$I_{47}=V_{conv1}/(47^2*X_s) = 0.037$A,

$I_{49}=V_{conv1}/(49^2*X_s) = 0.034$ A

$V_n = V_1/n$

$V_5=V_{conv1}/5 = 53.74$ V

$V_7=V_{conv1}/7 = 38.38$ V

$V_{11}= V_{conv1}/11 = 24.4$ V

$V_{13}= V_{conv1}/13 = 20.66$ V

$V_{17}= V_{conv1}/17 = 15.80$ V

$V_{19}= V_{conv1}/19 = 14.14$ V

$V_{23}= V_{conv1}/23 = 11.68$ V

$V_{25}= V_{conv1}/25 = 10.74$ V

$V_{29}= V_{conv1}/29 = 9.26$ V

$V_{31}=V_{conv1}/31 = 8.66$ V

$V_{35}= V_{conv1}/35 = 7.67$ V

$V_{37}=V_{conv1}/37 = 7.26$ V

$V_{41}= V_{conv1}/41 = 6.55$ V

$V_{43}= V_{conv1}/43 = 6.25$ V

$V_{47}=V_{conv1}/47 = 5.717$ V

$V_{49}=V_{conv1}/49 = 5.48$ V

NPTEL

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(e) THD in VSC AC voltage, THD_V =

$$\sqrt{\frac{V_5^2+V_7^2+V_{11}^2+V_{13}^2+V_{17}^2+V_{19}^2+V_{23}^2+V_{25}^2+V_{29}^2+V_{31}^2+V_{35}^2+V_{37}^2+V_{41}^2+V_{43}^2+V_{47}^2+V_{49}^2}{V_1^2}} = 30.02\%$$

(f) THD in the AC current, THD_I =

$$\sqrt{\frac{I_5^2+I_7^2+I_{11}^2+I_{13}^2+I_{17}^2+I_{19}^2+I_{23}^2+I_{25}^2+I_{29}^2+I_{31}^2+I_{35}^2+I_{37}^2+I_{41}^2+I_{43}^2+I_{47}^2+I_{49}^2}{I_1^2}} = 11.59\%$$

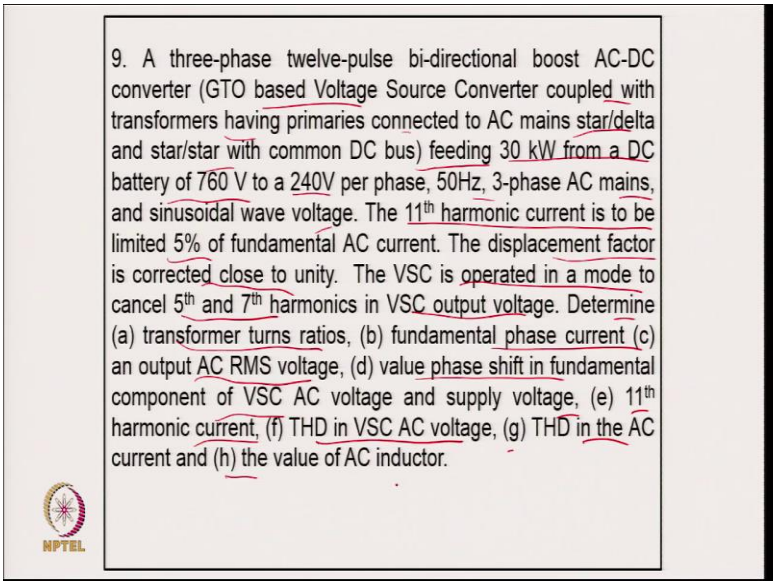
(g) The value of AC inductor

$L=X_s/\omega = 10$ mH

NPTEL

The solution of this problem is given in the abovemention slides.

(Refer Slide Time: 36:24)



Now, coming to next example. A three phase twelve pulse bi-directional boost converter AC-DC converter feeding 30 kW from a DC battery of 760 V to a 240 V per phase, 50 Hz, 3 phase AC mains. The 11^{th} harmonics current is to be limited 5% of the fundamental AC current. The displacement factor is corrected close to unity. The VSC is operated in the mode to cancel 5^{th} and 7^{th} harmonics in VSC output voltage. Determine (a) transformer turns ratio, (b) the fundamental phase current, (c) an output AC RMS voltage, (d) the phase shift in fundamental component of VSC voltage and the supply voltage, (e) 11^{th} harmonic current, (f) THD in VSC AC voltage, (g) THD in AC current, and (h) is value of AC inductor.

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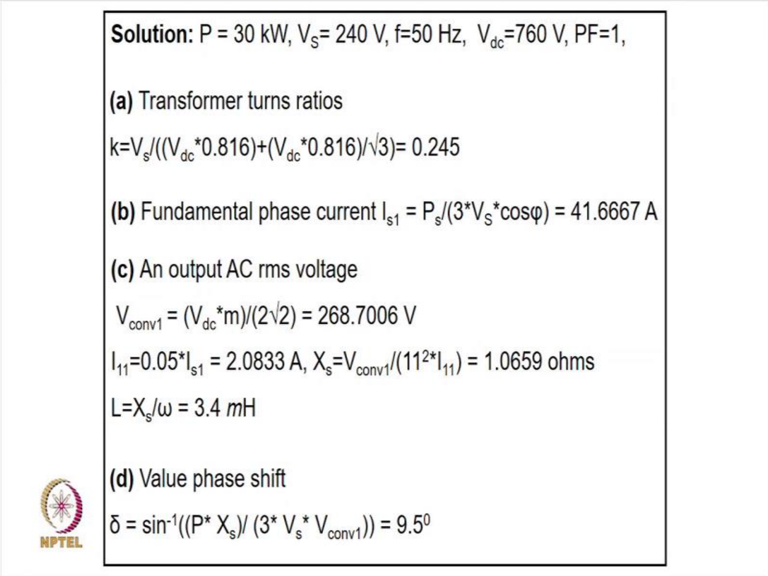

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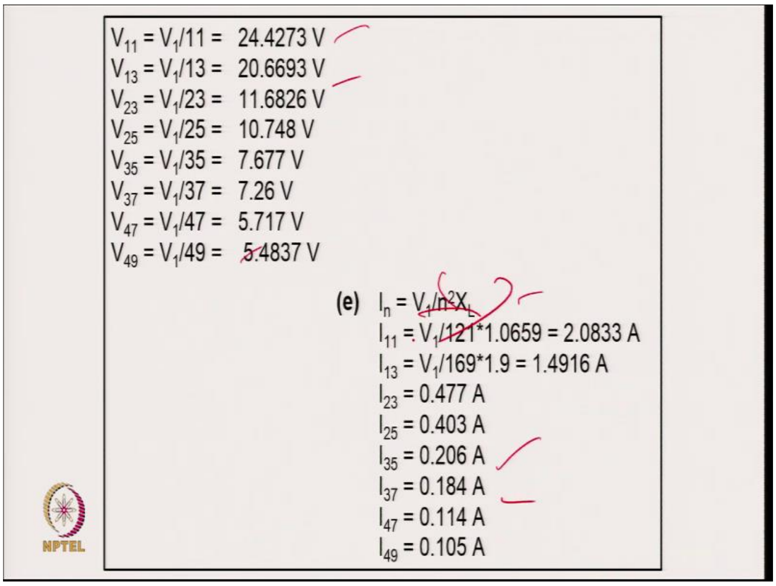

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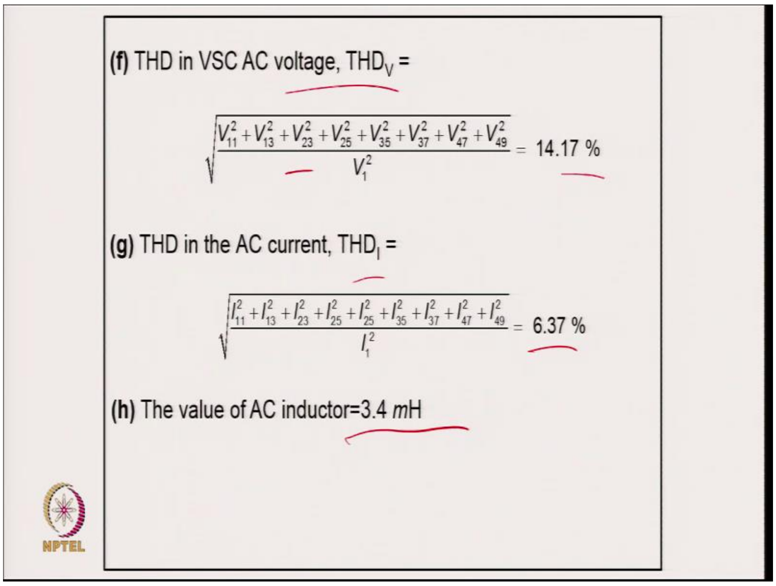

The solution of this problem is given in the abovemention slides.

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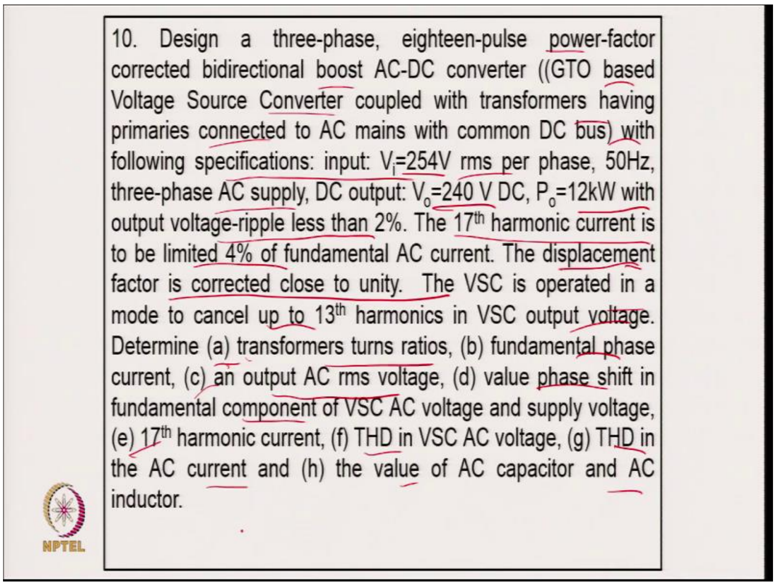

Now, coming to next problem: Design a three phase eighteen pulse power factor corrected bi-directional boost converter with the following specification: Supply voltage per phase is 250 V RMS and 50 Hz, 3-Phase AC supply, DC output is 240 V, output power 12 kW with output voltage ripple less than 2%. The 17^{th} harmonic current is limited to 4 % of fundamental AC current. The displacement factor is corrected to unity. The voltage source converter is operated to cancel up to 13^{th} harmonics in VSC output voltage. Determine (a) transformer turns ratio, (b) fundamental phase current, (c) an output AC RMS voltage, (d) value of phase shift in fundamental component of VSC AC voltage and supply voltage, (e) 17th harmonic current, (f) THD in VSC AC voltage, (g) THD in AC mains current and (h) value of a AC capacitor and AC inductor.

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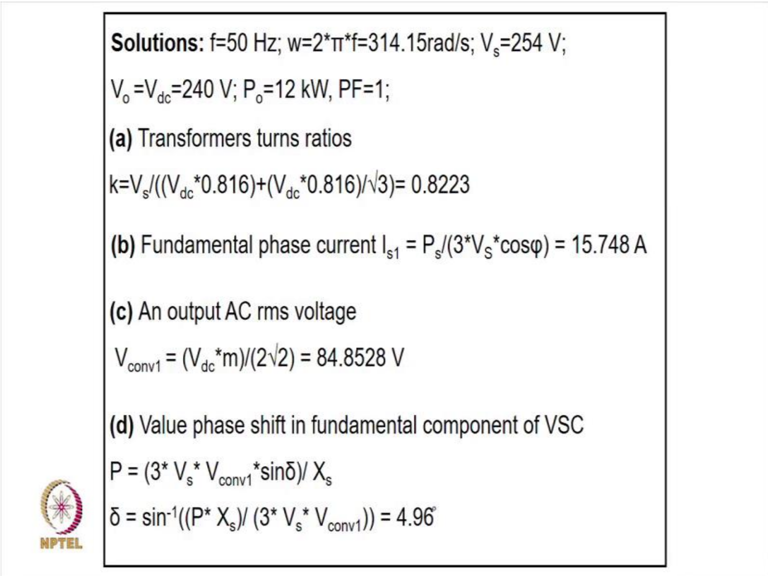

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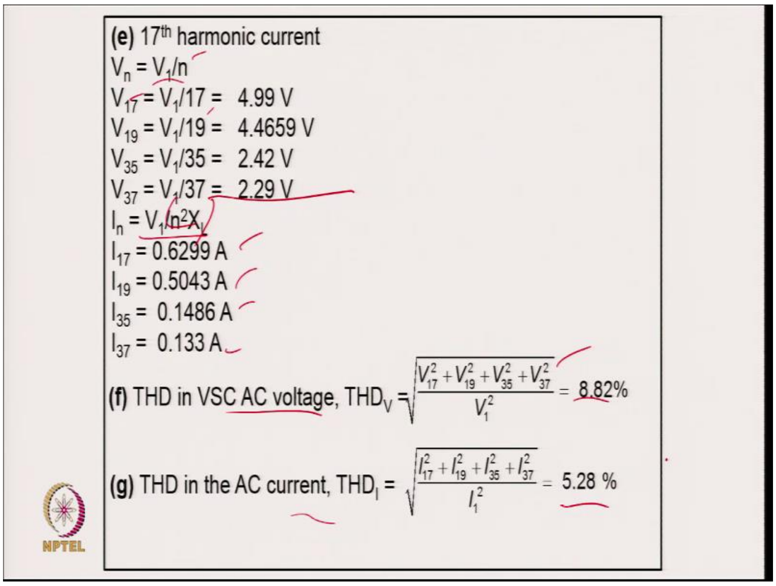

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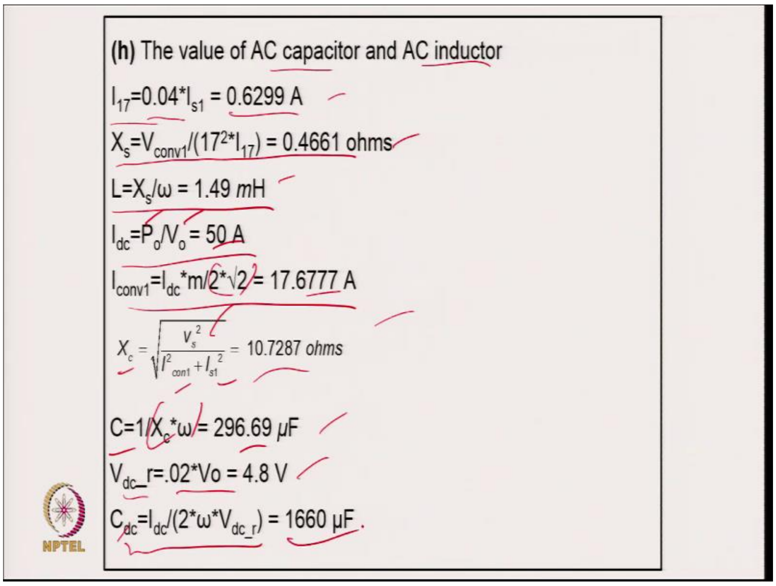

The solution of this problem is given in the abovemention slides.

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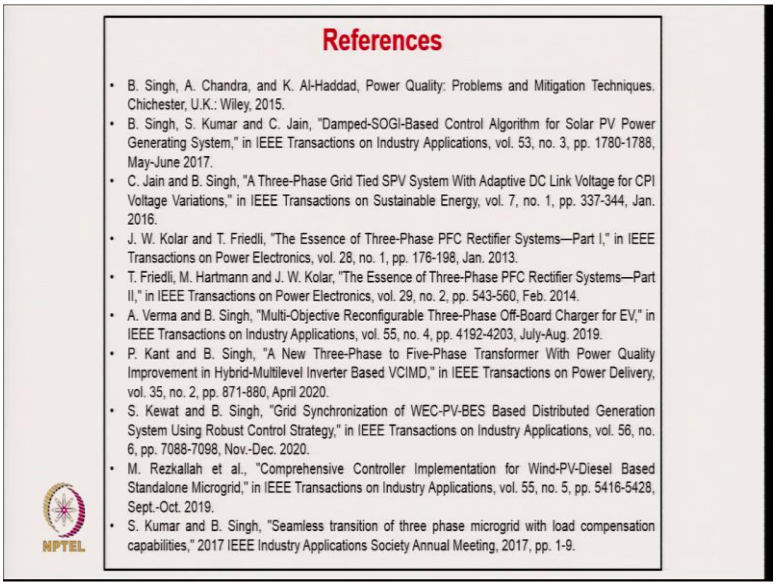

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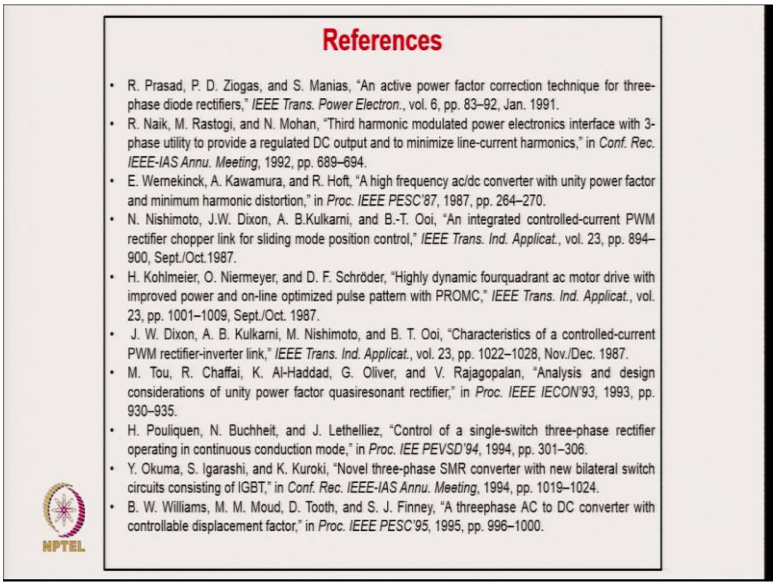

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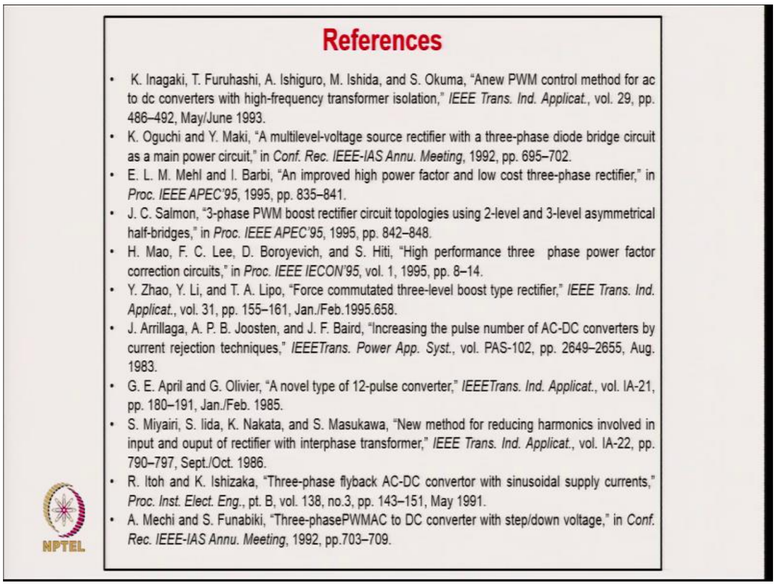

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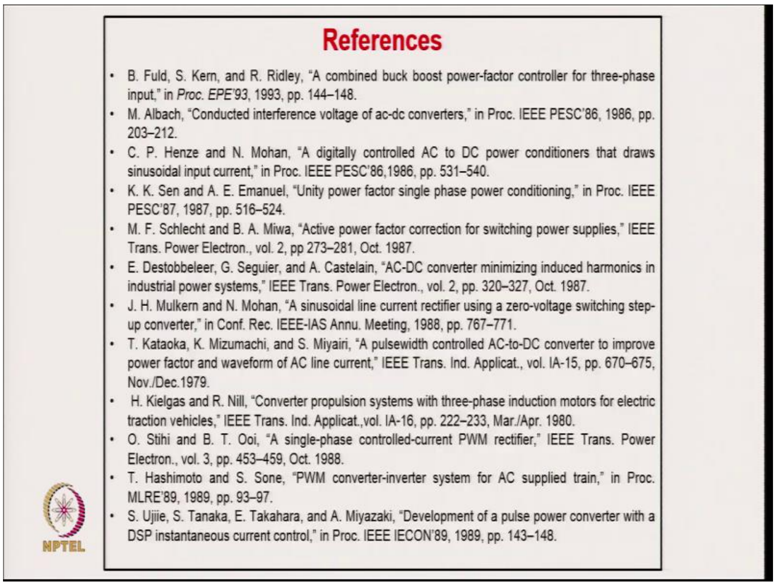

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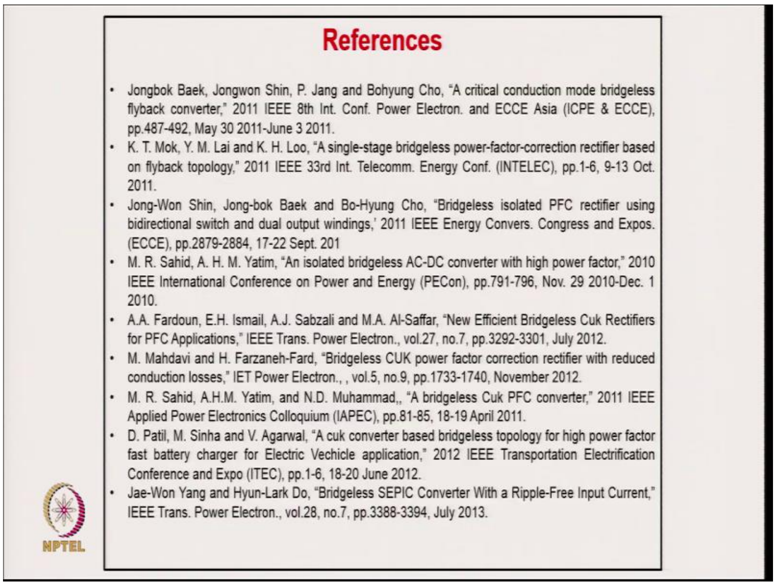

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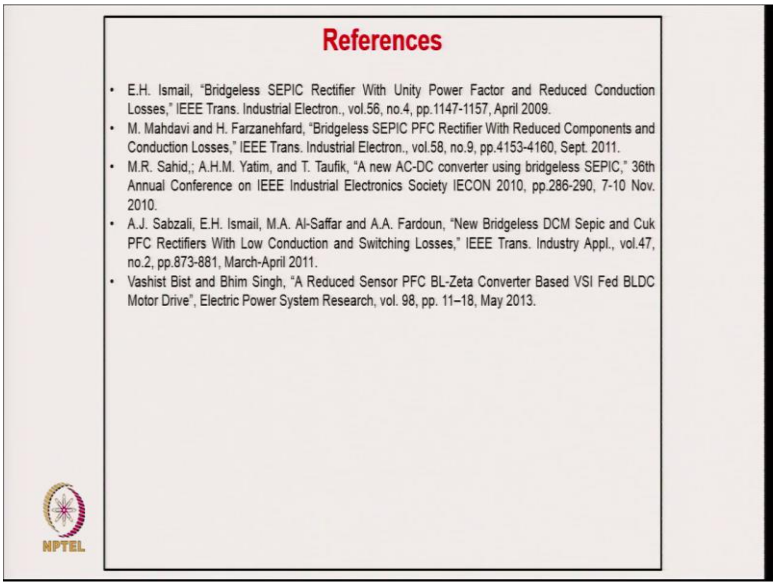

And these are the references.

Thank you very much.