Advance Power Electronics and Control
Prof. Avik Bhattacharya
Department of Electrical Engineering
Indian Institute of Technology – Roorkee

Lecture - 32
SVM III and AC to AC Converters

Welcome to our NPTEL lectures on advance power electronics and control. Today will continue with space vector modulation but it is applied for the multilevel inverter. Let us see that we have discussed for the two-level inverter how this concept can be extended to the three-level inverter.

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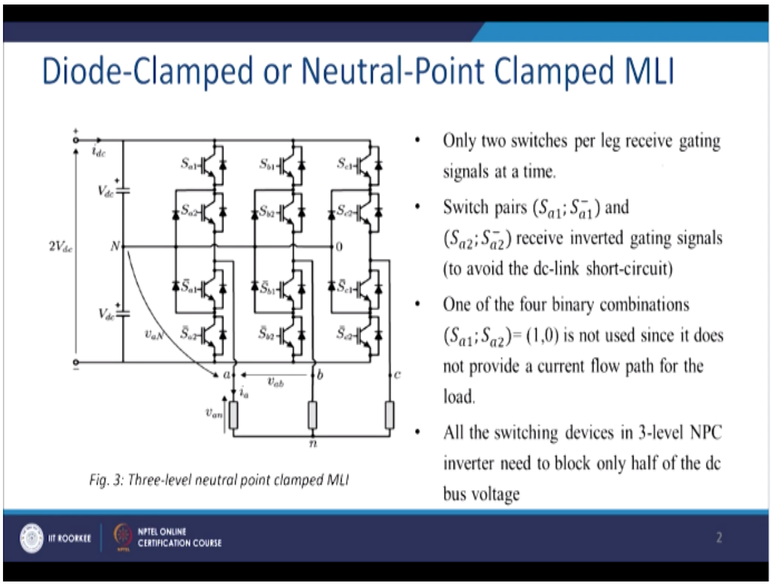

We shall revisit diode-clamped inverter again but purpose here to discuss the diode-clamped inverter is something else we will be discussing three-level inverter and its space vector modulation for this purpose we require little actually recap. For this reason, I decided to again speak about the diode-clamped inverter. So as you know that basically you know it is a three-level inverter diode-clamped inverter.

So it has been realized by the 4 switches and switch pairs actually Sa1 and Sa1- and Sa2 and Sa2- receives the inverted gate signals. So this switch and this switch are inverted in actually will have inverter logic and this a2 and a2 prime will have an inverted logic. So for this reason, one of the four binary combinations is Sa1 and Sa2, 1, 0 is not used since it does not provide any current to flow to the load.

So we have to remember that there are few actually states which cannot be incorporated in a diode-clamped inverter and all the switching devices in the three-level NPC needed to block half of the receiver's voltage that we have discussed already in our diode-clamped inverter.

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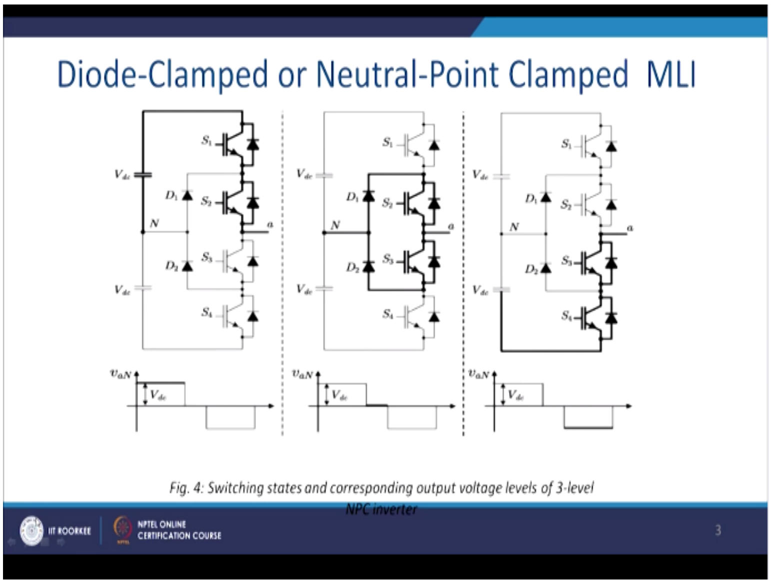

Now you know that actually the different mode of operations, once you get this voltage Vdc basically you will have this S1 and S2 are conducting. Thus, you get the total Vdc and you know when you want basically Vdc to be conducted again you want to get a zero voltage you can get this S2 and S3 as conducting and similarly once you want to get the lower DC bus voltage, it is –Vdc then S3 and S4 should be conducting.

See actually you can say that this one is Sa1 and then this one will be Sa1 prime so S1 and S3 are the complementary logic and S2 can be said to be Sa2, similarly it can be said to be Sa2 bar. So this is the way we will be synonymously choose the represent when we say actually will prefer this kind of notation for sake of simplicity it is actually correlated. Sa1 is S1 and Sa2 is S2 and Sa3 is actually Sa1 prime and S4 is Sa2 prime.

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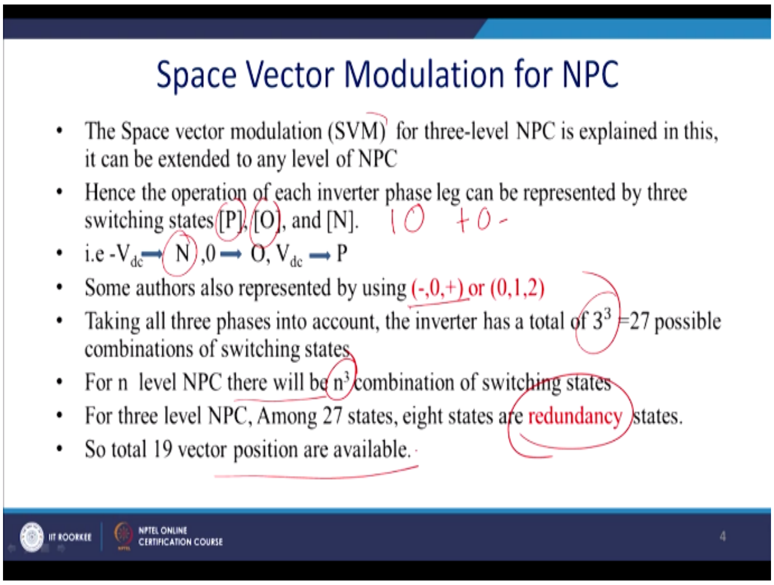

Now this is the logic. Now we will implement the space vector modulation. The space vector modulation for the three-level NPC will be explained here and can be extended to the any level NPC and students required to actually understand it and question can be given for the higher level NPCs also. Hence, the operation of this inverter's phase leg can be represented by different way of notation; different book follows the different notation.

For this reason, we try to incorporate all the notations so that student does not get confused and different kind of notation have actually put into the different kind of books. So basically switching state P, O and M that is actually some books also write 1 actually. Basically, 1 which is way to the two-level space vector modulation. We are happy to do with 0 and 1 and going to say three-level generally actually we have to choose basically this one or we sometime rate +, 0- either of this notations will be used.

So where actually –Vdc stands for N, 0 stands for O and the positive Vdc stands for P. Some authors represent that is what said is basically that is what I was representing -, 0, + or 0, 1, 2. Now let us see that how many states are possible, taking all the three phase into the account inverter has a total count of 3 to the power 3 that means 27 possible combinations of the switching projects will be possible.

But the other redundancies and there are some actually states which cannot be incorporated getting the logic that S1 and S3 are the complementary and S2 and S4 are the complementary and for N level switches, the NPC will be actually into the power sorry if it is actually 5 level it will be 5 to the power 3 combination switching states will be there. For these three-level

NPCs among 27 states, there are 8 redundant states and so we will have 19 basically the position vectors available, let us see those.

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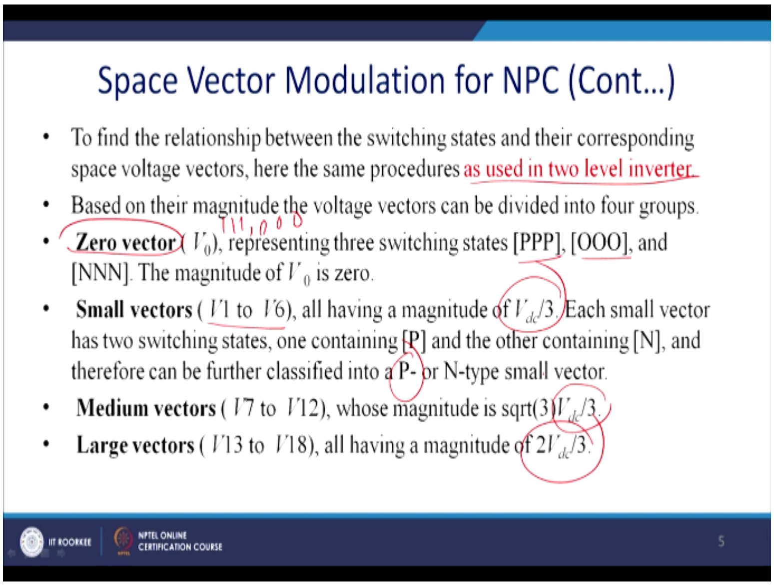

And to find relationship between the switching states and the corresponding space voltage across there is some procedure used for the two level inverters. So that procedure will be extended, this concept will be extended to the three-level inverter. Based on the magnitude, the voltage vector can be divided into the 4 groups, one is actually the zero vectors because we know that actually in the two level inverter either 111 or 000 was the actually the zero vector.

But that is basically where it will be represented by this OOO or 000 or NNN, minus minus minus for the magnitude of the zero vectors. There will be small vectors that are V1 to V6; we shall show that all vectors will have a magnitude of Vdc/3. Generally, actually all the vectors of the two-level inverter has a magnitude of that if you follow the (()) (06:53) it is actually 2/3 Vdc, so it will be half vector for this reason or small vectors.

Each small vectors has 2 switching states 1 containing P and the other containing N and therefore can be further be classified actually P-type or the N-type small vectors and medium vectors basically these are the medium vectors it is for we name them to 7 to 12 those magnitude basically actually Vdc/3 and the large vector will have a magnitude basically 2 Vdc/3.

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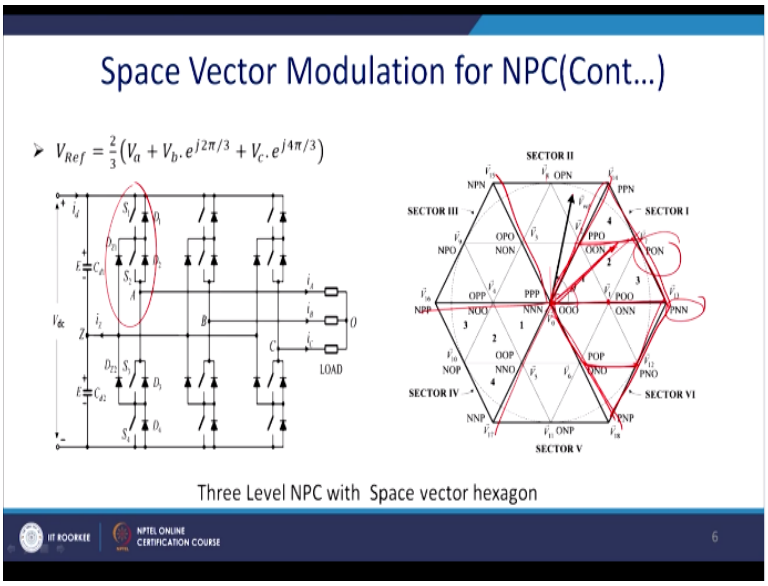

So this is the three-level diode-clamped inverter and these are the different vectors OOO so this is a zero vector, thereafter you can have this state if you want to get it here you have a combination to choose, there is a redundancy here, it is POO that means this switch would be closed and here you have to manage so get POO. Again, same state you can get here with the ONN similarly but you know if you wish to generate basically this vector 13 or basically what we have seen please recall.

Basically, 1 to 6 are the small vectors so 1 to 6 are the small vectors so this vector is actually 1, this vector is 2, this vector is 3, this vector is 4, this vector is 5 and this vector is 6 and if you extend till this, this is 13, this is 14, this is 15, this is 16 and this is 17 and this is 18 and you know there are few vectors this is basically vector V7, V8 these are half angle vector, angle is 30 degrees.

So along this actually there are these numbers of vectors available and we have to generate the different switching states based on that. See we require to do little bit of calculations, we can see that this vector is this sectors or it may be in this sector then what we require to do we require to shift the origin and ultimately this may boils down to actually a two-level inverter. So since it is here since this vector is located we have to find it out actually the hexagon.

Let us assume that it is available here instead of here. Then, what we will choose, we will choose these numbers and ultimately you will shift this origin, so ultimately you have to add this vector basically V1 and thereafter you can think of this is actually made of now this vector we require to generate. Now of course, you can be sure that so this is actually the categorically it becomes again a two-level inverter solution.

And because you can see that here in this particular hexagon what are the switching state available to you, so this is basically you know this is not a three-level switching. In this hexagon, it becomes basically a two-level switching. Why? Because you see the state available to you, add this PNN fine so it is positive and others closed. So here it is basically this is a one bit change PON and here it is PNO.

Similarly, here actually you can get OON or POO so thus any these vectors you know it boils down to a actually a two-level inverter and ultimately because of this a symmetric switching pattern, students are required to go through the (()) (11:18) books which is very well explained in that particular books. Now we have to find the timing of this actually vector.

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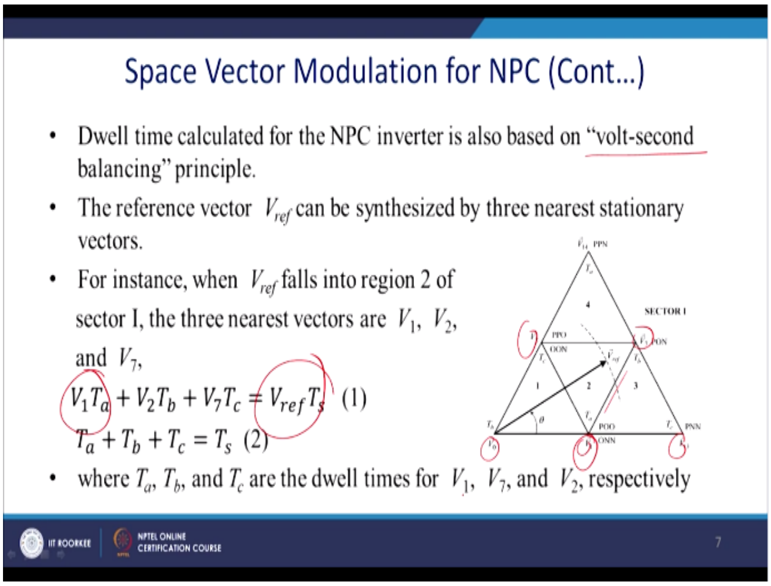

So we have taken this part of the vector that actually will be there. So see that we have this reference vector to be generated and that has been made by you know V0, V13, V1 and so on. Ultimately, you can understand that actually you have to make this vector by this. So we required to calculate the time duration for the individual vector to generate this V reference. The dual time calculations for the NPC inverter is also based on volt-second balancing method as we have done in further two-level inverters.

The reference vector V ref can be synthesized by the nearest stationary vectors, these are the nearest stationary vectors and for instance V ref falls in the region 2 of the sector I, the nearest vector that will be actually used to actually fabricate these vectors are V1, V2 and V7; V1, V2 and the V7 so this vector is V7. Now let us see so we required to calculate the time for the each relation.

So this class it should be equal to V ref and rest of the time should be given to the null vector and Ta, Tb, Tc equal to should be Ts and where Ta, Tb, Tc are the dual time for the V1, V2 and V7 and V2 respectively.

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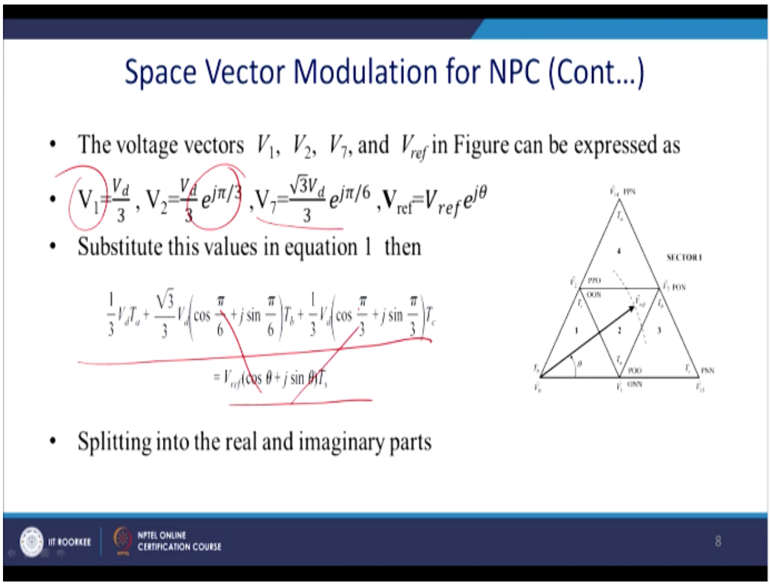

Now you see that will calculate it, the voltage vector V1, V2, V7 and the reference figure can be actually shown there since actually these voltage V1 is the small vector, its magnitude is basically Vd/3 and V2 is actually the vector half angle vector that is Vd/3 it is 60 degree. Similarly, this is the half angle vector actually V7 it is root 3 Vd/3 e to the power 30 degree. So for this reason, this is your V reference.

Thus, we can write this volt equation balancing so 1/3 Vd instead of V1, root 3/3 Vd for we can split into axis of the cos and sin, so thus it becomes this and 1/3 Vd also cos and sin and now you can see one thing. Actually you can equate the real and imaginary part that is actually real part and that is the imaginary part.

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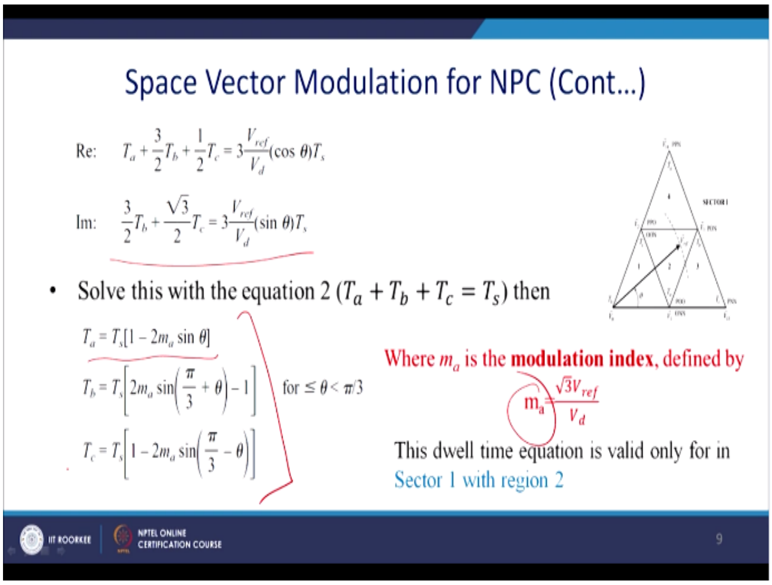

And splitting the real and imaginary part what essentially you get this and imaginary part is this. Now we require to solve these equations, another is Ta+Tb+Tc=Ts then from there actually you can get basically Ta equal to now we have to substitute this, this is something like modulation index in a sin triangle PWM so that is root 3/Vd so ultimately you substitute here so you get Ta=Ts 1-2m sin theta similarly.

So this will be Tb will be this and Tc will be this okay. So these are actually the expression for Ta, Tb, Tc, very simple expression and since you know the theta so of course you substitute and you know the magnitude of V ref/Vd. So all those magnitude will be given and you can calculate all the timing required for you.

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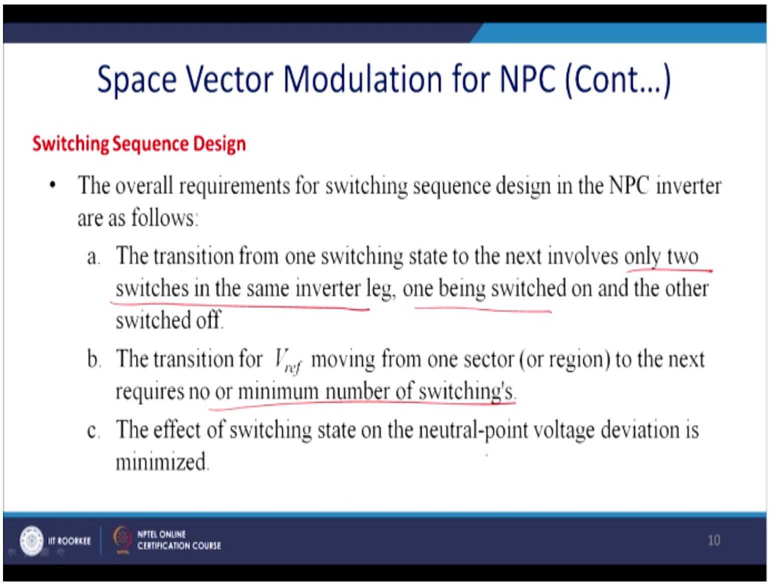

So this is all about to calculations of the NPC. The overall requirement of a switching sequence of designing NPC inverter are as follows that is briefing out how we require to do that. The transition from the one switching state to the next switching state involve only two switches in the same inverter leg. That is what we have actually what we have done you know we have actually though it is a three-level inverter in a particular hexagon; it behaves like a two-level inverter.

One leg being switched and other legs are switched out. Transition of V ref moving from one sector or the region in the next sector require no or minimum number of switching. So that is something we require to be actually incorporated and the effect of the switching states of the neutral point deviation require to be minimized.

Based on this principle, we shall actually calculate the switching timing of the reference vectors for diode-clamped three-level inverter and of course you can actually go for any level of inverter by same method.

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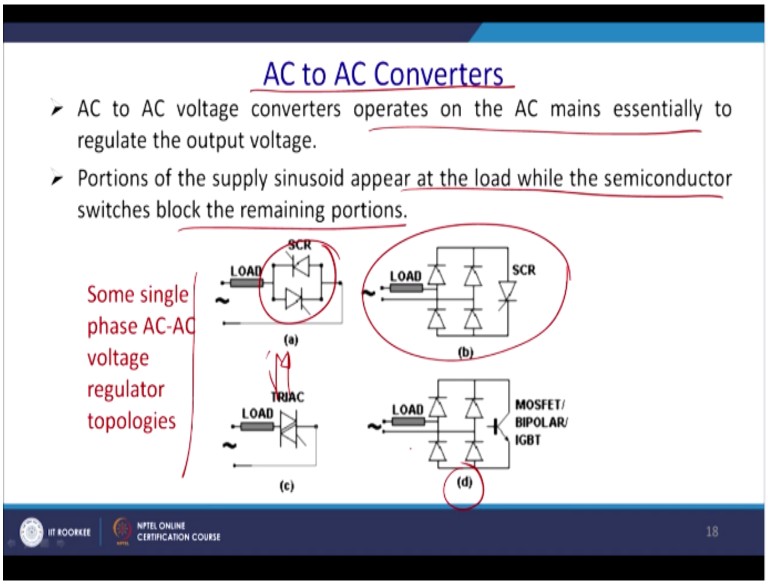

Now let us see direct AC to AC converters. The AC to AC voltage converters operates on the AC mains and we required to have it. Problem is that you know most of the cases actually we require AC to AC conversion. For example, we take an example like modern elevators and air conditionings. You got a compression that is AC and you are feeding with the AC but problem lies you know you require variable frequency AC and variable voltage AC.

But that cannot be actually achieved without the help of the power electronics. So for this reason, we can have AC to AC regulators or converters. AC to AC voltage converter operates on the AC mains essentially to regulate the output voltage, portion of the supply sinusoidal appear at the load while the semiconductor switches block the remaining portion of it. So essentially this is basically we have seen this example like you know you may have a try at that is essentially a simplest actually AC to AC converter.

But it actually chops the portion of the voltages in both the direction and it is applicable for the low power loads and if you increase the power then you can have a antiparallel thyristors. Anti-parallel thyristors can actually generate essentially are AC to AC conversion. So these are basically the different way of AC to AC conversion and apart from that you know you can have this combination also that is load that is AC and you can have SCRs.

So this SCR can be shorted or opened depending on you can convert AC to AC that we will see later these circuits and these circuits.

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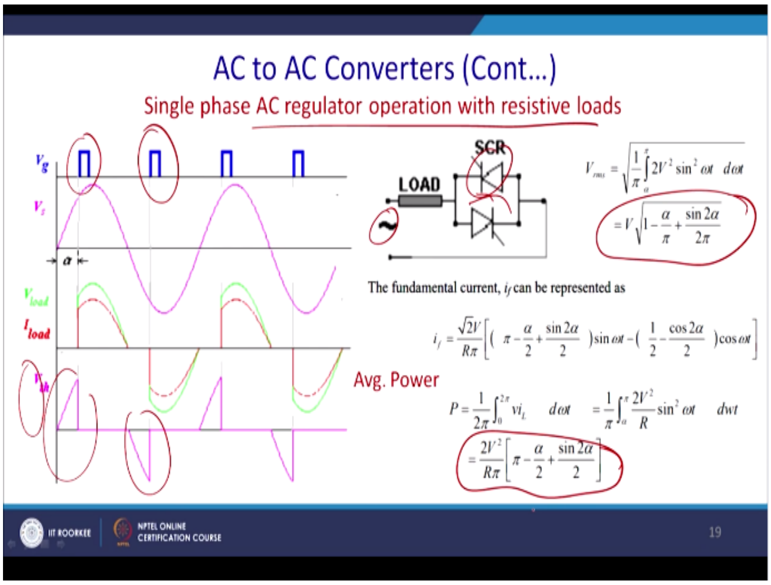

So this is the example of the AC to AC conversion of the single phase AC regulator operation with the resistive load. So this is the applied voltage and you have thyristors, thyristors is triggered at an instance here in the positive half cycle. So you gate actually the V load as a green portion of it and a load actually the red portion of it. Again, you have trigged in a negative half cycle so this one is this thyristor is actually triggered.

And thus you get a lower portion of it and essentially thyristors blocking voltage is basically the pink one. So what should be the average value of this voltage, you can integrate over it 1/pi 0 to alpha V square sin omega t d omega t and essentially this will be the actually the RMS voltage of this AC to AC conversion with dual thyristors. So the fundamental current if can be represented by if=under root 2V/R pi so this is actually the voltage so we have to divide it by R.

So you can get this value plus this value so this will be the current and average power you have to multiply with this actually Vl*Il. So if you multiply definitely you will get V square/R pi pi-alpha/2+sin 2 alpha/2. So this will be the average power across this basically RMS power across this load.

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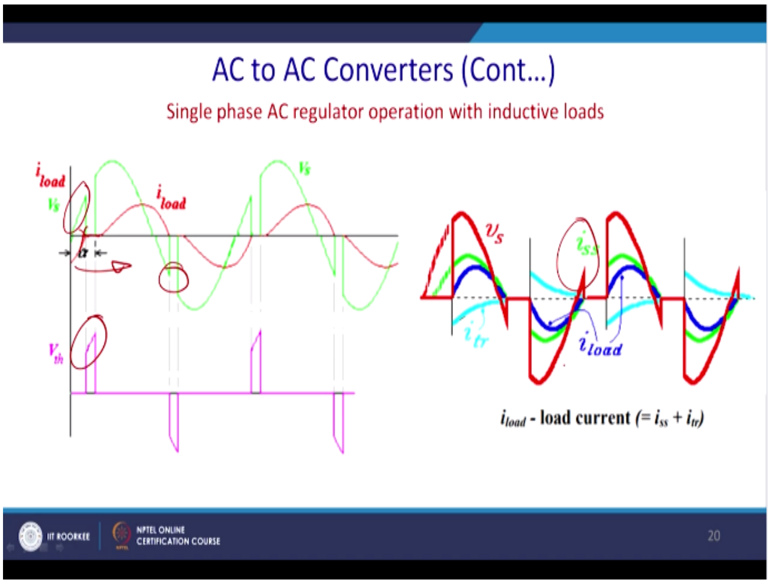

Now if it is inductive load, then essentially what will happen actually current will lag so this is the kind of thing and here at this stand current becomes zero. So as long as current is conducting any of the thyristors, you will get a voltage across a load. Then, once current becomes zero then only you can chop and so you have to chop it, basically chop the voltage when the current become zero.

So this is the one of the distinction while operating. You cannot turn off the thyristors at your will once this current goes zero then only you will turn it off and that duration can be extended if you wish and accordingly things will change. So thereafter again you have to turn it on, so you again this current again you have chopped it at this point. So you are blocking this voltage whatever the voltage part which has been missing Vth here.

And thus the load current you know will be actually iss is this basically this source current and plus the thyristors current that is basically itr where this blue one is i load and green one is iss and this one this tr is essentially the thyristor current. So there is a distinction how you trigger if your load is inductive for AC regulator.

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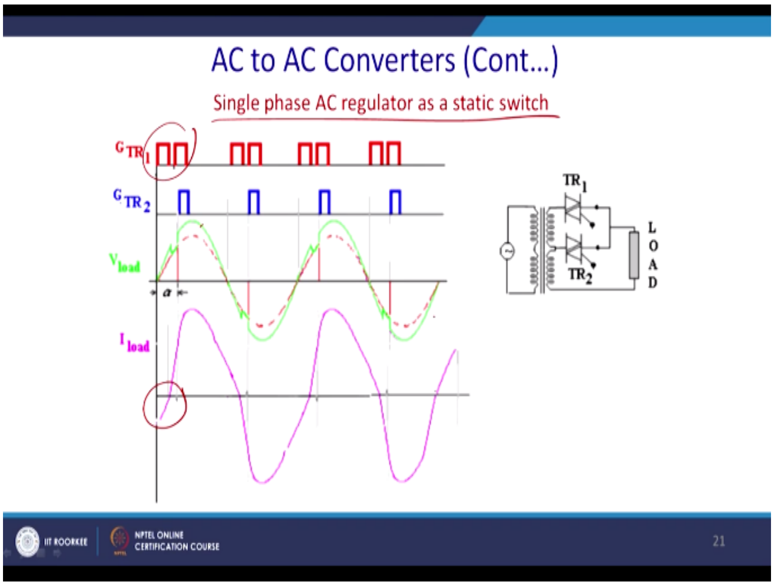

So you can have AC to AC converter single phase so you are getting this thyristors and this is essentially a tap changer which is frequently used in our transformer applications for regulating the load voltages. So this is where actually you are getting TR1 so once you are getting TR1 and a single phase regulator as a static switch it will work so it will be having a delay of angle alpha.

We assume that you know it will be delayed by small angle alpha and generally loads are inductive so this will be the profile of the current and it has been delayed like this so we will get this kind of profile of load voltage across the load so that is for and this one this red one for when actually upper thyristors is gated and TR1 actually red one is for the when lower thyristors is gated so that amplitude will come down, same sequence will be followed.

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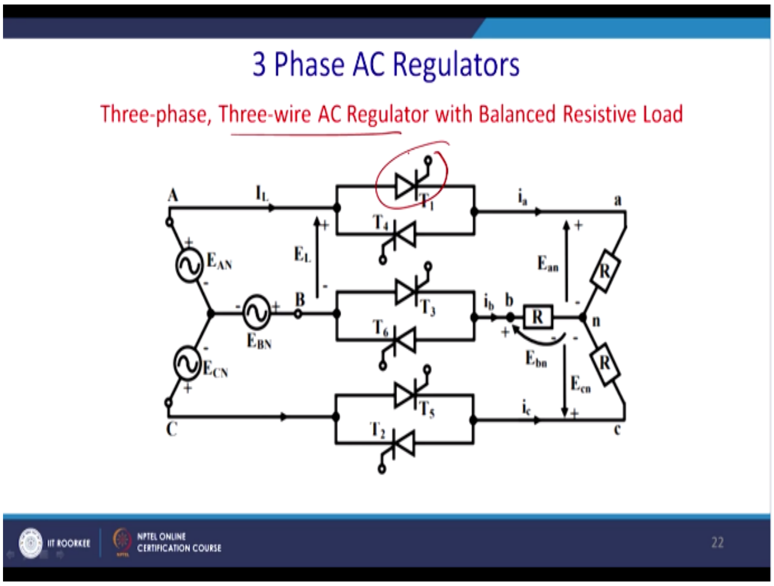

Now this concept can be extended for the three-phase system. Once you extend it for the three-phase system, you have a three-phase three-wire AC regulator with the balance resistive load. So since it is nothing special here of the resistive load, you will get same thing, so you have to maintain the sequence, most positive phase should conduct from the and we have to see that most positive phase and the most negative phase of the thyristors.

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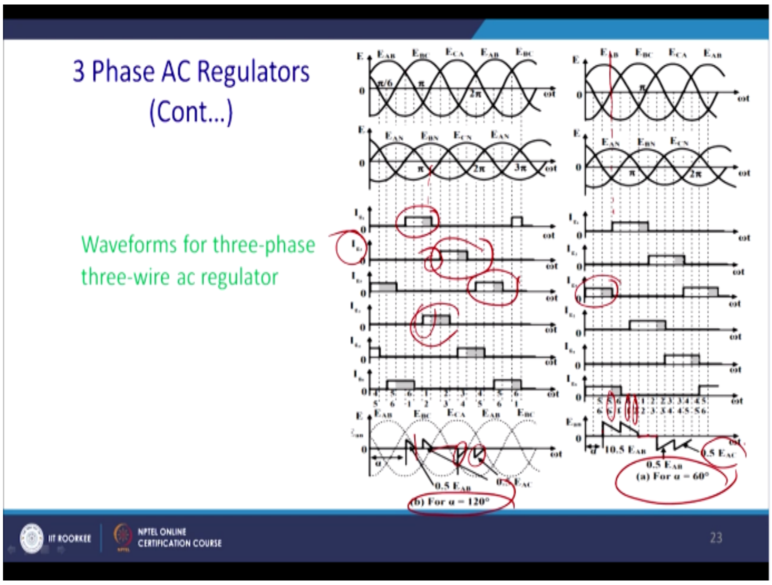

So it is the same sequence has been followed here, so what we have seen in case of the converted into the AC to DC application, these are the three-phase voltages and these are the actually these are the phase voltages, these are the line voltages and you have to get it since the inversion operation you know you will actually you will give to the gate Ig1 and it will conduct for the actually for alpha equal to here it is 120 degree.

So it will be actually given a k triggering at an angle of 120 degree and it will be off at this point. Similarly, another positive side thyristors that is Ig3 so see that this is actually T1 and T4, this is T3 and T6 and this is T5 and T2. So another positive thyristors will be triggered here, so another positive thyristors will be triggered actually at an angle of 120 degree. Similarly, this is for the g5 and this is for the g2 and g6.

And essentially what voltage you get is basically you know if you see that you know this is the voltage you will get and since from upper end only T1 is conducting and from the lower end this voltage is conducting so will get this voltage. Since this duration there is no thyristors is conducting, there will be a gap. Thereafter, a pause of 120 degree, so there will be no thyristors is conducting and will get a huge pause of 120 degree.

Thereafter, again these spikes will come and you will get these voltages and instead of that if you change this voltage to 60 degree or triggering angle at 60 degree so you trigger it here from a zero crossing of this and C phase is essentially this part. So you can find that corresponding to it, it will conduct previously actually you know g5 was conducting so you are getting voltage.

Here you can see that in this configurations 5 and 6 is conducting, thereafter 6 and 1 is conducting, thereafter 1 and 6 is conducting, thereafter 1 and 2 is conducting, thereafter 1, 2 is conducting but voltage is same so you would not get any voltage similarly you will get a 2 and 3 is conducting same voltage but actually 2 become more negative than 3 and thus we get a negative voltage and so on.

And effective value of ECC will be equal to 0.5 in this configuration. So this is the way actually by triggering thyristors we can have an AC regulator. So similarly you can have a three-phase delta connected AC regulator for balance three-phase load.

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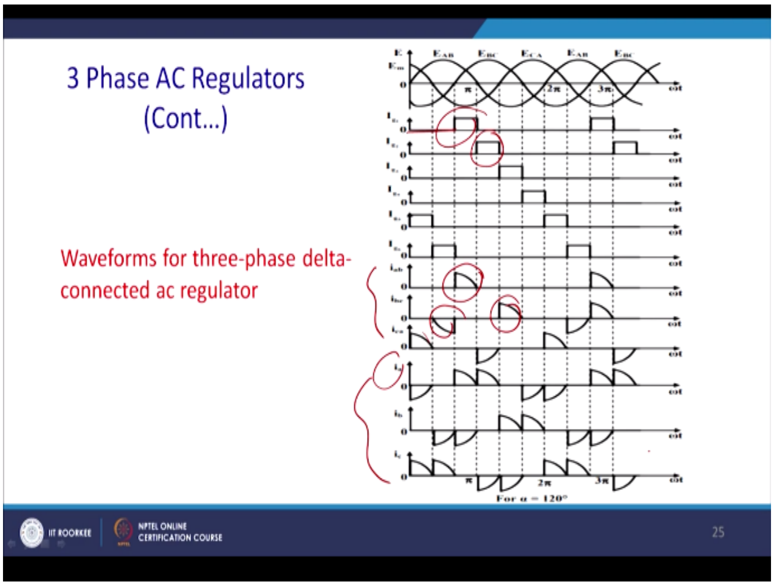

Now again you trigger at an angle 120 degree so this is actually Ig1, this is for Ig2 for duration of 60 degree and you will find that basically you know this is Iab, this is Ibc so the negative part of it so Ibc basically this is Ibc and this is Ica so Ia will have this kind of situations, Ib will be this kind of situation since the delta connected so you can talk about more about the current.

So there will be a different between the line voltages, there no difference between the line voltage and the phase voltage but there will be difference between the, these are the line current and these are the phase current for angle 120 degree. So you get this kind of configuration.

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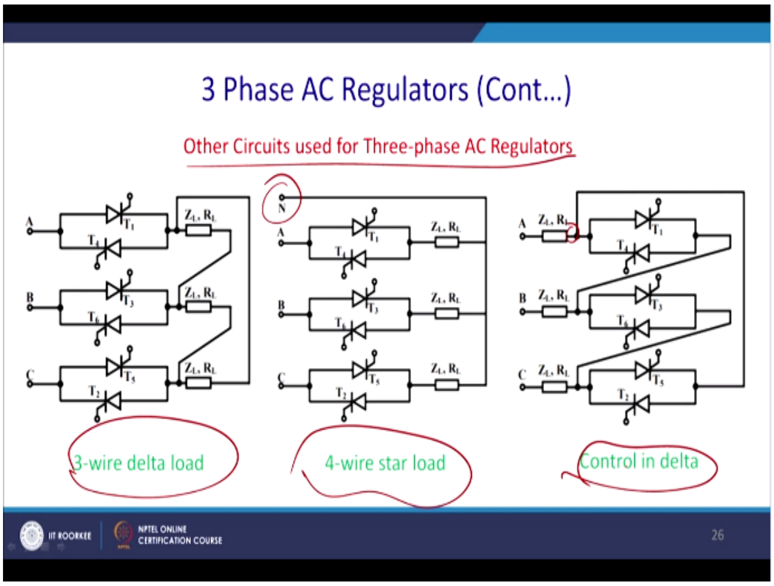

So what happen three-phase AC regulator is actually we can have a different kind of configuration. This is essentially a delta connected load where current is the consideration and thereafter you may have some places you have neutral point so neutrality available so this is basically three-phase four-wire star connected system with neutral and you may have a control delta so actually your basic difference is that you know this point actually connected at this point. So this is the 2, 3 configurations that has to be considered.

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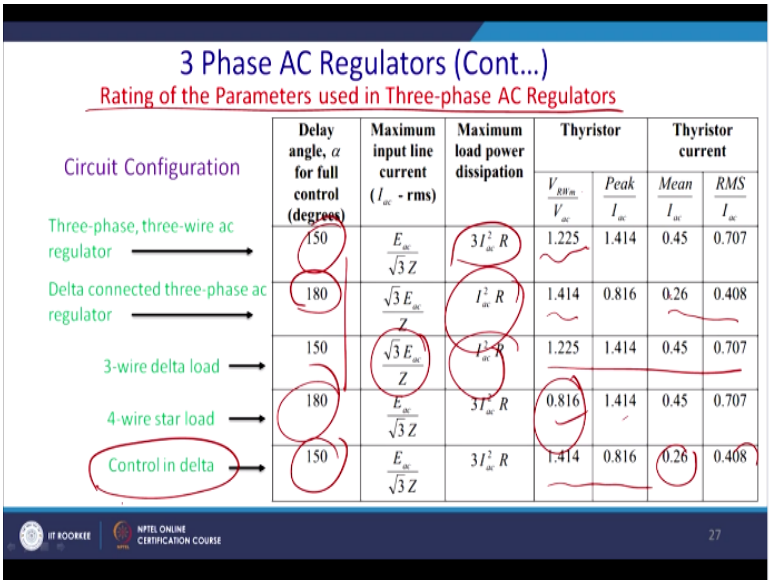

So let us see in a compression table, so three-phase AC regulators rating of the parameter used in the three-phase AC regulator. Delay angle alpha in 150 degree the maximum input line current is Eac/root 3 Z and maximum power dissipation will be the same so for the thyristors it will be actually VRWm/Vac. So it will around 20% more. I peak will be actually 1.44 that is two times more.

And mean ac current of the thyristors it will be 45% and mean RMS current will be basically 70% or 1/root 2. Delta connected three-phase AC regulator so your minimum line current is basically root 3 Eac/Z. So maximum power dissipation is this so you have thyristors rating will be more and peak current rating will be actually thyristor current rating will be reduced so this one is actually preferred.

Though, again you can see that it is for same delta connected load of a three-phase system this value is same, this value is same, this value is same and this value, so there is no difference of the three-phase three-wire AC regulator and three-phase delta connected load. So these are essentially same and three-phase three-wire load for 180 degree you can see that this value of the maximum input current is the same but here this ratio is reduced so you have an advantage.

But the peak current ratio will be the same is higher, so but mean is same and the thyristor rating is same and control delta which we have same. Here you can find that, these values are actually the same of this 180 degree open action. So delta connected three-phase AC regulator what you get in 180 degree mode of conductions, you get same thing in control delta for 150 degree mode of conduction.

So far this reason, control delta sometimes is preferred over the delta connected three-phase normal load. Now till now what we have actually discussed essentially, we have actually controlled the magnitude ok now till now what we have actually discussed essentially; we have actually controlled the magnitude of the AC system but that actually essentially it is something like you are applying reduced voltage to the machines.

But with a modern control technique is placed, we require to also control the frequency of the regulator or the output. So for this reason, we require a converter which not only change the magnitude of this actually applied voltage but also the frequency of this applied voltage.

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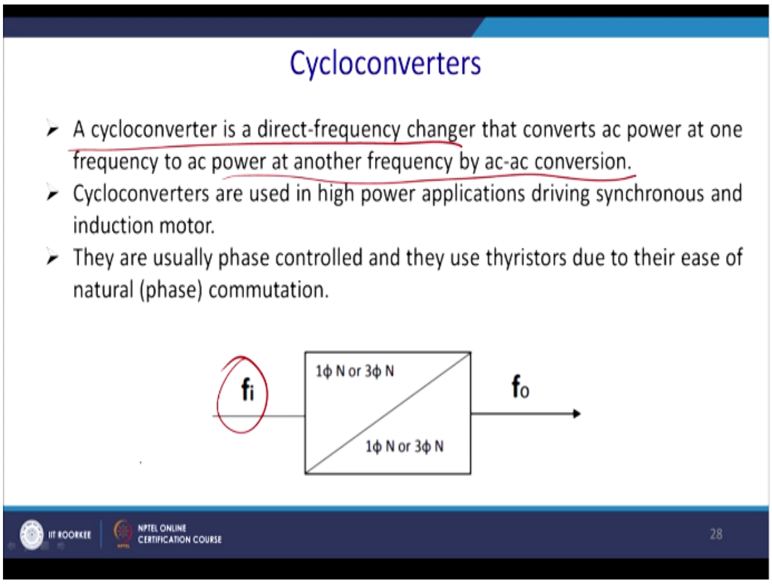

And for this reason cycloconverter is a direct-frequency changer that converts AC power to one frequency to AC power at another frequency by AC to AC conversion. Cycloconverters are used in high power high application drives driving synchronous and induction motor that usually phase controlled and they use thyristor due to their ease of natural or the phase commutations. So let us see.

So this can be actually this frequency can be changed, this is something like universal transform but not only the magnitude but also the frequency of this input and output can be changed. So we have discussed about dual converter while discussing DC to DC converter.

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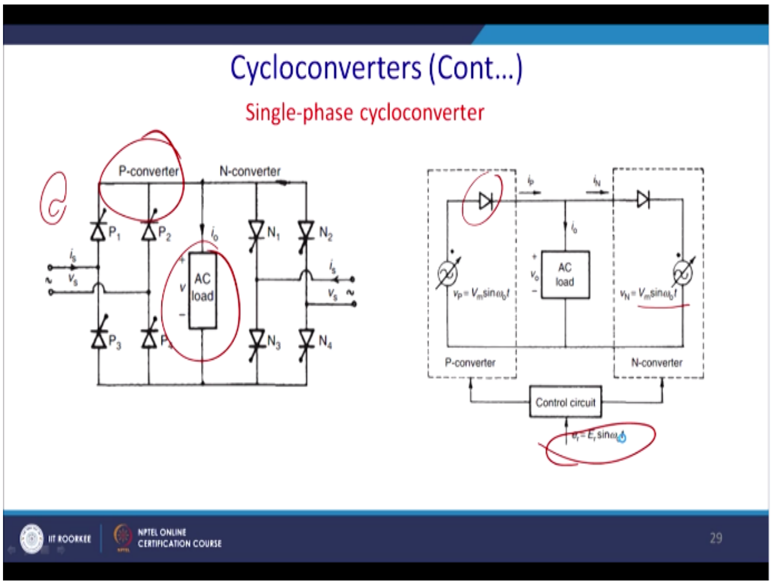

This is one of the example of the essentially a miniature of the cycloconverter but this you have we say that it is a P-type converter and this is a basically the inversion operation you feed this actually the thyristors and ultimately you got an AC load here and here also you got an AC load, so here previously we had DC to DC converter. Here it has to be operated in alpha and it has to operate at 180 degree-alpha.

But here this load is DC so for this reason what happen you have actually Vm sin omega t and this side also you got Vm sin omega t and you will control in such a way you get a different frequency by subtracting or adding and this will be the control circuitry that will be controlling this actually the phases of this two voltages.

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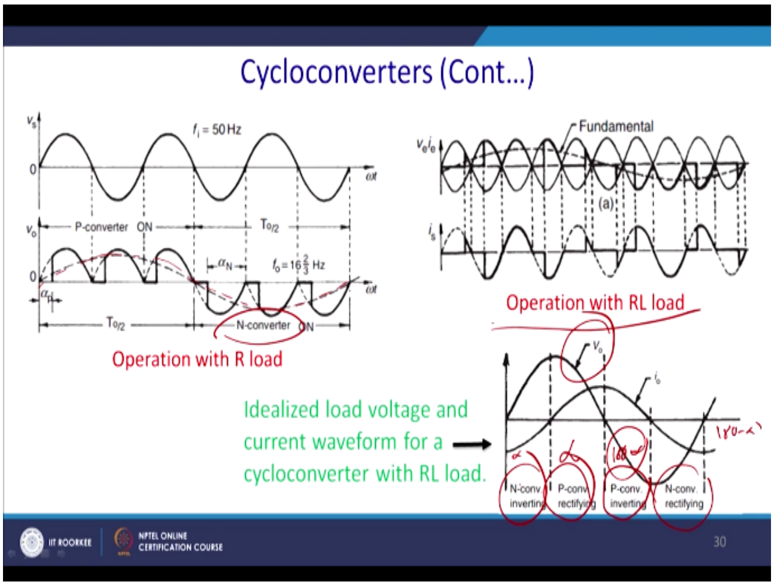

So let us take an example, so this is the example and we assume that load is resistive. So this is the P-type converter when it is on so you get these positive voltages and you continue to on for few seconds so you get only this kind of waveform. Thereafter, you turn it on the lower converter or the N-converter so then it will generate the negative portion of the waveform and thus what you will get, you get some harmonics.

So you will get this actually the amplitude of the voltages, so this basically acts as a frequency step down transform. So by chopping basically in this way, you are getting high frequency to low frequency conversion and this is a way you will get and if you have a RL kind of load where voltage and current will have a phase lag then you have to actually turn it on when current through the thyristors, turn it off when current through the thyristor is zero so will get this kind of Is into the system.

So this is the operation with the RL load. So this is the example of the idealized load voltage and the current waveform with the RL load. So this is the source voltage, this is actually output voltage and this will be the current load and this part when it is actually negative portion of the current that will be controlling by the N-converter, when both are positive then it is basically rectifying operation.

Then, it will be contributed by P-type converter, again it will continue its continuity and this will be alpha then, this will be 180 degree-alpha because it will be operating in a inverting mode. Similarly, here in this case, this cycles and this cycles are having 180 degree-alpha for shift and this will have basically again if it is alpha here again it will be having 180 degree-alpha. This way you will be sequencing and thus you will be generating this actually high frequency to the low frequency.

Now this can be extended to the three-level inverters, it can be extended to three-phase inverters.

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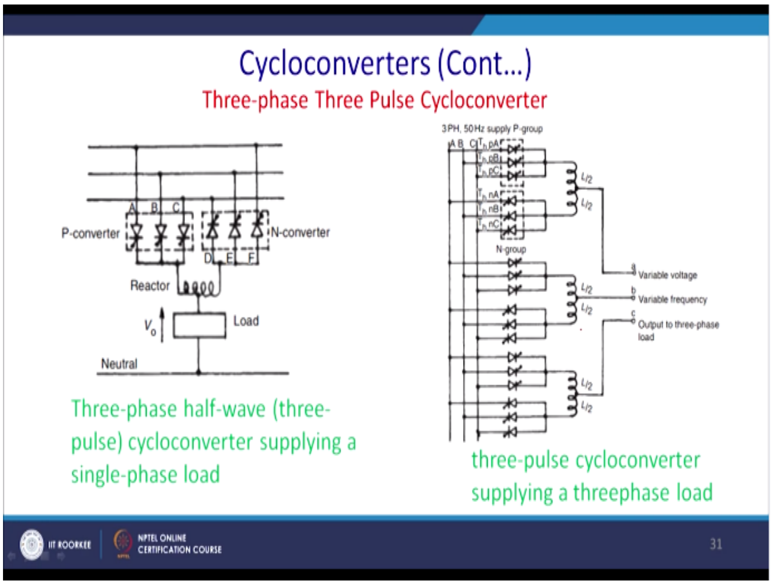

And thank you for your attention. This will be discussed in our next class so this is the combinations of the thyristors that can be used for the three-phase half wave cycloconverter and same thing you know you can extend to the this is a complex circuit, we have to explain, explanation require time so for this we are postponing our discussion in our next class. So this will be the three-pulse cycloconverter supplying the three-phase.

We shall start from this actually three-phase cycloconverter in our next class. Thank you for your attention.