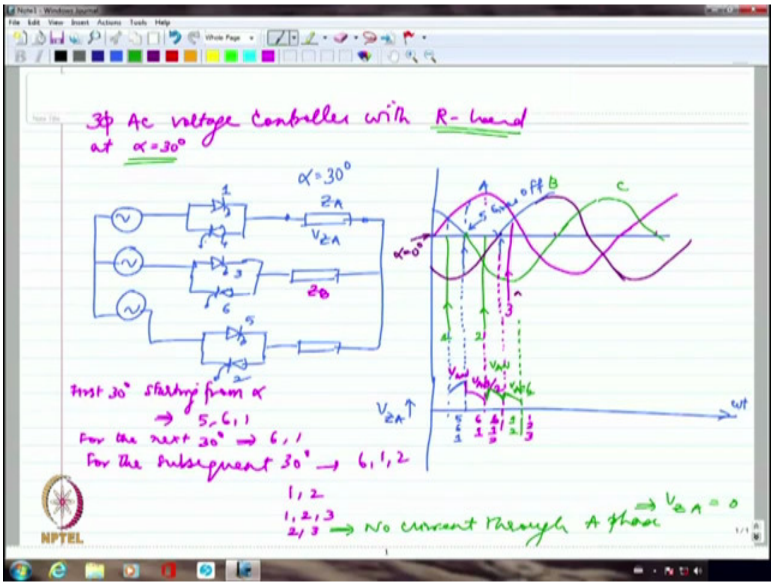
Power Electronics
Professor G. Bhuvaneswari
Department of Electrical Engineering
Indian Institute of Technology, Delhi
Lecture No. 14
Three-phase AC Voltage Controllers and Cycloconverters

(Refer Slide Time: 00:23)



So, we had started on three-phase AC voltage controller with R load at a firing angle of 60 degrees. So, we will look at it for a firing angle of 30 degrees which we will probably tell you how you are really having variations in the voltage waveform. So, let me try to take it for $\alpha = 30°$ for R loads so I am trying to look at R load with $\alpha = 30°$, then we will proceed to RL and with that we will conclude AC voltage controller we are not are going dwell on it for too long.

So, we said that we are going to have three-phase voltages and I am going to have 1 this is A phase so 1 and 4 then I am going to have B phase which we call 3 and 6 and then C phase which is going to be 5 and 2 and then we are connecting the load here I have taken star connected source and star connected load and AC voltage controller is just connected in between.

So, if we are looking at this with $\alpha = 30°$, so, these are the three-phase voltages that I need to draw. So, this is one of the phase voltages so I am going to have this as the 60 degree gap and then let me draw the second phase which is going along somewhat like this, and third phase which will go along somewhat like this so this is A, this is B and this is C and we are firing at 30 degree which means we are going to fire 1 here.

So, 1 has to be fired here and 2 has to be fired here. So, 2 is fired here then 3 is fired here and so on, you understand that this is $\alpha = 0°$ for AC voltage control. So, because of which I have 1, 2, 3 and so on like this. So, when I fire 1, I assume 5 and 6 are conducting.

So, if 5 and 6 are conducting 5 corresponds to C phase but C phase negative happens only from this point not before that. So, I am going to have C phase negative only from this point. So, I still have 30 degree interval before device number 5 goes off. So, I am going to have so let me draw the intervals. So, this again ωt so here 1 is fired and here I am going to have actually 5 going off, 5 will go off only where I have shown like this so here 5 goes off.

So, that means for 30 degrees I am going to have 5, 6, 1 conducting. So, for this duration I will have 5, 6 and 1 conducting even for R load I am talking about R load, if 5, 6 and 1 are conducting all the three phases are connected to the load. So, if I am trying to look at the voltage across Z_A so this is V_{ZA}. So, V_{ZA} is going to be V_{AN} itself. So, this is going to be the voltage waveform, this is V_{AN}.

If you look at this portion between these two that is where 1 is fired and 5 is going off that is exactly this portion off V_{AN}. So, I am going to have V_{AN} coming up during this portion but after that I am going to have 6 and 1 conducting until 2 is fired, so 2 is fired only at this point. So, until 2 is fired I will have 6 and 1 conducting, if 6 and 1 are conducting 6 belongs to B phase and 1 belongs to A phase so it will be $V_{AB}/2$.

Please note, if I try to look at V_{AB}, V_{AB} is going to be actually 30 degrees ahead of V_A. So, it would have almost reach peak even earlier so it would have been coming down slightly. So, I have to look at what is the difference, but this is going to be $V_{AB}/2$. I will have $V_{AB}/2$ because I am going to have V_{AB} coming up across these two loads simultaneously that is Z_A and Z_B respectively.

So, I have to look at what is the voltage across Z_A so load per phase voltage, we are looking at per phase voltage of the load. So, it will be $V_{AB}/2$ then again when I fire 2 I am going to have until this point where I am going to have the voltage of B goes into positive direction, 6 will continue to conduct, 6 will not go off. So, I will have 6, 1, 2 conducting here 6, 1 and 2 conducting here.

If 6, 1 and 2 are conducting here anywhere 3 devices conduct I will have per phase voltages coming up directly. So, I will have the per phase voltage which is again the V_{AN} so I may have a jump in the voltage something like this and then this is coming down, so this is again V_{AN} during this portion. So, I will have V_{AN}, $V_{AB}/2$ again V_{AN} then 6 will go off so 1 and 2 will come, 1 and 2 will correspond to V_{AC} so $V_{AC}/2$ will come.

So, I am going to have line voltage half of line voltage and phase voltage coming up alternately, but will there be any zero voltage at all, that we have to check. So, if I say that 1 and 2 are conducting here may be, I am going to have this is $V_{AC}/2$ maybe I do not know the magnitudes, I have to analyze it clearly or the unless I really analyze the magnitudes it is difficult.

After this 1 and 2 have conducted now 1, 2, 3 will conduct I hope you understand when I fire 3 still for 30 degrees, I will have 1, 2 and 3. So, 3 is fired here, 3 is fired at this point. So, I am going to have in all probability 1, 2, 3 conducting.

Here, I have a made a mistake in writing the firing angles this is 1, this is 2, this is where 3 is. So, when 3 is fired still there is some amount of positive A phase voltage left over so 1, 2, 3 will conduct together. So, I am going to have for the first 30 degrees starting from α, I am going to have 5, 6, 1.

Then for the next 30 degrees I am going to have 6 and 1 then for the subsequent 30 degrees I am going to have 6, 1, 2 then I will have 1, 2 then I will have 1, 2, 3 then I will have 2, 3 this is the sequence that it is going to go on. When 2 and 3 are conducting there is no A phase voltage, A phase will not carry any current, A phase load will not carry any current. So, here there is no current through A phase.

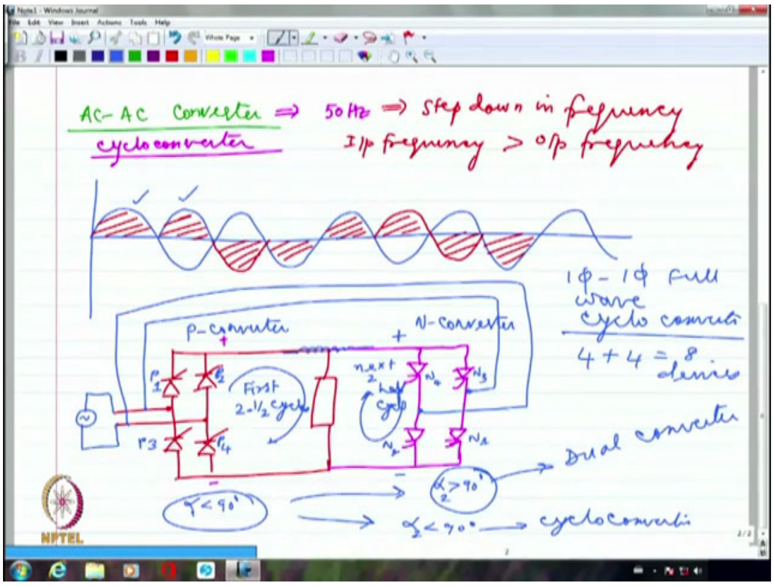
So, I am going to have essentially whatever is the V_{ZA} will be 0 during this 30 degree interval after that we will fire 3, 4. Once we fire 4 again, we will get negative side voltage because it will essentially allow the current to flow in the opposite direction. We are looking at each of the conduction of the device in like what is the combination of devices that conduct for one interval and I have taken a specific case alpha equal to 30, when I take $\alpha = 30°$ with R load this is the way it is.

If it is RL load it is more complication I hope you understand because if it is RL load the inductance will forward bias the device even after the voltage goes negative, the voltage goes negative still I am going to have the device to be forward bias. So, if the device is forward biased, I am essentially going to see that even after for example here we said 5 will stop conducting once I have the C phase voltage start going negative but 5 will continue to conduct even after the C phase voltage goes negative.

So, which means the three device conduction can extend for longer and longer depending upon how much is my inductance voltage but if that continues until the next device is also fired, then always three devices will conduct that is when you will not have any control all the time per phase voltage is going to come up. So, in which case you will hardly see any control over the output voltage.

So, you would see more control over the output voltage especially in the case of RL load only if α is somewhat larger otherwise you are not going to see much of control over the output voltage at all, so much so far AC voltage controller. So, in AC voltage controller we had seen only single phase and three-phase star connected case R load, RL load and for single phase I said why α greater than 5 only will give you control where 5 is the load power factor angle. We have not looked at any rigorous mathematical expression I just want you to understand how it works that is it.

(Refer Slide Time: 13:14)



Now, the next one that we are going to take up for AC to AC converter. The second type of AC to AC converter is cycloconverter. Cycloconverter are again generally made up of SCRs, thyristors that is the reason I am taking up all those circuits which are involved with thyristors, I am talking up all those circuits and that is the reason why I wanted to just take up this also along with line commutated circuit, what I mean by line commutated is supply voltage is trying to make sure that the device that goes off is reversed biased for sufficient amount of time, you do not have to apply any external voltage.

The supply voltage itself is taking care of the current transfer from one particular device to another device so cycloconverter also falls under that category. So, because of which this one heavily depends upon the supply voltage been AC. The output voltage is not going to aid in commutation more than that the supply voltage is going to aid in commutation that is the way it is going to work.

So, this converts AC to AC directly and if I have 50 hertz for example, I may be able to convert it only to a lower frequency hardly ever we will use it for a higher frequency conversion. So, cycloconverter will convert both magnitude as well as frequency but the frequency will be decreased or step down in frequency as far as input output relationship is concerned.

So, normally input frequency will be higher than the output frequency that is the way normally the cycloconverter works. So, if I am trying to look at the basic principal of a cycloconverter we look at the circuit a little later if I am going to have let us say an AC supply single phase somewhat like this, I am going to have the single phase AC supply like this.

If I use a rectifier for rectifying one cycle so I am going to rectify this as well and I am going to rectify this such that I am going to get basically this as the output across the load for two half cycles, I am talking about two half cycle. For rest of the two half cycles I am going to have another rectifier which is connected exactly it like dual converter in the opposite sides then I will have this portion and this portion coming up as the output voltage across the load.

So, I have got two halves of positive half cycle, two halves of negative half cycle this is going to repeat itself. Let us say I am going to again have two halves of positive half cycle and then I am going to have two halves of negative half cycle. Now, what we will be the frequency? Forget about the wave form, wave form is not sinusoidal, very clear, there is no doubt but what about the frequency? If this is 50 Hertz, I am going to get 50 divided by 2, that is 25 hertz. I cannot do this with diodes I hope you understand because diodes will conduct no matter what if they are forward biased.

So, I cannot even have a dual converter with diodes I hope you understand I cannot connect back to back it is going to essentially burn completely because one will have plus on the top and minus at the bottom, the other one will be the other way around so you will try to connect the two plus and minus. Imagine the dual converter I am talking about the dual converter, so I am going to have something like this, single phase.

So, I am normally going to have it with thyristor as it cannot be made with diode. I am going to have a load here, and this is my input supply voltage. On the other side, I am going to have again another fully controlled converter somewhat like this. So, if I am having diodes, I will not be able to delay the conduction at all. So, for this if this is plus and minus for this actually this will be plus and this will be minus if it is diode.

So, I am trying to connect the plus and minus together directly and that is definitely not done, huge current will flow. So, you cannot do this that is the reason why in the dual converter we wanted to have this as plus and this as minus we make this $\alpha > 90°$ whereas this $\alpha < 90°$ if you may recall this is what we did in the dual converter, and after all we had the input from the same AC voltage.

So, I would say maybe this went here and this went here, this is all they were connected. You remember, this is the way the AC supply voltage was connected so here is my AC supply. Cycloconverter is no different from the dual converter as far as the such a diagram is concerned, only difference is in dual converter we were operating one at $\alpha < 90°$ the other one at $\alpha > 90°$ and we were making sure that $\alpha_1 + \alpha_2 = 180°$, this was the control that we wanted to have if you may recall.

So, that the average voltage across this and the average voltage across this average are the same, not the instantaneous values they were different. So, the averages were the same because of which we actually had put a reactance here if you may recall we had put some reactance here. So, that if there is any $\frac{di}{dt}$ that will be limited and the reactance will also have some amount of resistance because of which the current will be limited, magnitude of the current will also be limited.

But in this case in cycloconverter case, if I may call this as a negative side converter which is N converter, I may call this as positive side converter or P converter, I will make P converter work for a distinct number of half cycles, I will make the N converter work for a distinct number of half cycles both of them will not work simultaneously. They will not work simultaneously and each of them functions as a rectifier in it is own right, when P converter is functioning it is working as the rectifier on its own and N converter is quiet, it is not working because you will not give any pulses to the N converter.

So, N converter pulses will not be released until P converter current comes down to 0 then you will release the pulses to N converter holding off the pulses to the P converter. So, what is going to happen is for the first 2 half cycles for example I will have the current flowing like this, so this is during P converter operation, so this is first 2 half cycles. Then next 2 half cycles I will have a current flowing like this, this is for next 2 half cycles.

So, I am going to have for the first 2 half cycles the current is going with plus here and minus here, for the next 2 half cycles the current is going with plus here and minus here. So, which means in both the cases I will have $\alpha < 90°$ only both α_1 and α_2. So, this is for cycloconverter operation, both alphas will be less than 90 but they will work completely disjointly, they will not work together when one is working the other one will not be working and vice versa.

Whereas when I am talking about dual converter these 2 works together, one work as the rectifier the other one works as an inverter and they work together such that I am going to have the DC link voltage average value to be the same. So, here this is for dual converter. So, what I can do is to have basically multiple number of half cycles being worked with P converter make sure that the current goes down to 0.

So, if I have RL load I have to continuously sense the current, if I do not sense the current I can get into trouble because I will still have maybe some positive negative left over and if I try to fire this there will be a dead shot because this would not a gone off and this will start conducting. So, I can have really a dead shot circuit between the 2 converters P converter and N converter.

So, I have to make sure that the current really goes down to 0 in the P converter and the load and after that I should start the other half cycle of the output. So, we are looking at 2 input as well as output both are AC, so I have to talk about whether it is positive half cycle of the input, or positive half cycle of the output, negative half cycle of the input or negative half cycle of the output.

So, if I want positive half cycle of the output, I have to make use of P converter, if I want a negative half cycle of the output, I have to make use of the N converter. So, distinctly I have 2 converters which are connected back to back, which are going to work in such a way that one is disjoint with the other they are mutually exclusive, they are not going to work together but I have to make sure that the current comes down to 0 before I release the pulses for the next set of devices.

And when I released the pulses to the devices just like what we did 1 and 4 will be given pulses during positive half cycle of the input and 2 and 3 will be given pulses during the negative half cycle of the input and I may call this as P_1 because P converter P_2, P_3 and P_4. So, P_1 and P_4 will be given pulses during the positive half cycle of the input provided I want positive half cycle in the output as well.

Whereas, if I want other way around, if I want a negative half cycle at the output then I have to take care of these devices. So, if I may call this as this is coming to A so if say that this is coming to this one so I should call this as N_1 so this will be N_4 and this will be N_2, this will be N_3. So, I should correspondingly make sure that N_1, N_4 will be given pulses.

If I want negative half cycle in the output but prevailing thing is the positive half cycle as far as the input is concerned. So, I have to look at the input as well as output simultaneously. So, this is going to be the way your complete converter works. So, this is single phase to single phase operation, I can have the same thing for single phase to three-phase, three-phase to three-phase, three-phase to single phase.

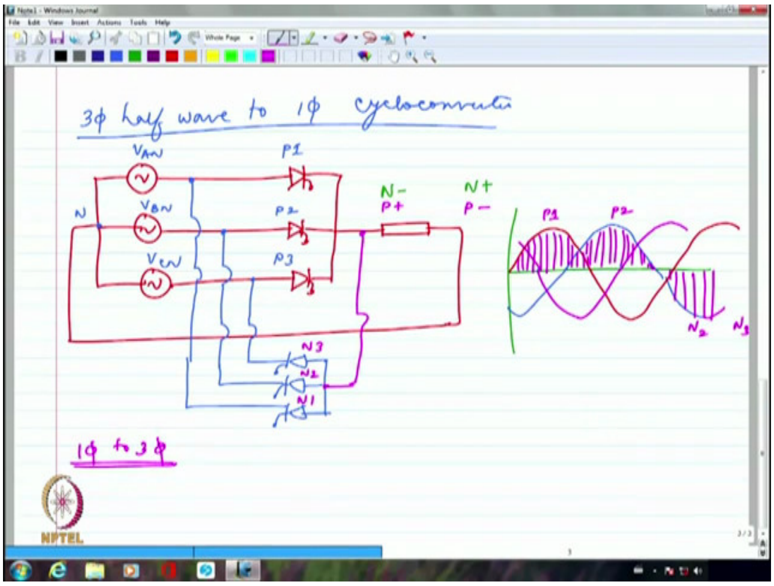
So, I can have multiple types of cycloconverter connections. So, when I am talking about the single phase to single phase that to full wave because I am not leaving off the other half, I am always using both the halves of the input wave whether it is positive half or negative half I am making sure that I am making use of both of them. So, it is a full wave controlled converter what I have used, is a full wave fully controlled converter.

So, when I use of fully controlled converter even single phase to single phase conversion will require 4+4 at least 8 devices. So, if I want single phase to single phase full wave cycloconverter, I will require 8 devices minimum. I will require at least 8 devices only then I will be able to do full wave to full wave. If I want now one third of the frequency, I can make 3 half cycles positive, 3 half cycles negative.

So, you know how to reduce the frequency further, but we will not be able to increase the frequency with single phase because the thyristors will go off only when it is starting to go into the negative half cycle. So, I cannot increase the frequency unless I use some kind of forced commutation but the moment you use forced commutation the entire thing will become very, very complex.

So, generally we do not use SCR based cycloconverter for increasing the frequency because if you want to increase the frequency you necessarily need to put forced commutation circuits you have to turn off the devices somewhere in between.

(Refer Slide Time: 28:36)



Let us try to take a look at a three-phase half wave to single phase cycloconverter. I am going to use a three-phase half wave rectifier which is hardly ever used, just for continuity sake, I am slowly increasing the complexity. In a half wave rectifier for three-phase we said that for every phase we have to have one thyristor.

And then if I connect the load, the load will be connected between this and the neutral, this is the way it is connected. This is the half wave rectifier, we have not included the N converter because this is a P converter if I may call this as the P converter, I should call this as P_1, this is P_2 and this is P_3 and this is V_{AN} this is V_{BN} and this is V_{CN} with this being the neutral.

Obviously, I have to have 1 more converter with opposite connection of the SCR. So, I can imagine that from all these 3 terminals because I am using the same source, I am not going to use a new source, the same source is being used but I am going to have essentially 3 thyristors connected in the opposite sense, so this is the second one and this is the third one, 3 thyristors are connected in the opposite sense and these are star connected now and I can connect this to the same point here.

So, if I try to fire P_1, P_2, P_3 I am going to have this as positive, so this is P positive and P negative. Let me say this is N_3, this is N_2 and this is N_1, so if I try to fire N_1, N_2, N_3, I am rather going to have this as negative so I should say this is N negative and this is N positive because it is exactly connected in the opposite sense but in this case we will get only half wave conversions.

So, if I am trying to draw all the three-phase voltages. For example, I am going to have something like this, so this is the second phase, and this is the third phase. So, I have to wait until my other phase actually that is the P converter current becomes 0 that is what I told you.

So, if I am actually firing the P converter and starting off from here, I may get all these voltages corresponding to P converter. So, I have given firing pulses only to P_1 and P_2 and I am not giving the firing pulse P_3 I will wait until the current drops down to 0. Now, I can try to give the firing pulse to the next converter which is the N converter I am just showing as though I have got only 2 overlapping half cycles.

So, I have given this correspond to P_1 and this is corresponding to P_2 and I have not even given for P_3 but I will give for again this corresponds to probably N_2 then I will give it to N_3 and so on. So, I will have again reduction in the frequency, but I have taken as though $\alpha=0$ or even less than that. So, I am starting right from the transient condition otherwise α should be calculated from what like this that is what we said.

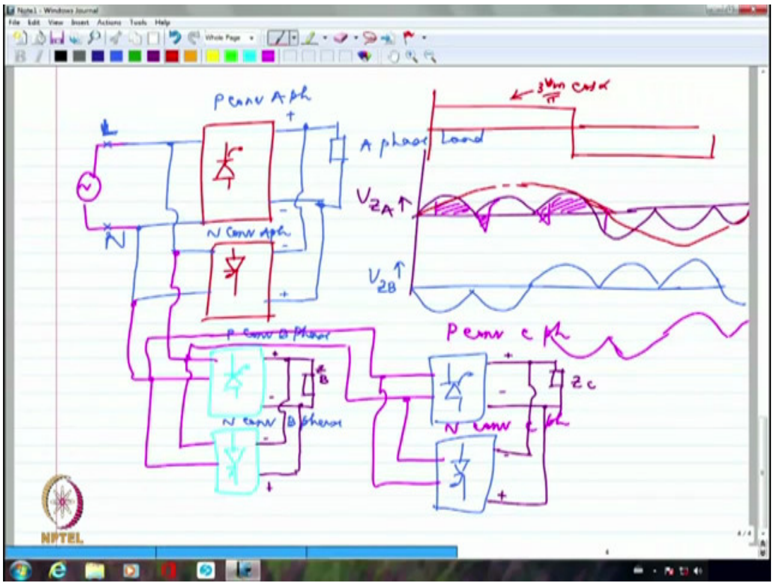
So, we are looking at the whole thing as though we have to fire the P converter such that ultimately the current will come down to 0 if you keep on giving firing pulses the current will never come down to 0 say we will not be able to go to negative half cycle at all. So, once you hold off the firing pulses to the P converter you should wait until the current comes down to 0.

So, it is very important in a cycloconverter to sense the current, without current sensing you cannot release the firing pulses to the other set of converter otherwise you will have a dead shot circuit, you will have a big problem with the connection of the 2 converters, because you are trying to connect completely opposite polarity together, that is the reason.

So, this is typically a three-phase to single phase cycloconverter where I have three-phase supply in the input whereas the output is single phase and it is still not sinusoidal. Now, if I want three-phase to three-phase (for example) or let us say first of all single phase to three-phase cycloconverter, how do we really connect single phase to three-phase? I have 3 different loads clearly, R phase, Y phase and B phase; because at the output I am going to have three-phase but what I have in the input side a single phase.

So, I have to have for each of the phases one P converter and one N converter, each of the phases should have independently one P converter and one N converter. So, if I have three-phases I will have three P converters, three N converters. So, I will have 8 multiplied by 3 which will be 24 devices, cycloconverter uses really large number of devices.

(Refer Slide Time: 35:44)



So, let us try to draw for single phase to three-phase. So, I am going to have this as my power supply which is common for all the converters. So, I am essentially going to show it in the form of let us say, simply let me show it like this, this is the P converter, and let me show the other one either here or I can show it here as well so I am going to have the other one as the N converter.

I have to show similarly 2 more things, so this is A phase or red phase then I am going to have 1 more yellow phase or let me say this. So, I am going to have 1 more set of P converter and N converter and I will have 1 more set of P converter and N converter. So, I have got each of them having 4 devices there are fixed such things so 24 devices. Now, I will connect this first of all to this.

Now, the output is connected to a load, and normally I am going to have plus here and minus here if it is working as a rectifier. The same thing when this is working as a rectifier I am going to have plus here and minus here, but this plus has to be connected here and this minus has to be connected here the other way around like a dual converter.

So, I have connected just opposite polarity, so this is A phase load, and this is P converter A phase, this is N converter A phase. Now, from here I am going to connect this to this, from here I am going to connect this to this, same single phase supply goes everywhere I am not having any more supplies, I have only one single phase supply it is going here.

So, if I may call this as 1 and 2 these are the input sides of the rather, I can say line and neutral otherwise, this is line and this is neutral so between line and neutral all the converters are connected. Now, I am going to have similarly this is P converter B phase and this is N converter B phase, and this is going to be P converter C phase, and this is going to be N converter C phase.

Now, the input is very simple I am going to connect it the same way so from here again I will take it up I will connect it here and from here I will take it up I connect it here, from here I will connect it. So, all of them are connected to the same input, the input is essentially the same. So, I have to again show from here; from the same point I can connect it to this and I can connect it.

So, I have to take it here, so I have taken it here so the same thing I can connect it here. All the inputs I have to connect but when I give the firing pulses I have to make sure that I give the firing pulses always to 1 and 4 together and 2 and 3 together as far as every converter is concerned and if 1 and 4 are conducting during positive half cycle I better connect them in such a way that they will connect during positive half cycle of the input supply voltage, these things I have to take care.

So, when you make a cycloconverter circuit diagram if at all you do that in PSIM there is a demo available also for cycloconverter, you should see how it is connected together; so, this is how it is connected. Now, I have to again connect a load, so maybe I just take a load like this, this is connected here, this is connected here, this is B phase load, so this is Z_B.

Let me show this as Z_B that is B phase load, this is positive and this is negative for this converter and as far as this is concerned here it is going to be positive and this is going to be negative, so this positive should be connected to negative and vice versa the other way around. Same thing is true for this particular case again I am going to have here this as Z_C.

So, I will have this as positive and this as negative here I am going to have this as positive and this as negative so this positive will be connected here and this negative will be connected here. So, that the current flows in the opposite direction when it is rectifying it is P converter is rectifying I will have the current in this direction, when N converter is rectifying

I have the current in the opposite direction that is all the it is facilitating, you are going to exactly have dual converter kind of connection.

So, if I have made a connection like this how will I make sure really that I am going to have you know the A, B and C phase supplies 120 degrees away from each other, they have to be 120 degrees away. So, normally when I try to do single phase to three-phase I would like to have 3 half cycles or 6 half cycles or 9 half cycles. So, that if I have 3 half cycles of you know the input coming up at the A phase then from the second half cycle or third half cycle onwards my B phase can start, you get my point?

If I am going to have my A phase output somewhat like this and then it is going to have 3 half cycles like this, this is A phase Z_A voltage V_{ZA}, V_{ZB} can be from this half cycle it can start. Because this entire thing corresponds to 180 degrees what I want is 120 degree shift. So, 2 half cycles will correspond to 120 degree shift as far as the output is concerned.

So, I would have essentially these 2, 3 coming up as the half cycle here and these 2 will come like this and so on. So, this will be V_{ZB}, V_{ZC} obviously have to start from here, they have to essentially be shifted by 120 degrees of the output wave. So, I am going to have essentially this going as positive half cycle. So, I will have essentially negative half cycle coming up like this here, 3 half cycles like that.

So, this will ensure that I get exactly 120 degree phase shift between A phase, B phase and C phase, respectively. So far whatever we have talked about we are not having any voltage control, ideally what I would like to have as the wave form is somewhat like this it should be sinusoidal, this is what I would like to have and in the other side also I should have sinusoidal voltage like this, ideally this is what I would have like to have.

Because most of my loads will accept only sinusoidal output voltage, they will not accept non-sinusoidal output voltages, what I am getting is definitely non-sinusoidal I hope you understand because we are getting $\frac{3V_m}{\pi}\cos\alpha$ that is the value I am getting if I am firing it at a particular α continuously.

So, it is as good as having a square wave voltage on an average basis if I try to look at it, it will look as though if I look at the average value I will have a square wave like this and then I will have a square wave like this, this value may correspond to $\frac{3V_m}{\pi}\cos\alpha$ this is how it is, it is somewhat like this and definitely I do not want that especially if I am trying to apply to synchronous motor drive or induction motor drive. Cycloconverters are generally used with synchronous motor drives in the big way.

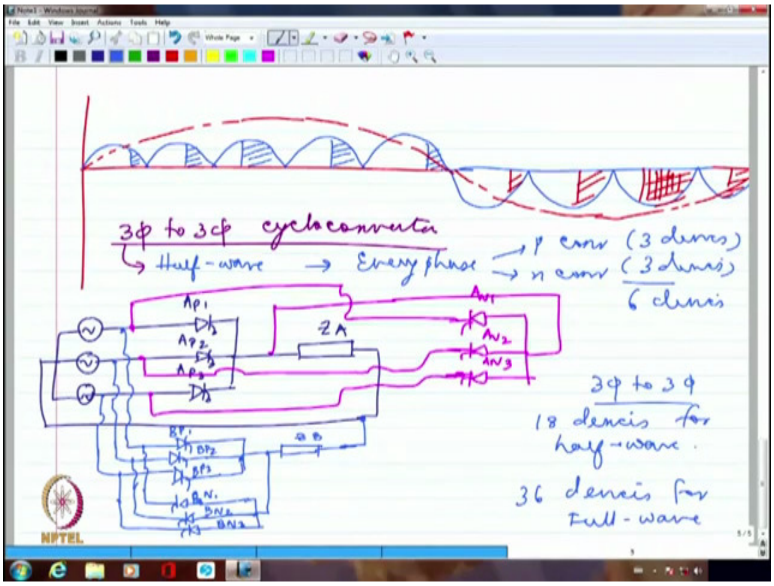
Because synchronous motor drives normally are of megawatt level rating very, very large capacity most of the times; and synchronous motor drives generally, because they are of large rating, they will also have a huge inertia, very large inertia. If they have a large inertia, it is going to take a while for them to vary their speed $J\frac{d\omega}{dt} = T_e - T_L$ that is the equation F=ma something similar to that.

So, you are going to see that, it takes a while before the speed changes even a little bit. So, the response time is really, really large for a synchronous motor drive which corresponds to megawatt level rating, SCR is also slow, and they can handle very large power so they all match very nicely. Thyristor based any converter will work slowly they are much slower than IGBT or MOSFET or any of them and they can handle single handedly almost 30 megawatts of power without any difficulty.

Because of which you know for high power drives we generally tend to prefer thyristors and cycloconverters reduced the frequency, most of the times synchronous machines maybe run at slow speeds for some kind of cement mill where you are trying to grind lime stone and so on and so forth. all those things work very slowly, it is inching most of the motor drives will be inching slowly.

So, in those cases these can come in handy from 50 hertz you may come down to 10 hertz or 5 hertz, so in those cases cycloconverters come in handy. So, motor drives will not accept generally anything other than sinusoidal. So, how I am going to really get a sinusoidal that is what we will have to think about.

(Refer Slide Time: 47:36)



So, if let us say my output wave is having maybe 5 or 6 half cycles like this. In fact, if I am going to say 50 Hertz to 10 Hertz I will have 5 half cycles in the positive and 5 half cycles in the negative, if I am coming down to 5 Hertz I will have 10 half cycles in the positive, 10 half cycles in the negative. So, I may have something like this continuously coming up. So, this is the way it is going to be.

I can approximate this to a sinusoid provided my average voltage is really small here, somewhat larger here, somewhat further larger here, then again it comes down here, comes down further here I can do that, I can always control my firing angle in such a way that first half cycle I have it close to 90 degree so that the voltage is very, very small, the next half cycle I can make it 60, the next half cycle I can make it 30 or even less then the next half cycle I can again make it you know 60 then the next half cycle I can make it you know close to 90.

So, this will essentially approximate my output voltage to something like this, it is starting from very minimal value it is reaching a peak here and then it is coming down to small value. So, the control for cycloconverter is not very simple because it is a continuously varying firing angle, I will be definitely varying the firing angle but if it is an RL load like a synchronous motor I will have to take into account definitely there will be some negative portion of the voltage coming up that is the reason I told you that for 90 degrees output is 0 only if it is continuous conduction.

So, I need to know what kind of load I am connecting to and accordingly I have to calculate what is the kind of firing angle I have to give such that my output voltage approximates to a sinusoid. So, it is the same thing I will be doing in the negative half cycle as well so I may get only small voltage this is a little larger, this is much larger and then I am going to get you know smaller and smaller voltages.

So, this is also going to approximate this entire thing you know to a sinusoid somewhat like this. So, I can control the output voltage approximately to a sinusoid it is not a perfect sinusoid, it is only an approximation to a sinusoid. So, I am calculating the area under the curve which is actually $\frac{3V_m}{\pi}\cos\alpha$ normally and then correspondingly I am trying to look at not $3V_m$, $\frac{2V_m}{\pi}$ for single phase we are talking still about single phase.

So, I have to calculate for that and then make sure that the firing angle is adjusted accordingly that will make sure that what I apply as the voltage is from what sinusoidal and the same thing has to be replicated for B phase shifted by 120 degrees and the same thing has to be again duplicated for C phase again shifted another 120 degrees. So, this control is definitely not simple but especially when there were no other devices other than thyristors that was in 1970s this was really leading, it was ruling the roaster for as far as the synchronous motor drive control was concerned.

Even now many of those drives are there in many of the power stations which are working quite well NTPC powers stations many of them use cycloconverter effect synchronous motor drive for many of the controls and they are still working well so nobody has tried to retire them, they are still working very much fine that is not a problem. Now, actually with the advent of wind energy conversion system these things are coming back somewhat.

Because as far as wind energy conversion system is concerned we will have a variable frequency of output from any of the AC generator, if I have an AC generator it will be rotated by a wind turbine and the wind turbine is definitely going to have a variable velocity it is not going to have a constant velocity if it has a variable velocity the output what I am getting from the generator that is going to be at a different frequency.

If I want to fed it to the grid I have to ultimately convert that into 50 hertz. If I had to do that normally what we do as of today is to first of all rectify the AC voltage into DC and DC is again converted back into AC with the inverter. So, you have 2 stages of conversion because of which there are lot many losses and huge amount of complex control, I am not saying cycloconverter is a simple control but this is one stage of conversion directly you are converting from AC to AC but the question is whether we can convert from a variable frequency always back to 50 hertz? So, for that there are several control methodologies that have evolved.

So, cycloconverter is again having a rebirth although it was almost it had become obsolete now people are looking at it with a renewed vigor because it can be used basically for the control of wind energy conversion system form variable frequency output to a constant 50 hertz output which can be fed to the grid. So much so forth the voltage control I am not getting into great details of cycloconverter because this is really not taught by many of the power electronics teacher, but I thought because it is reviving, at least you should know what is a cycloconverter that is the reason.

Let us try to take a look at three-phase to three-phase cycloconverter. If I want three-phase half wave to three-phase, ultimately the output cycloconverter half wave requires 3 devices, three-phase half wave require 3 devices, P converter will require 3 devices, N converter will require 3 devices so 6 devices per phase and I want three-phases at the output.

So, which means 18 devices minimum I will require if I want three-phase half wave if I talk about half wave. I will require every phase will have one P converter and one N converter and P converter will require 3 devices, N converter will require another 3 devices so I will require 6 devices per phase so I will require 18 devices if I am talking about half wave.

If I talk about full wave, I have to double it, I will require 36. So, we will require 36 thyristor devices or SCR devices and their control independently if I want to do it from three-phase to three-phase. So, if I am talking about half wave basically the circuit will be somewhat like this so these are the 3 phases and I am going to have 1, 2 and 3 so I should say P_1, P_2, P_3 corresponding to A phase, and I will also have the neutral of course and from here I have to connect it to, so this is Z_A

So, I have to show N converter again so I may show something like this. So, these are the 3 terminals and I am going to connect this here and I can call this as N_1, N_2, N_3 for A phase. So, this has to be connected here, so I have to connect this and then connect it here. Now this has to be connected the other way around. So, this has to be connected here and this has to be connected here second phase and this has to be connected here third phase that is it.

So, it is just other way around, neutral is already connected so I do not have to do anything with respect to neutral. Now, from the same 3 terminals I have to do this for B phase then I have to do this for C phase. So, I have to have 3 more devices for example connected from here so one phase, second phase and third phase so all 3 again I have to have one like this and then I can have from the same 3 terminals I can connected the other way around.

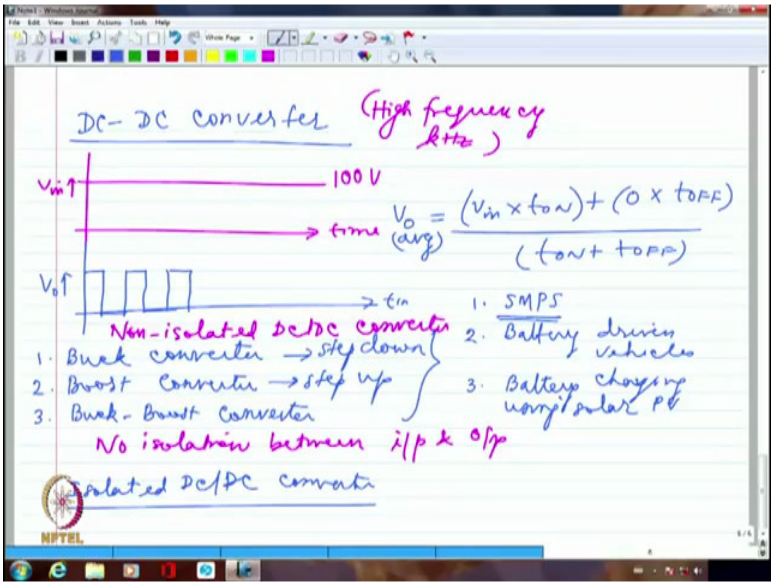
So, this will be BP_1, BP_2, BP_3 this will be BN_1, BN_2 and BN_3. Now, these 3 are connected together and I am going to have a load which will be Z_B and that will be connected with the neutral, this is neutral same neutral so I can connect it here. This is the neutral, so I have connected it here. So, the same thing has to be done with respect to this as well.

So, these 3 terminals are coming here, these are connected together now this has to be connected here neutral is anyway connected already so it does not matter. Similarly, I will have to do it for C phase. You are taking the same three-phase supply, 3 devices in forward direction, 3 devices in reverse direction half wave. So, I want you guys to draw the full wave I am sure you can do it, it will take some time, or you use just as positive connected symbol and negative connected symbol does not matter, I am sure you can do that, it should not be a problem.

So, this will require totally 18 devices for half wave three-phase to three-phase, whereas 36 devices for full wave. So, AC to AC converter basically we have discussed only 2 types. There is one more thing called matrix converter which I am not getting in it, we will see if time permits towards the end, I will look at matrix converter otherwise I do not want to get into matrix converter.

There is one more converter which is AC to AC conversion is possible that is matrix converter, matrix converter I am not looking into right now. So, we have seen only single phase and three-phase AC voltage controllers where frequency can be a will be a constant and magnitudes could be changed, RMS value of magnitudes could be changed but the major problem is non-sinusoidal output.

And the other one what we have seen is cycloconverter which can convert single phase to three-phase or single phase to single phase, three-phase to single phase or three-phase to three-phase all of them can be done but frequency generally is reduced, and sinusoidal output approximation can be done, it will be very difficult to obtain exact sinusoidal voltage. (Refer Slide Time: 62:17)



So, the next topic that we are going to start of is on DC to DC converter, I will just tell you what we are going to cover, today I will just leave it at that. We will really be mentioning to DC to DC converter in the next class. So, DC to DC converter is something similar to what we had seen as AC voltage controller. So, we are going to probably chop off some portion of the voltage, we will not apply the voltage for some time, we will apply the voltage for some portion of the time.

So, if I take you know a switching action which has a period of 10 kHz, high frequency, really high frequency so normally DC to DC converters work on high frequency in terms of kilo hertz at least. It can be of the order of megahertz if I am talking about very, very small power levels, if I am talking about motor drives then it maybe of the order of a few kilo hertz.

So, if I am having a DC supply like this, this is the input, with respect to time I am not writing ωt because it is DC with respect to time it is a DC this is a input. If let us say, this is 100 volts but what I want as the output is 50 volts, if I apply 100 volts for 50 percent of the period and rest of the 50 percent, I do not apply any voltage.

So, I am essentially looking at a voltage somewhat like this maybe I am going to apply it for 50 percent of the time I do not apply it for the rest of the 50 percent again I apply it for 50 percent of time I do not apply it for 50 percent like this, I repeatedly do this. So, I am doing on off control basically nothing else. So, when I do on off control like this and if I do it fast.

So, if I am applying it for example to a DC motor it may not realize it is not getting any voltage the current will start coming down but because of the inductance that is present in the DC motor and I may add some inductance in my circuit the current will increase, decrease, increase, decrease but the ripple may be limited which will indirectly you know give me 50 percent of the voltage only as the output because I am going to get the average voltage, V_0, so V_0 average will be,

$$V_{0(avg)} = \frac{(v_{in} \times t_{ON}) + (0 \times t_{OFF})}{t_{ON} + t_{OFF}}$$

So, how long I keep the switch on as compare to $t_{ON} + t_{OFF}$, it happens to be the period of this particular chopping action. So, this is essentially the typical working of a DC to DC converter. So, obviously I cannot use a transformer to step down or step up DC voltages it is only meant for AC voltages. So, I can use this kind of a power converter with the switch which can turn ON and turn OFF at very high frequency rate because of which I will be able to get a variable output DC value.

So, DC to DC conversion is very commonly used in certain applications one of them is SMPS switch to mode power supply which we used in many of the personal computers, all the personal computers normally PCs use SMPS switched mode power supply. So, there what I get maybe very high value of DC from that I may try to get 5 volts, 15 volts, +12V, -12V whatever my CD-ROM drive requires, whatever my other IC's require all those things maybe obtainable using DC to DC.

Another one is battery driven vehicle control you might have seen in many of the airports and all for cleaning or for going from one terminal to another terminal there will be a vehicle going which will be pretty quiet because it is having an electric motor it does not have any IC engine because pollution has to be avoided there. So, normally what it has is a battery inside and the speed control is done using a DC to DC converter, stopping, starting, acceleration, retardation whatever you want to have all those controls can be implemented very easily with the help of a DC to DC converter.

So, battery driven vehicles and some of the battery charging circuits those also use DC to DC converter. For example, I may I have a solar PV from which I want to charge a battery so in which case solar PV may not give the voltage, what is required by the battery so I might have the use some kind of DC to DC converter to adjust the voltage level of the solar PV output to match with what is the battery voltage.

So, because solar PV will not have a constant value of output voltage all the time it depends upon the temperature at which it is operating and the also on the illumination level. Illumination level normally decides how much is the current that is coming out and the temperature indirectly decides what is the kind of voltage and what kind of load I have connected that also decides the voltage, so you are not going to have a constant voltage.

So, if I want to connect the solar PV to a battery generally it is not done directly it is done through a DC to DC converter so I can say battery charging application using solar PV. if I want to charge a battery using solar PV in these cases also DC to DC converters are used. So, what I have shown you is to reduce the voltage because I cannot increase the voltage using this kind of a configuration.

There are configurations which may have the capability to increase the output. The power cannot increase obviously whatever I give as the input power will be equal to the output power assuming that the DC to DC converter is lossless. So, I can have so this kind of converter is known as Buck converter where I am going to step down the voltage. The second type of converter which we will be studying will be Boost converter which will be step up converter which will do step up operation.

Here normally we will have an inductor inside which we will try to store some energy then we will try to release it whenever it is required. So, it is like creating a myth believe kind of situation where the inductance stored energy plus the voltage together will look as though the output voltage is increased. So, step up converter invariably uses a large inductance to store the energy for some time and then release it whenever I want to higher voltage at the output, so this is the second type of converter we will be looking at.

The third type of converter we will be looking at will be Buck-Boost converter which can either reduce or it can increase the voltage. So, Buck-Boost is another third type of converter which may be used typically again in a solar PV application because I may have a range of voltage in solar PV, let us say from 36 to 48, but my battery voltage maybe only 42 so I may have to step up the voltage or step down the voltage.

So, whenever I have a variation huge amount of variation in the voltage whereas the output voltage, I required is somewhere in the middle I would like to use a Buck-Boost converter and all these 3 converters what we will be looking at are not going to have any isolation between input and output. So, these are basic DC to DC converters without any isolation between input and output, isolation normally is always obtained with the help of a transformer.

So, when I do not have a transformer these are generally known as non-isolated DC to DC converter, these 3 are known as non-isolated DC to DC converter. Whereas we will also be looking at a few isolated DC to DC converter. As we proceed, I will tell you what are all the isolated DC to DC converters that we will be looking at. So, we will start of in the next class with Buck DC to DC converter or Step down DC to DC converter.

For this portion specifically I will be referring to Daniel Hart's book. Daniel Hart has given this portion extremely nicely. So, I will try to refer to that book specifically for DC to DC converters alone.