High Voltage DC Transmission

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Module No. # 02

Lecture No. # 03

Selection of Converter Configuration

Welcome to this lecture number 3 of module 2 and in this lecture I will discuss about the selection of converter configuration. In the last lecture we saw that is various requirement and those requirements here you can say we require high pulse number for having the better configuration of rectifier circuit or converter circuit.

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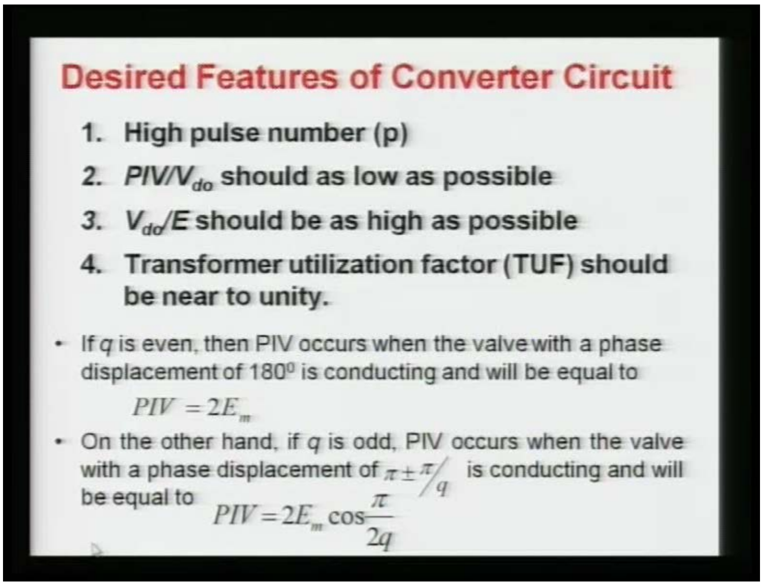

We should have the peak inverse voltage over this V d o that is a dc output voltage without any delay should be as low as possible. And we should have the dc output voltage that is a ratio of E that is a impress voltage should be as high as possible and the transformer utilization factor should be near to unity. So, first requirement already I discussed in the previous lecture that is we should go for the high pulse number to reduce the number of harmonics so, that we can reduce the requirement of the our (()) filter circuit. And but, it cannot be very high due to the limitations of the converter cost and etcetera. So, we can normally go for the 6 pulse and the 12 pulse converters configuration.

Second is that it is a peak inverse voltage, it is also related to the cost of the valve if it this value the peak inverse voltage is very high, then we have to go for the very expensive valves and therefore, we have to go for the as low as possible. To make it general, the if q as you know this is number of valves in a commutating group if it is even then the peak inverse voltage will be the twice of the peak value of the impress voltage that is a E m. If your voltage of secondary side is E m sin omega T or sin omega cos omega T, then it will be twice of the its peak value. And this normally occurs when the valve with the phase displacement of 180 degree is conducting then it will be 2 E m. But on other hand if it is a q is odd the peak inverse voltage occurs when the valve with the phase displacement of pi plus minus pi upon q is conducting and will be equal to that is already explained this 2 E m cos pi by 2 q.

So, this value if the V d o already we have derived, what will be the V d o in terms of series and the number of series valves as well as the number of commutating valves in a group. So, peak inverse voltage divided by V d o for the your even number this will be your this and for your odd numbers this is your.

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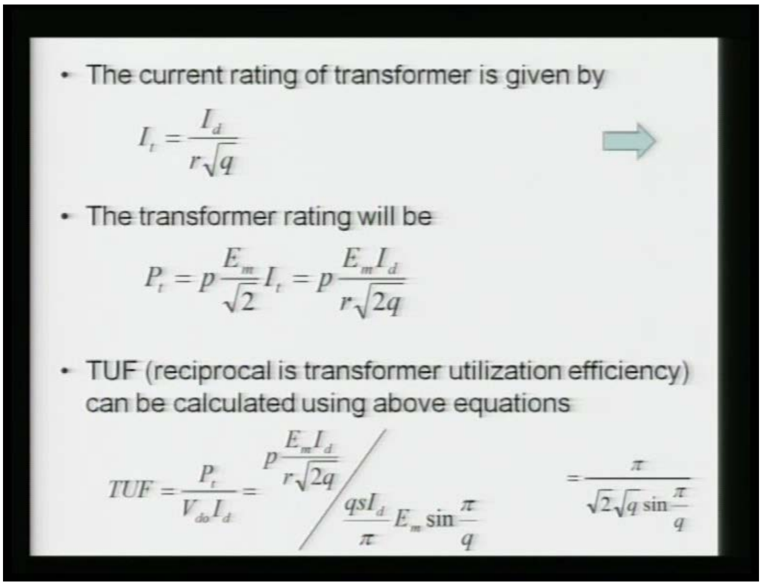

When this q is even we are going to have this value and once your q is odd we can get the pi upon s q sin pi upon 2 q. We will see this value for the different value of s q and r and for given a pulse number we will see in the next slide. Another requirement as also I discuss that is we require this the dc output voltage that is a V d o, when o means there is no delay divided by E, E is the r m s value of the secondary side voltage will be again given by this value. So, your V d o upon E is under root 2 q s divided by pi sin pi upon q. Now, another important criteria to have a converter circuit that we should use our, the transformer utilization factor should be as much as possible means, it should be properly utilize.

So, here the transformer utilization factor basically it is a defined as the ratio of the transformer rating. Here the valve side we are talking about the secondary side to the DC power output. And this should be as low as possible. Means the transformer utilization factor shows that if you reverse it one over TUF gives your efficiency of the transformer. So, this is again you will see in the mathematical term it is defined as your nothing but, it is your TUF it is your Pt divided by your V d into I d.

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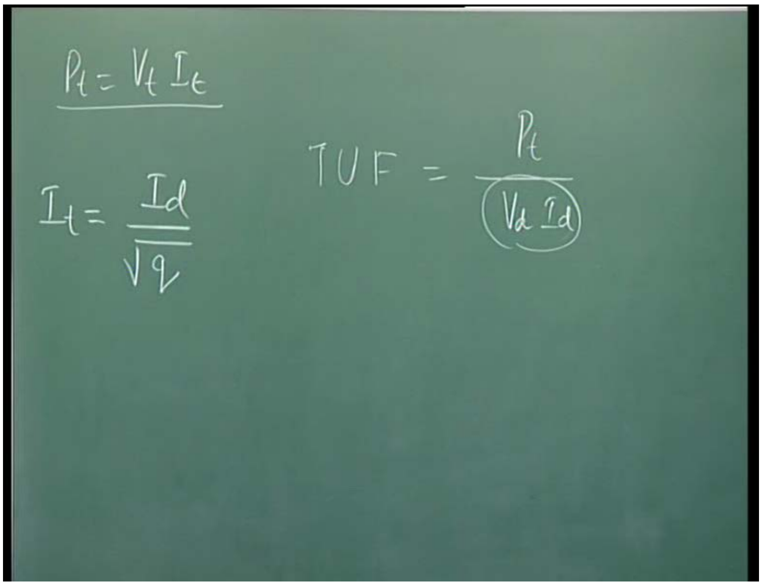

The Pt is nothing but your the secondary side here your r m s a c r m s divided by the your DC power. To calculate what will be the Pt? This is very clear in any output of the converter circuit, it is the V d that is a output the DC voltage and I d is the DC current and we have assume this DC a current is constant in the your DC link.

Now I t we can generalize this I t you know that is Pt is nothing but your V t I t means here we are talking the V a rating. So, this is a voltage r m s voltage multiplied by the current r m s value again it is the valve side that is flowing in the valve. To make it general, this I t we can write it will be this value that is a depending upon your q. q is again your number of valves in a commutating group. To see this impact, how I have generalize this? Here you can see if it is 3 phase rectifier, one way we are getting this is your, this 120 degree this is a conduction period and for remaining period here 120 and 120 here it is off for one valve.

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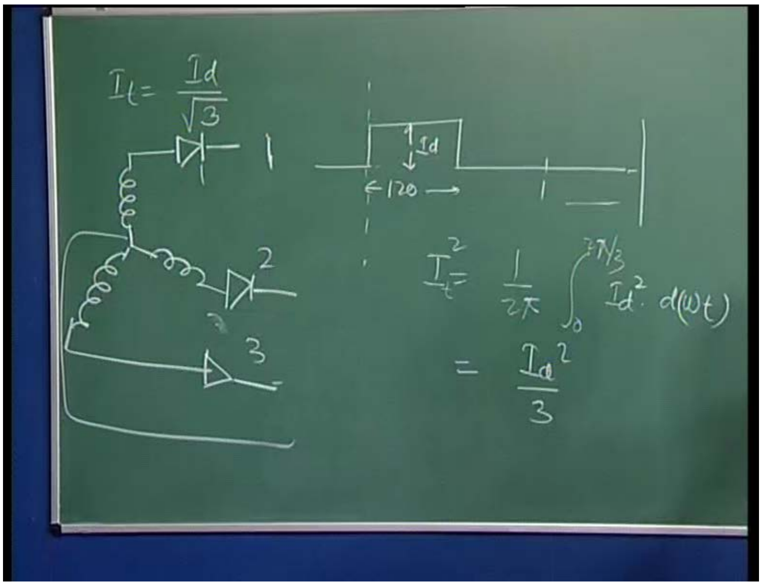

Similarly, you can find this is valve 1, here you will get valve 2 and valve 3. Means it is conducting for 120 degree and this value is your DC I d. So, we can get the r m s value if take this is axis and if you want to calculate what will be the r m s value of the valve side of the secondary here you know this is your one over we have to go for the twice pi this is I t square and here we are integrating 0 to this value is 2 pi by 3 remaining will be 0. Your I d here d omega T this will be a square, this square this will be square. So, r m s value here this we have to take under root. So, if you are going to put this value and you are going to solve it, how much you are going to get it here? It is your I d square by 3. Because, this 2 pi 2 pi here will be 2 pi by 3 this should be cancel you are going to get this means we are getting your I t it is your id over under root 3. And this 3 is nothing but, the 3 valves in a commutating group.

Similarly, you can see for other cases as well. So, we will get this expression in general that is true for all type of configurations. We can write this r m s value of the valve side it will be equal to your the DC current. Again this DC current is assume it is a constant which is flowing the DC link divided by under root of the q, q again it is a number of commutating valves in a commutation group. Now, if the valves are in parallel here if you will see this configuration is nothing but we are having the windings here. This is your 3 windings and we assume that is we are having here valves 1 here we are having another valves here we are having another valve and the neutral is as the return path if remember.

So, this is valve 1 2 already we have written here. So, in this case it is the valve is only one in the series here there is a possibility you can have the 2 valves in the parallel. Then that value here this will be appearing here with r. r is the number of parallel valves that is here connected with the winding here. So, this is I t is your general term this expression that we have to use here.

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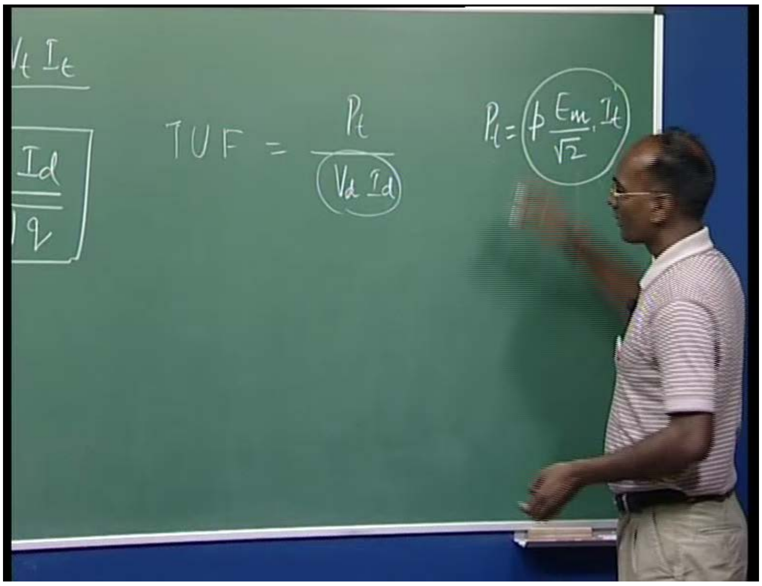

Now, another term here is your voltage means here is the Pt here it will be your is defined as E m by under root 2 this is r m s voltage of the secondary side. This is secondary side already all the equations we wrote in the secondary side we are never here for this case. Because, here whatever I am writing it is I m sin omega T, it is your instantaneous voltage of phase. So, this will be here another 2 this is r m s value into your this current which is flowing for that pulse and if the number of pulses are P it will be multiplied by P here.

So, here number of pulses are 3 so, it will be 3, you can also visualize here it is a 3. So, you can say 1 phase multiplied by 3 but, it is not always you cannot say it is a phase wise because the some of the transformer having the auto transformer or they are having the centre tap transformers. So, it is the phase are single but, they are tap together. So, it depends upon the pulses that is a more convenient rather than using the here 3 phase are 6 phase like.

So, the P basically I am writing is the pulse number and here this is your a c side r m s value of voltage, the current and then we have to write the transformer utilization factor. That is why here you see I have written this Pt is equal to P into E m over under root 2 multiplied by I t and that will be equal to your P here that can be simplified because we can put this I t value in this expression we will get this value here.

Now, again the transformer utilization factor if you are going to calculate this value, just put this value of I d and V d here. This V d which I wrote here this is basically we are talking there is no delay. And that is V d o into I d here, just put this value and just if we will simplify because the V d o already we have express in terms of your the q s and this sin pi by q. Just simplify this expression you are going to get the transformer utilization factor which is your pi over under root 2 under root q sin pi upon q.

Here, the as I said the reciprocal of the transformer utilization factor it is nothing but it is just like a transformer utilization efficiency. Mind it is not a transformer efficiency it is a transformer utilization efficiency we are talking, both are totally different. Transformer efficiency normally we go for the input over the output and the losses etcetera is consider. Here we are not talking about the losses, we are even the assume is the transformer is loss less, it is the utilization means any material there is going to utilization that information it is giving.

So, one observation we can see from this expression that the transformer utilization factor is only dependent on q. Even though r is also disappeared because r was appearing but here this r is also (( )). So, to get this the transformer utilization factor optimal value, we can just differentiate it then equate it is equal to 0. And we can get the, what will be the optimal value for the transformer utilization factor so that we can just differentiate here this factor and you will find this q will be the 3.

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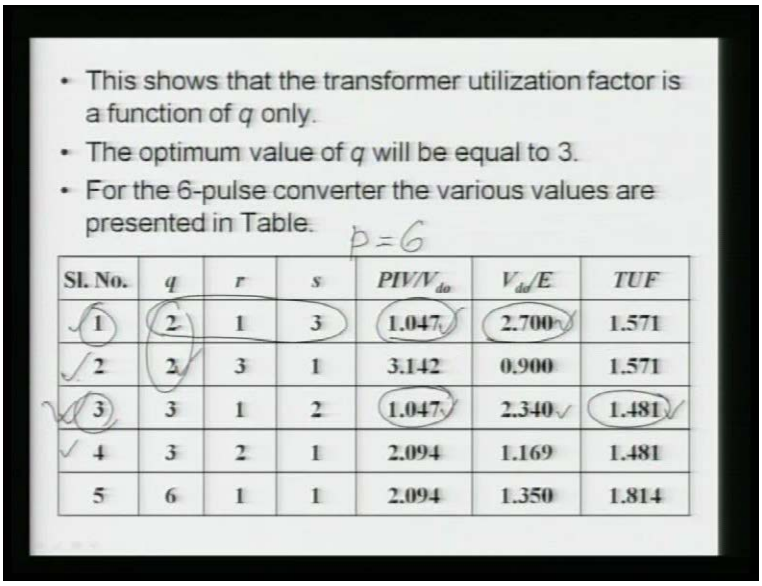

- This shows that the transformer utilization factor is a function of q only.
- The optimum value of q will be equal to 3.
- For the 6-pulse converter the various values are presented in Table.

Sl. No.	q	r	s	PIV/V_{do}	V_{do}/E	TUF
1	2	1	3	1.047	2.700	1.571
2	2	3	1	3.142	0.900	1.571
3	3	1	2	1.047	2.340	1.481
4	3	2	1	2.094	1.169	1.481
5	6	1	1	2.094	1.350	1.814

Means in that factor if you are going to take the what will be the TUF optimal value, you will find the q is equal to 3 will come. Simply just differentiate that (()) fact to q and equity is equal to 0 solve it you will find the q should be 3. Now, here the q is 3 that is optimal value and now you can also see this whether is the 3 is correct or not you can see from this table for the 6 pulse.

This table shows that for a given 6 pulse the possible combinations are the 5 combinations we can have means always the multiplication of these 3 quantities it is your 6 value. So, for the q can be 2, q can be 3, and q can be 6 as well. So, here for this you can have the 2 q's here q is equal to 2 q is equal to 2 and then corresponding r and s value will be 1 and 3 r 3 is 1. So, you have the 5 here is possible combination for it if this value is P is equal to 6.

Now, if you will put this value for all the q r and s, you will find this table where we are just going for. Now, you can see as our requirement this peak inverse voltage divided by V d o should be as minimum as possible now we have the two cases here this and this is minimum and both are same. Means this value and this value others are very high so, we are having two values means your serial number 1 and serial number 3 is giving minimum peak inverse voltage over your V d o. Now, your V d o upon E is the maximum for this and of course, second option is your this but the maximum we are getting for the serial number 1.

Now, the transformer utilization factor if we will see as I said it should be as near to unity so, option here is only your this is less compared to other two. Now, again with this combination it shows the optimal configuration can be either 3 or 1. Because, the 3 also here this is a second position this value but this is the better in the 3 configuration at the when you are going for q is equal to 3, 1 and 2 here you are having this is better and this is better. For one configuration we are having this better and this better.

Now, choice either it will 1 or 3 but it will be prefer that we can use 3. The reason is because we are having 3 phases and very easily we can identify the number of valves in a group because you are having 3 phases q is equal to 3 is very easily it can be 3 or it can be multiple of 3. But in this case the 3 is only we are getting here one so this option is better and again this improvement of the transformer utilization as well we can improve upon. Means this can be further improved by having the 3 phase configuration we will see. So, this option here is the better option compared to the option one. No doubt here the dc voltage output is more than this value but, this is utilization is better here compare to this. You can argue that is difference between this is not very much, but here the difference is I think it is a sometimes 5 something, but here this utilization is more more important because the cost of the transformer is very expensive.

We can go for a some series edition of the valves even though sometimes we put some extra valves. No doubt we put several extra valves so that even the 1 valves get puncture then we can we should not take it the converter circuit out from the h V DC link. So, it was believe that having this 3 is another advantage that we are going to have the q is equal to 3 due to that we are having 3 phases.

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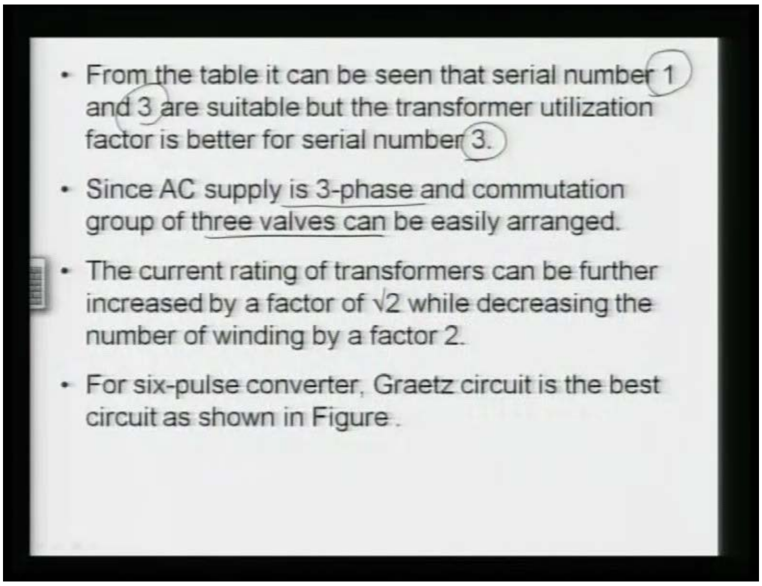

So, it is very easily we can form the commutating groups and we can very such as fully we can operate the converter circuit. So, here as I said whatever I said here it is written your number 1 and your number 3 are the suitable, but the transformer utilization factor is better for 3. Since a c supply is 3 phase and commutation group or 3 valves can easily arranged. Is very easily arranged otherwise you can say two in one group here and there it is very complex system.

Another, the best advantage of having 3 is here, you can see the transformer utilization factor can be further improved by factor under root 2 while decreasing the number of winding by a factor 2. What it is meaning? Means we are suppose you are going to have the 6 winding transformer in the same 3 winding transformer you can use for the return as well means one winding can be use one is going another can be use as the return at the same time. And thereby what happens we can get our utilization factor will be improved by under root 2. Where it will be improved? It will be only improved here this I t will be now is not like that.

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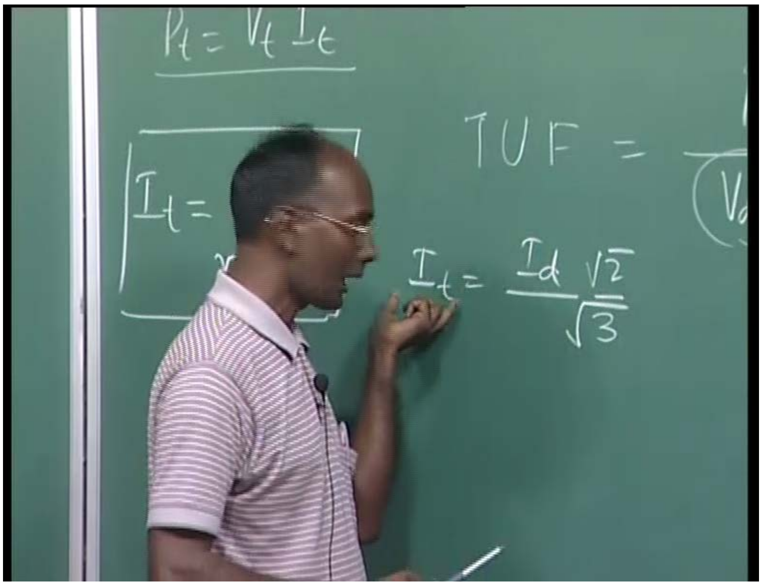

For you can see the for this circuit, this value your r m s value will be here, your I d by what will be this value under root 2 by 3. Means here this r m s current is improved by under root 2 times. How? You can see here. What happens if you are going for the bridge converters? Now you can see the figure here.

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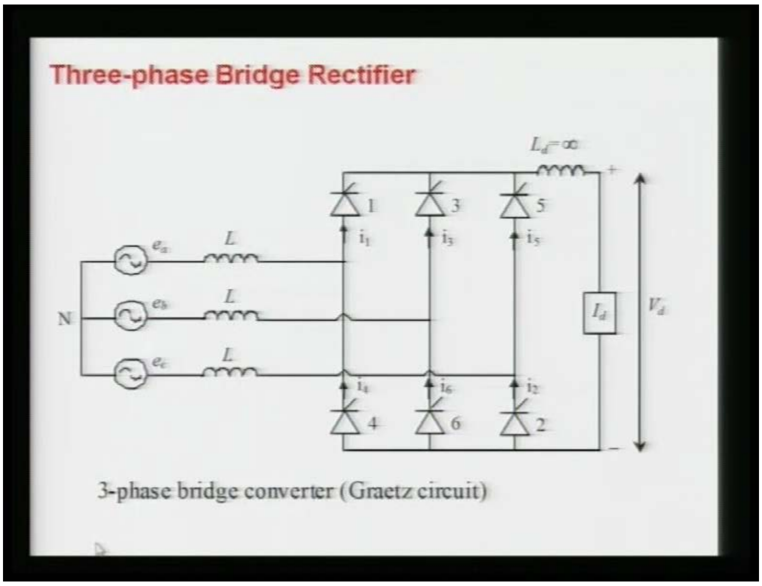

In this case, here your valve here one is conducting for 120 degree and then it is coming here may be your one and two is conducting here this is coming. And again you will find sometimes one is also conducting means this phase current here will be one 120 here conducting then 60 of both side and then we are having here 120 for valve 1. So, your the current in the phase a will be here 120 it is conducting for valve 1 and here your valve 4 is conducting. Now, you can see the now r m s value here is now we are getting for this one if your axis is this. Then you have to add here another value that is, this is your twice pi by 3, this is 60 degree you are adding. How much this value? Pi. And this value is, how much? This is a, you can add 5 pi by 6.

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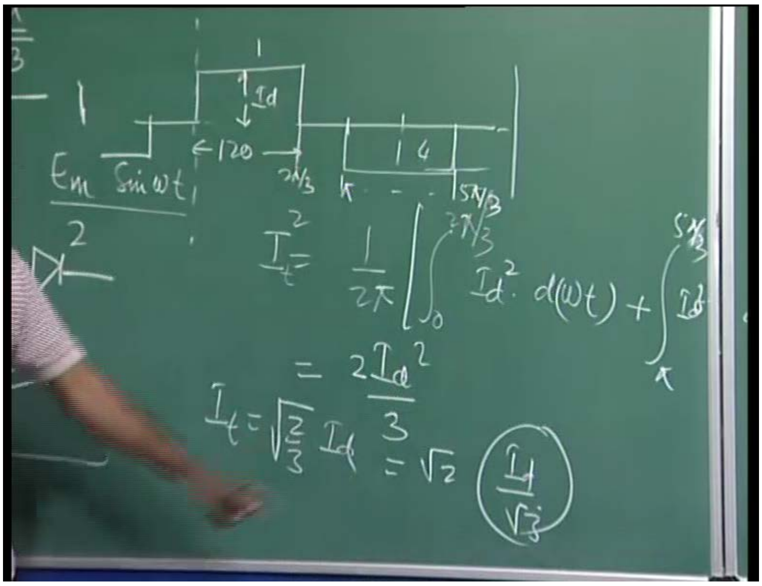

So, here we are just again integrating to 5 pi by 6, 5 pi by 3, yah. So, it will be here 3. Now, we are getting I d square d omega T. Simply what happens? here this value becomes twice. And then you are going to take here this is your I t will be under root twice by 3 your id. Now, you can see this r m s value here is improve by under root 2 times. Means I can write here it is your under root 2 id divided by under root 3 this was your q is equal to 3 now you can say this is general. So, by using the arranging in a such way here and that is why this bridge rectifier also knows as the gractz circuit is the best popular combination for the converter application both rectifier as well as inverter.

So, here with this whole analysis now we have also arrived this bridge converter is the best suitable for our h V DC application as well because we are getting all our desired features for our converter configurations. Here this is the circuit here now we have to analyze this circuit. And in this analysis it is assume that here the inductance this is having the winding inductance here but, this value is very insignificant we are having the balance 3 phases of the secondary side. And the numbers are made in a such a way that we will see the conduction pattern should be in the symmetrical order so that there should no need to remember. So, that is why here 1 3 5 4 6 2 are denoted and here it is assumed same which is I said is the DC current is the constant in this link.

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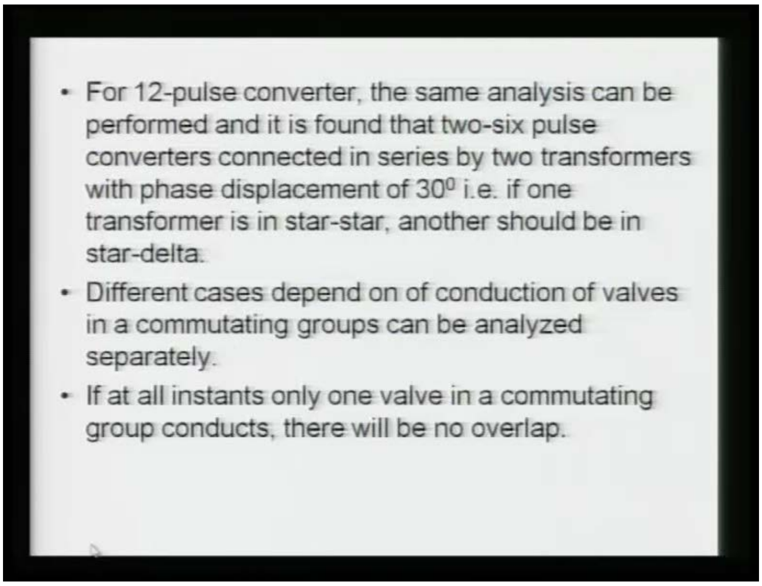

Now, in this analysis we have to see now one is the very important thing here that we have to go for the phaser or concept where it should be very clear. Before that here now again you will see the for 12 pulse converter same analysis can be repeated. Whatever the table which I have represented for the 6 pulse you can again write for the your 12 pulse. And you will find that here your q is equal to 3 will be optimal and just you have to find which value is the optimal.

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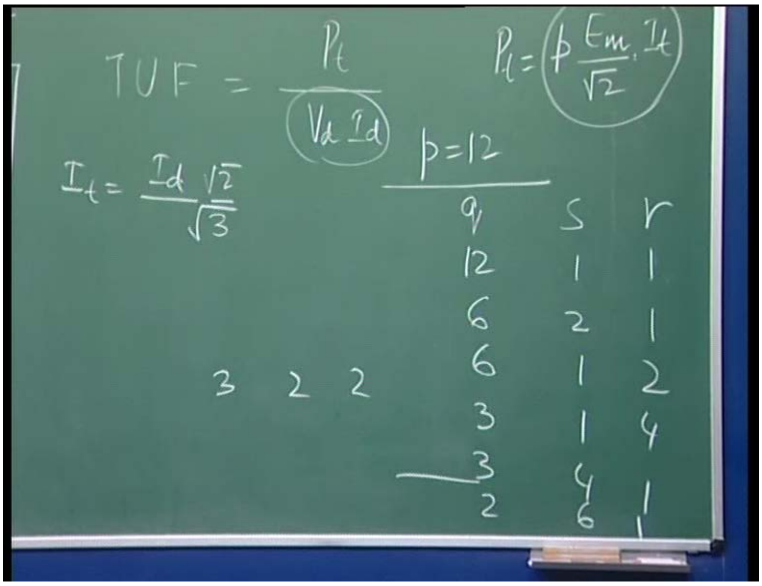

For putting all this possible combination because for your P is equal to 12 you have a lot of options it is your q, s and r. Now you are going to have here let suppose 12 1 1 then you are having 6 here, here 2 into 1 here 6 1 into 2 then you are having 3 1 into 4 and here 3 4 is to 1. Then what else option we are having? 2 we are having 2 also 2 6 here 1 even though we can have the two here also means we can go for this option here 3 2 and 2. So, you are having large options and again from that table you can write the values and you can find that which one is going to be suitable options. So, you have to choose the suitable options and then you have to decide which one will be the better option. And this will be your assignment one of the problem of your assignment to calculate all these value and see which option which alternatives or which combination is giving the best option.

But if you will find from here and if you can use the same configuration here, if you see, if you are shifting by the 30 degree because we are having the transformer connections star star and star delta there is the 30 degree shift and if you are adding the two 6 pulse converters you will find the best solution. So, in this case what happens you will find the q is still 3 and then you will find there are 2 s is equal to 2 and r is equal to 2 and you will find some combination, just you go and see what value are going to get.

Now, to analyze the circuit, we have to see what are the conduction pattern of the valves. And you know there is a various type of conductions one is the very ideal case when the current from 1 valve is suddenly taken care by another valve of the same commutating group. Again the commutating group here I will if you will see here the commutating group in our case this is one commutating group this is another commutating group. So, for example, if your valve 1 and 2 are conducting and 3 is going to get the pulse after 60 degree. Then the current from here 1, which was flowing here I 1 that was I DC now it is going taken care by the valve 3, means suddenly it should be changed. So, this is the ideal condition, but it will not happen due to the inductance of the winding it is not so, there will be some overlap degree over (()) of from the current which is taking care from valve 1 to valve 3.

So, if at all the instant only one valve in a commutating group conducts then it is called there is no overlap. Again the same concept here that is, here if valve 1 in this 1 is only one is conducting at a time either upper and the lower. So, for example, your 1 is conducting and your 2 is conducting then it is and then after if you have firing 3 1 is suddenly off and 3 2 3 are conducting means it is there is no overlap. So, it is a ideal case first will go for analyzing the ideal case then we will see if 1 and 2 both are in the same commutating group the two valves are conducting. And then what will be the output voltage, what will be the pulses, what will be the harmonics, what will be the current in each valve and how they are going to share will analyze completely for this 6 pulse 3 phase bridge converter circuit?

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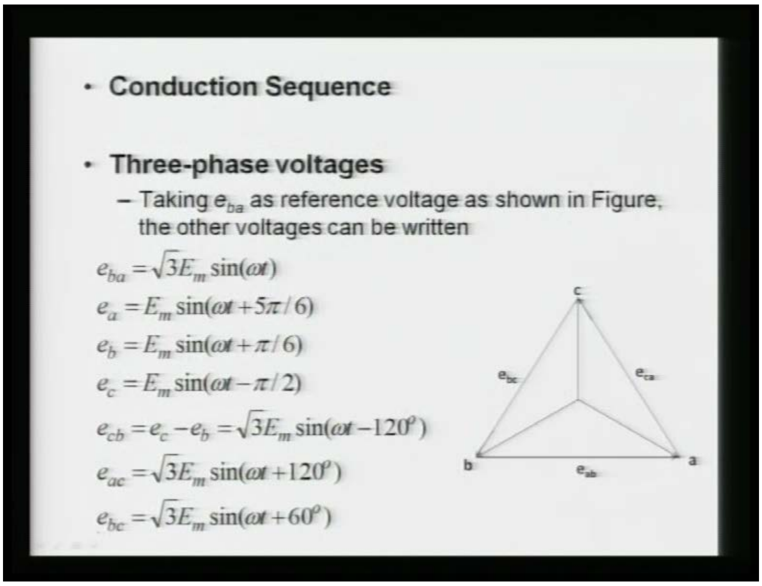

Now, here let us see the conduction sequence conduction sequence as I said the name the numbers of the valves are given in a such a way that you can very easily recognize.

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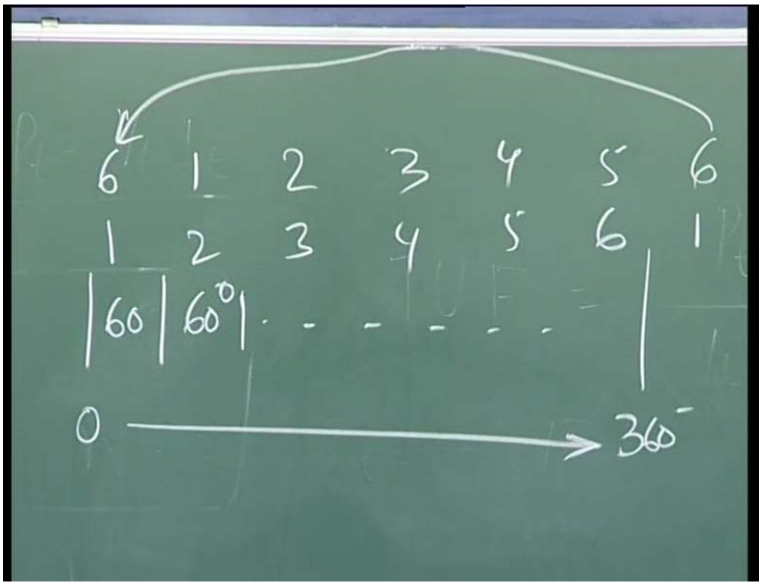

For example, as I said here let suppose 6 valve is conducting then 1 is fired. So, 6 1 are conducting, then it will be your 1 2 then here 2 3 here 3 4 4 5 5 6 and then again we are getting 6 1, means this is again the repeated. So, all this pairs they are conducting for 60 degree. So, this is a complete cycle, if we starting from here this will conduct for 60 degree, this will be for 60 degree and so on so forth. Here you will find it is 360 degree from 0 to this. Now, if the two valves in a same are in a conducting so that can be represented by the graphical way and it is very easy to then recognize.

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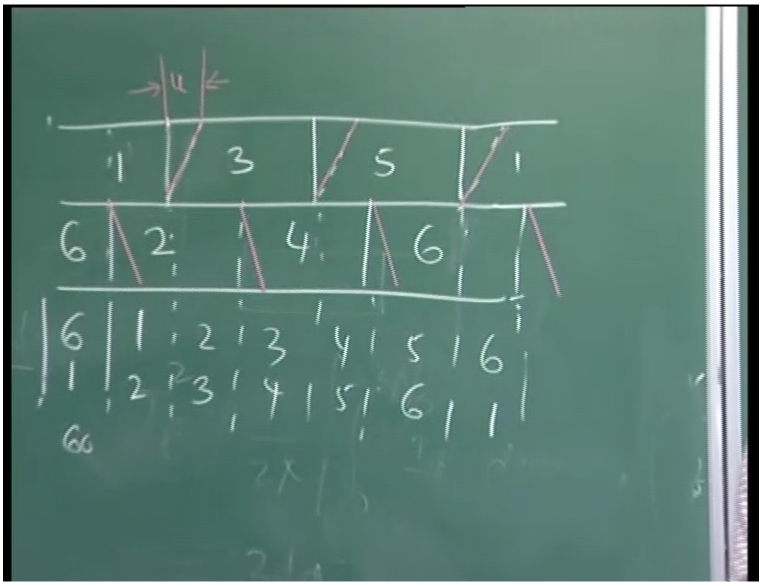

You can see here, if I can draw the upper valves number here. Upper valve is your 1 3 here 5 then again it will be 1. The lower valve here, I can write here, lower valve here always it will be the mid of this. So, this is your 2 here 6 here your 4 here again 6 and again here we are getting the same 2 and etcetera.

Now, you can see here, the pattern which is conducting now you can write here is easy to write and then we will see because why I am writing here. At the later stage we will see what is the overlap angle when the two valves are conducting when 6 valves 3 valves are conducting or 4 valves are conducting this very easily can be calculated by this figure. So, in this case here you can see 1 and 6 so I can write 6 1 are conducting. Here you can say in this period it is 1 and 2 are conducting as the same sequence we are getting. Here it is your 2 3, here it is your 3 4, here your 4 5, here it is your 5 6, here again we are getting 6 1 means it is repeated.

So, this is basically conducting for 60 degree, means all this here 60 60 60 now, you can say 6 pulses. So, it is total 360 degree in a one cycle. Now, if it is slightly there is a current is not suddenly change from 1 here, now, I can change here it is just means, it is taking some time. To simply here I just I draw the dotted line or I can use the different color to clearly mark it. So, here I can say this is your this, this and here this. Similarly, here also we have to change it here I can say here, here and here and here. Now, here we were assuming that is it was a instantaneously changed but now you can see it is taking some time, and this period here is known as overlap angle u. The U will be used for the overlap angle means this is the period in the degree that the current sum 1 is going to be shift to 3 means this period taking. Means both one and three are conducting during this period and this period is known as your overlapped angle.

Now, you can see; now, whole your pattern is now going to change and now we are going to get. Now, in this case, here you can see if you are going to write at this point this point 1 6 and 2.

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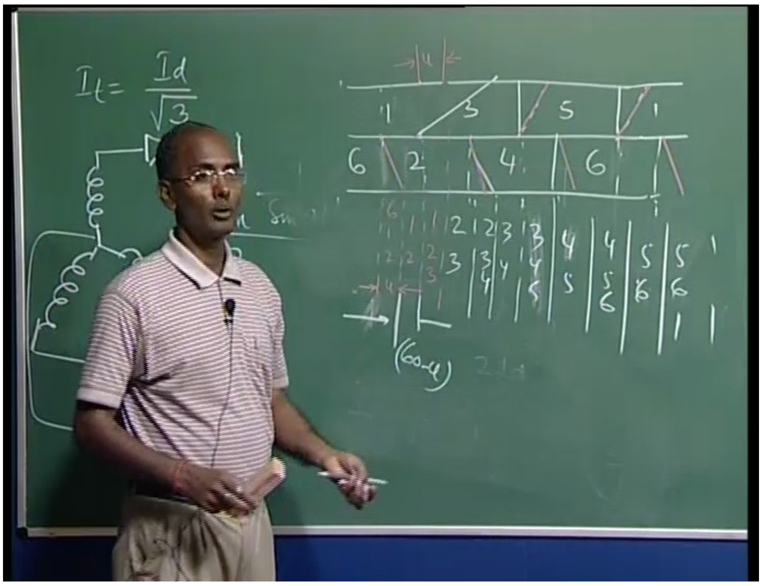

So, here 6 1 and 2 are conducting during this period. To know it and this is your angle U. Means your 6 here you can just see here this at if you are drawing the point here 1 2 and 6 means 6 1 and 2 are conducting at this period. Now, in this period you can see here up to here is one and two is only conducting. So, it is one and two. Similarly, we can write here it is 1 2 and 3 and so on so forth we can write again here it is 2 3, here 2 3 4 up to here u, here we are getting 3 and 4, here your 4 5 6, not 6, it is a 3 4 5 here we are getting; Where why it is 3 here? Basically, it is not a drawn properly here because this u will be small, here this will be this. But sequence pattern we are getting 6 1 2 then 1 2 6 will off because your 1 6 and 2 are in same commutating group. So, here this 6 will go away. So, 1 2 1 3 4 here, 1 2 3 here then 2 3 because 1 will off because 3 is taking care, now 2 3 4, now here 3 4, now 3 4 5, now we will get 4 5, now we will get 4 5 6 and then we will get your 5 6 and then again 5 6 1 and so on so forth because again we are coming back to this.

So, now we can see at the certain point of time, the 3 valves are conducting and certain period it is your this is a 2 valves are conducting. But with the total duration here is your 60 degree. So, what happens the remaining here this is your 60 minus u degree when two valves are conducting.

This is not always correct because if your u degree is very large. Means for example, let suppose this is taking care a longer time, means this is going up to here. So, there are possibility because the current from one changing from another here 1 2 3, it is taking longer degree which depends upon so many factors which depends upon your inductance, which depends upon your circuit condition whether weak ac system or the strong ac system, what is the dc value of the link so many factors are involved. So, if it is taking more now there is a possibility that you are getting the 4 valve conductions.

And once it is getting 4 valve conduction, this is just like a short circuit. Even though there is a possibility that this is taking the 60 degree u. So, we will get the different modes of operation means if your u is 0 then it is always it is your two valves conductor. If U is 0 as say it is ideal case, it is your two valve are conducting at a time, one from one commutating group another from another computating group. If u is less than 60, here it is not coming up to this point means we are getting the 2 or 3 valve conductions. 2 or 3 means, sometimes 2, sometimes 3 already this is the example when u is less than this. If your u is 60 then it will be 3 valves always. If your u is greater than 60 then you are going to have 3 or your 4 valves. And once you are coming here at the 4 valves, it means there is a that short circuit in your converter circuit somewhere.

So, always we try to operate our converter circuit that should be less than 60 degree u overlap angle. But there are some conditions especially during the fault conditions or abnormal conditions you have no control over u. And therefore, it can land up here in this cases and that is a very dangerous. So, we will analyze all these cases one by one and we will see when it will be short circuit what will be the harmonics that will be injected to the circuit. So, all this various modes I can say the modes of operation, this is a mode 1 mode 2 mode 3 and so on so forth and we will analyze in detail.

So, here now as I said to make analysis very clear and concise now you can see, now we are landing in the very complex scenario. When the various valves are conducting what will be the output voltage, what will be your valve voltage, what will be current and for the deferent modes we must be very careful about the phaser concepts. Because this phase if you are missing here and there then certainly this you cannot analyze the circuit and you cannot get the complete output voltage of either valve or your dc circuit.

Now, just I will go for some review on the 3 phase circuit voltages which will be used for this analysis. Now, you can see here, I have taken we will see here this slide here e b a I have taken as a reference voltage. The reason is here e b a is the commutation voltage for valve 3. Now, in whole analysis what I will follow, I will take the valve 1 and 2 are conducting and 3 is going to be fired. For in this circuit now you can see that what will be the commutation voltage because that is a commutation voltage is also very important here for this valve.

Let suppose, your valve 1 and 2 are conducting, what will be the voltage here when it will be going to be positive? If your one is conducting then the voltage here at the cathode of this valve will be e a. Now, if you are the two here is conducting so, what will be the voltage here? This is always e b at the positive. So, the voltage across this is e b minus e a. And this is the voltage, if it is a positive and you are giving a gate pulse then only it will conduct. So, the commutation voltage is a voltage when your valve is going to conduct if there is a gate pulse. Because if it is a e b a is negative it will never conduct whatever the pulse you are going to get.

So the e b a is the commutation voltage of valve 3. Similarly, you can calculate the commutation voltage of other valve here I want to calculate what will be the commutation valve of 6. Means if you want to calculate the commutation voltage of this valve 6, you have to see before that 6 is going to come what were the contacting pattern, it was your 4 and 5. Before this 6 4 and 5 were conducting now we are giving the pulse to 6. Now, 4 and 5 are conducting means here your 4 is conducting, means here it is your e a, This 4 is conducting means and this phase is coming here this short circuit means conducting is the 0 resistance here at the positive is a e a and here it is always e b. So, it is e a b is the commutation voltage of this valve 6.

So, similarly, you can find out the commutation voltages for all the valves means this is the voltage when it is being positive and the gate pulses is given then this valve will conduct otherwise it will not conduct. So, in my here the voltage representation, I am going to take as a reference here as e b a is a as a reference. Here this line to line voltage of e b a is we are going to take here as a reference the reason here.

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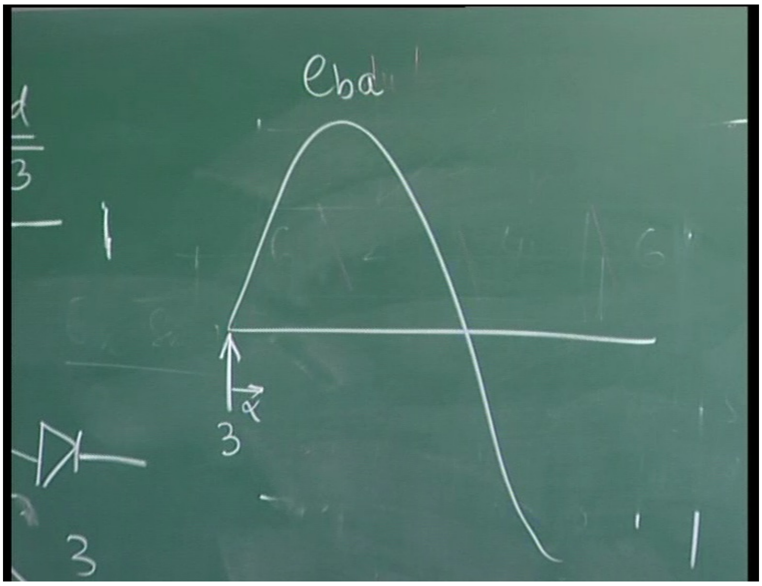

Now, this is your let suppose, here it is e b a I am taking as a reference. Means here this will be the instant when the valve 3 can be fired. Because this is a commutation voltage means you can fire at this instant or even though after delay of any angle alpha this valve can be fired because before that 1 and 2 were conducting. So, 3 can only ignite I from this position to up to this position.

So, in our all analysis I assume that 1 and 2 are conducting and 3 is going to be fired. So, here as I am telling here I took this e b a as a reference only the reason that the e b a is the commutation voltage of valve 3 and will analyze all other circuit assuming the 1 2 were conducting and 3 is going to be fired. Now, once e b a is given to you then you have to write the other phase voltages and the line voltages as well. And if you know this and you can draw correctly then you can have the complete wave shape across the any valve as well as the your dc output voltage.

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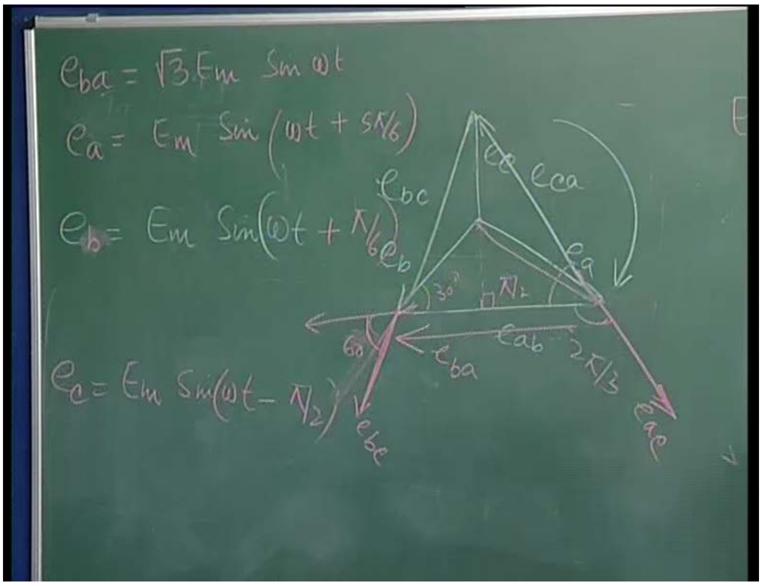

So, here you will see this is a 3 phase circuit, here I can say this is your e a, here it is your e b, here it is your e c, now this voltage will be your e a b. Because always we write here this voltage minus this voltage will be the arrow here is your e a b. Now, this value here I can write this will be your e c a because e c minus this will be your this voltage and here it is your e b minus c. This is as you know we have assume the balance 3 phase circuit and it is the positive sequence voltage. So, here your this sequence will be a b and c that is clock wise. Now, you can see here e a b is just like your (()) e a b not e b a. But our reference which I have assumed here it is your e b a means here it is our reference this is your e b a.

Now, with this reference here I want to write what will be the first your the phase voltages. This is your a to write here the expression for this e a, I want to write first we can write here e b a it is your under root 3 times E m sin omega T. Now, this E phase I want the angle between these two will be your the angle. Now, I can write here it will be your E m because the phase voltage here it is line to line voltage is under root 3 times so, phase voltage will be E m. So, we can write here sin omega T, now we have to the phase difference whether plus or minus.

Now, what will be this angle? Here you this angle will be is 60 degree. Are you sure? So, this is your 60 degree. What will be this angle? 120 means 2 pi by 3, no this angle will be 30 degree.

30 degree.

So, this will be your 30 degree just see it here, this degree is 60, this is half of this is a 30 degree here it will be 150 degree means it is 5 pi over 6. So, this will be your 5 pi by 6. Basically, from this phaser that is very important, that is you should know which angle is how much. And you know for writing this difference here, we have to take the tips of this. Either you for angle here both vectors are going out so, this angle will be the phaser angle difference the minimum angle or if the both are coming here you can also take this angle then that is also equal because you know the 6 (()) it here this angle will be the same.

So, to calculate the angle always it is not like that is you are taking this and this angle here. So, this is wrong, so that is why here I am telling this is a very important to know the phaser concept here so that you can write the various voltages. So, it can be ask to write your DC output voltage in terms of phaser value, in terms of your land line values or even the valve voltage, in terms of our land line or you can phase voltage. So, this is very important to calculate it. Now, we have derived that this angle is 150 degree that is your 5 pi upon 6 now whether is a leading or lacking, whether is a plus or minus. So, it will be you just rotate here it is just behind this so it will be plus.

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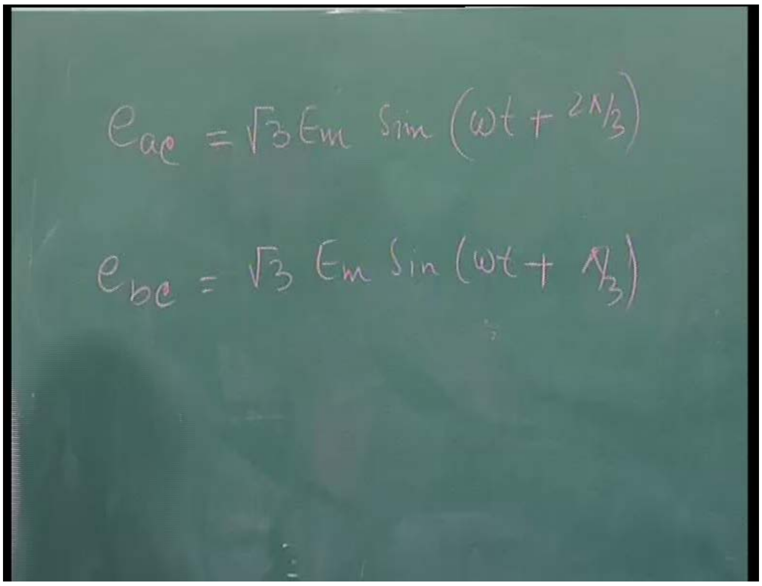

For example, in this sequence this angle here, this is your V, this is I this here the reference this current here is a negative. Because, this is ahead the current if it is this side it is your positive. So, you just see it is rotating here you are having the positive and this will be positive.

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So, again we have to see whether is a 120 degree or 5 by 6. Now, here again we can write no problem. So, we derived here we wrote this equation for the phase a voltage that is E m sin omega T plus 150 degree that is a 5 pi upon 6. Similarly, I want to write for e a, this will be again it will be E m sin omega T. What will be the angle?

Now, we are talking about this your, e b sorry, here because already we have written here e b and e b is this phase. So, this a both tips are coming here so, this angle will be 30 degree. So, what we can do? Now, we will see which one is lacking, which one is leading so this angle is your 30 and 30 is nothing but, your pi upon 6. So, it will be your pi upon 6. Now, whether it will be your positive or negative?

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It will be positive because this here you will see this is just behind this. Now, we can write your e c, e c will be your E m sin omega T now we have to see plus or minus. Where is a c? This is c. You see; so, this is here this is here means this angle is your pi by 2. And what will be this angle? You see this is here, this is your, this c is your.

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Lacking, so, it will be minus. To again this is your e b a this is your e c. so, just rotate here you will find means we can write this is your e b a and this will be your e c. so, this is lacking and lacking means it is a minus degree so, minus pi by two. Similarly, we can write for this, other line to line voltage means I want e a c, I want e b c. So, no doubt this is the phase voltage is E m, this magnitude of the peak magnitude means r m s is here means E r m s is your E m by under root 2. So, here it will be under root 3 times E m now, sin omega T. Now only we have to find what will be your plus or minus the phase angle. Similarly, I can write here under root 3 E m sin omega T, we have to find the plus minus what is the leading or lacking the angle.

Now, from this figure again, now this figure becomes very dirty, but still we can find it, now, I want to write e b c. e b c is your b c as I said it will be this your e b c now this angle is 60 degree, means it is pi by 3. So, here it will be your pi by 3 now you have to see it your plus or minus. So, this is your e b c it is your plus because it is your leading. Similarly, we can write for this that is your e c a it is written, here means we are going to have e a c will be this one. Your e a c again I can write here this is your e a c will be this arrow because this e c a is this direction.

So, this is a board tip here this angle will be 120 degree, because this is your 60. So, it is your twice pi upon 3 and I can write twice pi upon 3. What will be angle? It will be again plus because so these are the various voltages, again which I have written the same here. And you know if you are going for change here from c a here it will simply the difference it.

So, either you change here minus or you change here angle you can add it you will get the same or you can write from here again that is why I am telling you this concept should be clear then you can get every each and every voltage very clearly. How this phasers, taking any reference now I can change the reference you can get the other values of that reference. So, these will be used when we will discuss about the complete analysis of the converter. Means we have to go for the various voltages, we have to draw on the even the sheet here. And then we will see the various voltage which is going to appear across the valve. And what will be the DC output voltage at the same time?

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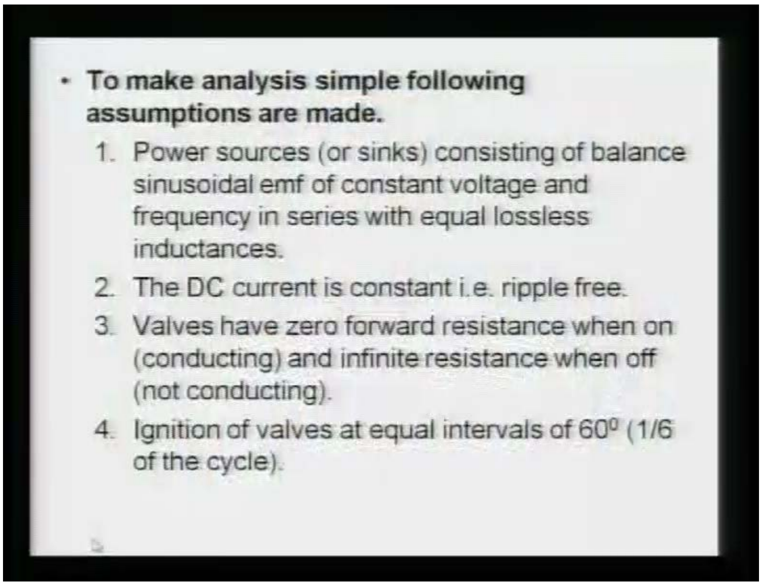

Now, to make the analysis of the converter circuit again we have to go for the various assumptions. Here the assumptions even though up to 3 are the same. Here as I said the power sources or the sink they are the balanced, consisting of the balance sinusoidal E m F of the constant voltage and the frequency and we are assuming that it is lossless. Source it is giving imperfect voltage and current having your the voltage is constant, frequency is constant, but the current can vary depending upon the conduction of valve.

This second assumption is your the DC current is ripple free means we are having the perfect DC current. And then here the we are assuming the ideal valves. Means valves are lossless and they are offering the 0 resistance in the conduction mode and offering the infinite resistance, when it is in non conducting or off stay.

Another, fourth assumption here which are extra we are using compare to the previous assumptions we made when we are going for the rectifier circuit analysis. Here the ignition of the valves are equal intervals of the 60 degree. Means here we are giving the pulses to the valves at after every 60 degree.

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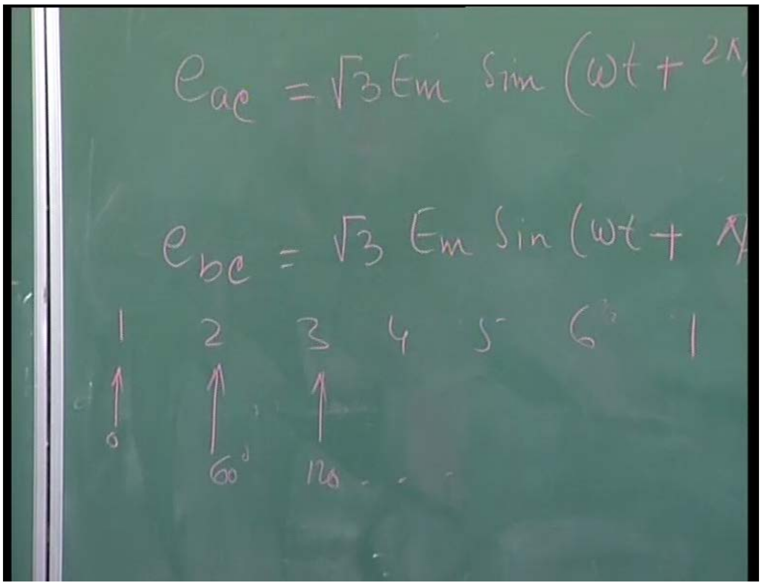

Means here, your let suppose here valve 1 2 3 4 5 6 and it is one again. So, if we are giving here at the 0 instant here this valve is going to be given you are taking this as a 0 axis, then this valve is going to get a pulse after 60 degree. Similarly, here now it is going to be 120 degree and so on so forth. And it is a equal intervals here we are giving the pulses. The reason here we are assuming the symmetrical conduction pattern that is appearing across the converter circuit. There is a possible you can delay here it is 0 you can give this valve 2 after may be after 60 degree. But we do not want, because if we are delaying here, it will conduct because if the commutation voltage across this is a positive. You are giving the pulse even though after certain degree, it will conduct. But the your output pattern will be not symmetrical and it will give lot of harmonics to the your system, current will be something different. So, we never want it, we always we operate in the very systematic manner.

So, this assumption shows that we are giving the valve pulses to the valves after every 60 degree to the consequent valves so that we can have perfect ripples in the DC output and also our conduction pattern should be symmetrical. So, this fourth assumptions is very important now, because we are going to analyze our converter circuit. And with this we will see the various voltages, various output, various currents, various frequencies here even the harmonics we will analyze for the various modes of conduction.

So, here in this lecture today's lecture I can see now, what we did? We analyze the configuration of your 6 pulse converter configurations for the various value of q or s for P is equal to 6. And then we analyze this what will be the voltages those are taking e b as a reference, the various voltages we saw which will be used in your next lecture. So, with this, I just close this lecture and the next here we are going to analyze the 6 pulse converter circuit with without overlap angle means, u is equal to 0. And we are going to use all these sinusoidal voltages for getting the valve voltage, output voltage. And also we will find the current across the conductor valve. With this I can close this lecture. Thank you.