Advanced Electric Drives

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Lecture - 40

Hello, and welcome to this lecture on advanced elective drives. In the last lecture we were discussing about the semi controlled converter fed dc traction motor. We are trying to control a traction motor using semi controlled converter, and we know that this is much better than having contractor based control. We do not have any mechanical contractor. We can vary the armature voltage smoothly by controlling the triggering angle alpha. Now if we use a semi controlled converter, what are the advantages, and what are the drawbacks? Now let us look at the circuit diagram of a semi controlled converter fed traction motors.

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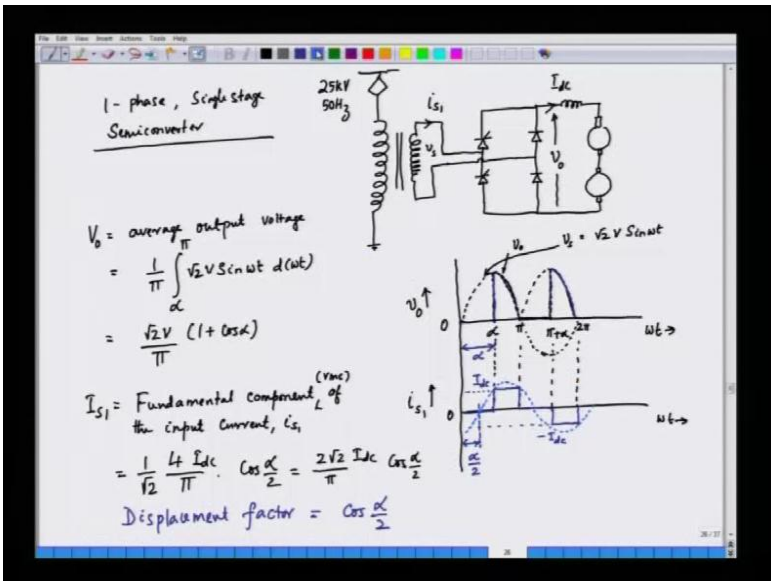

So, this is what we have here. We have a semi converter here; it is a semi controlled converter or a half control converter, because we have two SCRs in this case and two diodes, and we have two traction motors. These are the traction motors here, separately excited traction motors; the armature is shown here. The field may be separately excited from a different converter. So, in the control for the field we are assuming that the field is kept constant. And here the output voltage in this case v naught can be written in the following fashion.

The average output voltage is integral from alpha to pi; the output voltage will look like this. It is basically the triggering angle is alpha, from alpha to pi we have the powering region; from pi to pi plus alpha we have the freewheeling region. So, this is the output of the semi controlled converter. And if we find out the average value of this average voltage we obtain root 2 v by pi into 1 plus cos alpha where v is the RMS value of the input voltage. Now if we see the current, the current which is drawn from the supply is not a sinusoidal current. In fact, it is a quasi rectangular current. It has got some part a 0, some part would be the dc current, i dc, and it looks like this. We have the current which is a quasi rectangular current. This is i dc, and this part is 0. And then we have again minus i d c and so on.

And what is i dc? I dc is the dc current here. So, when it is freewheeling, the freewheeling can take place to the diode because we have a filter inducted here, and the armatures are also having the inductances. So, the current can freewheel from pi to pi plus alpha through the diodes. So, this is the freewheeling circuit or the freewheeling path. And when it is freewheeling the v naught or the output voltage will be equal to 0; and the output voltage is equal to 0 means the motor is disconnected from the supply. When the motors are disconnected from the supply the input current or the supply current will be equal to 0, and that is shown in the waveform here. We see in this case that for this region from pi to pi plus alpha this is pi plus alpha here. It is 0, and then when from pi plus alpha to 2 pi it is again minus i dc; it goes on like this.

And if we take the fundamental component of this current; this current, obviously, is not a sine wave; this has got lot of harmonics. Now we need to find out the fundamental component of this current and see what is the displacement factor or the displacement of this current with respect to the source voltage; the triggering angle here is alpha. So, if we find out the 4 year components and take the fundamental component, we see that the fundamental component is lagging behind the voltage by alpha by 2, and that is the displacement angle. So, this angle is alpha by 2. It means the fundamental of this current is lagging behind the voltage. The voltage here is V s.

The V s is sinusoidal in nature varying like this, and this current the fundamental of this lags behind the voltage by alpha by 2, and that is a displacement factor; cos of alpha by 2 is the displacement factor that we discussed in the last lecture And the RMS component or the RMS value of the fundamental component of current can be given by this expression 1 by root 2 4 i d c by pi into cos alpha by 2. And this is the final expression for the fundamental component, the RMS value of the fundamental component of current.

Now since we know the input voltage and we know the current we can find out the reactive power that is drawn from the supply. Now this current i s 1 drawn from the supply is having a displacement angle of alpha by 2. So, it is basically a lagging angle. So, this converter is demanding a lagging current from the supply, and if alpha increases alpha will increase the voltage is less or the speed is less for low speed application; for low speed operation alpha will be low, and hence the displacement angle will be more; alpha by 2 will be more.

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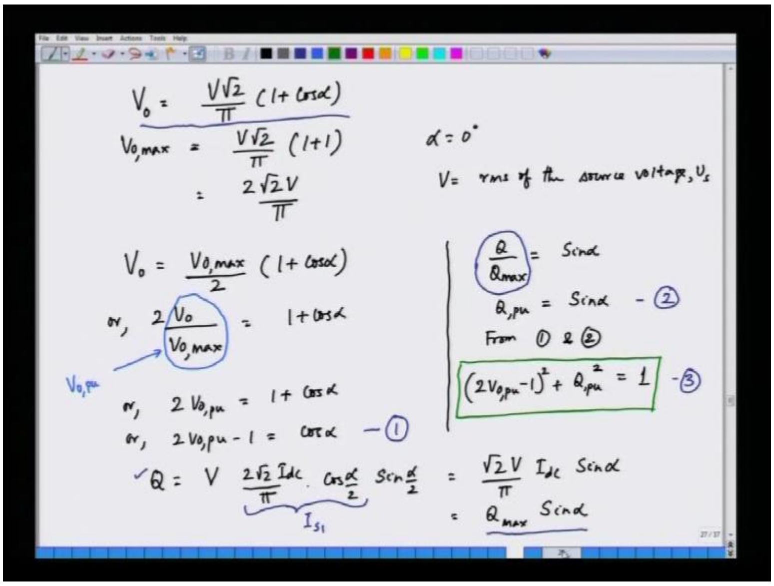

So, if we calculate the reactive power here we can find out the reactive power like this. This is q is the reactive power that is given by the voltage into the current. This is the current that we have, the RMS of the fundamental component, and we ignore the harmonics, because harmonics do not contribute to any average power. So, we are only concentrating on the fundamental component, and we are taking the displacement of the fundamental component with respect to the voltage ignoring the harmonics as harmonics do not contribute to any average power. So, the interaction of 50 hertz component with 50 hertz component the 50 hertz voltage and the 50 hertz current, and 50 hertz current is precisely the fundamental current.

And that is what we are seeing here that 2 into root 2 i d c by pi into cos alpha by 2 is the current that is i s 1 into sin of alpha by 2, and this alpha by 2 is the phase angle. So, if we want to find out the reactive power, we have to take the sin of the angle between the voltage and current. So, that is what we obtain here. And if we simplify this, what we obtain here is an expression as a function of sin alpha, and we can write that q equal to q max into sin alpha. So, this is what we have here. And similarly from the output voltage we know the output voltage here is v naught that is given by this expression v into root 2 by pi into 1 plus cos alpha. And then the maximum output voltage is v into root 2 by pi; when the sin alpha is 0 we will have the maximum output voltage, and that is equal to 2 into root 2 into v by pi.

So, we can write down the output voltage v naught it has v naught max by 2 into 1 plus cos alpha, because this is v naught max. So, this by 2 into 1 plus cos alpha is v naught. And we express this in per unit. We in fact take this v naught maximum to the left hand side, and what we obtain here is 2 into v naught by v naught max that is equal to 1 plus cos alpha. And v naught by v naught max is v naught per unit. It is the per unit output voltage. If you divide the output voltage by the maximum possible voltage we get the per unit output voltage. So, v naught by v naught maximum; v naught maximum is the maximum output voltage. So, v naught by v naught maximum is the per unit output voltage that is v naught per unit.

And that we see in this equation that v naught per unit is 1 plus cos alpha. We separate this cos alpha out. So, 2 v naught per unit minus 1 is cos alpha. So, this is equation number 1. And from the reactive power similarly we obtained q naught max into sin alpha is q and we take this q naught max from the left hand side q by q max. This quantity is basically q per unit. Exactly in the same way if we divide the reactive power by the maximum reactive power we get the per unit reactive power. So, that is q per unit, and that is equal to sin alpha, and that is equation number 2.

So, we have the second equation that is q per unit is sin alpha, and from the first and second equation the first equation gives cos alpha; the second equation gives sin alpha. And from these two equations we can write this cos square alpha plus sin square alpha equal to 1. So, we get this third equation 2 v naught per unit minus 1 square plus q per unit square that is equal to 1. Now we get an equation which shows the variation of the reactive power with the output voltage. It means as we change the reactive power, as we go on changing the output voltage, the reactive power demand also changes. Now this is the equation, and this equation is an important equation. This equation has got square terms here. So, we can plot this in the following fashion.

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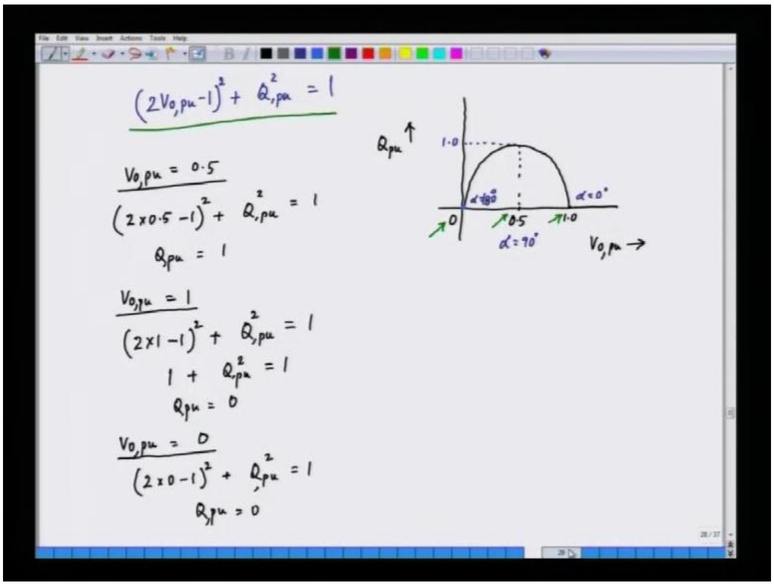

So, what we do here we plot this equation. This is the equation that we have. And when we plot this equation this equation will be something like this. It is not a circle, but it is a quadratic equation in terms of v naught per unit and q per unit; we will have this kind of set. We can find out the discreet values here. Now suppose we put v naught per unit is equal to 0.5; now if we put v naught per unit is 0.5 what we have here 2 into point 5 minus 1 whole square plus q per unit square that is equal to 1. So, this is zero. So, what we obtain here is that q per unit is equal to 1.

So, it means when v naught per unit is 0.5 as the output is the half of the maximum output, and that is the point when we require the maximum reactive power. Now we can see that corresponding to this v naught per unit equal to 0.5, what is the triggering angle? The triggering angle alpha corresponding to this would be 90 degree. So, when alpha is 90 we have maximum reactive power drawn from the source. It is maximum. If alpha is 0 alpha by 2 is 45 degree, and that is why what we have here is that we have maximum reactive power here; that is q per unit is 1.

And suppose we take in this case v naught per unit is 1 we want to obtain the maximum possible output voltage. So, v naught per unit is 1. So, if v naught per unit is 1 what about q per unit? We can substitute the same value in this equation; we have the equation here, let us substitute this value. So, we have 2 into 1 minus 1 whole square plus q per unit square that is equal to one. So, what we have here is 2 minus 1 that is equal to 1 plus q per unit square is equal to 1 or q per unit equal to zero. So, it means when we want to obtain the maximum possible voltage the reactive power requirement is 0. It means the converter is operating at the minimum triggering angle that is alpha equal to 0. And hence there is no delay of the current. The current is not lagging behind the voltage; it is in phase with the voltage.

When the current is in phase with the voltage we get the reactive power equal to zero. So, this is what we have here that that 0.5 in this case and here we have 1 and corresponding to this q per unit equal to zero. So, as we change again we can say that if v per unit is 0 let us say, we can again substitute these values here. So, again we have 2 into 0 minus 1 whole square plus q per unit square is equal to 1, or what we have here q per unit again is equal to zero. So, we have three different points in this case; v per unit is 0.5, v per unit is 1, and v per unit is 0. And this is the three points here v per unit is 0, v per unit is 0.5, and v per unit is 1.

So, it means as we go on increasing the output voltage from 0 to half the maximum values to the full maximum value the reactive power changes, and it attains a maximum at v per unit equal to 0.5. Now this is one of the biggest drawbacks of semi control converter that the power factor as the reactive power drawn from the source increases, and it changes with alpha. And hence we have to have some compensation technique to compensate for the reactive power drawn by this converter. So, there is a solution to this, instead having a single converter; now this is expression for a single converter. Now we use two converters which are connected in series, and they are operated in sequence, and that is called sequence control.

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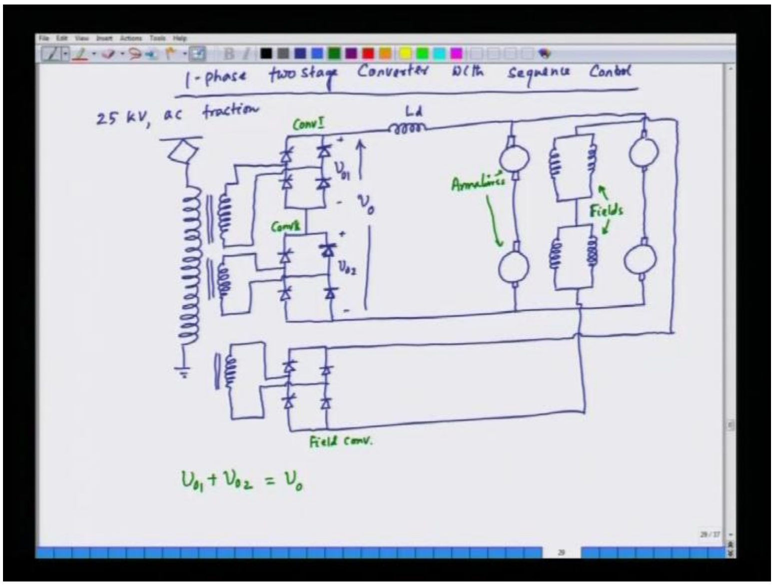

So, we will be discussing right now the single phase 2 stage converter with sequence control, single phase 2 stage converter with sequence control. Now let us draw the circuit diagram first; we have 25 KV ac traction. So, we have the traction supply here 25 KV, and then we obtain this through the pantograph, and then we have this primary of the high voltage transformer. Then we have two converters here, and the converters are semi controlled converters, but we do not have any single converter. So, we have two converters. So, this is another converter, and each one of this converter is half control bridge. It is also a half control bridge here, and these are series connected.

And here is the dc link; we have filter inductor here, and it supplies to the traction motors which have separately excited motors, armature of the traction motors. So, we have another set of traction motors in series, and these converters are fed from the individual secondaries. So, we have the secondary transformer here for feeding these converters, and this is the dc link inductor L d, and this is the output voltage that is V o. And we have V o 1 converter 1 and you have converter 2 V o 2. These are the two converter voltages. We have this transformer which gives a coupling here, and we have the field of this motor; the field are connected similarly in series and parallel. So, we have parallel field connection here and these two fields.

This in fact, we have four motors, we have four fields here. They are connected to a third converter for the field supply. So, this is the supply for the field. So, we have the field;

we have another secondary of the transformer. So, these are the field supply, and this is the armature. So, in this case we have four dc traction motors. And in fact each motor is a separately excited dc motor. So, four motors, two are connected in series and two series combinations are connected in parallel. Now this combination of traction motor is fed from two series connected semi converters. So, we will name this converter as converter 1 and converter 2 respectively.

So, we will call this to be converter 1 and this to be converter 2, and they operate in the following fashion. First what we do we start with converter 1, both the converters are off. When the converters are off means the triggering pulses are not applied; the voltage output is 0, because the load is short circuited through the diode. In fact, what we have here we have these diodes here. These diodes will freewheel the load current. We have two diodes here and two diodes here. So, these are the diodes we have, and this diodes will be giving a freewheeling pass for the current to freewheel. And hence when the triggering pulses to both the converters are off we can assume v naught equal to 0; v naught in fact is equal to V o 1 plus V o 2.

So, we can write down this expression here that v naught 1 plus v naught 2 are equal to V o. So, if individual converters are 0, the output is 0. And this is the field converter which is only supplying the field side. We have the fields four fields here; the four fields are supplied from the field converter. Now if we want to keep the field current constant we can operate this field converter at a constant triggering angle. So, the field converter is only to control the field winding current, and the field winding current can be kept constant if need be. Now the sequence control is employed only for the armature side converters. We have converter 1 and converter 2; these converters are controlled in sequence. First both converter 1 and converter 2 are off. So, we can start the various steps here.

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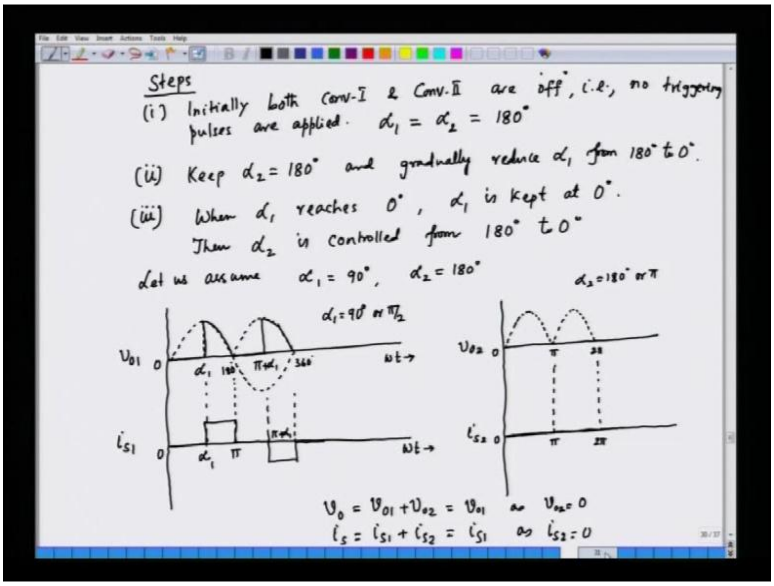

So, the steps are as follows. Initially both converter 1 and converter 2 are off, off means no triggering pulse is applied; that is no triggering pulses are applied. This also means alpha 1 equal to alpha 2 is equal to 180 degree. You can switch off the triggering pulses or you can choose to apply the triggering pulse at alpha equal to 180 degree, because if you apply alpha equal to 180 SCR is going to conduct. SCR will only be conducting between 0 to 180. If the triggering angle is 180 no SCR is going to conduct. So, it is equivalent to both the converters are off. Now what we do? We keep alpha 2 equal to 180 and change alpha 1 gradually from 180 to 0. So, that is step two. So, in step two what we do? Keep alpha 2 is equal to 180 and gradually reduce alpha 1 from 180 to 0.

What we are trying to do here? We are trying to gradually increase the output voltage, and the output voltage can be increased by decreasing the triggering angle. Because we know that the output voltage is root 2 v by pi into cos alpha 1 for v o 1 and root 2 v by pi into 1 plus cos alpha 2 per v o 2. So, if we gradually reduce alpha 1 the output voltage is going to increase. So, this is the situation here. So, we are gradually reducing alpha 1 from 180 to 0. And then the third step is when alpha 1 reaches 0 alpha 1 is kept at 0, then alpha 2 is controlled from 180 degree to 0 degree. So, when alpha 1 reaches 0 degree then it is kept constant at alpha 1 equal to 0. Then alpha 2 is reduced from 180 to 0 gradually.

So, it is basically controlled in sequence. First of all bridge 1 or the converter 1 is operated. We are gradually reducing the value of alpha, alpha 1. It means we are increasing V o 1 from 0 to the maximum value, and once the converter 1 has given the maximum value of voltage we gradually increase the voltage of converter two. So, that is called sequence control. In sequence control we do not use one bridge; we use two bridges, and the two bridges are operated in sequence. One bridge from 0 voltage to maximum voltage, then after bridge one reaches the maximum voltage, bridge two is controlled again from 0 voltage to maximum voltage. So, we have the same smooth variation, but here we are employing two converters, and we are operating them in sequence.

Now what is the waveform here? Now if we see the waveform the waveform is interesting. Now let us see the output waveforms of the converter 1 and converter 2 and also the overall output voltage waveform that is v naught. So, we can draw the voltage waveforms here. So, let us assume that alpha 1 is equal to 90 degree and alpha 2 is 180 degree. So, if we assume this let us try to see what is the output voltage. So, if we are plotting here v naught 1, v naught 1 will look like this. We have a rectified voltage here, and this is alpha 1; alpha 1 is 90. So, the output will be like this.

So, this is 180, and this is 360. This is alpha is 90; this is pi plus alpha 1. This is omega t here and what about the current? The current here i s 1, i s 1 is the current drawn by the converter 1; this is i s 1. Similarly, i s 2 is the current run by converter two. So, we are now controlling the first converter. So, we will find out what is i s 1, and i s 1 here will be as we seen before it will be quasi rectangular current like this. This is omega t; this is 0 here, and this is pi. This is alpha 1; this is pi plus alpha 1, and here alpha 1 is 90 or pi by 2, and what about v naught 1? Now v naught 1 here, this is our v naught 1, and we can also plot v naught 2, and similarly i s 2. This is 0 and 0 here, and alpha 2 here is 180 or pi.

So, here alpha 2 is 180 or pi. So, this bridge does not conduct. So, this is pi, and this is 2 pi. So, this bridge does not conduct. So, since this bridge is not conducting the current permanently remains equal to zero. So, this is pi, and this is 2 pi, and what about the total voltage? The total voltage v naught is equal to V o 1 plus V o 2. Now this is same as V o 1 as V o 2 is equal to zero. So, we see that the second bridge is not operative here; the second bridge does not have any voltage here because alpha 2 is 180. So, if alpha 2 is 180 the triggering angle is at the extreme point. So, second bridge is not conducting.

So, only the first bridge output is there, and hence the first bridge is drawing some current from the supply i s 1. The second bridge i s 2 equal to zero. So, what about the total current drawn from the supply? So, if we see the total current here, the total current which is coming in this case i s, i s is i s 1 plus i s 2, because we are interested to find out the combination of this converter 1 and converter 1. So, converter 1 is drawing i s 1, converter 2 is drawing I s 2.

So, the total current due to this armature converter is i s 1 plus i s 2, and that is equal to; we can also say that i s is equal to I s 1 plus i s 2; that is equal to i s 1 as i s 2 is equal to zero. Now let us see the next situation. The next situation is this alpha 1 has reached 0; alpha 1 has been controlled from 180 to 0, and then we are controlling alpha 2. So, we will take a situation where alpha 1 is 0 and alpha 2 is 90 or pi by 2.

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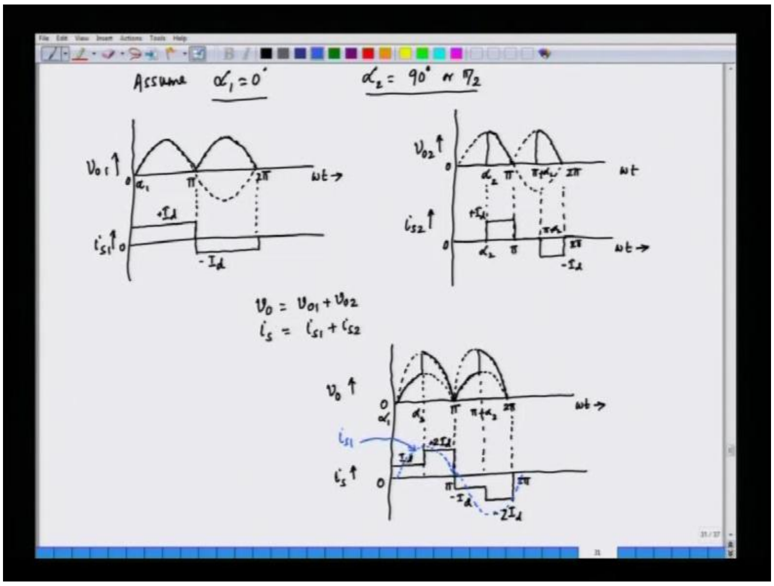

So, we take a situation alpha 1 is equal to 0 degree, and alpha 2 is equal to 90 or pi by 2. Now let us draw the waveforms here again. So, we can draw the waveforms. This is V o 1, and this is i s 1. Now what is V o 1, V o 1 alpha 1 equal to zero. So, we can draw this. This will be a simple rectified voltage. So, this voltage will be rectified voltage like this. This is pi, and this is 2 pi, and this is alpha 1, and alpha 1 is equal to 0 here. So, this is at the origin in this case, it is omega t. What about i s 1? I s 1 will be like this. Since it is fully conducting and the conduction here it is in alpha 1 is equal to 0, the current will be flowing from 0 to pi in the positive have cycle and from pi to 2 pi in the negative half cycle.

So, the current will be a rectangular current; there is no freewheeling interval. So, we will see the current, the input current i s 1 to be a rectangular current. So, the current in this case will be a rectangular current like this. So, this is 2 pi, and this is i d or i d c is the dc current in this case. If you say that this current is i d or i d c here. So, this one is plus i d and this is minus i d. What about the converter 2? The converter 2 alpha 2 is pi by 2. So, the alpha 2 is pi by 2 there will be some current which is drawn by the converter 2, and the converter 2 currents will be like this. We have this converter 2 current is i s 2, and converter 2 voltage is V o 2. So, we have the voltage here the rectified one, and alpha 2 is pi by 2.

So, we will have the voltage which looks like this, it is omega t. This is pi; this is 2 pi, alpha 2 pi plus alpha 2. And the current here as we have seen before it will be a quasi rectangular current with a positive side; then we will have 0, and then we will have negative side. So, this is pi, and this is 2 pi. This is alpha 2, and this is pi plus alpha 2 and this is plus i d, and this is minus i d. So, we have the converter 1 and converter 2. Now if we want to find out the total voltage v naught, the v naught in this case as before is the sum of the two voltages v naught 1 plus v naught 2, and I s is the total current is the sum of i s 1 and i s 2. Now we are discussing actually for the situation when converter 1 is operated at triggering angle equal to 0, alpha 1 equal to 0, and converter 2 is operated at alpha 2 equal to pi by 2 or 90 degree.

Now in this case we have seen these waveforms of both the converters, the converter output voltage and the converter input current. Now this is the converter 1 output voltage V o 1 and the input current is i s 1. So, this is basically for alpha 1 equal to 0, and the converter 2 is operated at alpha 2 equal to 90 degree or pi by 2. And here V o 2 has got the waveform like this, and the current here is a quasi rectangular current which is only flowing from alpha 2 to pi and pi plus alpha 2 to 2 pi. Now when we see the total converter; the total converter is the series combination of the two converters. The outer voltages will be added; V o equal to V o 1 plus V o 2. The input currents will also be added; I s equal to I s 1 plus I s 2.

Now we will see the net output voltage and the net output current of this combination. So, if we see the net voltage and current they will look like this. Basically what we have here? We have two converters. So, we will have the two voltages added together. So, the first converter is operated at alpha 1 equal to 0. So, the output voltage is full output voltage, and alpha 2 is pi by 2. So, there is a jump here. So, this is pi, and this is 2 pi, and this is omega t in the x axis; this is v o. Similarly, i s is in the y axis; here also we have the output looking like this, so on, and what about the current? The current will be the sum of the two currents and that will be of this nature.

So, this is pi, and this is 2 pi, and this is alpha 2. This is pi plus alpha 2, and this is alpha 1. Alpha 1 is in fact equal to zero. So, this is the nature of the current that we have here. Now this is the waveform of the voltages and current. In fact, if we see here the current are i d; i d plus i d will be 2 i d. So, we will have 2 i d here plus 2 i d. And this is i d, and this is minus i d; here we have i d or i d c, and this is plus 2 minus 2 i d. So, this is the nature of the current. Now we see that the current here is better than a single converter in the sense that this current will have a displacement factor which is closer to unity or which will be higher than that of a single stage converter.

So, if you take the fundamental component of this, this current will be lagging by an angle which is less than alpha by 2 or alpha 2 by 2. Now here if you take the fundamental component of this current, this will be closer to the input voltage. So, this could be i s 1, the fundamental component of this i s. So, when we operate this converter in sequence control, the input power factor improves or the input current lags behind the voltage by a lesser angle which means the displacement factor of the input current is better. Now this can also be proven mathematically. Now when we use the two converters, each converter will be giving us half the output voltage. So, the input voltage is half; the output voltage is also half. So, we can write an equation for the output voltage of these converters, and also in a same way we can float the reactive power versus the output voltage. So, we will have the equations as follows.

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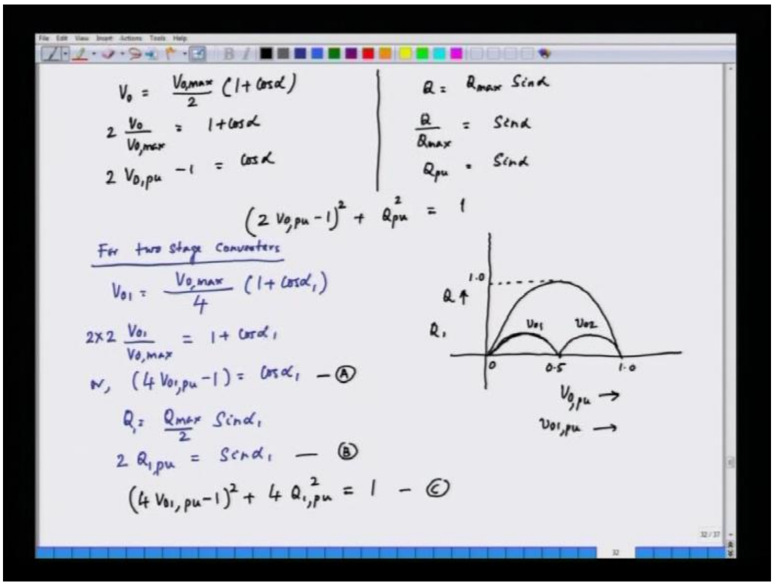

So, we have seen that in case of a single stage converter what we have here is the following that v naught equal to v naught max by 2 into 1 plus cos alpha, or from this we can say that 2 v naught by v naught max is equal to 1 plus cos alpha or 2 v p u v naught p u minus 1 is cos alpha. In a similar way, we can say that the reactive power q is equal to q max into sin alpha, or q by q max is equal to sin alpha, or q per unit is equal to sin alpha. And from this we have the equation v naught per unit minus 1 whole square, then cos square alpha plus q per unit square that is equal to 1. So, this equation has got the following graph. So, in the x-axis we have v naught per unit and the y-axis we have q.

So, we have a plot like this. This is 0.5, this is 1, and this is the maximum reactive power that is 1 per unit. Now when we have two single stage converters, each converter is going to give us half the output voltage. If the output voltage is let us say 400 volt dc, the capability of each converter here will be 200 each. Now if the converters will give us the half the output voltage, the input voltages also reduce to half. So, we can see this in the diagram here. So, this is basically the V s by 2 here and this V s by 2. We have half the supply voltage here, and v naught 1 will give us half the voltage, and v naught 2 will give us half the voltage. The output is basically the sum of the two voltages v naught 1 and v naught 2.

So, this we can see here that for 2 stage converter, we have let us say v naught 1 if you start with v naught 1. So, v naught 1 here is equal to V o max by 4 because this is half the output voltage into 1 plus cos alpha 1 let us say, or we can say here that 2 v naught 1 by v naught max 2 into 2 here, because we have 4 here; that is equal to 1 plus cos alpha 1, or we can say that 4 v naught 1 per unit minus 1 is equal to cos alpha 1. In a similar way we can also find out the expression for the reactive power. Reactive power here will also be reduce by half, because each converter is supplied with half the supply voltage v s by 2.

So, we can write down the expression for the reactive power as follows. So, we can say that q is equal to q max by 2 into sin alpha 1. Let us say we are operating the converter 1, or we can say that 2 q p u or q 1 p u is equal to sin alpha 1. If you say that this is our equation a, this is equation a, and this is equation b. So, we can say that 4 v naught 1 per unit minus 1 whole square plus 4 q 1 per unit square that is equal to 1. So, this is the plot we have, and if we also plot in this case v naught 1 per unit and this is q 1 here; what is the plot here? This plot will be like this. This is this is basically the equation c here, and the equation c will have a plot like this.

Similarly for v o 2 if you plot here v o 2 from this, so we change from 0.5 per unit to 1 per unit; this is converter 1, and this is converter 2. So, the graph will be like this, and this shows that the reactive power requirement in 2 stage converter is always less than that of a single stage converter for the same output voltage. Say for example, we choose an output voltage; we can select a voltage like this. So, if you select an output voltage equal to this, this is having a lesser value than the single stage converter. And that is the reason when we go for a single stage converter we have a higher reactive power burden compared to the 2 stage converter operated in sequence control.

By sequence control here we mean first of all we operate converter 1, then we go for converter 2 to get higher output voltage. So, from 0 to 0.5 p. u we operate converter 1; that is the operation for converter 1. And from 0.5 p. u to 1 per unit we operate converter 2. And that is why the each converter is having its own reactive power, and the sum of this will be always less than the total reactive power required here. So, this is what we have here. It shows that the reactive power required by single stage converter is higher than the reactive power required by the two converter operated in sequence control.

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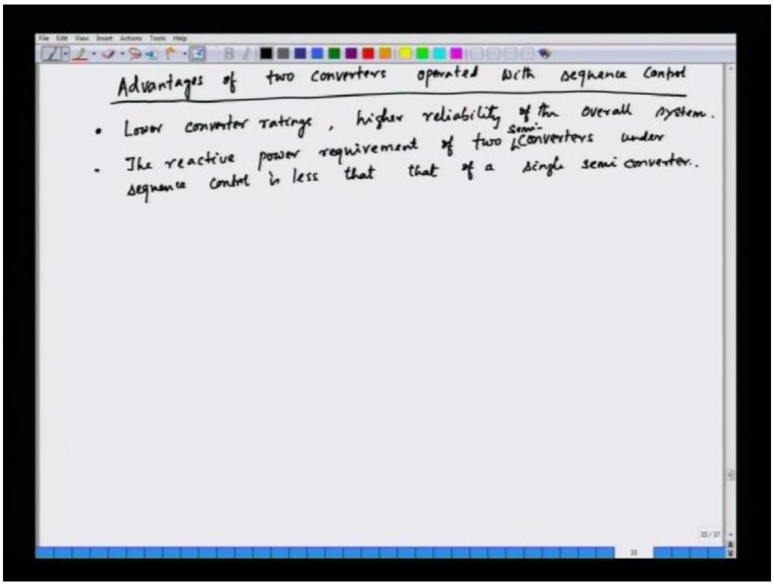

So, we can summarize the advantage of this, advantages of two converters operated with sequence control. First of all it gives the modularity; we do not have to have a very large converter. We can have small converters half the rating, and the rating of each converter is half of the total rating of the drive. So, it is modular and has higher reliability. So, load converter rating higher reliability of the overall system. So, even if one converter fails, if suppose one converter 1 thyristor has gone down. So, even if a thyristor fails to trigger or it is totally out of the circuit that converter can be bypassed and we can still operate at a reduce voltage; that is the meaning of reliability. And it is modular, because we have small modules of smaller size of the converters; we can use them as and when needed.

So, instead of a single converter we can go for 2 converters under sequence control. And the second advantage is quite significant advantage that the reactive power requirement in 2 converters under sequence control is much less than the reactive power requirement for a single converter operated from 0 to 180 degree triggering angle. So, we can say that the reactive power requirement of two converters under sequence control is less than that of a single semi converter. Two semi converters under sequence control is less than that of a single semi converter.

Now these are the reasons why be go for sequence control. Now this is about the sequence control of two converters, and this is for dc motors. We also have ac motors. The dc motors have their own drawbacks. Dc motors have got brush and commutators, and nowadays people prefer ac motors. So, the ac motor topology is basically to have an inverter after the ac to dc converter, and then we can use an ac motor following this ac to dc converter and then dc to ac inverter.

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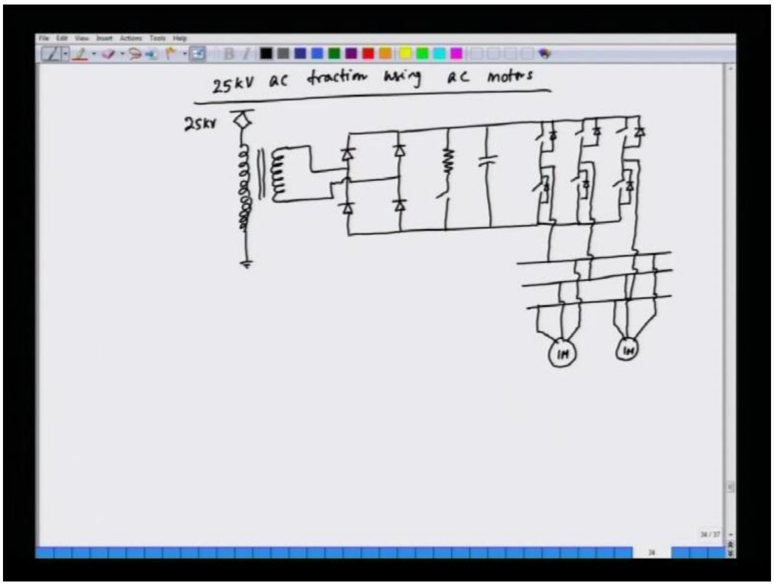

So, the topology will be like this, 25 KV ac traction using ac motors. So, what we have here is the following. We have the transformer here. It is 25 KV, then we have the step down. We can use this rectifier in this case, and followed by the inverters it could be 3 phase inverter. We can use 3 phase motors; we have the dc link in this case. So, we have the dc capacitor, and then we can have the breaking resistor for dynamic breaking, and we have the motors connected to the output of these inverters. So, these are the induction motors, and this is a voltage source inverter we have. So, this is a simple topology for a 25 KV ac traction with ac motors. What we do? We rectify the voltage, and then we use a 3 phase inverter, a voltage source inverter to feed a group of induction motors.

And for the breaking we can break this, the dc link we have a breaking resistor, and by using the breaking resistor we can go for dynamic breaking. So, in this lecture we have seen the single stage converter also 2 stage converter feeding dc traction motors. And we have seen the graph between the reactive power and output voltage for single stage converter as well as 2 stage converter. And we have also seen that the 2 stage converters require a smaller reactive power compared to a single stage converter.

So, this is the end of this lecture and of course, this is the end of this course on advanced electric drives. Nowadays the dc motors are gradually getting obsolete, and this dc motors are being replaced by induction motors. Induction motors control we have already seen they can be VF control, they can be vector control, they can be director control. So, we use ac to dc converter, and then we use inverters for the control of induction motors.