Advanced Electric Drives
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Lecture - 33

Hello, and welcome to this lecture on advanced electric drives. In the last lecture, we are discussing about a utility friendly induction motor drive. By utility friendly drive we mean the front end converter draws sinusoidal current at u d power factor from the grid. All these drive sub to be feed from the grid, the grid is the source of power. And when we draw current from the grid, this current should not have any harmonics. The harmonics current will distort the power supply in the grid and cause poor power quality. And further more when we operate a drive, we only require active power from the grid. If we can draw only active power in the grid the overall efficiency will be maximized and the line drop will be minimized.

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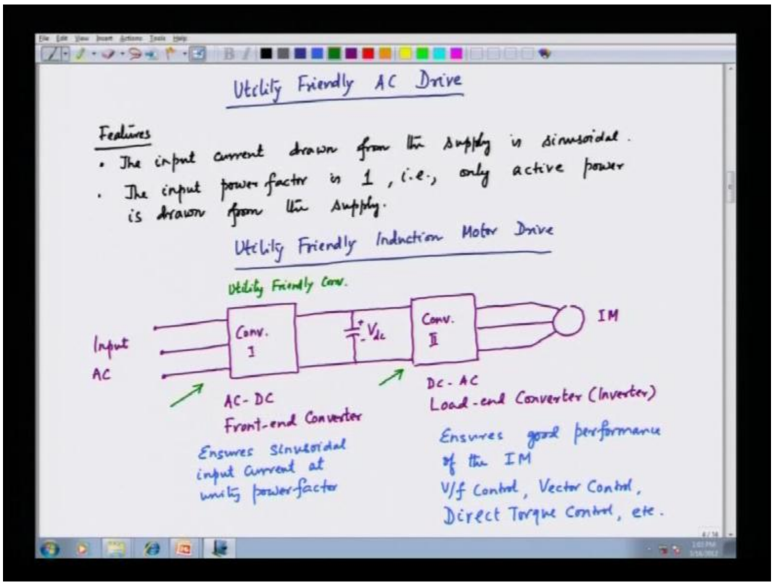

So, the block diagram is shown like this that we have 2 convertors, the first convertor is connected to the grid this is the convertor 1. And then it is converting AC to DC then the convertor 2 is converting DC to AC feeding an induction motor. So, this first converter 1 is a utility friendly converter. So, we can call this to be a utility friendly convertor, how do we achieve that. Now, these 2 convertors, the convertor 1 and convertor 2; 1 convertor is interfacing the grid with the system other convertor is feeding the induction motor. Now, when we talk about the first convertor, the first convertor and the second convertors are connected by means of a DC link. And they are shown in the following fashion.

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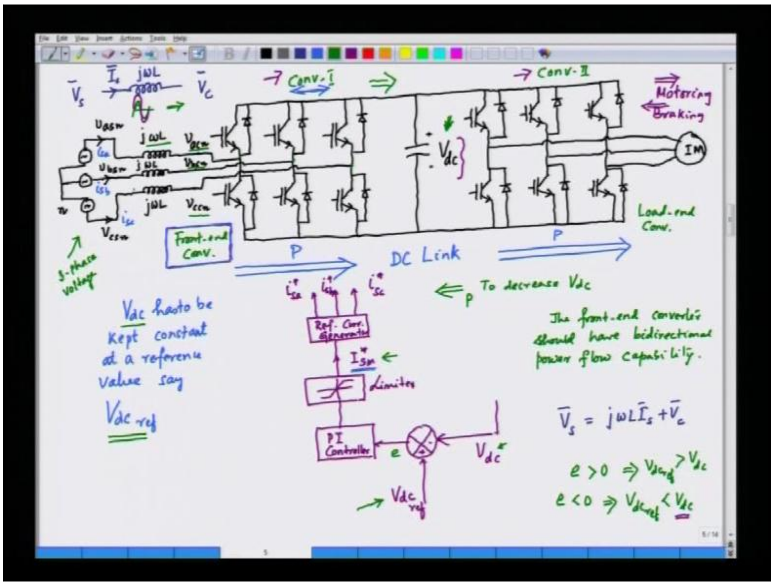

Do we have the first convertor and second convertor this is the convertor 1. And this one is the convertor 2, the first convertor is interface with the grid and it is basically by Dixon convertor it can. In fact, it can it is capable of exchanging power with the grid in by Dixon fashion. It can draw power from the grid it can also feed power to the grid. And what we do here the input current, what we draw from this we have 3 phases here phase a phase b and phase c. The phase a current is i s a, phase b is i s b and phase c is the i s c.

Now, these 3 currents a sensible in nature these currents are sign waves when the currents are sign waves the power quality is better. And we say that the drives are utility friendly further more the current and the voltage are in phase. If this is the current we have the voltage and the V and i are in phase it means the input power factor is 1. So, we are only drawing active powers in the supply that is the concept of utility friendly drives. The drive is not going to pollute the power system it is friendly with the grid friendly with the power system. And hence we call this to be utility friendly drive system. So, it is now drying nay harmonic and the power factory is 1.

Now, to achieve that what we do here, we keep the DC link voltage constant this voltage is kept constant and that is basically kept constant by a close loop control. So, what we do here is this we have reference DC link voltage that is V d c reference And we compare that with the feedback voltage, this basically the signal V d c which is feedback from the actual V d c by means of a sensor we have a voltage sensor we senses this voltage V d c. And then voltage is feed back here and the error is feed to a P I controller a proportion integral controller. And then followed by limiter, because usually the proportional integral control will have a proportional term and a integral term.

Sometime the integral term will go integrating the error and it may go to a very high value. So, limit the output to a practical value, we use a limiter the limiter limits the output of the P I controller to a practical value and that value here is the current that is i s m the big value of the current source current. So, it means if the DC link voltage is going down we need to draw more power from the AC supply. The power flow has to be from the AC supply to the DC link side, because a voltage is going down if V d c is going down the power flow should be induce in this direction.

It means the input current here should accordingly be high is this i s a, i s b and i s c. The amplitude of this current the 3 current should be high, it means we are drawing more power from the 3 phase supply. So; that means, if the error is positive the actual DC link voltage is less than the reference value. And hence e is positive which means the amplitude of the current that is I s m should be more similarly, if the error is negative is means V d c reference is lower than the actual V d c. So, if e is positive it implies V d c ref is greater than V d c if e is negative. The error is negative here this implies the V d c ref is lower than V d c.

So, show in the second case when the error is negative the DC link voltage has to be brought down the actual voltage is V d c that is more this is more than the reference value. So, if V d c the actual V d c is more than reference value the voltage has to be brought down. Now, how do we bring down the voltage? We bring down the voltage by decreasing the input current. So, this input current that is I s m this current reduce if e is negative if e is negative we have a P I controller that we reduce this i s m. The amplitude of the input current when this current is reduced the capacity of voltage is also reduce. Because the drive is now operating the drive is drawing some power from the DC link the capacity of discharge to the drive and hence the voltage will go down.

So, this is how we can control this DC link voltage and usually when we have an inverter specially voltage source inverter. The objective is to keep the DC link voltage constant we do not go for a variable DC link voltage. So, we have a capacitor and we keep that voltage constant for the proper operation of the drive system. So, this close loop control will ensure that the DC link voltage V d c is kept close to or equal to V d c ref that is the purpose of the close loop control And this is achieve by controlling the convertor 1 that is also called front and convertor.

So, this converter which is in the, which is converter 1 is also known as the front end converter. So, the V d c has to kept constant at a reference value which is V d c ref and when we talk about the second converter; converter 2 that is feeding an induction motor. Now, that converter is basically control as per the control algorithm whether it is by f control or vector control or director control depending upon that we control this converter 2 to ensure the control of the induction motor. So, there are 2 independent control, the control of converter 1 that is the first converter and control of converter 2 that is the second converter.

Now, we will here we will primarily concentrate on the control of converter 1 how we can control this first converter. So, that we get a finally, a utility friendly drive. So, if we if we see here the equivalent circuit of the power phase in this case we have the grid here this is a 3 phase supply. And then in each phase we have some inductor this inductance is having a reactance of omega L omega is the angular frequency that is 2 by f. Then this r connected to the converter in this case. So, this is this is the converter and for every phase we have we have the converter here. So, this is for the phase b a b and c and we call this voltage to be AC phase a converter voltage n with respect to the mutual of the supply. Similarly, for phase b here we call that to be this is for phase a and for phase b we call that to be V b c n and for phase c we call that voltage to be V c c n.

So, this basically these 3 voltages are free shifted by 2 pi by 3 and 4 pi by 3 respectively with respect to the phase a voltage. Now, we can we can draw a for phase equivalent circuit where we can show the source voltage then the inductance. And then the converter voltage and we are only concentrating on the fundamental frequency component although it is a p w mean water to smoothen out repels, we are own interested in the fundamental component. So, we will draw the fundamental power phase equivalent circuit of the front end converter system.

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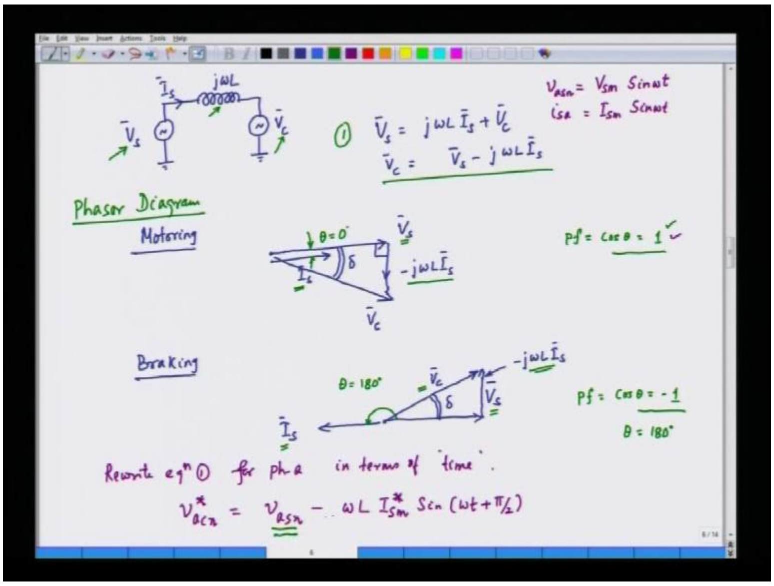

So, the fundamental equivalent circuit will look like this we have the source voltage power phase voltage, we ignore the resistance it is a good inductors. So, resistance is the very small. So, we have the reactant that is g omega L and then we have the converter voltage that is b c. So, this is the power phase equivalent circuit and we can we can write down this vector equation V s is equal to the reactants drop. That is g omega L I s cross V c V c is equal to V s minus g omega L S L I s and we can show this equation in terms of phase diagram.

So, we have the phasor diagram here and this is the phasor diagram for the motoring. The power factor is going to be 1 and for the motoring the power is coming from the AC side to the DC link, the motor is drawing the power. And hence the power is coming from the AC source, the AC source in this case is the 3 phase source and the power factor the input power factor is 1 cos theta is 1 or theta is equal to 0. So, if you put the input power factor angle theta equal to 0 and complete the phasor diagram we get the following diagram.

We have the current here I s this is the, I s and the voltage is V s there in phase. And we have to find out what is V c is the converter voltage that is as for the equation that is V s minus j omega L I s that is equal to V c. So, this is minus j minus j means logging this current I s by pi by 2o. So, this is minus j omega L I s and then we are adding that to V s to get what is V c the converter voltage. And when we get the converter voltage we can control this converter as per the voltage obtain. So, basically what we are trying to do, we are trying to calculate the converter voltage in this following fashion now this is call the motoring.

For the breaking what happens and we aim for regenerating breaking regenerate a breaking the motor kinetic energy is feed back to the supply. So, the AC grid now is not delivering power, but it receiving power and power factor is negative. And when the power factor is negative the power flow direction is reversed now, in this case cos theta is equal to minus 1. So, we are receiving active power from the motor side or from the from the converter side. So, if we could that condition here if theta is equal to if cos theta is minus 1 theta is naturally 180 degree that is to be a shown here. So, this is the voltage and we have the current here I s is phase, if a from this by 180. And similarly, we have the V s the voltage here and then this is the reactance drop and then we have converted voltage.

So, these are basically the phasor diagrams and we are talking about the r m s quantities and the phasors they are not the actual variables. So, what we need to do when we want to control the actual converter we have 3 different phases phase a phase b and phase c. We need to convert the phasor quantities to actual time varying quantities now, how we can do that. Let us take the first equation this is the equation that we have V s is equal to j omega L s plus V c. And then we have V c is equal to V s minus omega L I s. Now, let us assume here that we are only talking about phase a. Now, if we talk about phase a here we can write down phase a voltage source voltage V s a with respect to neutral that is equal to sum maximum voltage V s m or V m in into sin omega t. What about the current in the same phase? Now, if we find out the, or if you try to see the currents the same phase i s a is equal to or i s a. We are talking about the power phase current here i s a is equal to I s m sin omega t because the power factor is 1.

So, if we know V s a and i s a, there are basically instantaneous variable they are function of time we can convert this equation 1 2 the time varying equation. Now, we can rewrite equation 1 for phase a in terms of time it is a phasor equation, we want to write it as a function of time. So, we can say that for phase c for phase a, we have the converter voltages AC n. So, we can say that AC n with respect to neutral this also we can say V s a n as you have a s n here. So, we have in this case V a s n a S n. So, we can write here that is equal to V a s n minus this j means it is basically a phase c by pi by 2.

So, whatever is the current here we will shift it by pi by 2 and put it here. So, here we have omega is the frequency angular frequency L is the inductance of the link this is the inductance here omega L. And then we have I S corresponding to phase a will have I s m sin omega t and we have a j here j will shift the phase by pi by 2. So, what we are trying to do here is that we are trying to evaluate the phase a voltage of the converter by this equation. And this equation is a exact equation it is a time varying equation it in involves real quantities.

Now, if we have reference value of the current. So, this is basically I s star or I s n star the reference value and this is available from the grid. So, we can say that the reference value of the phase a converter voltage is given by this. So, this we can measure V s n, we can measure that is V s n sin omega t we can have a sensor to measure this voltage. And we will have a idea about sin omega t the sin omega t can be obtain by means of a phase block group. And then we can phase shift this by pi by 2 to get this and we can subtract this to be gets the final phase a convertible phase.

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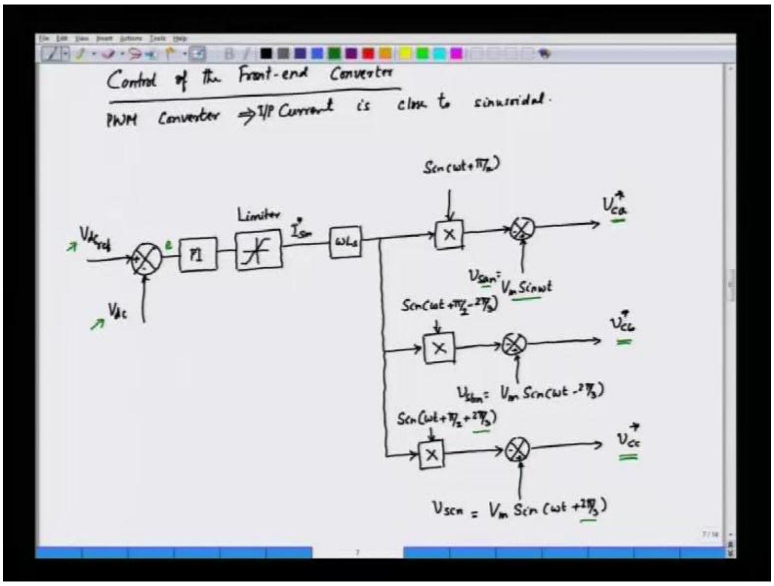

That is what we have done here that we have implemented this using a block diagram we have the DC link reference. And we have the actual feedback voltage we have error in this case then we have proportion interior controller the limited. Then we have the maximum value of the current the reference value we multiplied that by omega L s. This is what we have done omega L into I s m this is omega L into I s m. And then we multiply that V sin omega t plus pi by 2. So, this is what we have done here And then we subtracting this from V s a n then we have obtain V c n. Similarly, for phase b this signal is shifted by 2 pi by 3. So, we have omega t plus pi by 2 minus 2 pi by 3. And for phase c we can obtain this by again shifting by 2 pi by 3 or adding plus 2 by 3.

So, finally, we get the reference voltage V c S star V c b star and V c c star which are use to control the ford net converter. So, this reference voltages we will be use to control the front end converter and the front end converter is converter 1. That is interface with the grid as you have seen here that we have we have the front end converter here and this interface with the grid. So, we can control this as we know the reference voltages V c a V c b and V c c.

Now, this is about a utility friendly drive in which we have shown the control of the front end converter. The motor end converter is well know or we have already discuss previously depending upon method of speed control or motor control of induction motor. We can go for either P by f control or vector control or director control. So, this drives are high performance drive in the sense that these are applied for do the applications where we need good torque and speed response.

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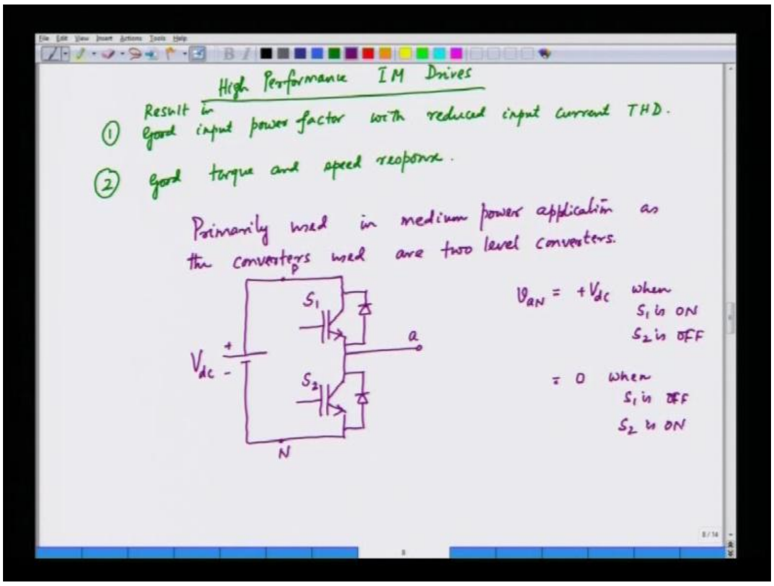

So, these are high performance drive systems induction motor drives. So, this result in good input power factor with reduced input current THD; total harmonic distortion and good torque and speed response. And these drives are basically use for medium power application because we have only shown a 2 level converter. So, largely whenever we use the 2 converters using 2 level structure by 2 level we mean the voltage output can either d plus c DC or 0. So, these converters are 2 level converters and these drives are used primarily in medium power application primarily used in medium power application as the converters used are 2 level converters. Because when we have a system like this a phase of this converter say for example, we have to I g b t s, we have 2 diodes here and input is V d c and the output.

Now, we can say this is basically positive bass P; this is negative bass n. And this is suppose phase a now if we say if try to evaluate, but V a n V a n we can call this to be S 1 the switch 1. And this is S 2 the switch 2 V a n is equal to plus V d c when S 1 is on and S 2 is off and V a n is equal to 0 when S 1 is off and S 2 is on. So, the converter output power phase output here as got only 2 levels either it is plus V d c or 0.

And hence these are call 2 level converters and when we have 2 level converters we cannot go to a very high power. Because the DC link voltage cannot be increased the V d c cannot be increase the V c d comes across each I g b t or each device power device switching device and that device has got a maximum with stand capability. So, we cannot have a very high DC link voltage. So, these drives are primarily employed for motors which are used for medium power application. And the motors are primarily low tension motor may be around 400 volts or 415 volt motors. Now, when we go to higher power instead of 2 level converters we go to multi level converters.

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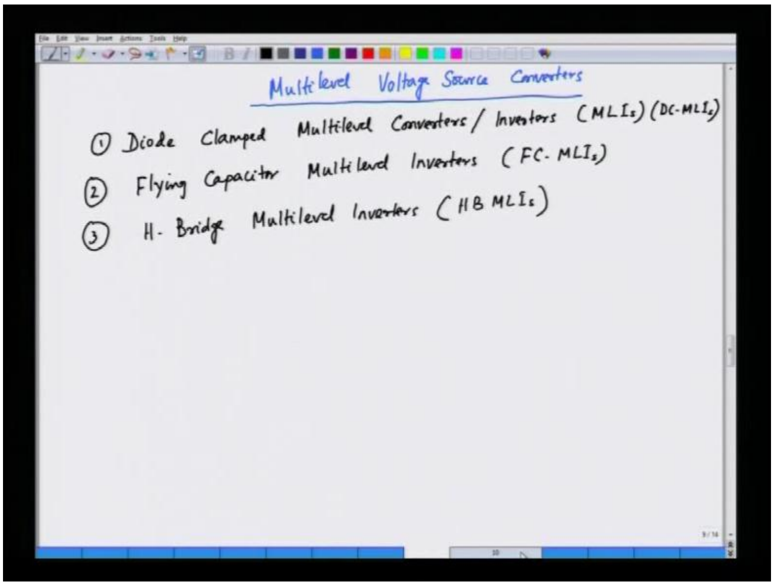

Now, we will be discussing something about multi level converters multi level voltage source converters. So, primarily what we have here the multi level converters means we can apply more than 1 level more than 2 levels. It can be 3 level it can be 4 level, 5 level and so on. So, we start with the minimum level the minimum 1 is the 3 level converter. So, this multi level converters are classified into primarily into 3 categories the first one is called a diode clamped multi level converters. So, we start with a first 1 diode clamped multi level converters or if we are talk me about only DC to AC converters we can say that multi level inverters.

So, we can say this is M L I multilevel inverters, the second one is called a plying capacitor a multi level inverter. So, this is FCMLI; the first 1 is the similarly, is known as DC the diode clamped multi level inverters the third category is called an H bridge multi level inverters. So, we can call this to be H B M L is. So, out of these 3 we will very briefly torch upon the 3 types of multi level inverters. And see the advantages and drawback of each one of them before selecting one of this for drive applications. Let us first see the diode clamped multi level inverter. So, we will start with a first one that is the diode clamped multi level inverter.

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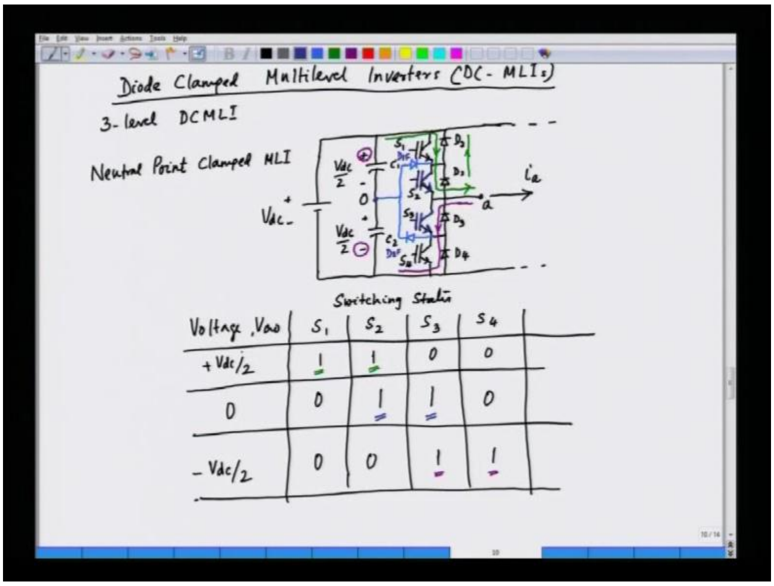

That is DC M L Is is. So, we will first take a 3 level topology. So, let us first draw the 3 level diode clamped multi level inverter with start with a DC voltage. And this DC voltage is connected to 2 capacitors like this. And then we have 3 4 switches here 1 2 3 and 4 they are I g p t switches. And each one is having its own feedback diode is switch it is having its own diode. Now, this is say for example, phase a and similarly, we can have for other phases also this for phase a. And we can have similarly, for phase b and phase c respectively. Now, when we have this V d c is the input voltage. And the capacitors are to identical capacitors, the capacitors of these 2 capacitors are equal. So, we can call them to be c 1 and c 2. And the voltage drop across each one of the capacitors is exactly same and each one is equal to V d c by 2. So, what we have here is this that this voltage is V d c by 2 and this is V d c by 2 and this we can call to be c 1 and this is c 2.

So, this is the midpoint of the of the capacitors and what additional thing we have here? We have a diode 1 diode connects this point to the capacitor midpoint, other diode connects this point to the midpoint is the following fashion. Now, these 2 diodes are additionally present here and this 2 diode are call clamping diode. Because of these 2 diodes structures sometimes this type of multi level inverter is also called neutral clamped multi level inverter. Because this point the midpoint of the capacitor is called the neutral point it is having 0 voltage. So, we can we can call this to be 0.0 and this diodes are clamping this point to the 0 voltage. So, this point is clamped in this point is clamped to 0 voltage. And hence this is called a diode clamped multi level inverters sometimes also we call this to be a neutral point clamped multi level inverter.

So, what we have here? We have 4 switches and the switches are named as S 1 S 2 S 3 and S 4 Now, let us try to find out what is the voltage output here when we turn on and turn off the switches. So, we can draw this or we can show this in terms of a table in the table we will write down V a o the output voltage against the switching status. So, the voltage output V a o and then we have the switching states and switching states are we have S 1 S 2 S 3 and S 4. So, we have 4 switches here. So, we can draw this table and here we will have 3 possible combinations in this case.

We will have the voltage plus V d c by 2 when we close S 1 S 2 and open S 3 and S 4. Similarly, we have the voltage minus V d c by 2 when we close S 3 and S 4 and open S 1 and S 2. And we will have the voltage equal to 0 when we close S 2 and S 3 and open S 1 and S 2. Now, when we say that the voltage is plus V d c by 2 we close S 1 and S 2 S 1 and S 2 are upper switches. So, in this case we can see that when we close S 1 and S 2 these 2 switches are closed. So, they are connected to the output here output is a, and this is coming from this plus V d c by 2. So, directly what we have V a o is plus V d c by 2 this is the equation when you have S 1 closed and S 2 closed and S 3 and S 4 are open. These 2 switches the lower switches of this particular phase is opened.

So, S 3 is opened and S 4 is opened. So, this is the lower legs are not connected. And then when we say that the voltage is minus V d c by 2 we close S 3 and S 4. So, when we close S 3 and S 4 these 2 are closed. So, when we close this 2 switches basically a is connected to minus V d c by 2 this potential is negative and the upper side is positive. So, when we close S 3 and S 4, we open S 1 and S 2 and we close S 3 and S 4. So, when we close S 3 and S 4 the point a is connected to minus V d c by 2. And of course, this basically this feedback diodes will facilitate bidirectional current flow load is a AC load. It could have positive voltage positive current negative voltage negative current.

So, the current and the voltages can at any point of time assume any sin. So, it means we can have negative current with positive voltage, positive current with positive voltage positive current with negative voltage and negative current with negative voltage. And this is ensured by the bidirectional nature of the switch the diodes actually facilitate the bidirectional current flow. So in fact, when we say that S 1, S 2 are close, so when the current is positive the current is conducted by means of the switches the I g b t S 1 and S 2. And when the current is negative this d 1 and d 2 will be taken this current And hence we have bidirectional flow current similarly, may be close S 3 and S 4. If the current is negative they are conducted by S 3 and S 4. And when the current is positive; positive means is coming out this is basically we can say this is I a. So, if we say that I a is positive is coming out, so if it is coming out this will be carried by D 3 and D 4.

So, we can apply plus V d c by 2 and minus V d c by 2, what about 0 voltage? The 0 voltage can be applied when we turn on 2 intermediate switches we have S 2 and S 3 when we turn on S 2 and S 3 we get 0 voltage. So, when we turn on S 3 and S 2 and S 3 it means we turn on this switch and this switch. So, what we obtain here through the diode we have the diodes in this case we can call this to be D 1 f and D 2 f this could be D 1 f and D 2 f that 2 diodes here. So, point o is available to the output through 1 diode and 1 transistor D 1 f and S 2 or it is the called is negative this point is connected to point o through S 3 and D 2 f. So, when we turn on these 2 switches S 1 and S 2 and S 3. The voltage output is 0 it is clamped to the midpoint of the supply that is o. And hence through this converter what we obtain we obtain 3 different levels plus V d c by 2 0 and minus V d c by 2.

Since we have will have use 4 switches in 1 phase as oppose to 2 switches previously if you see we are only 2 switches S 1 and S 2. So, this is basically 2 level converter. So, this 2 level converter will be use for or can be use for medium power application because the input voltage is limited here. Now, when we go for a 3 level converter as we have seen here per phase we have we are having 4 devices. And the voltage rating up is device can be reduced or in other words we can have twice the DC link voltage here compare to a 2 level inverter. So, whether voltage the DC link voltage is higher in this case we can use this type of converter for driving higher motor rating. The motor voltage can higher because we can go to higher DC link voltage. And that is mainly for high power application, in high power application the voltage rating of the motors are high. And hence this converter can be employed for higher power applications.

Now, the drawback of this converter is the following we are assuming that these 2 voltages across c 1 and c 2 are exactly same. They may not be exactly same, because 1 capacitor may discharge little more than other capacitor. So, that is a inherently voltage unbalance problem. So, the drawback in this case is the following disadvantages.

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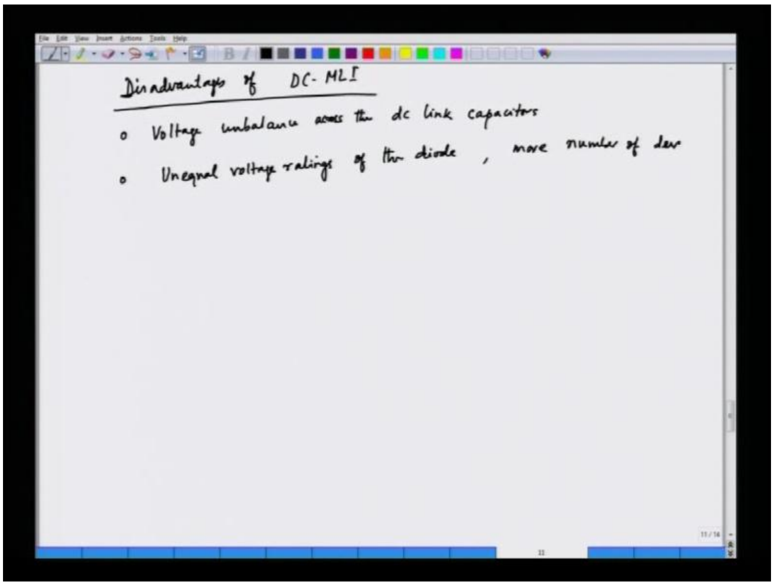

Of diode clamped multi level inverter number 1; voltage unbalance in the DC side across the DC side capacitors across the DC link capacitors. So, this is actually the main drawback that the we have a unbalance problem in this case. And this has to be tackle base some other means and then unequal voltage rating of the diodes here. So, we can say here that unequal voltage rating of the diodes and more number of devices although we have the drawbacks here the direct clamped multi level inverters are very popular for drive systems. So, we use this for mostly for high power drive, because the other advantages like it can with stand higher DC link voltage. And it can give better output way forms are more beneficial compare to the drawbacks. Let us see the second type of multi level inverter, the second type of inverter is the flying capacitor type multi level inverters.

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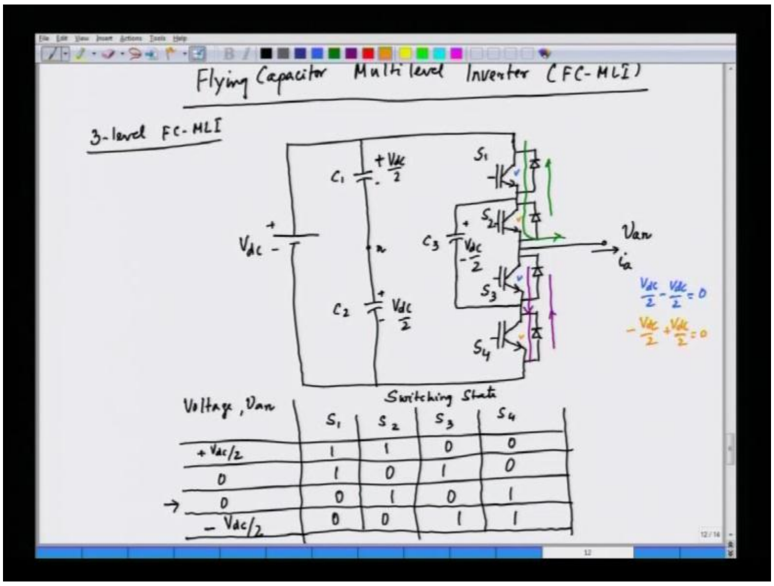

So, we will talk about the flying capacitor multi level inverter. So, this is FCMLI. So, we will again take a 3 level structure the voltages are basically 3 levels. The output voltage can have 3 different levels and see a power phase structure of this 3 level inverter. So, we will again take and 3 level FCMLI again we have 4 different switches. So, these are basically the I g b ts and each I g b ts having diode here the feedback diode. And this is the output we have phase a and this is connected to the DC voltage V d c. We have various capacitors here we have 2 capacitors here c 1 and c 2. And this voltage is r V d c by 2 this is V d c by 2 and then we have another capacitor here this is c 3. And this voltage is V d c by 2 and the switches are S 1 S 2 S 3 S 4 the 4 different switches. And we have the capacitor r S like this and this is the voltage that is V a.

And we can connect this voltage to the load this is a power phase circuit And what we do here we measure this voltage with respect to the input neutral point. And the neutral point is the midpoint of the capacitors c 1 and c 2 and that is V a a n. Now, here also we will have 3 different levels for the output and these 3 different levels can be obtain by various switch combinations. Let us have a look at the various switch combinations those can be used for obtaining 3 level voltages. So, we have the voltage here V a n and the switching state we have 4 switches here S 1 S 2 S 3 and S 4. So, we here we have 4 different combinations.

So, we can have 4 different combinations here. So, these are the various switching states And the voltages here can be V d c by 2 can be 0 we have 2 different combinations which will give the 0 voltage output. And then we have minus V d c by 2. So, plus V d c by 2 we have very straight forward combinations that S 1 and S 2 are going to be 1. So, we have S 1 is 1 and S 2 is 1 and S 3 and S 4 will be 0. So, what we have here is that we turn on these 2 switches. So, the current flow will be like this for positive current. And if the current is negative this is flow is the diode and V a a n is connected to plus V d c by 2. And similarly, when we have minus V d c by 2 when we require minus V d c by 2 we turn on S 3 and S 4 and we turn off S 1 and S 2. So, similarly, these 2 switches will be on. So, the current can flow like this or like this depending on whether it is negative or positive this is the direction of the positive current I a. So, when this S 3 and S 4 at closed the voltage V a a n will be minus V d c by 2.

And we can have 2 possibilities or 2 combinations that can give 0 voltage what we can do here is this that we can we can have 0 voltage for 1 0 1 0 or 0 1 and 0 1. Now, if we have 1 0 and 1 0 this is the upper switch is on this is conducting and this is conducting. So, when we say these 2 are conducting let us see how the voltage is 0. So, we start with plus V d c this is conducting. Then we have encounter here negative voltage in this case there is a voltage drop here. So, minus V d c and then we go here. So, when 1 and 3 are on the voltage here is V d c by 2 minus V d c by 2 that is equal to 0.

So, the 2 capacitor voltages will cancel out we have the voltage of c 1 that is plus V d c by 2 this is plus V d c by 2 in this case. And then when we proceed along this path there is a voltage drop here that is the capacitor c 3 voltage that is plus V d c that is a drop here. So, in that case we get the voltage here V d c by 2 minus V d c by 2 that is equal to 0 and there a similar fashion when we have this condition that is 0 1 and 0 1. So, what we have here is little different that is switch 3 2 is on and switch 4 is on when 4 is on this is minus V d c by 2. And when the switch 2 is on this voltage is added here

So, again what we have here is this minus V d c by 2. So, we have voltage increase here plus V d c by 2 that is equal to 0. So, for these 2 switch combinations the output voltage is going to be 0. So, we get a 0 voltage. So, this is basically flying capacitor a multi level inverter now the drawback of this inverter is that we have. So, many capacitors and the voltages across each capacitors have to be maintain precisely at the fix value. That is one of the major drawback of flying capacitor multi level inverters. And the third type of multi level inverter is the cascade multi level inverter H-bridge inverter in which we take a simple H-bridge inverter and cascade this H-bridge inverter. And we obtain the various voltages from this H-bridge inverter cascade in structure. Now, this cascading of H-bridge multi level inverters, we will be discussing in the next lecture.