Advanced Electric Drives
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Lecture - 32

Hello and welcome to this lecture on Advanced Electric Drives. In this lecture, we will try to discuss something on utility friendly AC drive, what do we mean by utility friendly? Utility is a AC grid that is available to us. The AC grid could be a single phase grid or it could be 3-phase grid, now when we have the AC supply that is available to us in the form of a 3-phase or single phase grid. And ultimately we are trying to control an AC motor, what are the various possibility that we have. So, let us try to list the possibility of controlling an AC drive, which requires variable voltage and variable frequency, when we have a fixed voltage and fixed frequency grid available to us.

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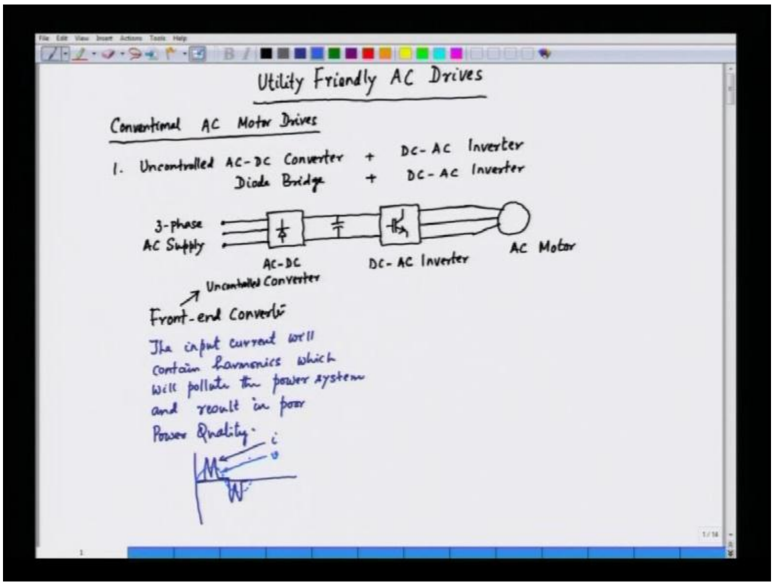

So, we have the following possibilities, so conventional AC motor drive, so what are the various possibility we have when we talk about the conventional AC motor drives, we want to have a variable voltage and the variable frequency output. And the available power supply is an AC voltage, so we can have first an uncontrolled converter, uncontrolled AC to DC converter followed by a DC to AC inverter. Now, this a first possibility, that the first stage, we have two stage in this case, we have the AC power supply available to us, we can convert that to the DC by means of uncontrolled converter.

And when we talk about uncontrolled converter, we usually talk about the diode bridge rectifier, so the first stage is basically a diode bridge; so this is the diode bridge that we have here, so this is a diode bridge and plus inverter. So, if we see the schematic diagram here, we have the diode first and then we have a inverter, the inverter could be made up of IGBT or GTO's for high power. And here we have a DC link and the input in this case could be a single phase or a 3-phase AC grid, when we have low power application say for example, if the drive is for low power application which is below let us 10 Kilowatt we can go for single phase.

So, in the input side what we have here is the 3-phase AC supply, then we have the AC to DC converter this is uncontrolled and then we have the motor which is connected at the output. And this is the AC motor and this is the DC to AC inverter, so this is one of the configuration we are converting AC to DC, the DC to variable voltage and variable frequency AC. Now, in this case if we see in the front end, we have a diode bridge this is called a front end converter.

So, this uncontrolled rectifier or uncontrolled converter is called a front end converter also, because it is coming at the front end of the drive system. When we talk about the drive we have a AC supplied that is available to us ultimately we have to control the motor which is an AC motor. And in the input side we have a AC to DC converter that is a front end converter, now when we interface with the grid or utility, the utility will be supplied in the current to the front end converter. Now, this current in case of a diode be rectifier will be full with harmonics.

In fact, if we see a six falls be rectifier and see the input current, the input current will be full with harmonics. And hence, the harmonics will be drawn from the power system, which is going to deteriorate the condition of the power systems and hence, the power quality will go down. So, the input current here will contain harmonics which will pollute the power system and result in poor power quality. So, this input current here, if we try to see the input current of a typical six falls diode rectifier, you will see that the input current contain the harmonics.

And harmonic will be of this nature, we have the input current here ((Refer Time: 07:35)), so this will have something like this structure, while the current is like the, this is the current. And the voltage will be sinusoidal this is the v, the voltage and we have the current, now current contains harmonics. And hence, this drive although we are able to control the drive through the inverter, this drive will have detrimental effect on the power system, so this is not a utility friendly drive. Now, what is the other possibility other possibility is to have a control rectifier that is also the conventional topology, in which in the front end converter is a controlled rectifier, so we can have another possibility.

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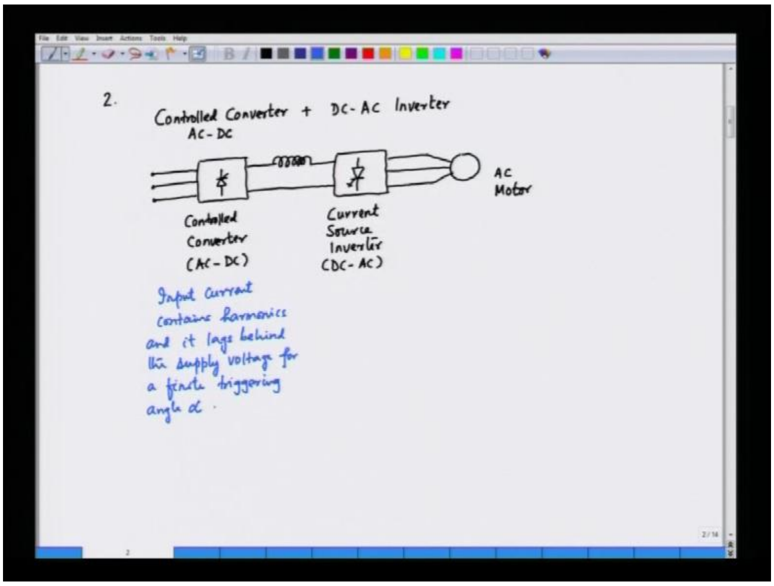

So, the other possibility is that, we can have control converter plus this is a AC to DC converter plus a DC to AC inverter, so we can have the structure like this, we can have usually we use a SCR bridge here, we have a SCR bridge in this case, we have a 3-phase supply. And in this case, when we have variable input voltage we usually have a current source inverter, so here in this case we can have IGBT is are GTO's or even SCR's. So, we show that by means of a GTO here, the front end is a control converter and after that we have a inverter, this is called a current source inverter.

And this is a DC to AC conversion and the front end is a AC to DC conversion, and we have the motor the motor is fade from this inverter, so we have AC motor. Now, in this topology also, if we see the front end is a SCR controlled rectifier having thyristors in the front end also will have harmonics, when we delay the triggering angle in this case the phase angle will also change. So, in this case situation is little different from the uncontrolled rectifier, here not only will have harmonics, we also have poor power factor in the sense that we have a delay in the current.

And hence, the phase angle of the current will be lagging the voltage and hence, we have both harmonics and reactive power, so this is also not utility friendly, we are injecting the harmonic current into the power systems and hence, the power quality is deteriorated. So, here the input current in this case, contains harmonics and it lacks behind the supply voltage for a finite trigging angle alpha. So, this kind of topology where we have a current source inverter feeding a AC motor is also not utility friendly, although we are able to control the motor.

We are not able to have a system, where the power system is going to be more free from harmonics, the power system in this case will contain harmonics and harmonics will bring down the power quality. Now, what is the other possibility, other possibility which is conventionally employed is a cycloconverter, in a cycloconverter what we do we feed the motor from AC to AC cycloconverter, it is AC to AC conversion; but again in the input side we have harmonics.

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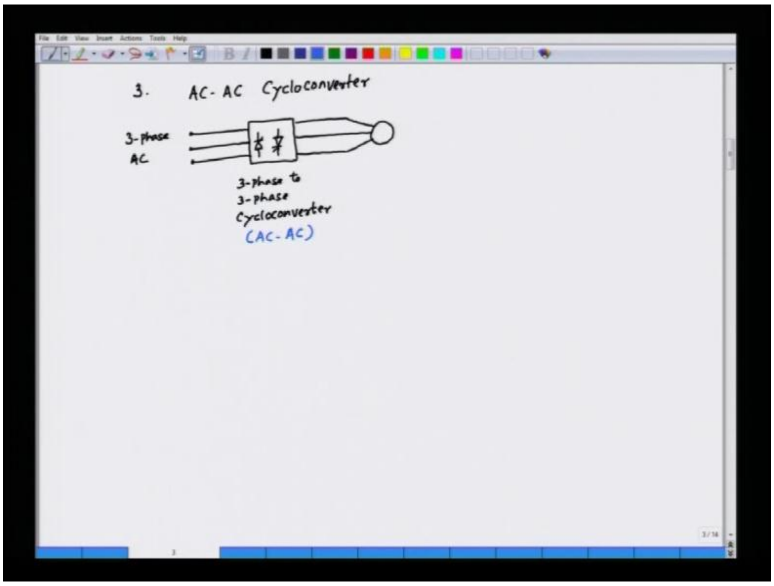

The third possibility we have in this case is a cycloconverter AC to AC cycloconverter, so in this case what we have here, we have the cycloconverter. And the cycloconverter is shown by means of a dual converter block like this, and the input in this case is a AC power supply 3-phase AC. And output here is the AC motor and what we have here is 3-phase to 3-phase cycloconverter, so primarily it is AC to AC conversion. In fact, what we do here is that from a fixed AC, the input power supply is usual in infinite bus, the input voltage and the frequency are constant.

So, what we do here is that by having a cycloconverter, we can generate variable voltage and variable frequency from a fixed voltage and fixed frequency, but in this case also the input current will have harmonics. So, all this three possibilities that we have for controlling AC drive are not utility friendly, so what is the solution, the solution is to have a topology in which the input current will not have any harmonics. And we will only draw active power from the utility, so the criteria of having a utility friendly drive are as follows, number 1 the input current should not have any harmonics; and the input current should be in phase with the input voltage.

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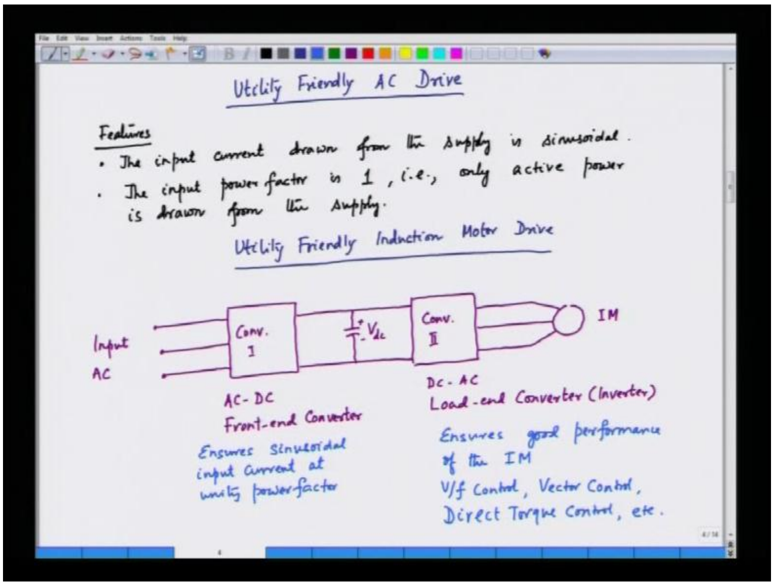

So, we will be talking about a utility friendly drive, utility friendly AC drive and the feature of this drives are the input current drawn from the supply is sinusoidal. And the power factor the input power factor is 1, which means only active power is drawn from the supply. So, if we try to analyze these two points, the first point says that the input current is sinusoidal, it means when we are controlling the motor from a inverter, the front end converter will only draw sinusoidal current no harmonics.

And when we do not draw any harmonics, the input is not polluted by harmonics and hence, the power quality is maintained. Number 2 that we are only drawing active power from the supply, it means the supply power factor is unity, the current is in phase of the voltage. And hence, we are only drawing the active power there is no reactive power and when we are not drawing any reactive power, the efficiency is better, because the effective current is reduced, because the reactive current component is 0 and associated losses with the reactive current is also 0.

So, this is a dry which is the state of the drive, in which we are not only taking care of the control of the AC motor, but also we are ensuring that the front end converter will maintain the power quality. Now, when we have these criteria we can go for a practical drive, now we have seen various types of motors, indexing motor, synchronous motor and other special motors right with reluctance motor etcetera. Now, we will apply this to very popular indexing motor, and we will have a configuration where will have a utility friendly indexing motor drive.

Now, we are a talking about two converters, converter 1 and converter 2, the converter 1 is interface with the supply that is a front end converter, so we have two converters here ((Refer Time: 19:39)), we have converter 1 and then we have the converter 2. And in between we have the DC link, this is V d or V d c and we have the motors the indexing motor we have, I M stand for the indexing motor. And then in the front end converter is connected to the input supply, so we have the input AC here, so this two converters are connected in cascade and the first one is a AC to DC converter.

So, we have here a AC to DC converter, this is called AC to DC frond end converter and then this is DC to AC load end converter and this is typically an inverter. So, this two converters are joined by means of a DC link and the DC link contains a capacitor or capacitor, and the capacitor maintain the particular voltage at V d c. Now, the control of this two convertors are somewhat independent of each other, the load end converter is controlled in a given control scheme which could be simple V by f control, it could be vector control or it could be director control, to ensure good performance of the motor.

So, the converter 2 will ensures good performance of the indexing motor, and we could do say for example, it could be a simple V by f control or it could be vector control or it could be director control. So, the load end convertor will control the motor, the responsibility of the lad end converter is to control the motor with good performance. Now, what about the front end converter, the front end converter ensures the input current is sinusoidal and input current power factor is unity, so the front end converter is called a utility friendly converter.

So, the job of the front end converter, this ensures sinusoidal input current at unity power factors, so these two converters are control some more independently. And the front end converter ensures sinusoidal current at input power factor equal to 1 and the load end converter ensures good motor performance. Now, after this we will try to discuss about the detailed topology of this two converters, converter 1 and converter 2 with the control scheme for an indexing motor drive.

Now, this two converters, if you see the structure of this two converters, they are let say we have 3-phase power supply available to us, they are 3-phase converter made up of IGBT's or GTO. If we go for medium power applications, primarily these converters will be made up of IGBT insulated gate bipolar transistors and these are the voltage source converter structure. So, the front end converter is also a voltage source converter, the lower end converter is also a voltage source converter, so we will see the detailed topology of these two converters.

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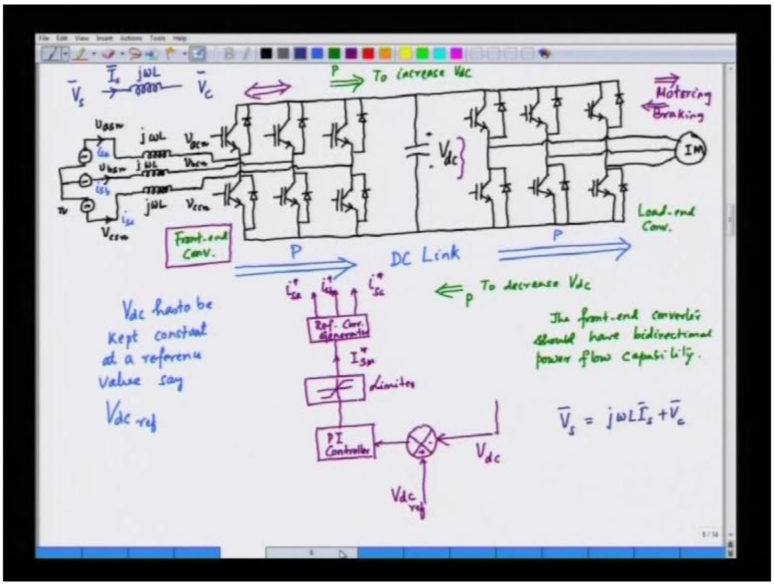

So, we have the structure like this, the front end converter will have a structure in which we have 6 IGBT's, so these gates of the IGBT's the feedback diodes and this converter is interface with the supply through three inductors, so inductor helps in control of current. So, when we want to control the input current free from harmonics and the input current should be in phase with the input voltage, we require this inductor essentially for current control. So, we have three inductors here for 3-phases, so this is for phase a, phase b and phase c, now this is connected to the first phase then we have the second phase and then we have the third phase.

And this is connected to the AC supply and we have the AC supply in this case, 3-phase AC the gird is 3-phase here, so we have AC supply in this case which is available to us. And this is the natural point n and we can call this to be V a n this is phase a, V b n and this is V c n or more preciously we can call it as V a s n, V b s n and V c s n, so this is a source voltage. So, we can call it to be V a s n, b s n and c s n, a, b, c at the various phases, s is the source and n is the neutral, similarly here we have the converter here.

So, we can call this as V a c n, V b c n and this is V c c n, c stands for the converter and this two are linked by means of an inductor, so inductor is of the same value for phase a phase b and phase c. And we can call this inductor as L, the value of the inductance L and the reactance is omega L, so it is j omega L here. So, the inductors each value of the inductor is L and the reactance is j omega L, and this is connected to the DC link, the DC link comes in between. So, we have the DC link here, which is having a capacitor and then we have the load end converter.

And that is the similar to the IGBT front end converter, we have a similar structure in the load end, so we have the same structure here we have an IGBT inverter here, having 6 IGBT's. We have the third leg also here, these are the feedback diodes which will facilitate bidirectional current into the windings, the gates circuit and this is the indexing motor which is connected to the 3-phases of the load end converter. So, this voltage is the DC link voltage which we can called V d c, and when we see the power flow diagram here the power is going from AC to the DC link to the motor, so it is from the source to the load for motoring.

So, for the motoring we can say that the power is going from the AC source to the load through the DC link, so the flow of the power is like this, so this is the flow of the power flow for motoring and again this power is flowing to the motor, so this is the flow of the power. So, here we have the DC link, now this converter when we talk about the motor the converters are voltage source converter, so the DC link voltage has to be maintain constant. And unless we have a constant DC link voltage it is very difficult to control the indexing motor, so the objective here is to keep V d c constant, so the V d c can be kept constant by controlling the front end converter.

So, the first objective in this case to keep V d c constant, so V d c has to be kept constant at a reference value say V d c ref, so the V d c has to be kept constant at a reference value say V d c ref. So, we will employ a close look control in which we will control the front end converter, so that the DC link voltage is kept constant at V d c ref. So, we will have scheme, a control scheme in which we will be comparing we have V d c ref here ((Refer Time: 34:28)), and what we do in this case is that, we have sensors, and we can sense this V d c.

So, we can we can sense this V d c and feed it here and then what we have is an error and error is fed to a P I controller, a controller here, so we have a voltage error and that is fed to a controller and the output of this controller we decide the input current. So, in this case we will have a limiter here to limit the value of the current, we can have a limiter in this case. And what we obtain is the reference current amplitude I s m and that is converted to the reference current by a reference generator, reference current generator into the three references, and the references are i s a, i s b and i s c.

So, this three current references are generated, now what are i s a, i s b and i s c, this i s a, i s b and i s c are the three currents that are drawn from the supply. So, if we have the supply we have the supply here and the supply is giving three currents and the currents are in this case i s a, i s b for b phase and i s c for the c phase. So, what we are trying to do here, we are trying to generate the three reference currents i s a, i s b and i s c of the front end convertor and the front end convertor would be; so controlled to ensure where the actual current follows this reference values.

Now, we know that the front end convertor has to be controlled to ensure that, the actual current i s a, i s b and i s c follow the reference values i a star i b star and i c star respectively. So, if we try to see the capacity of voltage has to maintain constant, so if we want to maintain the capacity of voltage constant, the power has to come from the source. So, if V d c has to be increased the power flow should be in this direction, so this is to increase V d c, it means if we want to increase V d c the power has to come from the source that the voltage in the capacity will be more, the capacity charges out.

And if the voltage goes to very high value, we need to decrease V d c the power flow has to be reversed, the power flow should be from the DC link back to the AC side. So, we have a reverse power flow we can say that the P has to be reversed like this to decrease V d c. So, the power in this case should be like this to increase V d c and the power flow should be reverse to decrease V d c, it means the capacitor has to be discharge. And if you want to discharge the value of capacitor we need to take out the energy from the capacitor, and that can be done by controlling the front end convertor, so this is the basic principle.

So, if we want to have higher and higher voltage, we need to have the current, the input current in such a way that the capacitor charges up. Now, if you want to reduce the value of the capacitor voltage that is V d c, we can drain the capacitor through the front end convertor and hence, the front end convertor should have the bidirectional power capability. So, the front end converter which is this one, this is the front end convertor and this is the load end converter. So, we can say that the front end converter should have bidirectional power capability, should have bidirectional power flow capability.

Now, if we see the front end converter delivers two types of power, one power which is fit to the motor and second power which supply the loss of the capacitor, and the overall system. So, if we want to increase a capacitor voltage, the front end converter has to supply the demand of the indexing motor plus extra power to charge of the capacitor. Now, similarly to discharge the capacitor has to bring down the voltage, the front end converter should supply the demand of the indexing motor plus the power which has to be drained from the capacitor.

And hence, the power flow through the front end converter has to be bidirectional, so this is the front end converter, this flow has to be bidirectional. So, we can say that the power flow can be bidirectional here, depending upon the situation that whether we want to increase V d c or we want to decrease V d c, whether the motor is operating under motoring region or this is operating under breaking region. In fact, in this case we can operate this both for motoring, we can go for motoring and as well as for breaking,, we can also have electric breaking.

For motoring the power flow is from the converter to the motor like this, and for the breaking the power flow has to reverse, so it has to from the motor to the DC link and back to the source. So, in fact this drive system is not only a utility friendly drive this also a four quadroon drive, we can operated motoring, we can operate in breaking in fact, we can operate in all four quadroons. We can operate in forward motoring, forward breaking, reverse motoring and reverse breaking. So, the drive can be bidirectional also the power flow can also be bidirectional, the drive can have forward rotation can also have backward rotation and the power flow can also be bidirectional.

So, let us concentrate on the control of the front end convertor, so the front end converter basically maintains the voltage V d c constant, so if we concentrate on the control of the front end converter, we can appreciate that by drawing a phasor diagram. Now, what we say here is the following that we have the system, and this is the source voltage V s phasor we represent the voltage by means of a phasor. And then we have a reactance and then we have a convertor which is V c and the current flowing through the reactance or the inductance here is I s this also a phasor. And the value of the reactance is omega L, so if we replace this in per phase quantity and try to write down the phasor equation, we can say that the source is supplying two quantities, one is the reactance drop other is the convertor voltage. So, we can say here that V s is equal to j omega L I s plus V c, so if we see little in a more detail way.

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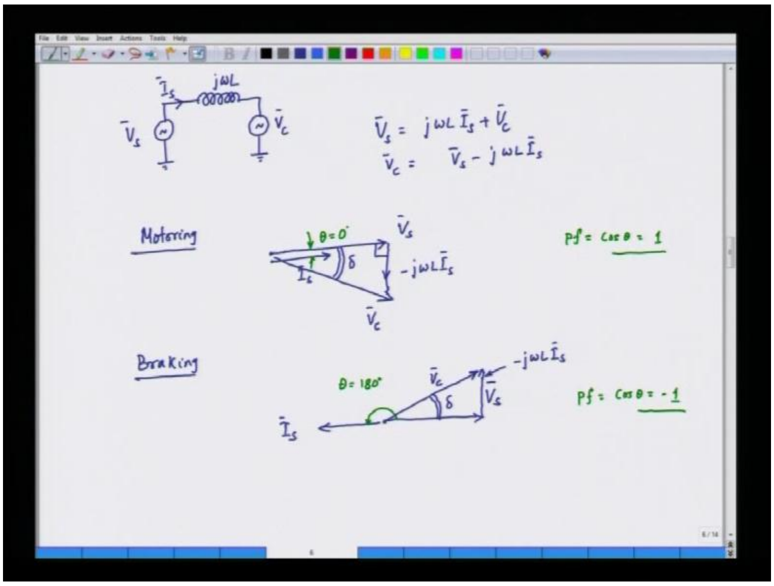

So, we have a system in which we having a voltage here that is the source voltage and then we have a reactance and then we have the convertor voltage and the current is coming from the source this is I s and this reactance is j omega L. So, this is our single line diagram equivalent for phase equivalent circuit, we are replace by the phasor quantities, the source voltage, the reactance drop and the converter voltage. Now, if we write down the vector equation it is V s is equal to j omega L into I s plus V c, so we can also represent this by means of a phasor diagram.

So, we start with the voltage that is the converter voltage, so we can start with the converter voltage here or we can start with the source voltage that is V s, and our object is that the source voltage and the source current should be in phase. So, this is I s and V s are in phase the power factor is unity, so we can calculate V c is equal to V s minus j omega L I s, so if we try to see what is j omega L I s this is basically a lagging quantity. So, we have this quantity is minus j omega L I s and this is 90 degree, and we can complete this vector diagram this is a vector triangle. And the third side would be the V converter.

Now, here we have fulfilled our criteria that the input power factory is unity, so the input power factor is maintain unity, because V s and I s are in phase. So, if we can control as per this phasor diagram, we can ensure that the input current of the convertor is 1, the input current which is drawn by the front end converter is 1. Now, this for the motoring unit condition, motoring means power is flowing from the AC supply that is a grid to the DC link to the motor.

What about the breaking in the breaking when we break a motor, the motor is usually having a lot kinetic energy when the motor is running it is having it is own mechanical inertia. And due to the mechanical inertia when the motor is emersion it has got lot of kinetic energy in the form of half g omega square. And when we want to arrest the motion, when we want to break the motor this energy has to be fed back somewhere and if we talk about a regenerated breaking, this energy in the mechanical inertia of the motor has to be fed back to the supply.

And hence, the supply is not giving power is receiving power and that means, the power factor is minus 1, so ((Refer Time: 48:23)) this is for the motoring where the power factor is 1, it means V s and I s are in phase. And for the breaking condition we have the voltages V s here and the current is out of phase in this case, so here theta is 0. theta is the power factor angle that is equal to 0 in this case, now here theta is 180. Now, in the first case in the motoring case we have power factor is equal to cos of theta that is equal to 1, and for the breaking case we have power factor is equal to cos of theta that is equal to minus 1, which means power is fed back to the supply.

Now, if we draw the phasor diagram for the breaking equation, we will have the following phasor diagram, we have to find out what is minus j omega L I s, so this is I s now negative of this is lagging behind this, so this is minus. So, this is minus j omega L I s and if we complete this vector triangle, the third side will be the converter voltage, here we can see that the converter voltage is leading this by an angle. So, it means the converter is supplying to the source, if you compare this with the motoring case, in the motoring case the source was supplying the converter like a synchronous machine.

Now, when the source is supplying the converter the converter volt voltage V c lacks behind the source, so this is basically the lagging angle, we can say this something like a power angle delta and delta is negative here, and here the delta is positive. So, in this case we find that the power flow can be reversible for the motoring, the power factor is plus 1, and for the breaking the power factor is minus 1. So, if we think about close look control, primarily we will be talking about the control of the front end converter, the front end converter is the one which maintains the power factor unity.

And hence, it ensures a utility friendly drive system, now if we talk about the control of the front end converter, we have to control the current in the converter. The converter is operated in PWM mode and current is control in such a way that the power factor is unity; so we will discuss about the control of the front end converter.

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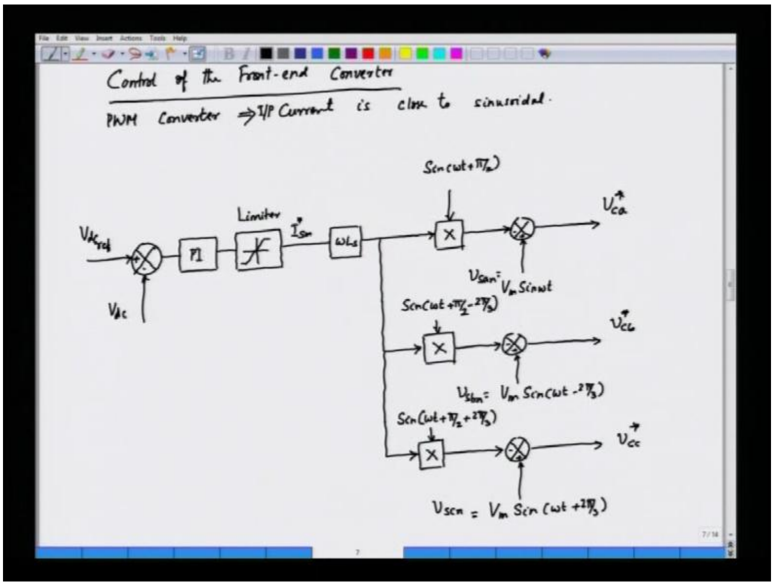

First of all it is a PWM converter, which means current input current is sinusoidal, close to sinusoidal, so what we do here is that, we want to maintain the DC link voltage constant. So, we start with a DC link reference that is V d c reference and we compare that with actual V d c and then we have a P I controller which is followed by a limiter. And then we generate the peak value of the current sin s m, this we multiply with omega L s the reactance and then for 1 phase, if we talk about only phase a we multiply this with sin omega t plus pi by 2. And then we have the voltage from the source V m sin omega t and we generate the, I phase reference V c a reference.

Now, this is basically for phase a, now phase b lacks behind a by 2 pi by 3, so if we talk about phase b, the phase b situation will be lacking behind this by 2 pi by 3, so to show that how phase b will be implemented here. We have a similar structure in this case a multiplier, now here what we do we multiply sin omega t plus pi by 3 pi by 2 minus 2 pi by 3 and then we have we have the voltage in this case V m sin omega t minus 2 pi by 3. And what we obtain here is V c b reference, now similarly for c phase if we implement for phase c we have again another multiplier.

In fact, this voltages are V s a n and this is V s b n source voltages and similarly, we have the phase c we multiply with sin omega t plus p by 2 plus 2 pi by 3-phase shift and then we have this voltage V s c n is equal to V m sin omega t plus 2 pi by 3. And what we obtain here is V c c star, now this at the equation that we are implementing from the phasor diagram, form the vector equation we are converting the corresponding equation into the time domain. And we are generating the reference signals for phase a, phase b and phase c voltages of the front end converter, one the voltages are known V c s star V c b star and V c c star.

We can feed this to the modulation block to generate the modulating signals and the drive signals for the for the front end converter. So, this is how we can control a utility friendly drive, in which the input current is sinusoidal, because the converter is a PWN converter and we are insuring that the input power factor is unity. So, we are only drawing active power from the source, in the next lecture we will be discussing more about this. And also see some topology of high power drives, and how we can implement utility friendly configuration in high power drive system.