DC Microgrid and Control System
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Lecture - 08
Power Electronic Converters in Microgrid Applications

Welcome to our NPTEL courses on the DC microgrid system. We are going to discuss the power electronics converter in microgrid application. We have seen that bidirectional DC to DC converter in DC microgrid application. We will continue to discuss this.

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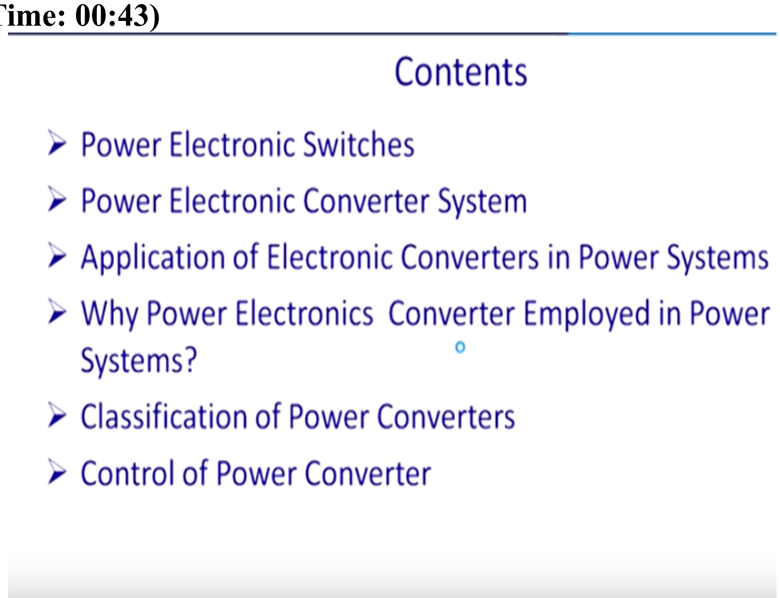

So we shall now little go deep on the power electronics, that is power electronic switches we will briefly discuss and the power electronics converter system. Then applications of power electronics converter system in power system and thus in microgrid. Why power electronics converter employed in the power system. That the classification of the power converter and the control of the power converter and thus this is a part also the DC microgrid control.

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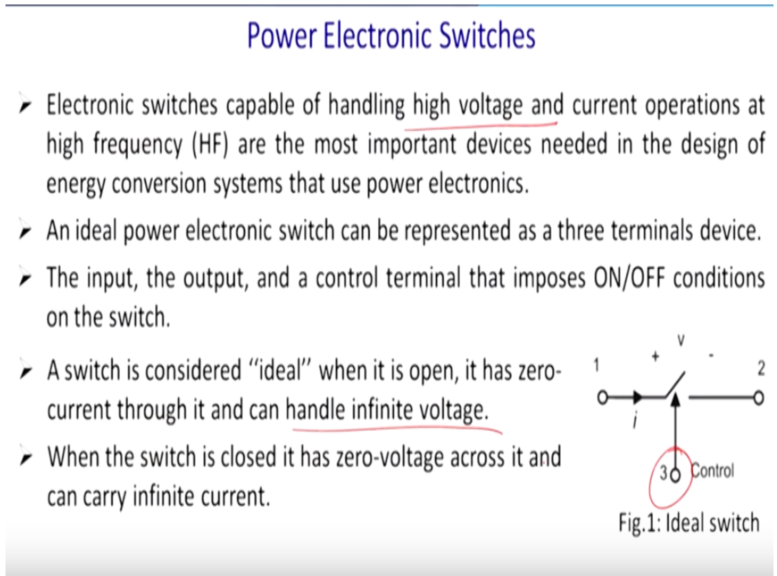

Electronic switches are capable of handling high voltage current and voltage operation at high frequency are most important devices needed to design and needed in the design of the AC to AC conversion system or AC to DC conversion system or we will say that energy conversion system that uses the power electronics. The ideal power electronic switch can be represented by three terminal devices.

That is the input and this is the control and second is the output. Power will flow point 1 to point 2 if it is unidirectional according to the control switch and thus reverse 2 to 1 if it is bidirectional and that is something can be done. So the input and the output and the control terminal imposes on off condition of the switch. The switch considered ideal when open, it has zero current through it and can handle infinite voltage that is what it should be, but it has a practical limitations.

When the switch is closed, it has zero voltage across it and can carry finite current and that is also has a practical limitation imposed by the switch.

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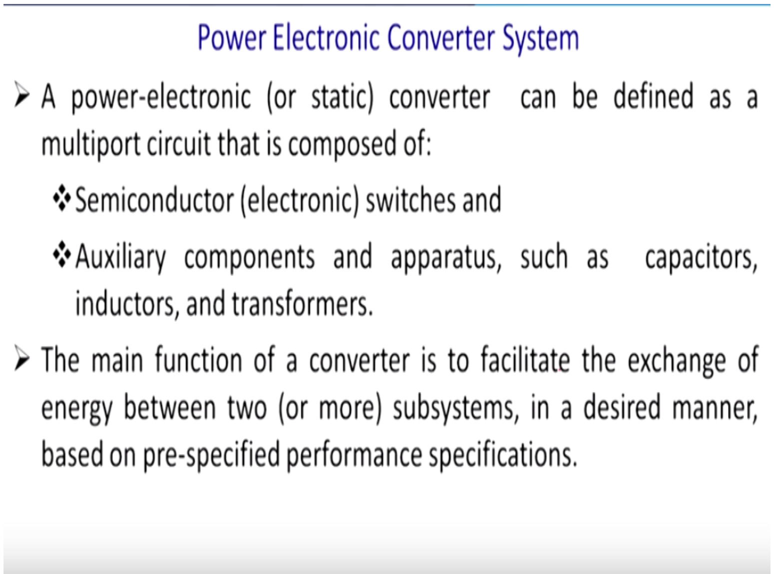

Power electronics or the static converter can be defined as a multiport circuit that is composed of semiconductor or electronic switches and auxiliary component and apparatus such as capacitor inductor and transformer. The main functions of the converter is to facilitate exchange of the energy between two or more subsystem in a desired manner, based on the pre-specified performance specification.

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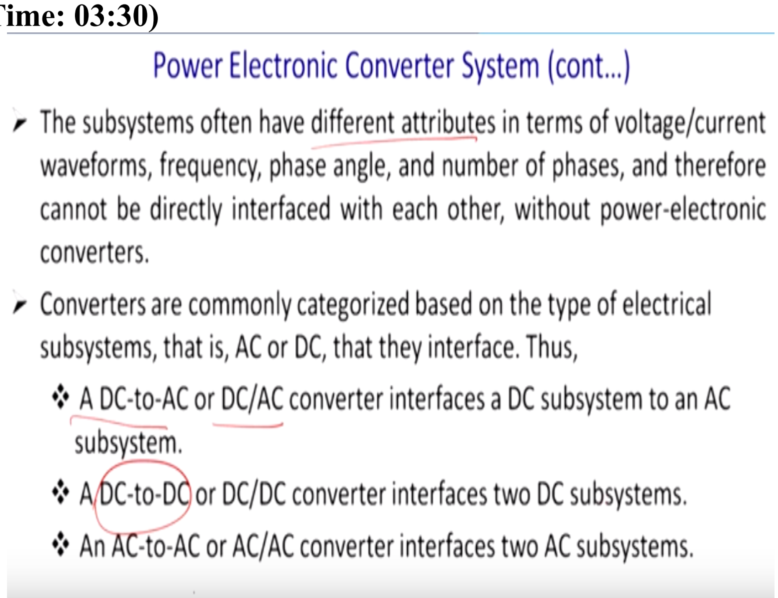

The subsystem often have different attribute in terms of voltage current, waveform, frequencies, phase angle, and number of phases and therefore, cannot be directly interfaced with each other without power electronics converter. Bus voltage is some level and your battery voltage is at some level. You cannot directly couple them and you also require to control the flow of power.

Sometime battery to bus and sometime bus to battery. So you cannot do that without the power electronics devices. Converters are commonly categorized based on the types of the electrical systems, these are AC or DC. Thus, you may have a AC to AC conversion that is matrix converter indirect matrix converter, direct matrix converter. DC to DC converter essentially this is inverter. Interfaces the DC subsystem to an AC subsystem.

You may have a DC to DC converter that is from one level of DC voltage you are going to the another level of DC voltage or DC to DC converter interfaces to DC subsystem and AC to AC converter or AC converter interfaces with the AC subsystem.

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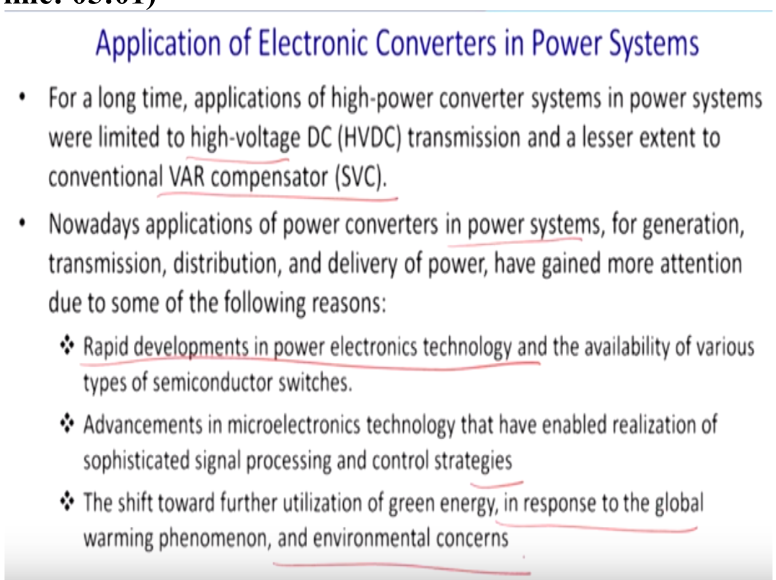

For long time, application of the high power converter system in power systems were limited to high voltage DC that is HVDC transmissions system and a lesser extent to the conventional VAR compensator and different kinds of fax devices. That is fixable AC transmission system. Now it has further penetrated to the lower edge.

Nowadays the application of the power electronics converter system for generation of the transmission**,** for generation, transmission, distribution, and the delivery of power have gained more attention due to some of the following reasons. Rapid development of the power electronics technology and the availability of various types of semiconductor switches.

Advancement of micro electronics technology that have enabled realization of sophisticated signals processing and controls strategies. The shift towards further utilization of the green energy in response to the global warming phenomena and environmental concern.

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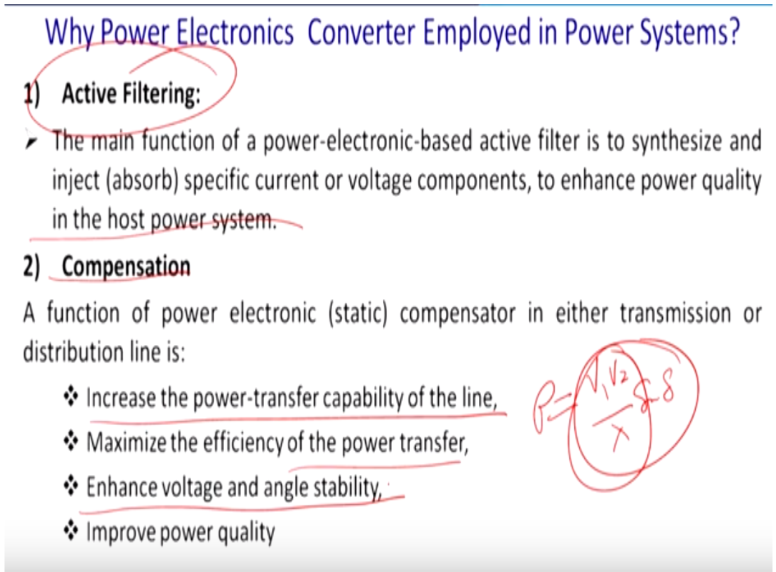

So power electronics converter in power system. One of the application is active filtering. If the penetration of the power, you know that whatever power is generated 80% has been fed to the drives and this drive essentially nowadays uses adjustable speed drive and this adjustable speed drive uses power electronics and since it is a nonlinear conversion it injects harmonic into the system, you have heard about the 6 pulse converter, 12 pulse converter, 18 pulse converter, 24 pulse converter, different kind of converter.

So ultimately what happened so power electronics though makes our life more beautiful definitely or the beautiful the word should be debated or not that is different issue, but that we can make our modern living by power electronics. But problem lies due to those power electronics concentration the power system has been polluted by the harmonics and you can choose the passive rectifier but prepare passive filtering but it generally derates itself with the time and efficiency will not be same.

And it may also cause resonance with the power supply and due to the reason, we talk about active filtering. The main function of the power electronics based active filter is to synchronize or inject the specific amount of voltage or the current component to enhance the power quality of the host power system. So whole system is related to the power quality and that is one of the aspects of the application of the power electronics in power system.

The call of the deterioration of this power quality is the power system, but we find solution by power system. That is itself is a dichotomy. The compensation. So function on the power electronics, the static compensator is either transmission or the distribution line that increase the power transfer capability of the line that we use in case of the fax devices, you know that. You can refer to my fax courses in NPTEL for more detail.

V 1 V 2/X into sin delta is the power flow between the line A and B. So you can play around by the power electronics. You can reduce the value of X and thus power handling capability will be increased. So thus increase the power transfer capability of the line. Line impedance can be changed with the help of the power electronics.

Maximize efficiency of the power transformer and that can be dynamic in nature. Say when you are in a colder temperature, you know and you know that there is a huge thermal limit, you can play around in some part of it you know V1 V2 and you know that thermal limit will not be caused, let us go for the little higher current and thus you can send more power.

Enhance voltage and angle stability. So in a line when you see that it has got a accelerating when torque angle oscillates that when delta oscillates you have a problem of the oscillations. You can damp out the oscillation by reducing the accelerating power or the decelerating power and improve the poor quality that comes under mostly active filtering. Then, comes to the power conditioning.

Whatever power that grid supplies to us, it may not be suitable for my equipments. We now talk about inverter fed air conditioning. So what happen inverter feeds better power to my air conditioning.

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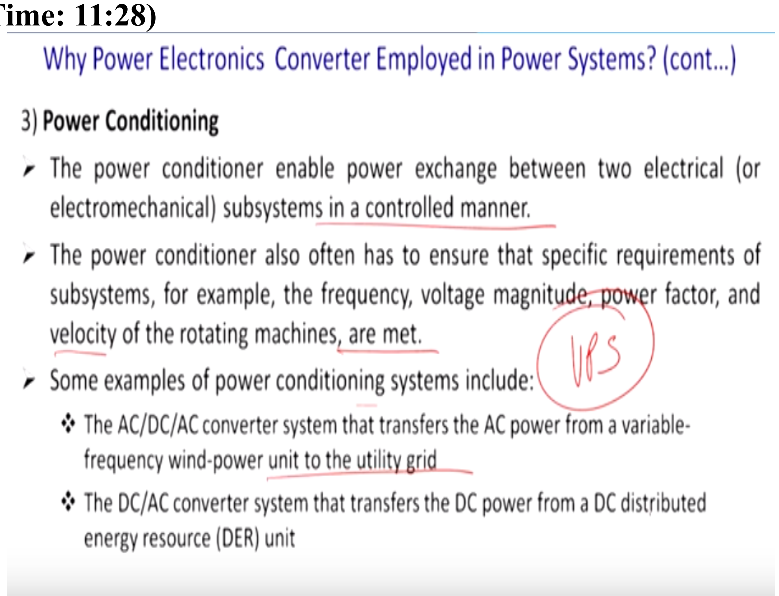

So thus what we can say that the power conditioner enable power exchange between two electrical or electromechanical system in a controlled manner. The power conditioner also often has to ensure that specific requirement of a subsystem for example, the frequency, voltage magnitude, power factor and velocity of the rotating machine etc. are being met.

For example, you are talking now, you know you have a different kind of UPS. UPS is one of the example in a interruptible power supply that you use for your mostly computers. You know offline UPS, you have online UPS and you have a line interactive UPS. These are all comes under power conditioning unit. If you have a online UPS ultimately it will rectify and it will fit to the your computer a processed pure sin wave.

And if power is off then it will protect the power from the battery but if it is a offline UPS it will be in idle, once power goes off it will use power from the battery from this UPS to the computer. So online UPS is a current conditioning unit. It will give very pure power to this computer for its considering its high sensitivity.

Some example of the power systems are definitely the example taking the UPS are AC to DC system of transformation of the power from a variable frequency wind power unit to the utility grid and DC to AC converter system transfer DC power from the distributed generation to the different energy sources.

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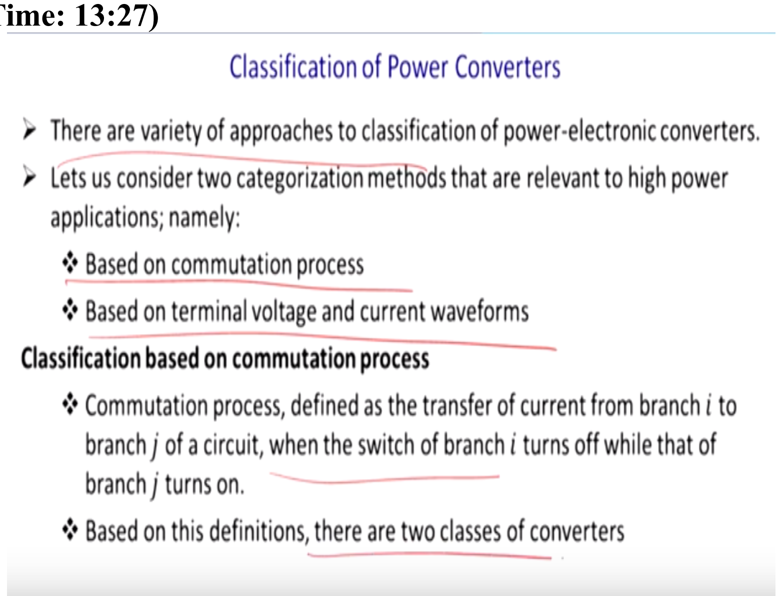

Now let us come to the classification of the power converters. There are many way to classify power converter, but we shall see to it from the application point of view. There are variety of approaches to classification of the power converter. So for reason let us consider two categorization method that are relevant for the high applications, high power application namely based on commutation process whether it is a cell commutating devices or you require a force commutating devices.

And another issue is based on the terminal voltage and current waveform. So see that commutation process defined as the transfer of current from branch i to branch j into a circuit when the switch of the branch i turns off while that of branch j turns on. Based on that definition, there are two classes of the converters.

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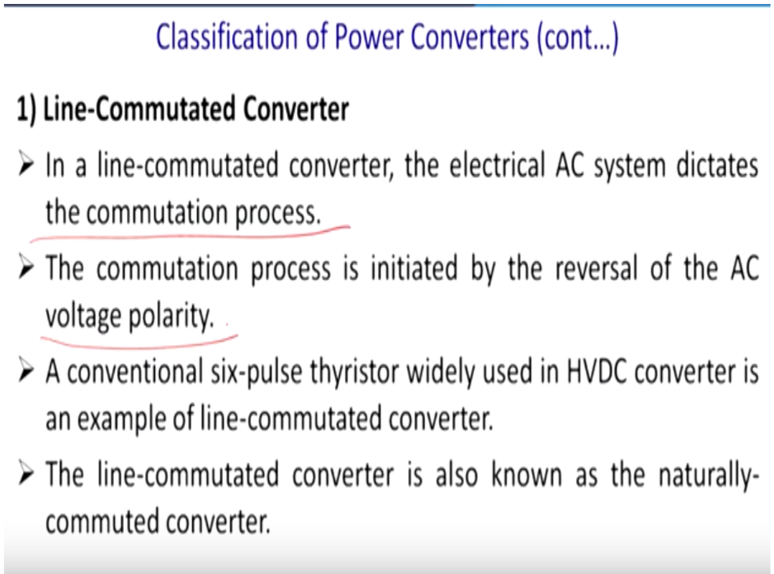

One are the line-commutated converter. The line-commutated converters the electrical AC system dictates the commutation process. The commutation process initiated by the reversal of the AC voltage polarity most of the cases. The conventional six-pulse thyristors are widely used in HVDC converter is an example of the line-commutated converter. The line-commutated converter is also known as naturally commutated converter.

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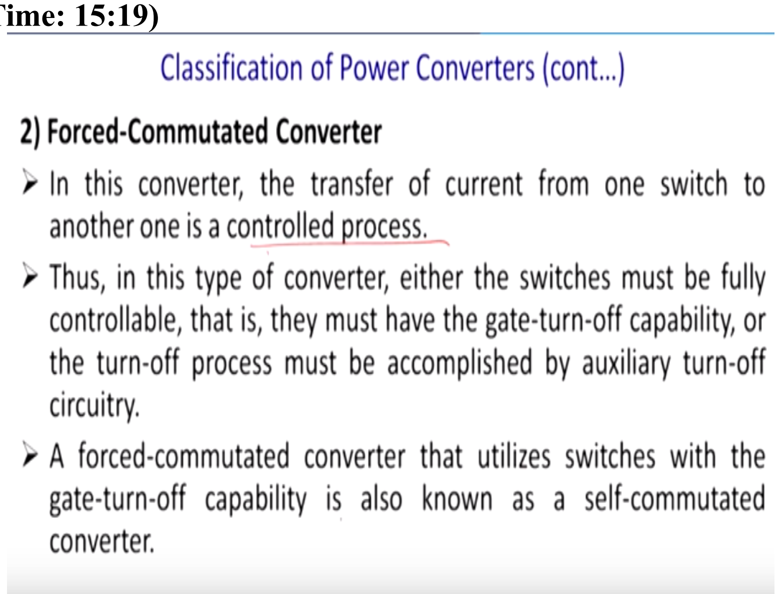

Now this comes to the forced-commutated converter. In this converter the transfer of content from one switch to another is controlled by the control signals. Another is a control process. Thus, this type of converter either the switch must be fully controllable and that is they must have a gate-turn on and off capability like GTO like IGBT all kinds of devices or turn off process must be accomplished by auxiliary turn-off circuit that is a force commutation that which we use in case of the thyristors.

Forced commutated converter that utilizes switch with the gate-turn-off capability and is also known as self-commutated converters.

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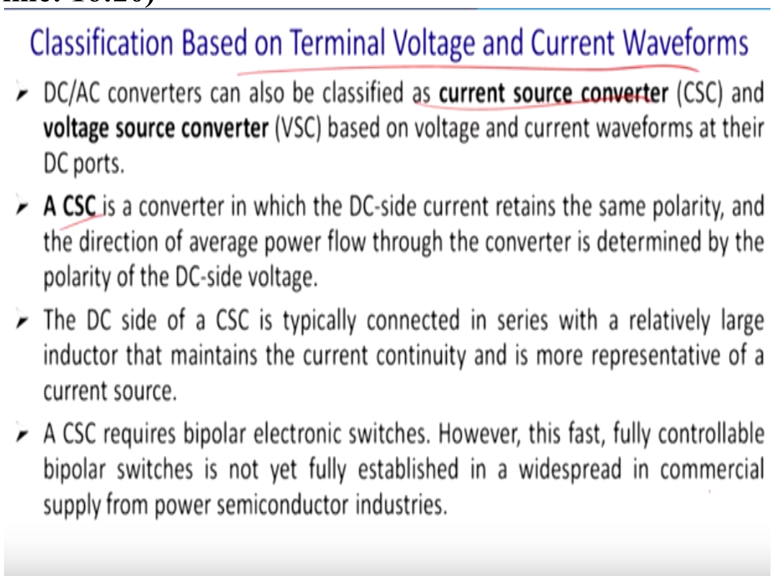

Now classification based on terminal voltage of the current waveform. DC to AC converter can also be classified as current source converter or inverter and the voltage source converter based on the voltage and current waveform in their DC port. This abbreviation is CSC, that is current control converter or current source converter is a converter in which the DC side current retains the same polarity.

And the direction of average flow to the converter is determined by the polarity of the DC side of the voltage. The DC side of CSC is typically connected in series with a relatively large inductor that maintains the current continuity and more representative of the current sources. So it will mimic the characteristics of the constant current source. So a CSC require a bipolar electronic switches.

However, the fact is that fully controllable bipolar switches are yet to be established in a widespread in a commercial range. And for this reason, we may not have this kind of current source converter and thus we see a frequent small application of current source converter. Another type is of course the voltage source converter.

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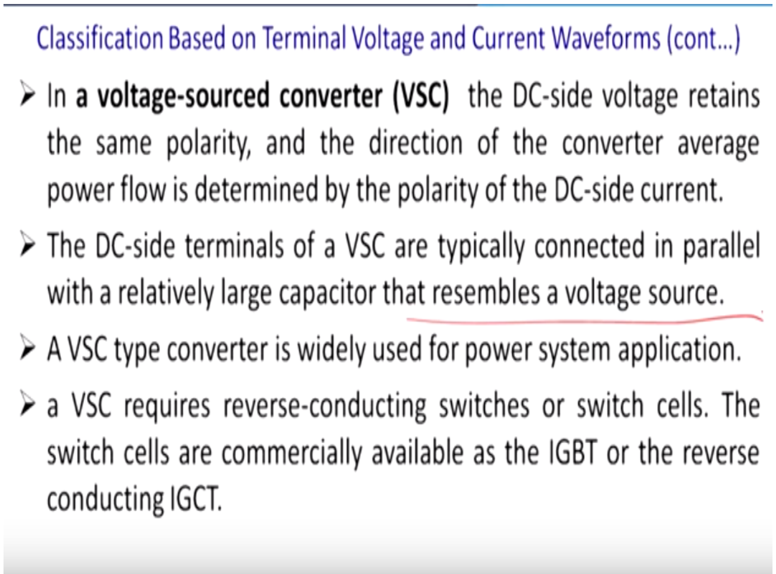

The DC side voltage retains the same polarity and the directions of the converters average power flow determines the polarity of the DC side current. The DC side terminal voltage of VSC are typically connected in parallel and relatively large capacitor that resembles a voltage source and getting this thing is also cheaper than the current source. Thus, this type, the basic type of converter is widely used for the power system applications.

The VSC requires reverse conducting switches, anti parallel switches, which sometime we say or the switch cell we call it. The switch cells are commercially available as IGBT or the reverse conducting IGBT are placed in anti parallel fashion.

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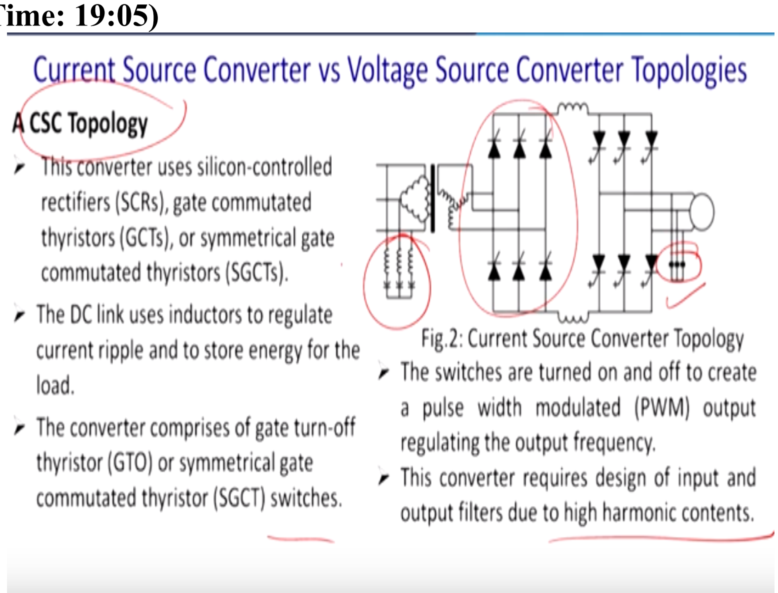

Now current source inverter versus voltage source converter topology and this is converter versus converter topology whatever you say. This converter uses silicon controlled, this current control converter topology uses silicon controlled rectifier, gate commutated thyristors or symmetrical gate commutated thyristors. The DC link uses inductor to regulate the current ripple and store the energy for the load.

The converter compromises gate thyristor generally GTO for the high power applications or symmetrical gate commutated thyristor switches. So this is applications of a current source converted typology. So here you have structured data conversion, then you have a dual converter. So it is a rectified operation, then you have the inversion operation. This inversion operation is done through GTO or SGCT.

The switch are turned and turned off to create the PWM pulse width modulation output regulating the output frequency. The converter requires to design from the input and the output filter due to high harmonic content. So these are the filter you have to place it and ultimately this will reflect back and you have to suppress filter also the input of the supply. Otherwise utilities power quality will degrade.

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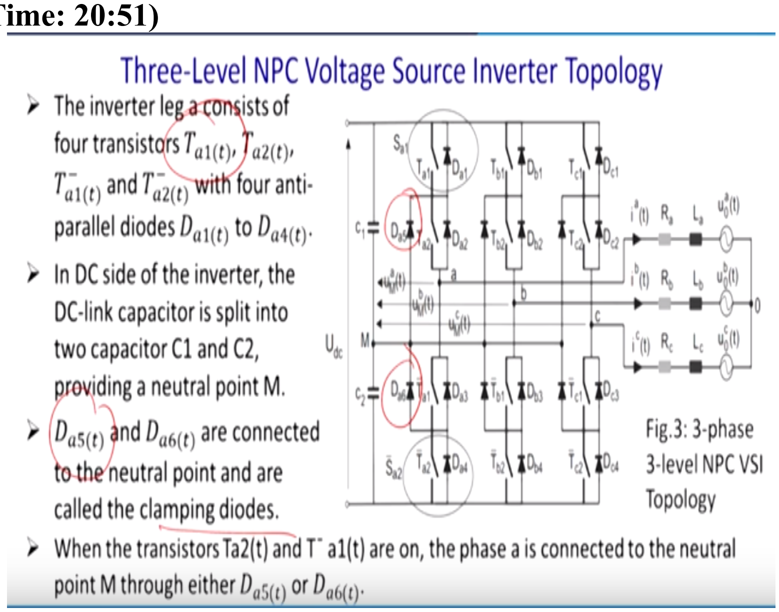

Now one of the applications that is we use very frequently that is three level NPC voltage source inverter apology. Mostly this finds application of the solar inverter and also DC to AC conversion and also you can have a active rectifier. So this inverted leg consisting of T a 1 and T a 2. Thereafter T a bar and T a 2 bar with 4 anti parallel diode that is called diode clamp system.

The DC side of the inverter, the DC link capacitor is split into the two capacitor that is C1 and C 2. D a 5 and D a 6, this two diodes are connected to the neutral point and are called the clamping diode. When transistor T a2 and T a 1 bar are on, the phases a is connected to the neutral point with M through either D 5 or D 6. And same thing happens for the other phases.

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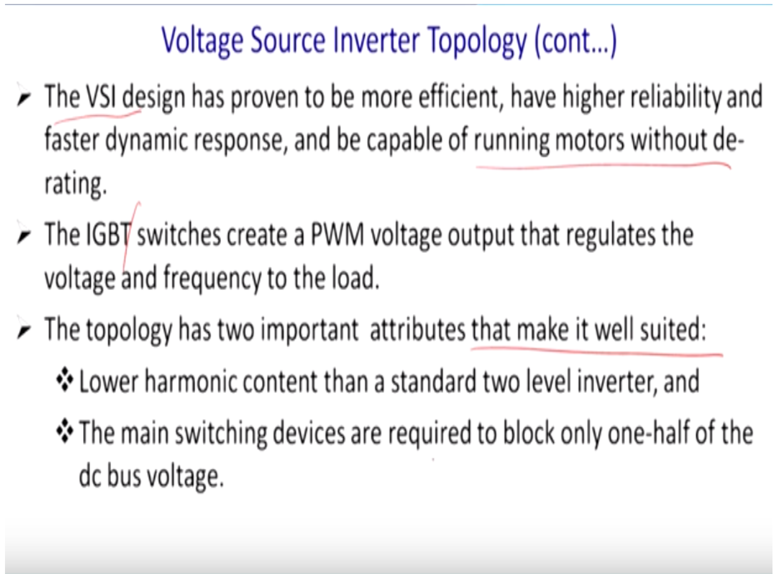

So please students are requested to refer to this multilevel diode clamp inverter. I have advanced power electronics courses. Students can refer to the courses of (()) (22:43) in advance power electronics. So due to lack of time, we are not discussing that topology here. The VSI design has been proven to be more efficient and have high reliability and faster dynamic response and be capable of running motor without derating.

IGBT or GTO whatever if you wish to have a little high frequency go for the IGBT. Nowadays with the penetration of the high bandwidth devices like SIC, we can have the IGBT switches create a PWM voltage output that regulates the voltage and the frequency to the load. The topology has two important attribute that make it well suited. Lower harmonic content that are standard two level inverter and the main switch device are required to block only one half of the DC bus voltage.

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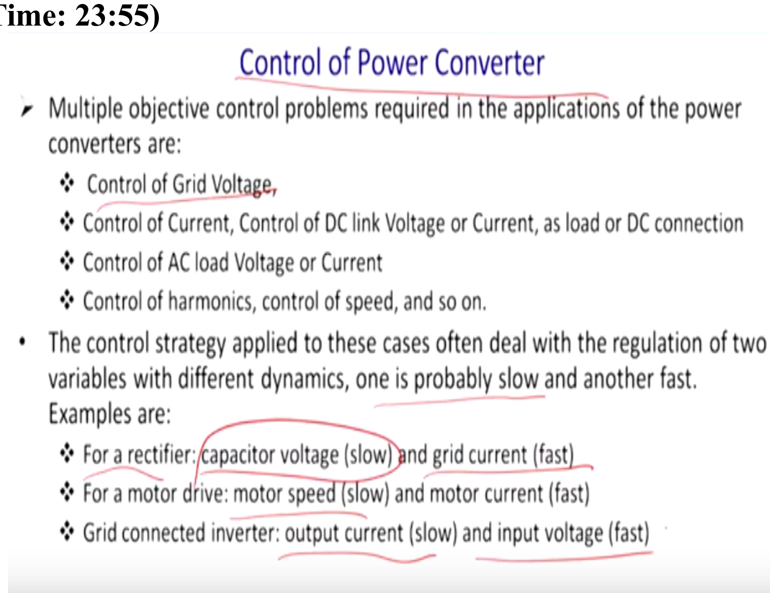

And then let us come to the control of the power electronics converter that is the heart of our power electronics. So multiple objective of control problem required in application of the power electronics converter are control of the grid voltage, sometime so that will be done by if you have a problem of power quality like sags and swells. So there are dynamic voltage regulator. Current control, control of the DC link.

Voltage or current that is active power filter required to do that as load or the DC connection. Control of AC load current. Control of harmonics, control of speed and so on. The control strategy applied to this cases often deal with the deregulation of two valuable with different dynamics. One is probably slow and another quite fast.

So generally you can see that when you are applying capacitor that is quite slow, for a rectifier capacitor voltage will be a slowly varying quantity because of the inertia of the capacitor and the grid current will be the faster, you require a faster control load, current control load, that is grid current.

Now motor drives, motor speed will be a slowly varying quantity and that will be reflected in at the back EMF and while the motor current is a fast moving quantity. Similarly, for the grid connected converter output current will be a slow moving quantity and input voltage will be a fast moving quantity. So accordingly you have to design the power loop or the control loop. Consider control of the voltage and current.

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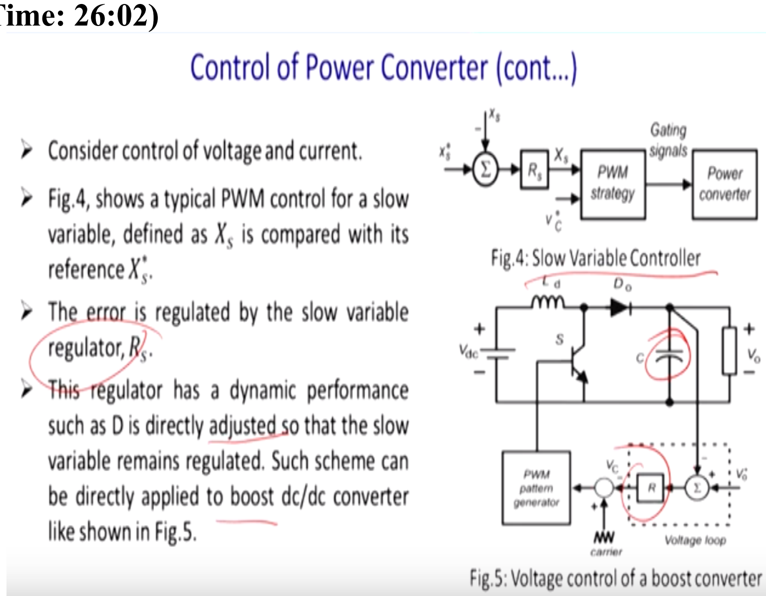

It is a, we say that current control DC to DC converter. Ultimately, you have your basically you have the voltage drop loop. Then you are comparing it and if you are feeding to the PWM converted to run this switches on and off that is slow variable control. Ultimately, you will try to control this DC bus voltage. Consider control of voltage and current.

Now this figure 4 shows the typical PWM control of the slow variable defined as X s compared with this reference X s prime. Here it is nothing but a DC bus voltage and reference AC bus voltage. The error is regulated by the slow variable regulator R s. That is the PI controller maybe. The regulator has a dynamic performance such as D is directly adjusted so that the slow variable remains regulated.

Such scheme can be directly applied to for example, this is a boost converter. It can be any other converter as shown in the figure 5. So this is called voltage mode control of DC to DC converter.

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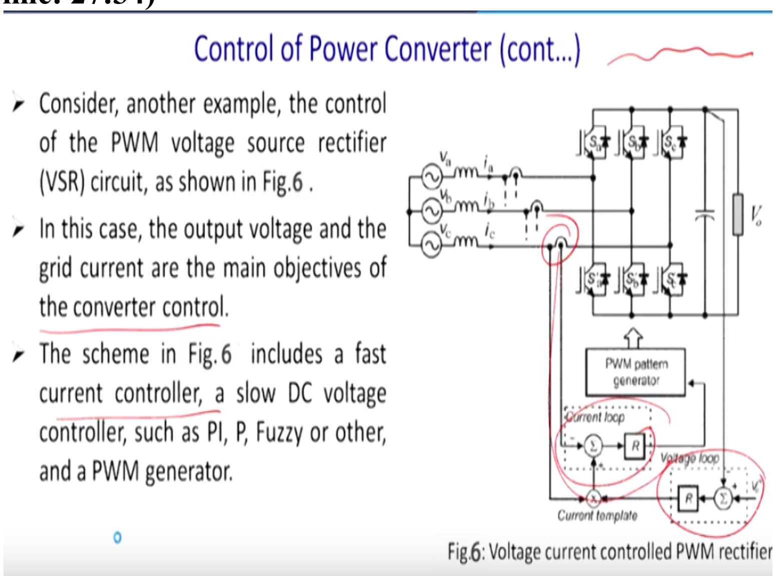

Similarly, consider another example of the control of the PWM voltage that is active rectifier we say. In this case, what happen you require to sense the voltage and you have a voltage loop and you have the inner current loop. So what happen you sense the current and you, this is the current template, and ultimately you generate that reference current pattern from this current loop.

It is called inner current loop and it is called outer voltage loop, inner current loop. Since the capacitor voltage is changing like this is a very slow device because of the high value of the capacitor. But, however, this current here it is changing very fast in sinusoidal quantity. It is in a steady state. So for this reason we require to have a very fast acting current loop and considering that you will generate the pattern.

So let us considered that in this case the output voltage and the grid current are the main objective of the converter. You require to maintain the DC bus voltage as well as you require to take power in sinusoidal in nature and unity power factor. So scheme 7 includes a fast current control. It is a inner control loop and slow voltage controller such as PI, proportional, fuzzy or other as a PWM. That can have a some computing, that is not a big deal.

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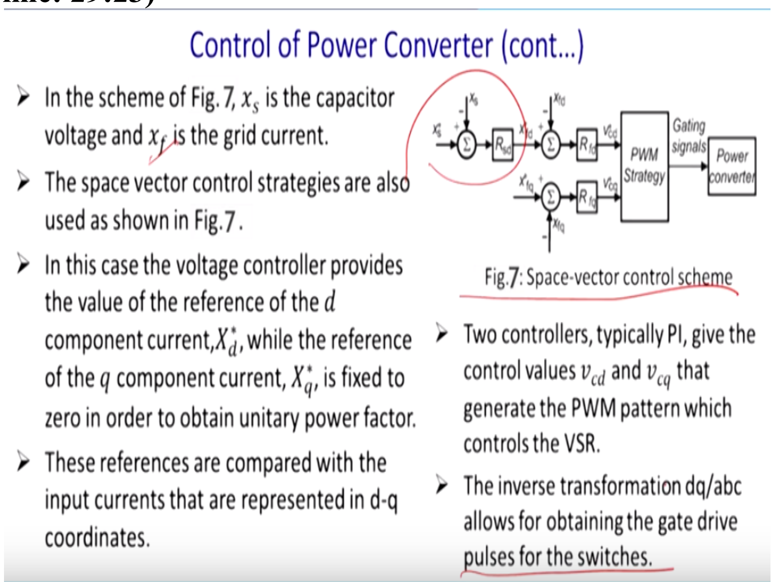

So the schemes in 8, this is the schemes on the space vector modulation mostly used for the inverter applications. x is the capacitor voltage and x f is a grid current. You see that x s you have a slow process then you generate some error. And ultimately, you have that x f and you will generate the other controller. The space vector control strategies are shown in figure 8. In this case voltage controller provides a value of the reference of the D component of the current.

X d while the reference current while the reference of the q component of this current is X q is fixed to the zero, when you want that actually just real power to be taken. If you want some amount of the reactive power you can choose the X q star as it is whatever suitable for you. This reference are compared with the input current and are represented into the d-q coordinates.

This two controller typically PI gives you the value of v cd and the v q that generates the PWM pattern and control this VSR. The inverse transform of the dq allows to obtain the gate driver or the pulses for the switches. So this is the control of the space vector modulation based technique for the active power based on the current control.

Thank you for your attention, we have discussed few control technique and try to correlate with this actual application. One is for the DC to DC converter another is for active power filter or active rectifier with the PQ control. That is a very much part of our DC microgrid system. Thank you.