DC Microgrid and Control System

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Lecture - 12
Modeling of Converters in Microgrid Power System (DC/DC Converter Modeling and Control)

Welcome to our lectures on the DC Microgrid and the control. We were discussing about the design and the modeling of DC site with the active rectifier with the voltage control voltage source sine control mode of operation. Now this class our concentration will be our designing of the different kind of DC to DC converter, designing and modeling both.

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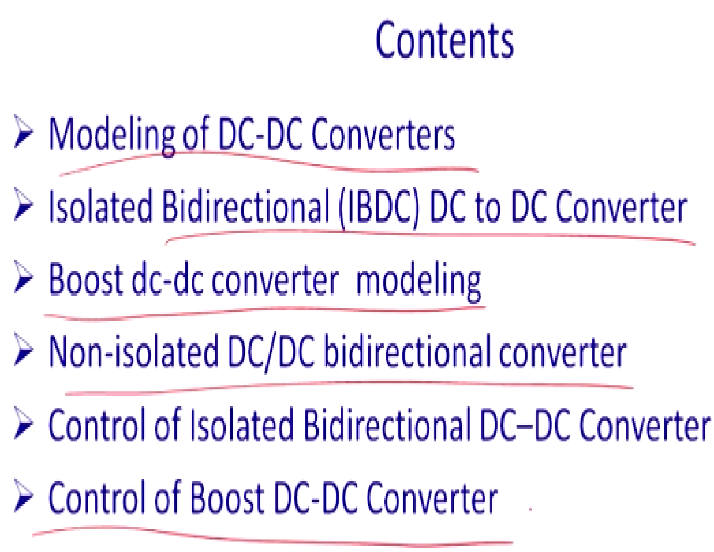

So we shall talk about modeling of DC to DC Converter, isolated bidirectional DC to DC converter, we shall talk in details. Now a days, we generally prefer high power rating DC to DC converters are mostly we require galvanic isolation and are mostly bidirectional DC to DC converter. Then we shall see also the boost DC to DC converter modeling which can be used for trapping wind energy and also non-isolated DC to DC converter and control of isolated bidirectional DC to DC control converter, control of boost DC to DC converter.

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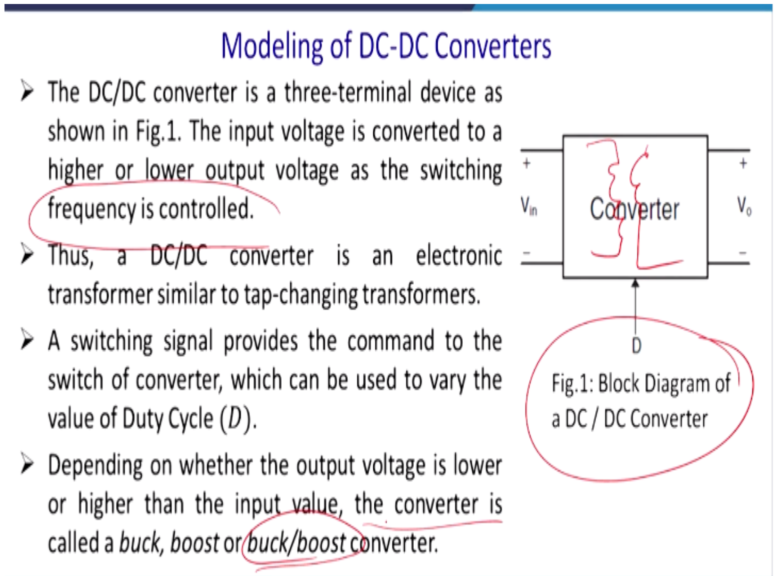

So, a DC to DC converter is a 3-terminal devices as shown in figure 1. The input terminal, the input voltage is converted into the higher or lower voltage as required lower voltage as switching frequency is being controlled. So, we will have a high frequency application in between and mostly if it is isolated converter, you will have a high frequency transformer. So, we can say thus a DC to DC converter is an electronic transformer similar to the tap-changing transformer because you can step-up and step-down.

What you can do in the voltage you can do the same thing, what is becomes AC voltages and you can do the same thing here. The switching signal provided provides a command to the switch switch of command to the switch of the converters that will come little later, which can be used to vary the duty cycle and thus control the output voltage. Depending on whether output voltage is lower or higher than the input value, you can have a buck converter, boost converter.

You can also have a flexibility to sometime, you buck it and sometime, you boost it, so you thus you have a buck/boost converter.

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- These DC/DC converters are commonly used for interfacing application in dc generating renewable sources and energy storage devices.
- The rapid development of distributed generation and energy storage has led to the increasing popularity of power conversion systems as an ever-lasting key interface.
- In DC Microgrid DC/DC converters are used for regulating the variable dc voltage in renewable energy sources (like solar and wind) whose output power is varying with input environmental conditions.
- The bidirectional DC–DC converter provides a power link between the energy storage devices and the DC bus.

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The DC Microgrid or DC to DC converters are used for regulating the variable DC voltage in renewable energy sources like solar and wind whose output power is varying with the input environmental condition. The bidirectional DC to DC converter provides a power link between the energy storage device and the DC bus.

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Isolated Bidirectional (IBDC) DC to DC Converter

- Fig. 2 shows the topology of dual active bridge isolated bidirectional DC/DC converter (DAB-IBDC), which composes of two full-bridge converters, two dc capacitors, an auxiliary inductor, and high-frequency (HF) transformer.
- The HF transformer provides the required galvanic isolation and voltage matching between two voltage levels.
- The auxiliary inductor serves as the instantaneous energy storage device.

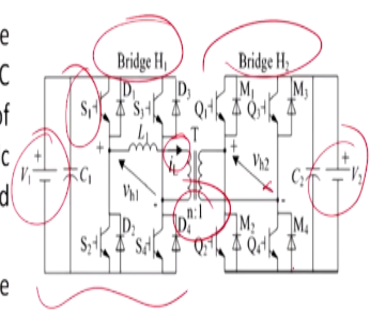

Fig.2: Isolated Bidirectional DC/DC converter topology

Isolated bidirectional DC to DC converter. This figure shows that this is a full-bridge topology, this is a it is called dual active bridge isolated bidirectional DC to DC converter. This is the abbreviation of it DAB-IBDC which composes of the full-bridge converter, to DC, two DC capacitor, an auxiliary inductor and high-frequency transformer. The HF transformer provides the required galvanic isolations and that is required to protect input to the output and vice versa and voltage matching between the 2 voltage levels.

Also if this ratio is very high then around 10, then problem lie is this control becomes very difficult with the non-insolated DC to DC converter because you will have an operation that is only very small region and thus you may require to transfer some of the burdens in a ratio. For this reason, it has a flexibility, you can control also that is a duty ratio as well as you can control the turn ratio. The auxiliary inductor serve as the instantaneous energy devices.

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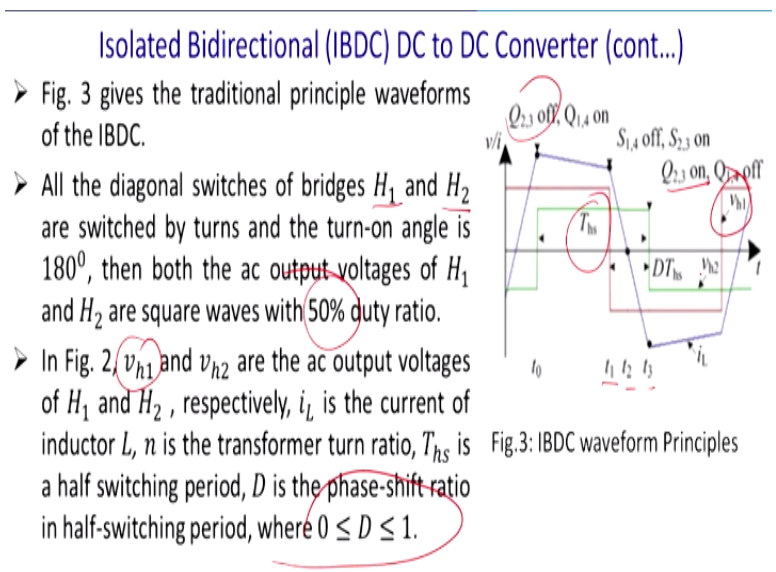

So we can see waveform. Figure 3 gives the traditional principle of the waveform of IBDC. So you can see all the diagonal switches of the bridge H1 and H2 as switch by turns and turn-on angle is 180 degree, then both the ac output voltages H1 and H2 are the square wave with assume that with a 50% duty cycle. In figure 2 you have seen that Vh1 and Vh2 are the ac output voltages of H1 and H2 respectively and L1 is the current of the inductor L and n is the transformer turn ratio.

Ths is the half switching period, D is the phase-shift ratio in half switching period where D is within 1 where D is the turn on by turn off. So you can see that in this region when current rams on, so you can see that Q1, Q3 are off and Q3, Q4 on. Similarly here S1, S4 are off and S2, S4 are on, similarly here Q2, Q3 are on and Q1, Q4 are off. This one is Ths and in this region is t1, t2, t3 and essentially this is a current so the inductor because you have an auxiliary inductor placed in the transformer this is essentially the same.

This one this red line is essentially Vh1 and this green line is Vh2. Let us go back so this is iL. This voltage is Vh2, this voltage is Vh1 and these sides are named S1, S3, S2, S4, S is called is the primary side or named as bridge 1 but it is bidirectional, you can convert power this side to this side and vice versa. It is a typical case of battery charging applications you may feed it from the grid or you can also of the great you can also take it power from the grid and you got a bridge H2, you have this reference.

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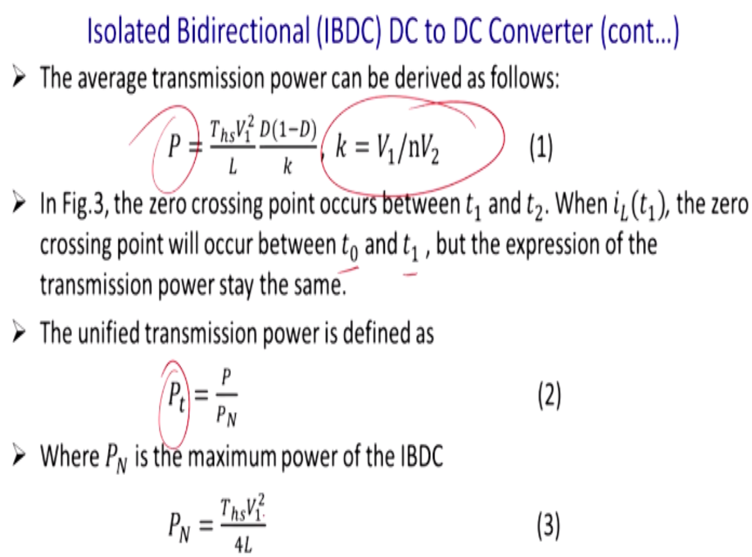

So in the average transmission, the power can be derived as follows, that is P = TshV1 square/L D(1-D)/k where k is essentially given by it is coupled with the turns ratio, k = V x n x V where n is n1/n2. The figure 3, the zero crossing output occurs between t1 and t2 when iLt1 is 0, crossing point occurs between t0 and t1, but the expressions of the transmission's power stay the same. The unified transmission power is defined as Pt = P/PN where PN is the maximum power of the IBDC and is given by TshV1 square/4L.

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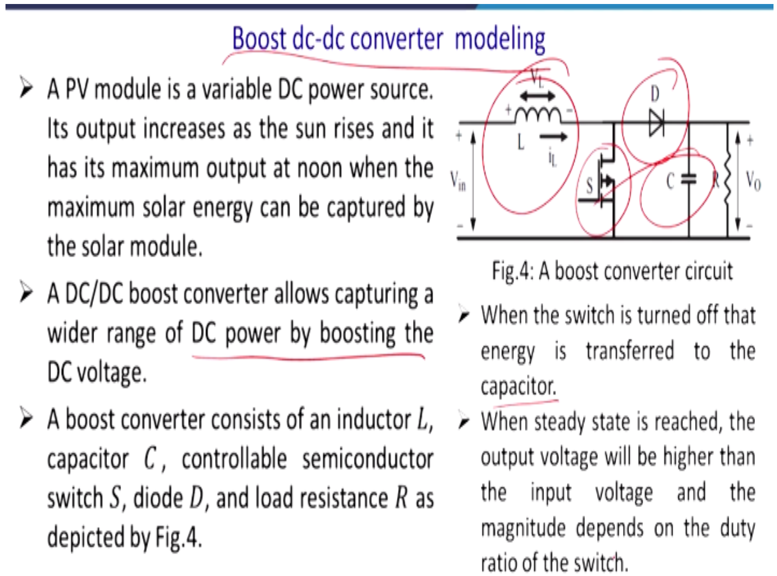

Now let us model, we have already modeled bidirectional DC to DC Converter. Now let us come to the modeling of the non-isolated DC to DC converter namely the boost converter and you would saw in many application in case of the DC microgrid kind of application because you have a you have a wind turbine that will be generating a variable frequency DC, you require to track the MPPT and thus you have kind of converter to be placed or a PV module you require to boost it and also require to track the MPPD to feed the inverter voltage, there also this can be used.

A PV module is a variable DC voltage source. Its output voltage increases as the sun rises and it has maximum output at noon when maximum solar energy can be captured by the solar module. A DC to DC boost converter allows capturing a wider range of DC power by boosting the DC voltage. A boost converter consists of an inductor L, capacitor C, controller semiconductor switch S, diode D, and load resistance R as depicted in the figure. So, this is the inductor, this is the diode.

This is the switch. Depending on the switching frequency and power handling capability, it can be (( )) (12:23) most spread, this is a capacitor and resistance. When the switch is turned off, the energy is transferred to the capacitor. When a steady state is reached, the output voltage will be higher than the input voltage and the magnitude depend on the duty ratio of the switch.

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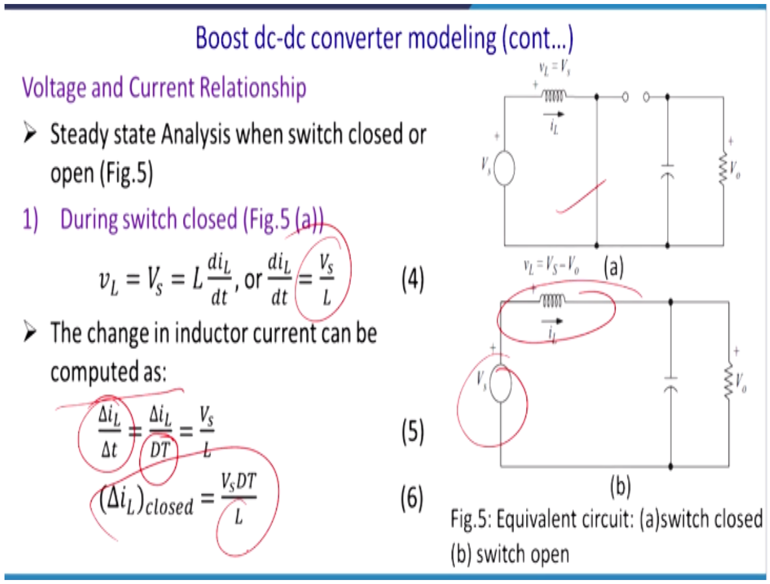

Voltage and current relationship, the steady state analysis of this boost converter. Now when the switch is, one this stage the switch is closed, another stage is switch is open. When switch is closed that means that this switch is closed and that what happened, this point voltage is becoming 0 and this is higher and thus this diode become reverse bias and in terms so in this is the duration when switch is closed. So VL = VS = L di/dt = di/dt = Vs/L.

Similarly, when switch becomes open, the voltage of the source and the energy stored of the voltage across this inductor as shown to be VL, so both will sum off and will charge the battery or the capacitor. So charge the change in the inductor current will be as can be computed del L/del t = you can replace del t as D of T that essentially is Vs/L, so iL closed equal to that is the ripple current present into the inductor will be VsDT t x L, so this is the relation between the current ripple and the different parameter associated with the boost converter.

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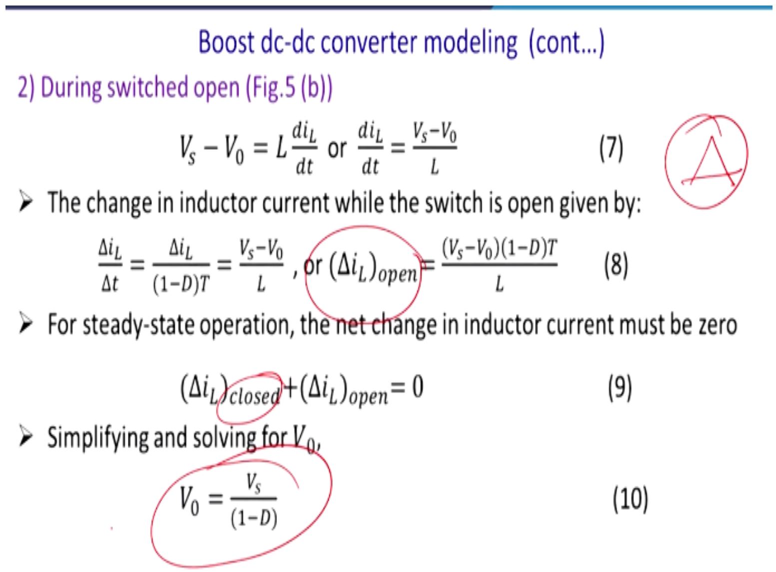

So Vs-V0 = Ldi/dt and during this is open circuit, so you can rewrite this equation as VL di/dt = Vs-V0 and thus the change in the inductor current also you can compute so that will be the for the open case will be (Vs-V0) (1-D) T/L. So for the steady state of operation, we have we know that this ripples, for there we will have positive ripple and the negative ripple, and ultimately average inductor current even same considering that this iL delta open and iL delta close should be equal to zero and you can simplify this equations and we can rewrite that V0 = Vs-Vd.

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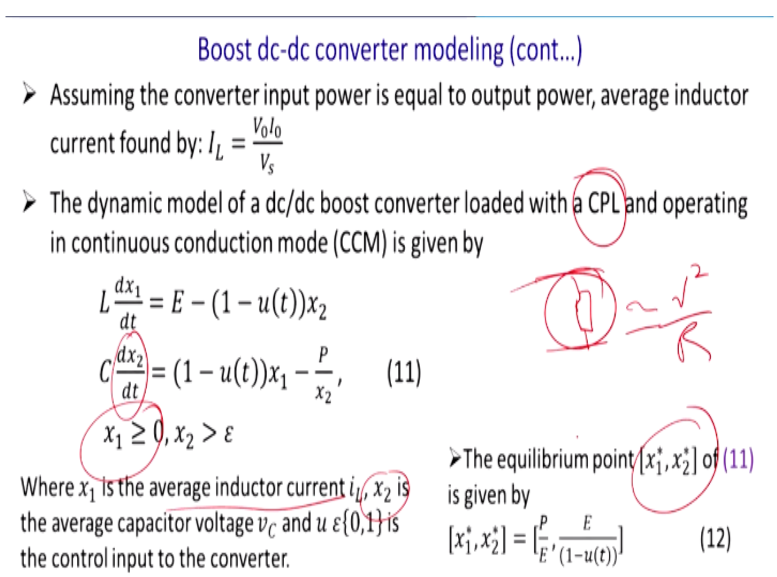

So, assuming this converter input power is equal to the output power, the average inductor current is found by IL = V0I0/Vs. The dynamic modeling of DC to DC boost converter loaded with a constant power load that is something we required to be think of, then only once we have parallel circuit within that load is connected if voltage drop what is generally reduced because it is basically proportional to V square/R and operating the continuous conduction mode or CCM, so you can write it down L dx/dt = E- (1-u) x2, similarly d2x.

Similarly, for the other parameter of the continuous current mode, it will be 1-ut x x1-Px, so where x1 and x2 should be, x1 is greater than 0 then x2 should be a small number. Now we now we define x1 and x2 where x1 is the average inductor current which is greater than 0 and x2 is the this is the these are called state entities that is the voltage across the capacitor and the current through the inductor, x2 is the average capacitor voltage vc and u is the controllable input of the converter essentially this is switching.

The equilibrium point so x dot 1 and x2 dot 1 is given by definitely pv and it is 1-E of P. So this is the modeling of the DC to DC converter and modeled in the it is called average mode of modeling and we require to compute the different mode of operation and it is works fine and you have this ratio holds good considering that it is in a continuous mode of conduction. Briefly we will have to touch up on these things because we cannot go to the detailed modeling, you would have required to refer to the DC to DC converter book.

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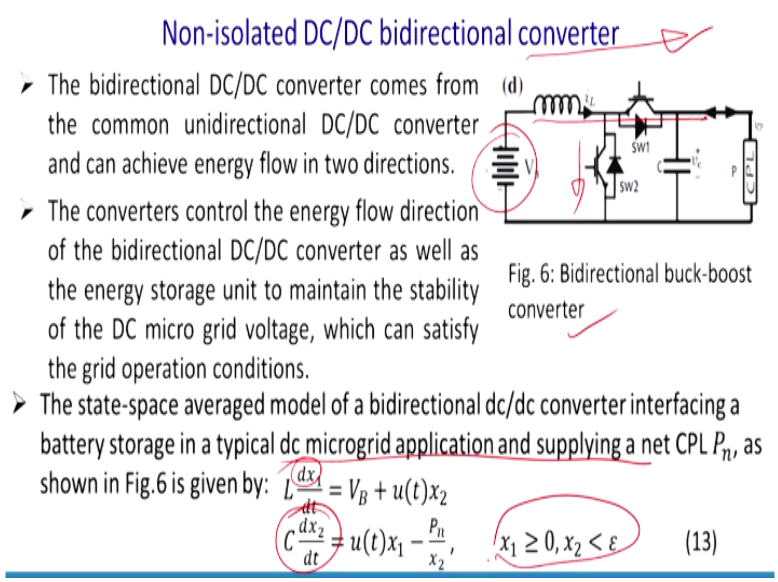

So now let us talk about another DC to DC converter which will be used in bidirectional operation. So, you can transmit power at the direction from battery to the load and load itself can regenerate and send you the sent back the power. The bidirectional DC to DC converter comes from the common unidirectional DC to DC converter and can achieve energy flow in the bidirectional way.

This converters control the energy flow direction of the bidirectional DC to DC converter as well as the energy storage unit to maintain the stability of the DC microgrid voltage which can satisfy the grid operation condition. Once you try to send the power, generator will be operated into the boost mode, so this power you require to switch it on and ultimately energy will flow this point to this point. Once you try to send power this point to this point, it require to buck it, you can see that is a buck operation and power can be sent back through this switch and the diode and this has a complementary logic.

The state-space average model of bidirectional dc to dc converter interfacing a battery storage typically is d microgrid application can supply a net constant power load Pn as shown in this figure here. So you can write that we had we know that current through the inductor we have considered x1, so same logic has been used here; L dx1/dt = VB + u t x x2, so that depend on the on and off of the switch. Similarly, C dv/dt that is written as Cdx2/dt = ut x x1 – Pn/x2, so same condition holds.

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- Where V_B is the nominal battery voltage, x_1 is the average inductor current i_L, x_2 is the average capacitor voltage v_C and $u\ \varepsilon\{0,1\}$ is the control input to the converter.
- Assuming that the system on the right-side of the converter consists of both CPLs and constant power sources (CPSs), the net load power P_n can be positive or negative. The equilibrium point $[x_1^*, x_2^*]$ of (13) is given by:

$$[x_1^*, x_2^*] = [\frac{P_n}{V_B}, \frac{V_B}{u(t)}] \qquad (14)$$

- When P_n is positive (discharging mode), and when $P_n < 0$ (charging mode).

Where VB is the nominal battery voltage, x1 is the average inductor current iL, and x2 is the average capacitor voltage vc and u is the control input to the converter. Assuming that the system on the right hand side of the converter consists of both CPLs and constant power source, the net load power Pn can be positive or negative. The equilibrium point x1 and x2 definitely will can be recalculated and you can find out x1 and x2 = Pn/VB and VB/ut, where Pn is the Pn is positive in discharging mode and where Pn will be negative in charging mode.

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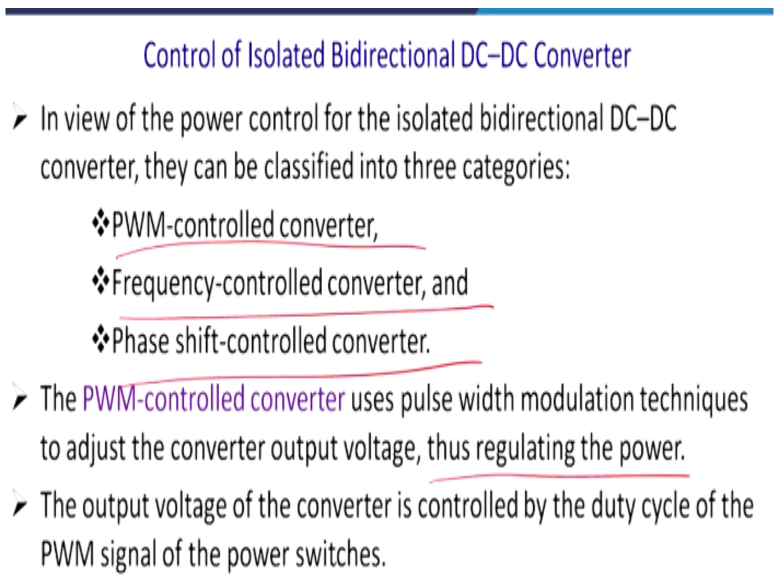

So now come to the control of isolated bidirectional DC to DC converter. So in view of the power uh power control of the isolated DC to DC converter, they can be classified as PWM-controlled converter, frequency-controlled converter, and the phase shift-controlled converter. So PWM-controlled converter uses a pulse width modulation technique to adjust the converter output voltage, thus regulating the power, and second one the output voltage of the converter is controlled by the duty cycle o by the duty cycle of the PWM signals of the power switches.

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- The frequency-controlled converter uses the operating frequency to control the power transfer.
- This type of converter usually contains a resonant tank which can suppress the undesired frequency components to regulate the output gain.
- The duty ratios of the PWM for all the switches are fixed as 50%, and the operating frequency is changing according to conversion gain of the converter.
- Resonant converter is a very good candidate for the fixed voltage gain applications since it can achieve very high efficiency when it operates at the resonant frequency.

Next is the frequency-controlled converter uses operating frequency to control the power transfer. This type of converter usually contains a resonant tank which can suppress the unidir the undesirable frequency component to regulate the power gain or output gain. The duty ratio of the PWM for all the switches are fixed around 50 cycle percent and operating frequency changes is actually is changing according to the conversion gain of the converter.

The resonant converter is a very good candidate for the fixed voltage gain applications since it can achieve very high frequency, very high efficiency when operate at the resonant frequency.

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- The phase shift-controlled bidirectional DC–DC converter is mainly used for different kinds of dual active bridge converter.
- The power-flow direction and magnitude can simply be controlled by adjusting the phase shift between v_{h1} and v_{h2}.
- The converter in phase-shift control can be represented by a simplified scheme comprised of two square waves voltage sources linked by an inductance.

Now let us come to the phase shift-controlled bidirectional DC to DC converter. It is mainly used for a different kind of dual active bridge converter. The power flow bidirectional and the magnitude can be simply controlled by adjusting the phase shift between the vh1 and vh2 which you have seen in the figure previously. The converter in phase-shift control can be represented by a simplified scheme comprised of the 2 square voltage sources linked by the inductance.

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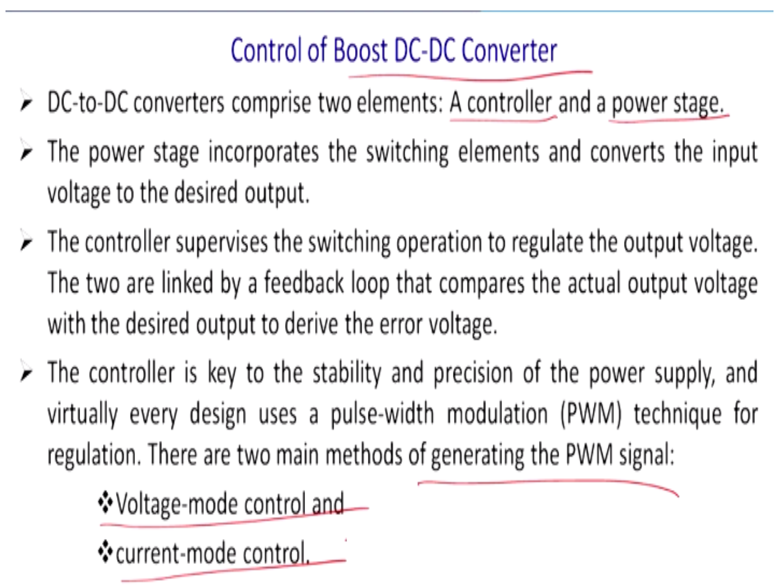

Now let us come to the next topic that is control of boost DC to DC converter. The DC to DC converter comprises 2 elements, one if controller, another is a power stage. The power stage incorporates the switching element and converter the voltage to the desired output level. The controller supervises the switching operation to regulate the output voltage. The 2 are linked by the feedback loop that compares the actual output voltage with the desired output voltage to deprive the error voltage.

The controller is key to the stability and precision of the power supply and virtually every design uses a pulse-width modulation technique for regulation. There are 2 methods of generating the PWM signal. One is we shall discuss voltage control modem, another is definitely the power control mode.

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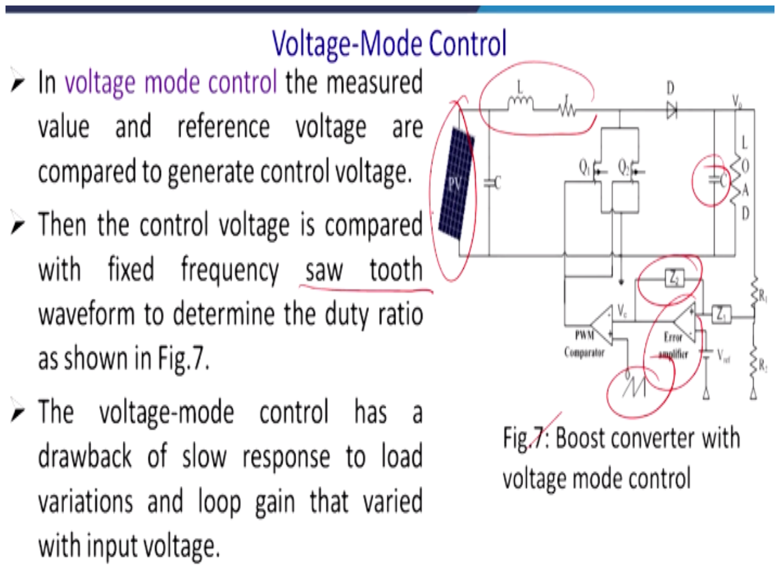

Fig.7: Boost converter with voltage mode control

So this is the voltage controlled mode. You have a solar PV panel where we have taken a practical application, we have to require to maintain the regulated voltage to the load. The voltage mode control is measured value and the reference voltage are compared to generate the control voltage. Then the control voltage is compared with fixed frequency, saw tooth waveform to determine the duty ratio as shown in the figure 7. So, this is the PV panel, then you have an input capacitor, then you have an inductor and thereafter you have both the switches.

It can be entirely power converter or required to increase the current rating may be due to that reason you require the 2 switches, then followed by the diode and ultimately you will have the reference signal, reference voltage here, and that can be compared with actual voltage and this si essentially error amplifier, error amplifier may be made to the PI controller by connecting a capacitor and with a resistance so that as a with a particular bandwidth. Then it is compared with the a saw tooth wave and the saw tooth wave is fed to the with a limiter.

It will be fed to the switches to control the duty cycle of this Q1, Q2 and thus voltage will be maintained here, but only the disadvantage. One of the advantages of this thing is that very easy to implement, disadvantage is that it does not have a inbuilt short circuit protection. So the voltage mode control has the drawback of the slow response to the load variation since this capacitor will be there, it will change slowly, it won't act fast and loop gain that varied with the input voltage if the voltage if the input side is running, then there is also problem of this control.

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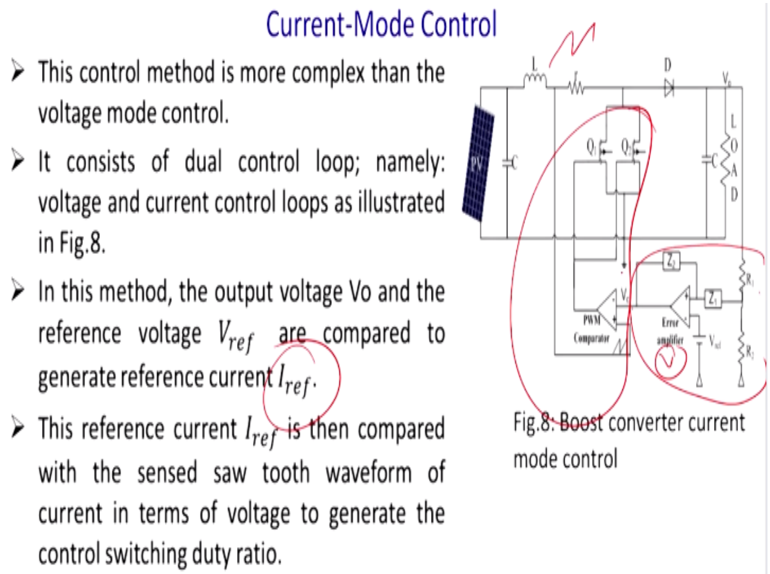

So in addition to the voltage control, you can have another loop that is called, this part is same as a voltage control that you have a this is called, there are 2 kinds of control, one is average current control mode, another is peak current control mode. This control method is more complex than the voltage mode. It consist of the dual control loop, namely the voltage and current control loop as illustrated in figure 8. This part of the control is the voltage control and this part is the current control.

In this method, the output voltage V0 and the reference current Vref is compared to generate the reference voltage Vref. The reference current Iref is then compared with the same saw tooth waveform current from the voltage to generate the switching ratio. So here since it will be peaky, so this current is checked in and is compared with the actual reference.

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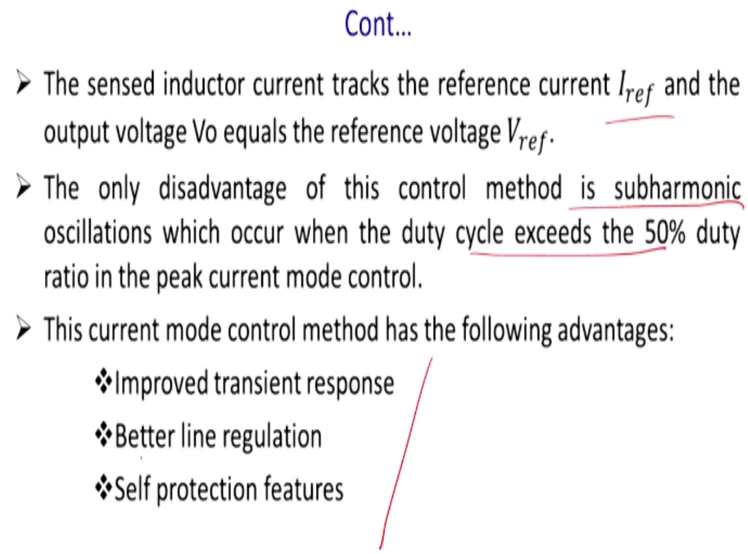

The sensed inductor current tracks the reference current Iref and the output voltage V0 equals to the V reference. There is a disadvantage, only disadvantage of the control method is that subharmonic oscillations canvas all those things, the nonlinear phenomena occurs, which occurs when duty cycle exceeds the 50% of the duty ratio in the peak current mode control. These are also control challenge. This different mode of control method has.

These method has the following advantage; that is improved transient response, better line regulations, self-protection features, it is inherently protected from the short circuit which you seen were absent in the voltage controlled mode and compact sizing. These are the few things and designing is simpler. So, considering that, we generally prefer self-mode current control. Thank you. Thank you for the attention. We shall continue through our discussion with DC Microgrid. I hope that these discussions were very useful to you. Thank you.