Advance Power Electronics and Control
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Lecture 25
Isolated DC- DC Converters IV and VSI & CSI

Welcome to our NPTEL courses on Advanced Power Electronics and Control. Today first, we will discuss with isolated DC-to-DC converter that is the remaining part of the isolated DC-to-DC converter. We have discussed a brief configuration, we have discussed slide back, thereafter we have discussed the forward, thereafter we have discussed push pull and we have discussed also the half bridge and then we shall do the another topology, that is called the full bridge.

Then, we shall switch over to the DC-to-DC application essentially that will be the inverter application and we know that there will be 2 kinds of inverter that is VSI, voltage source inverter and current source inverter and different kind of PWM technique associated to it. Okay, let us start. So these configurations you know, we have discussed in our previous class. We just little bit of recap that it is a half bridge configuration.

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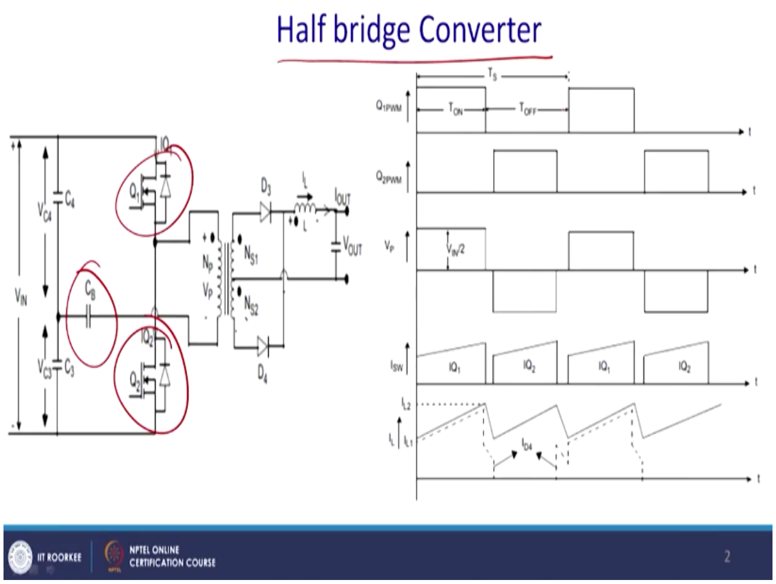

So since you are doing the bucking operation, so beam essentially you will get the half of the voltage and also you can control over the trans ratio as well as you can actually have a duty cycle. So you have multiple advantages, once you have bucking through the half bridge converter, but one essential disadvantage of it is that sometime, there might be mismatch between these 2 switches.

So this small mismatch over a period of time may actually lead to the saturation of this transformer, because of that there will be average DC in every cycle and that will be a cumulated over cycles and that will be returned to the structurally DC passing of the transformer and it may saturate. For this is what we required to give a blocking capacitor which will block the DC part into the transformer.

So essentially this is the Tn time of the ICBT or mass spread depending on rating and nowadays actually high band width devices are coming like SiC and GaN devices, so this rating can go high to the 3 times more as well as the switching frequencies. So again this is the second PWM and we have actually the BP that is across this transformer that is Pn/2 and accordingly this area has to be matched with this area, that is essential purpose of it.

And the current through the switches are essentially from Q1, then actually the diode conducts for the period. When it is off, we assume that continuous conduction mode and thus this region actually current drops into the circuit. Please remember that in power electronics positive time is associated with the switch and negative time associated with the diodes. So this is the time where actually that diode conducts.

And also in this case, you can see diode D3 and D4 conduct depending on the different criteria and this is the current through the inductor and we will have a ripple. That ripple will be suppressed by this capacitor. So what essentially you get here. What is the advantage over the other topologies that is actually we have discussed slide back, thereafter we discussed forward, thereafter push, pull, then it is this.

One of the advantage is that its power-handling capability can be very high because you can actually, there is no concept or resetting flux. You are resetting flux in every cycles and thus we need not to have a resetting, winding and stresses across the switch also will be low. Now let us see that the advantages of this half bridge converter.

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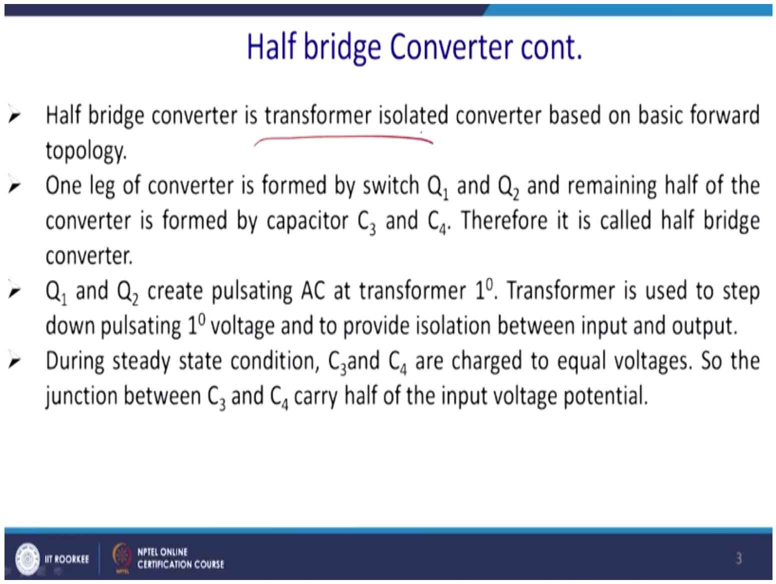

Half bridge converter is the transformer isolated converter based on basic forward topology that is actually dots or at the same point of the forward topology. The one leg of the converter is formed by switch Q1 and Q2 and remaining half of the converter is formed by C3 and C4. Therefore, it is called half bridge converter. Q1 and Q2 creates a pulsating exit to the transformer. Primarily transformer is used to step down mostly of the pulsating primary winding voltage.

And also provide isolation between the input and the output. During steady state condition, C3 and C4 are searched to the equal voltages, so that these junctions C3 and C4 carry half of the input voltage potential. So that is something you require to remember it.

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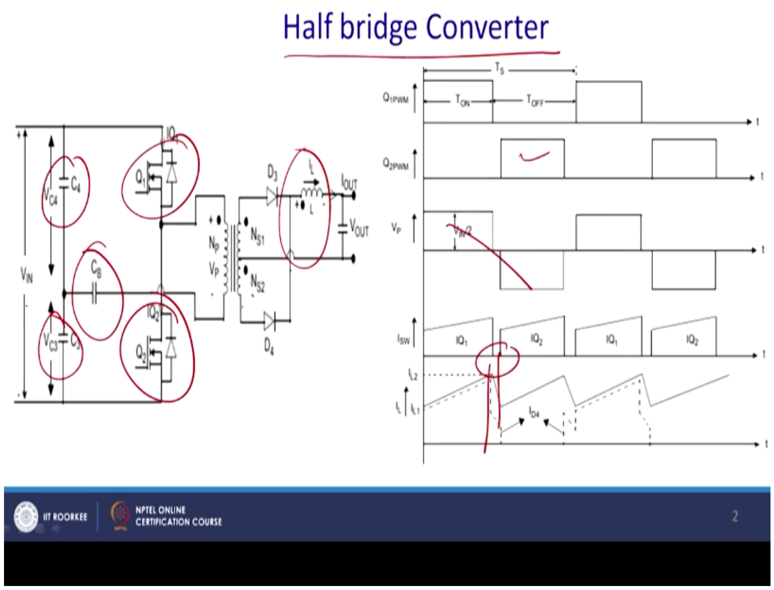

So these 2 voltages are equally divided, otherwise you have to provide the potential divided network by connecting a small resistance in series with them.

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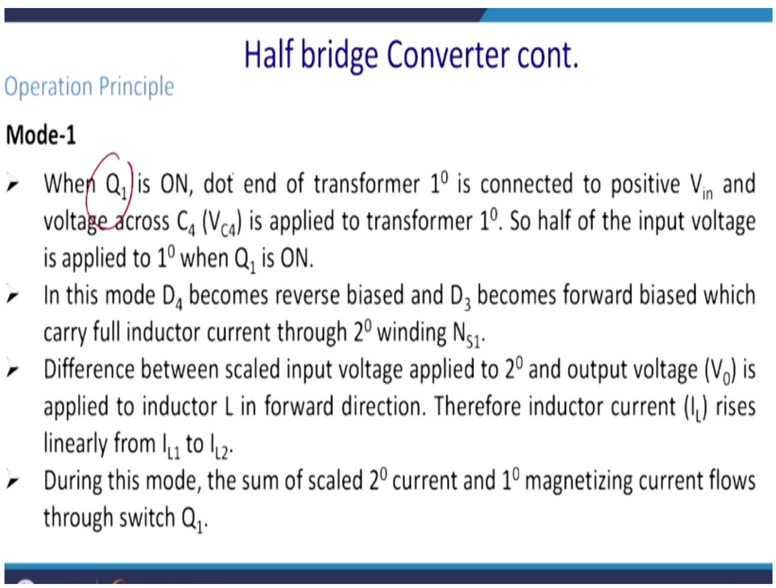

So what you can do here when Q1 is on, the dot end of the transformer is connected to the positive beam as switch on and the voltage across actually C4 is applied to the transformer primary, so half of the input voltage is applied to the winding when it is actually Q1 is on and that is the positive half of the cycle. In this mode, D4 become reverse bias and D3 becomes forward biased, which carry the full inducted current through the winding 2 for the winding NS1.

Difference between scaled input applied to the secondary 2 and then output voltage is applied to the inductor in the forward direction. Therefore, the inductor current IL rises linearly from L1 to L2 within the limit prescribed by the designer. During the mode, sum of this scaled secondary current and primary current flow through the switch Q1. This mode starts with end of T on period. In this mode, Q1 is turned off till end of the switching cycle TS.

Q2 is turned on after half of the switching period TS/2. Therefore, during T1/2 period or some of the both of the switches off as shown in the waveform. When Q1 is off body diode of Q2 provides path for the leakage stored in the transformer primary and D4 become forward biased. As D4 become forward biased, half of the inducted current flows through D4 NS2 and other half of the inducted current flows through D3 and NS1.

Therefore, equivalent opposite voltage is applied both the transformer secondary winding assuming both the winding have the same number of turns. As a result, the net voltage across the secondary becomes 0 and it maintains a flux flow conditions.

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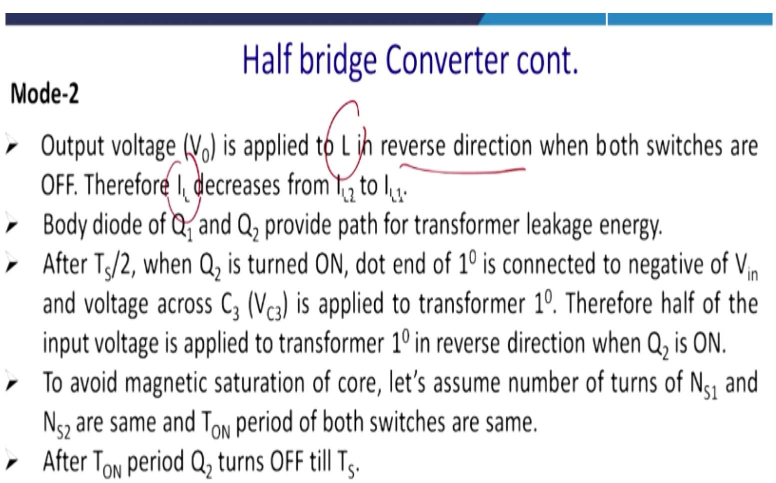

And this second mode is the mode 2. Output voltage is applied to the inducted L in a reverse direction when both the switches are off. Therefore, inducted current decreases from L2 to L1. Body diode of Q1 and Q2 provide path for transformer leakage energy. After TS/2 when Q2 is turned on, dot N of transformer primary is connected to negative Vn, input voltage is applied to the transformer in primary in reverse direction when Q2 is on.

To avoid magnetic saturations of the core that assumed the number of turn of NS1 and NS2 are the same and turn on period of the both the switches are same. After T on the period Q2 is turn off till the value complete the duty cycle, that value corresponds to TS.

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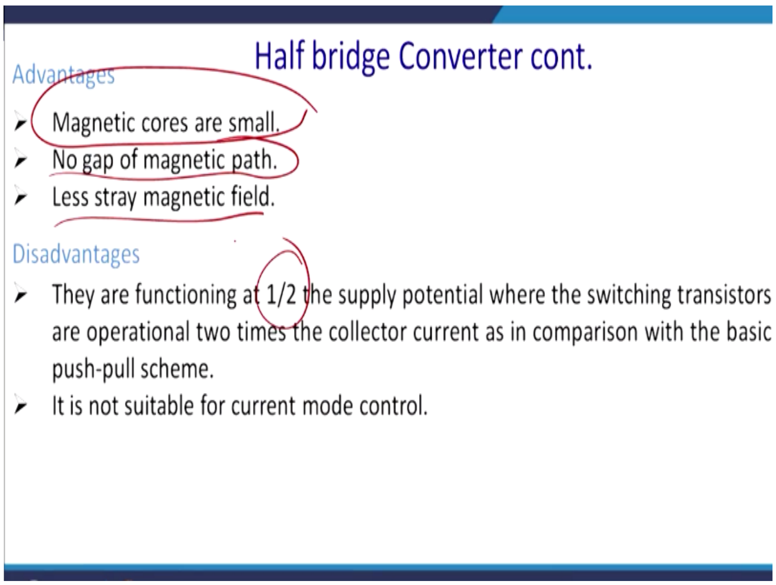

So what is the advantage, Advantage over the predecessors, these are flyback, forward, push, pull. You will find that magnetic core is small, so you can actually in a same size you can handle big amount of power handling capability, thus energy density is more. No air gap in the magnetic path. So designing of this transformer is much easier than the flyback. Less stray magnetic field because you are resetting the actual magnetic field by standing on the Q1 and Q2.

Disadvantages, this is not disadvantage. We must say it is limitation, they are functioning half of the supply potential where switching transistors are equal to 2 times of the collected current as comparison to the basic push-pull scheme. So this is the 1 of the things you have to keep in mind reverting of the switches and we will discuss little later, it is not suitable for the current mode control. Current mode control means actually there are 2 kind of current mode control.

We have already discussed, one is peak current mode control, another is average current mode control. So in this current mode control, it cannot be operated. So it will be more suitable for the voltage mode control.

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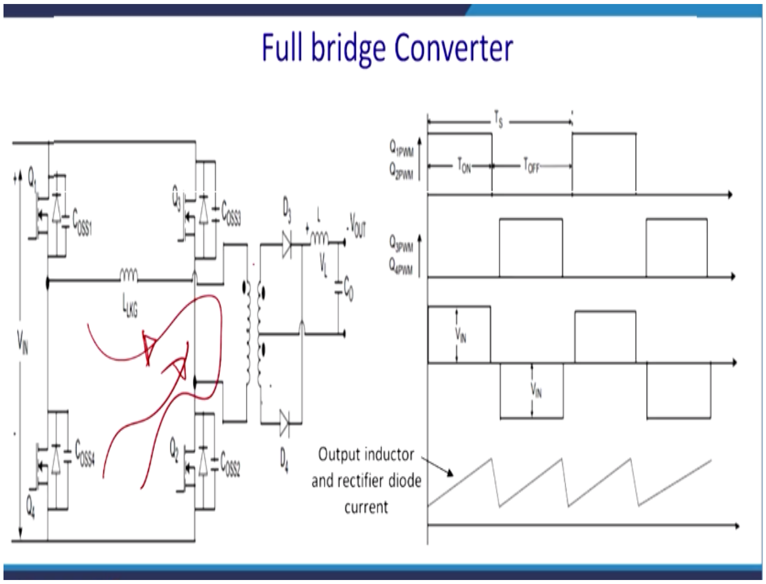

Now let us see the full bridge configuration. In this configuration, actually it will be replaced by the 4 switch. Thus actually when Q1 and Q2 on, then actually current flows this way. When Q3 and Q4 is on, current flows in this way. So it is a normal transformer operations or the inverter operation. So what happen here, you know, it is quite simple in the sense and it has the maximum power handling capability.

And what happened here where the transformer gets the whole voltages and thus you can have a better utilizations of these voltages and mostly this is applied for the high power applications and core is the smallest considering the KVA rating of the transformer and here what happen generally, this kind of, since we have all the problem while starting, we have said that isolated DC-to-DC converter has few drawbacks.

We have to mitigate the drawbacks by taking a proper action. First of all, we have to reset the flux. Since we cannot use DC in transformer, there since you have an incorporated a DC transformer into it, so we have to see that in every cycles, high frequency cycles, flux gets resisted. Here you can reset the flux and since Q1 and Q2 conducts, there will be a gap, while diode will conduct and thereafter again Q3 and Q4 conducts.

So automatically flux will reset in all the places and there is a huge rating it actually, it can handle rating same of the supply voltage. So another aspect is that actually switching stress across the devices since both the switches are opposing, this actually this voltage. So voltage stress across the switch is minimum compared to this all other circuit where you have employed the resetting circuits and also here you will get maximum power.

Here you get instead of VN/2 here you get total VN. So these are the few advantages and thus what happen, so once you have actually reduced the voltage rating of this transformer automatically you require to increase the current rating of the switches, that is one of the drawback of the half bridge converter, because here you get VN/2 automatically instead of I1, the 2I current will flow.

So current handling capability to have the same power rating, power handling capability of those device required to be doubled, but here current handling capability of the device is half compared to this half bridge converter. So these are the few advantages of the full bridge converter. Let us analyze it. Very simple to analyze, so once actually you have T1 and T off consequently pulses will be there. So you will get this voltage and you can see that your stress across the voltage is VN.

Please note that actually once it is off, it is blocking the voltage that value equal to basically the interim put supply voltage and this is the output inductor current here and we assume that this actually the current is continuous and please note that these two switches both jointly blocking the voltage B. So stress across the individual switch will be the half of the voltages.

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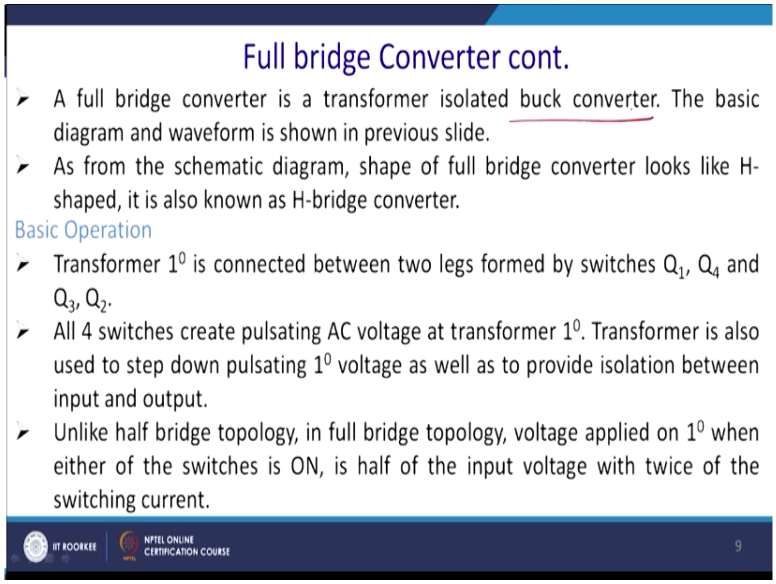

So full bridge transformer is isolated buck converter. So you can buck the voltage since you cannot increase the duty ratio more than 1. The basic diagram of waveform is shown in the actually the previous slide. As per the schematic diagram, the shape of the full bridge converter looks like the H and for this is called H bridge converter. Basic operation is almost same. Transformer primary is connected between the 2 legs and by the switches Q1 and Q4 and another is Q3 and Q2.

All the switches creates a pulsating AC transformer. Primary transformer is also used to step down pulsating voltage as well as to provide isolation between the input and output. Unlike half bridge topology, in full bridge topology, the voltage applied on transformer primary when either of the switches is on is half of the input voltage with twice of the switching current where voltage stress of the switch is twice of the input voltage.

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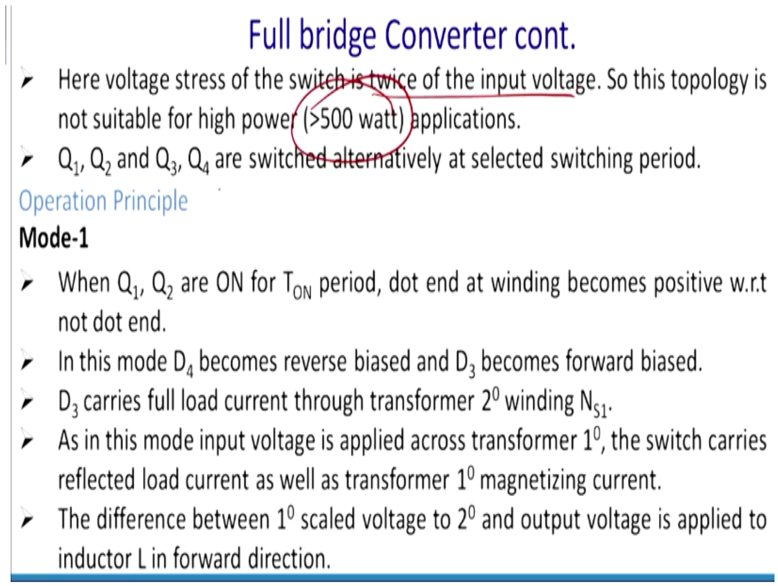

So this topology is not suitable for high power or actually around 500 watt. So that is the one of the actually consideration we have to keep in mind. Q1, Q2, Q3, Q4 are switches alternately selected for the switching period. So mode 1 when Q1 and Q2 is on, for the period T1 starts at the end of the winding, becomes positive with respect to the non-dot N and in this mode T4 becomes reversed biased and D3 becomes forward biased.

And D3 carries the full load current to the transformer, secondary winding, go up in NS1 as this mode of the voltage is applied across the transformer primary. The switch carries the reflected load current as well as the transformer primary magnetizing current. So this will gain both the current. The difference between primary winding scaled voltage and while secondary winding output voltage is applied across the inductor as it is same in case of the half bridge converter.

So mode 2, mode 2 is almost same, just we have to have another pair of switch. So at the end of period switch Q1 and Q2 are turned off.

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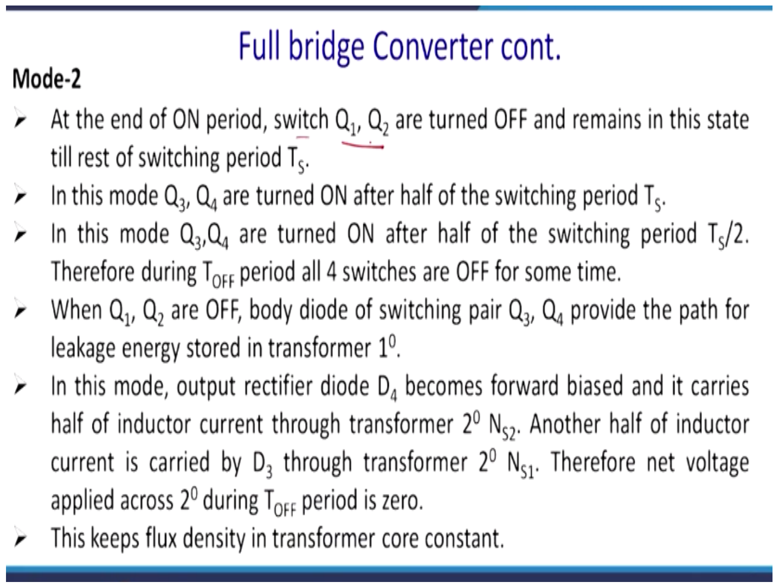

And remains in the state till the rest of the switching period of TS and in this mode Q3 and Q4 are turned off after some delay, because you want actually a diode to conduct, because when you get the pulse unless current does not decay. So another pair of switches will not turn on. So after half of the switching period TS, this mode Q3 and Q4 are turn off after half of the switching period TS/2. During T off period, all the switches are off for some interval of time.

When Q1 and Q2 are off, the body diode of the pair of the switches Q3 and Q4 provides a path of the leakage energy stored into the transformer. Primary so diode will conduct. So what will happen, once actually Q1 and Q2 is conducting, then unless you trigger Q3 and Q4 till that time, the body diode in case of the MOSFETs or the antiparallel diode in case of the IGBT are connected to the opposite pair will take care of the conduction and it will demagnetize the magnetic circuit.

So this is the 1 of the features please keep in mind. In this mode, the output rectifier D4 becomes forward biased and it is carrying the half of the inducted current through the transformer secondary winding. Another half of the inducted current is carried by the diode D3 through the transformer of secondary winding NS1, therefore net voltage applied across secondary during T1/2 is 0 and this keeps the flux density of the transformer constant. This is the way actually full bridge transformer, full bridge converter works.

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Full bridge Converter cont.

Mode-2

- After $T_S/2$ when Q_3, Q_4 are ON, the dot end of 1^0 becomes negative w.r.t non dot end.
- In this condition D_3 becomes reverse biased and D_4 becomes forward biased. So D_4 carries full load current through 2^0 winding N_{S2}.
- As input voltage is applied across transformer 1^0, switches carry scaled load current with transformer 1^0 magnetizing current.
- As input voltage is applied to transformer in reverse direction, flux density of core changes from final to initial value.
- The difference between 1^0 scaled voltage to 2^0 and output voltage is applied to inductor L in forward direction.

And after TS/2 when actually it is same as actually the initial stage, when Q3 and Q4 was on, the dots end of the primary becomes the negative will respect to the non-dot end and in this condition, D3 becomes reverse biased and D4 becomes forward biased. So D4 carries the full current through secondary winding of NS2. As input voltage is applied across the transformer 1, switches carry scaled current with the primary magnetizing current.

As input voltage is applied to the transformer in reverse direction, flux density core changes from final to the initial value. The difference between primary scale voltage to secondary scale voltage and the output voltage is applied to the inductor L in forward direction. So assuming that the secondary winding turns is basically NS1 and NS2 are the equal to avoid the magnetic saturations of the core T1. Q1 and Q2, Q3 and Q4 are kept same.

So this will ensure the resetting of the flux. So if actually this is the TS time, drawing on the same positive Y axis, Q1 and Q2 if conducts and this is basically TS/2 you can start. Thereafter there will be a delay and this actually ratio and this ratio required to be same to reset the flux. After T on period, Q3 and Q4 remains off till the time TS, this is the time interval. During switch on period of the pair of the switch of the switching stress over the other pair of the switches of the entire voltage beam.

So Vout and Vin relationship, here you will find that assuming this continuous conduction mode if it is otherwise stated, the relation between the input and output voltage is same. You know basically 2VN*D where D is TN, TNS/NP. So you can actually play with the trans ratio and get the desired output voltage. So what is the advantage of it. This is the simplest in operation and you have 4 switches, stress across the switches is less.

You have a control over the controlling the duty cycle, so that you can actually actively reset the flux and you have actually highest power density. So size of this full bridge converter will be least than the other. So advantages are full bridge is used in application for the high voltage requirement. Mostly you know this finds applications in offshore winter wind. So you may have actually a seashore in a isolated island. From there actually you can put a huge windmills or wind forms and of course you know, it may be DC.

And you wish to transfer this DC from the wind shore to this actually the mainland, so you can use this kind of DC-to-DC converter and then actually instead of the stepping down, you may actually essentially step up and you will fit to the AC to DC line sometime.

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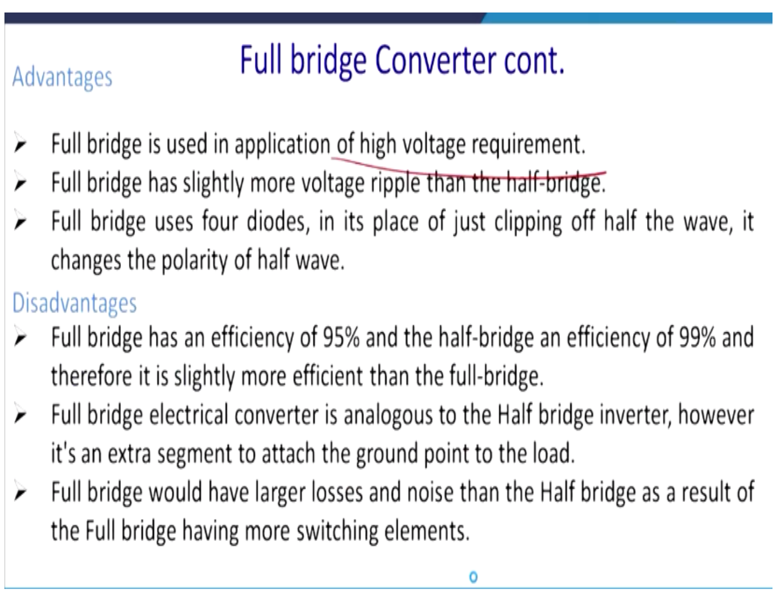

Full bridge has slightly more voltage ripple than the half bridge. This is actually one of the problems. So you will find that actually it will be to smooth out the ripple, it will be little bulky. Full bridge uses for diode in places of just clipping of the half wave. It changes the polarity of the half wave. Now let us take the disadvantage of the full bridge, of course the component count is maximum, you use the 4 active switches.

Though the cost of the switches is drastically coming down, then of course that logic is gradually getting negative and you have a derating of the passive devices and you expect that actually the switch will last longer and thus the component count cost has been not at all a disadvantage now. So since there is loss across the 4 active devices, 2 active devices always, so efficiency of this kind of topology will be less.

The bridge has an efficiency of 95% since it employs actually the 4 switches or the 2 switches consequently and the half bridge can have efficiency 99% for SI6 devices, GAN devices as well as actually soft switching when it is done by ZVS or Z series. Therefore, actually the half bridge is slightly more efficient than the full bridge, but power handling capability is maximum in case of the full bridge.

Full bridge electrical converter is analogus to the half bridge converter; however, it has an extra segment attached to the ground point to the load. So we have an extra element that is connected. Full bridge would have larger loss and noises than the half bridge; as a result of the full bridge converter has the most switch and the element. This is the overall discussion of the isolated DC-to-DC converter.

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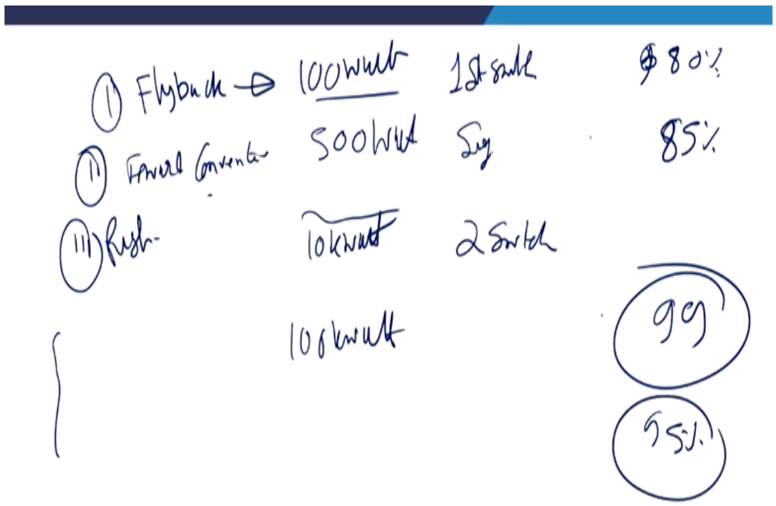

So we have discussed first fly back and it has power handling capability is around 100 watt and if you see the switches, it is one switch and efficiency in the range of 80%, which is the simplest circuit, it has uses one circuit, but this is the cause and power density is least. Then next comes into the picture is your forward converter. So it can go up to 500 watt, single switch and efficiency is little higher, because transformer there is actually a normal transformer.

So you can expect around 85% efficiency and thereafter it comes to the push pull, but it uses 2 switches and here this can be as high as 10 kilowatt. So thereafter you have half bridge and full bridge. This can handle the power around 100s of kilo watt if properly designed, it can handle the power in megawatt and efficiency is actually 99%. Maximum efficiency you will get in case of the half bridge converter.

Full bridge converter since it employs more component count, you will find that actually it uses, its efficiency will be little less around 95%. This is the some comparison of DC-to-DC converter and this is the matrix and based on that you will actually choose different kind of DC-to-‘DC converter for your application. Thank you. Thank you for attention. With next class, I shall continue with another very important entities of power electronics, that is DC-to-AC conversion that is the inverted operation.

We shall start with the voltage source inverter, thereafter current source inverter and we will see the different aspect of the voltage source and current source inverter by different kind of PWM technique. Thank you so much for your attention.