Design of Power Electronic Converters
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Lecture 05
Analysis of H Bridge

Today, we will begin with the analysis of another converter which is H bridge converter. The H bridge converter is a very popular converter and it is used in many different applications. So, this is another converter which we will be using as an example to explain the concepts of design. So, before doing that we will be analysing this converter.

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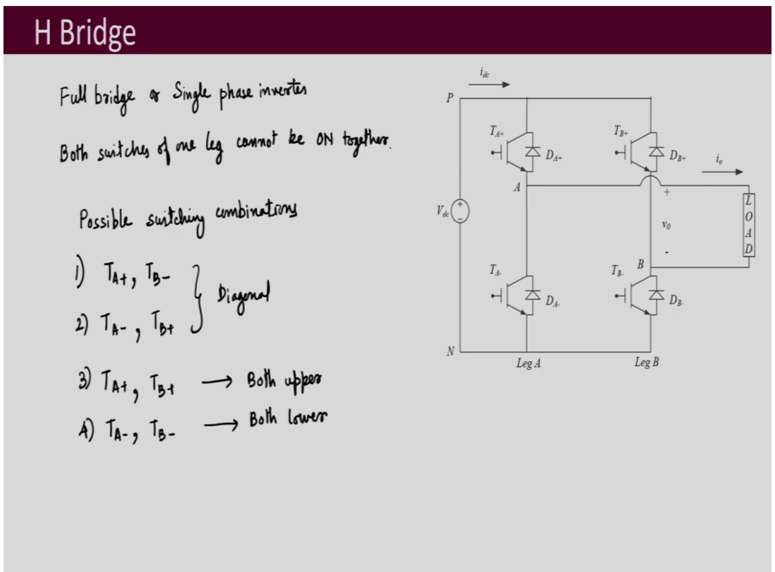

So, this is the circuit of H bridge converter. You see here that it has got four IGBTs. Now, 4 MOSFETs may also be there. It depends on the application. Here, I have shown four IGBTs and then there are 4 anti-parallel diodes. So, T_{A+} and T_{A-} has been named as the upper one and the lower one respectively. These two connected together are called as the Leg A.

Similarly, T_{B+} and T_{B-} are connected together, and they are called as Leg B. The midpoint of this is named by the symbol A and the midpoint here is named by the symbol B. Then, this is the DC bus and denoted by P and N and then the load is connected between these two nodes A and B. So, this is the voltage between A and B, which is denoted by v_O and the load current is denoted by i_O.

These diodes are named similarly as the transistors like D_{A+}, D_{A-}, D_{B+} and D_{B-}. The current through this DC bus is denoted as i_{dc}. So, now, let us begin with the analysis and before that also you may be knowing that this is also called as full bridge or it is also called a single-phase inverter. There is one rule which has to be followed : both switches of one leg cannot be on together.

You can see here that if you turn on both of these two switches together, it will lead to a short. So, that's why we always ensure that these two switches cannot be turned on together. So, excluding it, what are the different possible switching combinations that we can see? So, first we can see that these (T_{A+} and T_{B-}) diagonal switches can be on together and the other two diagonal switches also can be on together.

So, T_{A+} and T_{B-} is one switching combination and T_{A-}, T_{B+} is another possible switching combination. So, T_{A+} and T_{B-}, T_{A-} and T_{B+} are the two possible diagonal switching combinations. Next, we can see here that these upper two switches can also be on together or these lower two switches can also be on together.

So, the 3rd possible combination is T_{A+} and T_{B+}. That means both upper switches are on together or T_{A-} and T_{B-} also can be on together. So, these are the four possible switching combinations for H bridge converter. Now, let us look into each switching combination and the corresponding equivalent circuit.

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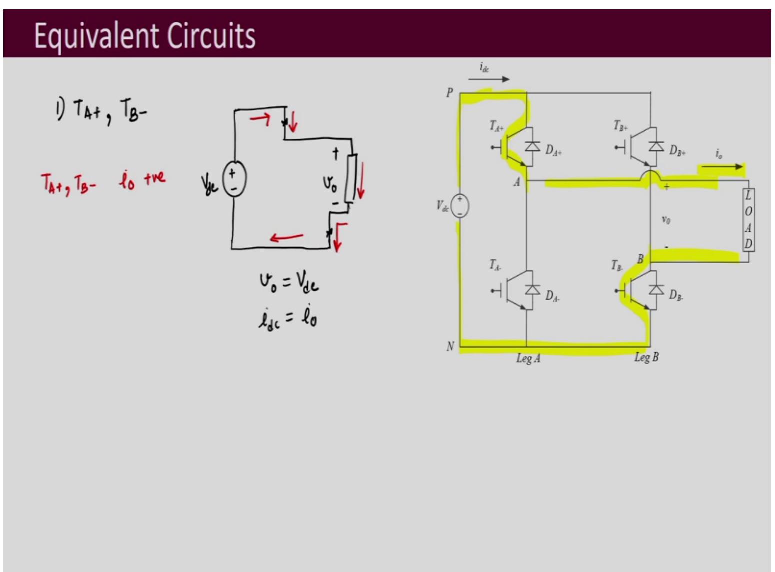

So, let us take the first one which is T_{A+} and T_{B-} being on together. So, here when this is shorted, T_{A+} and T_{B-} can be shorted. Now, the diode may also be conducting. We will see when the diode conducts and when the transistor conducts. But, to draw the equivalent circuit we can consider these as shorted, because we are considering it to be ideal.

Then let us draw the equivalent circuit. So, the equivalent circuit will be like this, this is V_{dc} and here this is the output voltage named by v_O and these are the ones which are turned on. Now, let us see what happens when it depends on the direction of the current. Let us say this direction of current is positive. So, if the direction of current is positive, we will see that the current will flow like this, it will be supported by the transistor and then it flows through this path and it comes back here and then again it is the transistor only which is going to support the path of the current.

So, we observe from here that when the switch is on, it is the transistors which are carrying the current and not the diodes. So, T_{A+} and T_{B-} are conducting when the current is positive. Then we see that these two are short. So, the output voltage v_O is equal to V_{dc}.

What will be the current? This current over here (i_{dc}) is the same as the load current. So, we can write that $i_{dc} = i_O$. Now, let us see what happens when the current direction is opposite.

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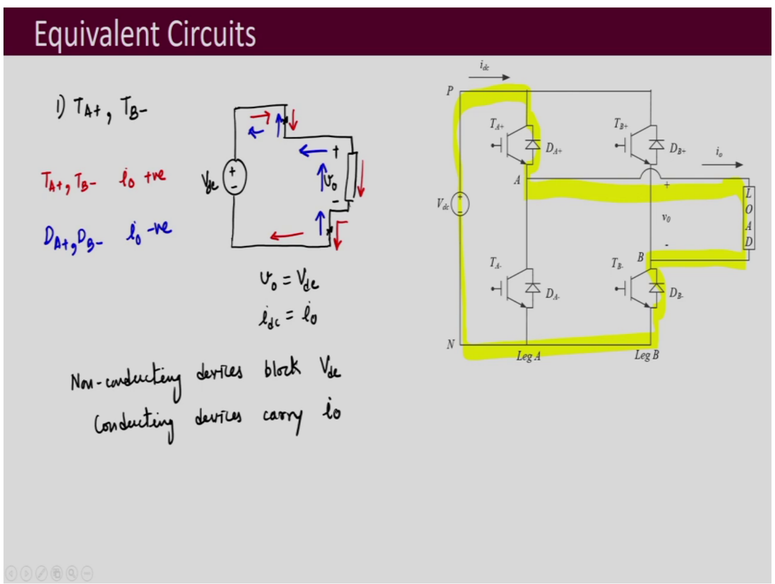

So, when the current direction is opposite the current flows like this, it has to come here and then since it is flowing in the opposite direction. It will be flowing through these diodes, it will come here and then it has to go again through the diode only because it is in upward direction and it flows through the load. So, this is the direction of the current. So, now the current is carried by the diodes, this current flows like this in the opposite direction when the current is negative.

So, the current is carried by the diodes D_{A+} and D_{B-}, when current is negative and these are, $v_O = V_{dc}$ and $i_{dc} = i_O$. These two remain the same irrespective of the direction of the load current. Also, one more thing is that we should see the voltage blocked by these devices. So, we see here that from the very equivalent circuit the voltage across these non-conducting devices has to withstand V_{dc} because this is shorted to V_{dc}.

So, here what it has to block? This has to block V_{dc} and this is also shorted here. So, this has to block the voltage V_{dc}. So, the non-conducting devices have to block V_{dc} and the conducting devices have to carry the current i_O. So, non-conducting devices block V_{dc} and conducting devices carry i_O. We have to remember that because we will be requiring it when we draw the waveforms.

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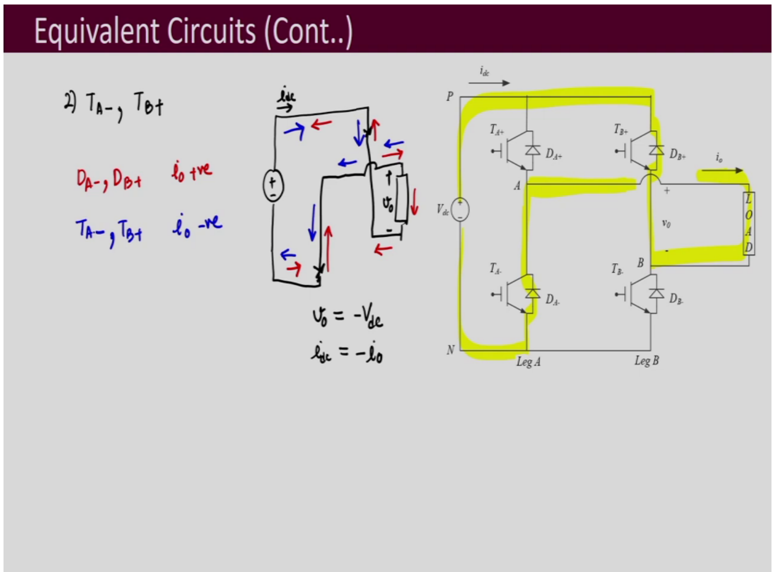

Next, see the second equivalent circuit for the second switching combination, which is the other two diagonal devices T_{A-} and T_{B+}. Now, let us say that this is the direction of the current. So, this transistor is on. So, if this transistor is on, the current is positive and it flows like this. It has to be conducted by the diode, it comes like this and then this device is on, so this also has to be carried by this diode.

So, this is the direction of current when two transistors T_{B+} and T_{A-} are turned on for current to be positive. So, let us draw the equivalent circuit. So, the equivalent circuit can be drawn just by shorting whatever has been turned on. So, here one is turned on, and this is v_O. Using this, we observe that v_O is coming here. This point is connected downwards to the negative terminal and this point is connected to the positive terminal.

So, the voltage $v_O = -V_{dc}$ and $i_{dc} = -i_O$. For example, let us see if the current is positive we just saw now, these diodes are carrying the current. So, $i_{dc} = -i_O$. When the current direction (i_O) is positive, the devices which are conducting, are D_{A-} and D_{B+}.

When i_O flows in the opposite direction, it has to be carried by the transistors, and it flows like this. It comes here, goes down and here also the path of the current is downwards. When the path of the current is downwards that means, it has to be carried by the transistors.

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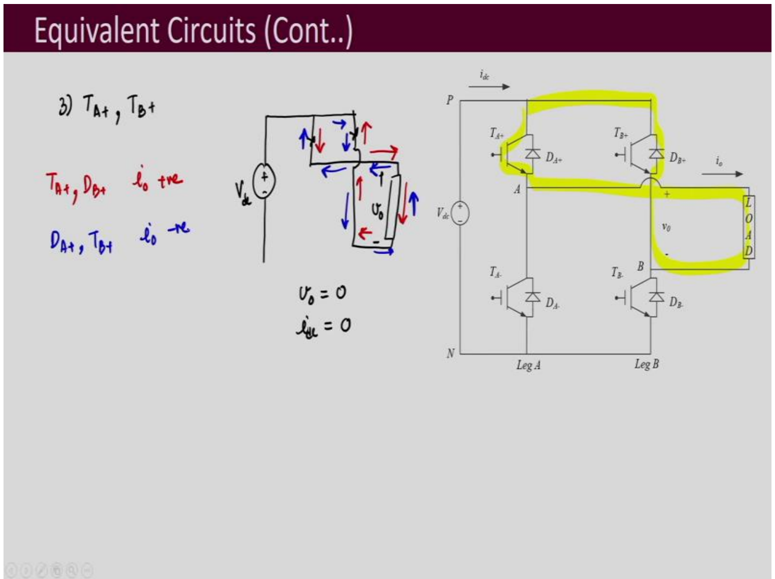

So, then the transistors T_{A-} and T_{B+} are carrying the current when i_O is negative. The blocking voltages for non conducting devices remain same here, and it is equal to V_{dc}. The current that is carried by conducting devices, is equal to i_O.

Now, let us look into the third switching combination, when both the upper switches are being on (T_{A+} and T_{B+}). Now, in this case both of these upper two are turned on. So, accordingly we draw the equivalent circuit. So, these two are turned on, this is here v_O. We observe here that both the terminals of v_O are connected to the same bus.

So, $v_O = 0$ and $i_{dc} = 0$. When the current direction is positive, we can observe that it is flowing downward, that means it is carried by the transistor and here it is carried by the diode. So, T_{A+} and D_{B+} are conducting when i_O is positive. When i_O is negative that means, it is flowing in the opposite direction, and it will be coming over here.

So, we observe that it is D_{B+} and the diode D_{A+}, which are going to conduct. So, D_{A+} and T_{B+} are conducting, when i_O is negative. The blocking voltages that remain same for non-conducting devices and this is equal to V_{dc} in this case also.

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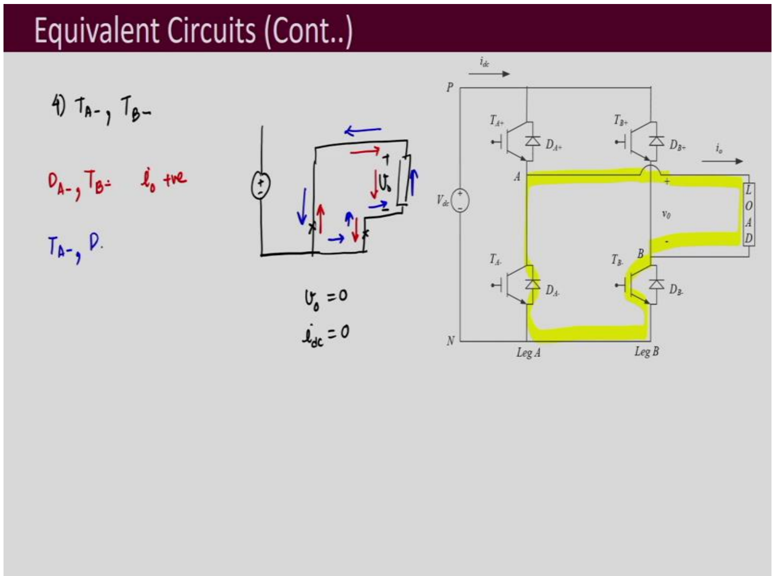

Now, the 4th one or 4th combination is T_{A-} and T_{B-}, where the lower two switches are being on. At that time, we observe here that the path will be like this. This is the circuit, and the path is going to be followed. So, let us draw the equivalent circuit again. So, the equivalent circuit will look like this.

So, $v_O = 0$. We can see that clearly that $i_{dc} = 0$. When the current is positive, it flows like this, it flows downwards here and in here it flows upwards. That means it is the diode D_{A-} and the transistor T_{B-} are going to conduct when the current is positive.

When the current is negative, it is flowing in this opposite direction, it flows downwards here and flows upwards here and then it is conducting in this way. So, we observe that it is the other two devices which are going to conduct now (T_{A-} and D_{B-}). Those are carrying the current, when i_O is negative. So, we saw all the four equivalent circuits.

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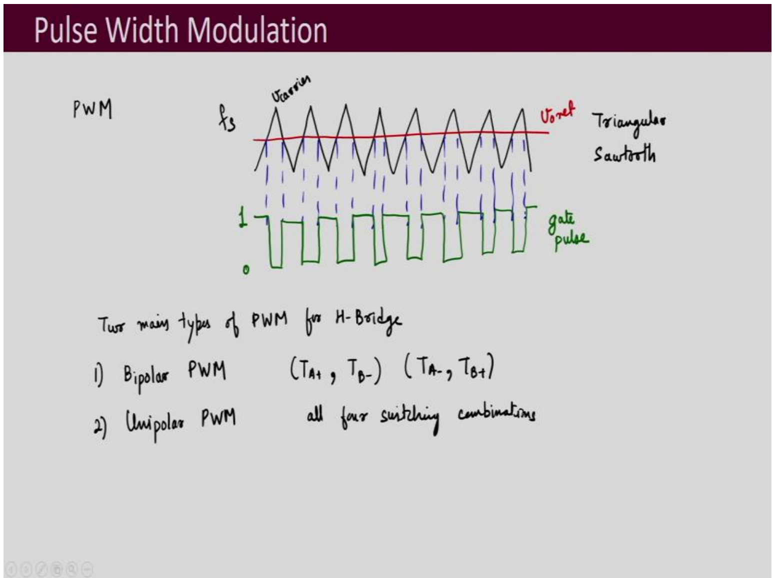

Now, you should be already familiar with the term pulse width modulation. In short, it is also called as PWM. So, what is PWM basically? Here is a carrier signal. This kind of a carrier signal which may be triangular in nature, or sometimes sawtooth. This has that frequency, which (f_S) is equal to the switching frequency. It is compared with a reference. Let us say this is the reference called as v_{oref} and we can call this as $v_{carrier}$ and then these are compared.

So, here in this way you compare it and we may use a logic that whenever this v_{oref} is greater than $v_{carrier}$, at that time, the gate pulse will be high. So, accordingly we can draw it. It will be 1 when $v_{oref} > v_{carrier}$, else it will be 0. So, we will be getting a pulse like this and this is also called as the gate pulse because this is given to the gate of the IGBT or the MOSFET. So, this is the gate pulse.

So, this is pulse width modulation (PWM). There are different types of PWM methods for H bridge converter, and also there are different types of PWM methods that are used. There are different ways in which modulations are performed, and not necessarily always pulse width modulation is going to be performed. Other types of modulations are also there. So, we will not be looking into all of them, but we will be looking into the ones which are very much used and are very popular.

So, there are two main types of PWM for H bridge, one is called as bipolar PWM. It uses these two combinations, the diagonal ones which are T_{A+} and T_{B-}, T_{A-} and T_{B+}. When these two switching combinations are only used, then it is called as bipolar PWM. There is another one which is called as unipolar PWM and it uses all four switching combinations.

Depending on the modulation method that we use, it affects the waveforms of the voltage waveforms, the current waveforms across different components and then it affects the design process because once the waveform gets modified, the device has to withstand, and the component has to withstand with the voltage, current, the frequencies. If that changes, then accordingly the design also changes. So, that's why we will be also paying attention to the modulation method.

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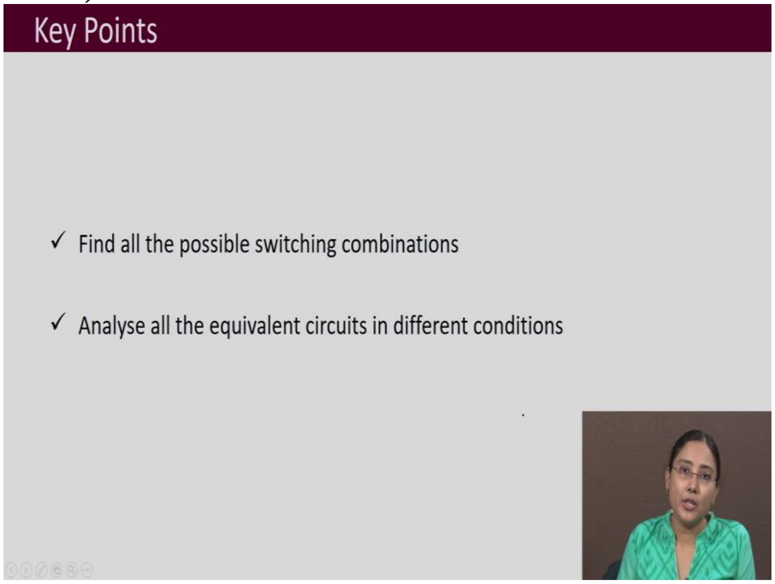

So, what are the key points of this lecture? When you take any converter, which has gone multiple switches, then you see all the different possible switching combinations for that converter. Then for each of the possible switching combinations you analyse the equivalent circuits. Then you find out the different voltages and currents that are flowing through different devices and components. That will help you in finding out the ratings of the devices during the design process. Thank you.