CHARGING INFRASTRUCTURE

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Week-02

Lecture-6

Lec 06: Revisiting Diode Bridge Rectifier - II

Hello everyone, welcome to this lecture number 6 of NPTEL lecture titled Charging Infrastructure. Before starting this lecture, let us recap what we have studied up till now so we have studied the various introductions or various nomenclatures related to EV charging system and after that we started discussing about things related to ac-dc converters and in ac-dc converter the simplest converter we were revisiting which is single phase diode bridge rectifier in single phase diode bridge rectifier we have seen half bridge configuration of the rectifier. so, we have seen that the single-phase half bridge rectifier feeling the resistive load and we have seen that how this particular converter works and we have also derived some of the expressions like the average output voltage or average voltage which will be appearing across the load.

And we have also seen one important thing which is in this particular circuit the power is being supplied to the load only in half the cycle that means in the positive half cycle when the diode is forward biased while in the remaining half of the cycle the diode will be reverse biased and will be blocking the voltage entire source voltage across it. So, we have also defined some of the ratings by which ratings which is governed by the circuit or governed by the external circuit which helps in deciding which diode to be selected. Once we define this voltage and current ratings like which voltage and which current to be ratings of the diode to be selected among that family. The diode with required forward voltage drop and diode with required dynamic resistances can be selected so in this we have seen the peak repetitive reverse voltage which this diode has to block is nothing but $V_{S,Peak}$ which is the peak of the ac voltage which is been applied and the average current which will be going through the diode is nothing but dependent upon the resistance R_L which is actually being put at its output and the rms current is nothing but

$V_{S,Peak}$ by $2R_L$. Now in this we have seen that if we see the current waveform let us write down some of the key points like what are the key points and understanding we obtain from this half bridge configuration diode bridge configuration. Let us see that so the first thing which we have seen that the source current or you can say the power is being delivered the power is being delivered to the resistive load, only in positive half cycle. Further the output voltage is pulsating or you can say that is varying between zero if you can see is the output voltage is varying between zero to the peak value which is equal to $V_{s,peak}$ and then coming down to zero again so the output is pulsating in nature output voltage pulsating in nature and the output voltage or the average output voltage average output voltage the average output voltage is proportional to $V_{s,peak}$ which is the applied voltage which is the peak of the applied voltage. That means the average output voltage is only dependent upon the input applied voltage or input AC voltage or peak of the input AC voltage it is independent or there is no other way by which you can control that average output voltage and you can also see from the figure that the current is only been drawn in the positive half cycle while it is zero in the negative half cycle so you can say that the current drawn is not continuous. So, these are the some of the inference we get from the single phase half bridge diode rectifier. Now, let us revisit single phase full bridge rectifier, single phase full bridge rectifier. Now, let us see what is the circuit and how this circuit works and let us try to draw different waveforms in the circuit, different critical waveforms in the circuit. So, the single-phase rectifier is again having a AC voltage source and then you have four diodes connecting in a manner as shown over here and it is again been supplying to the load RL which we have in the case of half bridge rectifier. So again, this is D1 D2 D3 D4 and you have v_s which is nothing but Vs, peak sine omega t. It has been connected to the midpoint of the two-diode connecting in this manner. The current which is going again is determined as the i_d and voltage coming across this is nothing but d and the average voltage if we do the average voltage we will get the average value of the DC voltage which is being applied across this resistance. Now in this particular circuit if we see instead of single diode in the previous case we have now the four diodes and in this four diode conducts in such a manner that it will allow the power to be delivered also in the negative half cycle now let us understand the functionality of this single phase polybius rectifier in this case when let us see first the case when v_s is in positive half cycle or you can say or you can say vs instantaneous value of v_s is greater than zero. During that point what is happening is this particular potential will be at higher voltage or will be at a higher value as that of this particular potential. At that particular point as a result of which this diode is forward biased and since this is at higher potential is applied across this cathode of this diode, this diode will be reverse biased. Since this is forward bias this particular thing will get connected as a result of which the voltage which is applied over here will be coming over here will be applying over here and as a result of which the the D4 gets forward bias. Since D4 gets forward bias the D3 will get reverse bias so let us see what will happen is that D1 and D4 gets forward biased and D2 and D3 gets reverse biased. Let us draw the circuit how it looks like, D1 is forward biased, D2 is reverse biased. Similarly, D3 is reverse biased, D4 is forward biased. and then you have the resistance R_L, i_d, $V_{s,peak}$ sine omega t at that particular point, and the voltage across this is v_d. So, as a result of which what you will see is that the input voltage which is there which is in the positive half cycle will be will be directly coming across this resistance R_L and there will be current drawing through this current R_L let us also define the current drawn from the source as i_s that's when we can write that my instantaneous value of i_s is nothing but equal to 'i_d' which is been going into the load and we can also write my 'v_d' the output voltage which i am getting is nothing but equal to the instantaneous value of the voltage 'vs' which is been applied from the source from the ac source because your D1 and D4 is forward biased as a result of which the voltage across this is same as whatever the voltage which is been there in the in the voltage source and because of this voltage there will be current 'id' and because of this current the same current will be flowing through. The flowing I mean will be drawing from the source which is nothing but an 'is'. So, that's why we will get this particular condition now let us see what will happen when 'vs' is in negative half cycle negative half cycle means your 'vs' value is less than zero. When your 'vs' value is less than 0, that is when you will see that your D2 and D3 is forward biased.

So, D2 and D3 is forward biased while your D1 and D4 is reverse biased. So, let us draw the circuit and see. So, the circuit will look like this is D1 is forward bias D1 is reverse bias. D2 is forward bias and your D3 is forward bias while your D4 is reverse biased. However, if you look very carefully, your 'v_d' voltage which you are getting in this particular case is nothing but minus of ‘vs’ and your ‘is’ value is nothing but minus of ‘id’ because this voltage will be now applying across this ‘v_d’ in a reverse manner because you know you see if you are having a ‘vs’ voltage.

This phase of this P and N point or P and N terminal of this voltage source, this P is connected to the negative of ‘v_d’ and your N is connected to the positive of ‘v_d’. That is when you are applying the negative of the AC voltage which is been there. So, let us draw by understanding this particular by having this understanding. Let us draw the particular waveforms. Of the circuit, so let me take the waveforms of the circuit. So, this is your first. Let us draw the ‘v_s’. This ‘vs’ will be having a sinusoidal variation. I mean, obviously, we have the AC source. Now, if you look very carefully, this is our vs sine omega t. Since the ‘v_d’, as we mentioned over there, let me also write down the conditions. When ‘v_s’ is positive, my ‘v_d’ is nothing but equal to ‘v_s’, and ‘is’ is nothing but equal to ‘i_d’. While when the ‘vs’ is negative, my ‘v_d’ is nothing but equal to minus of ‘v_s’, and ‘i_s’ is nothing but minus of i_d. So, let us draw the ‘v_d’ waveform or the waveform or voltage waveform which will be appearing across the load. So, let us draw the ‘v_d’ waveform.

Since, when ‘vs’ is positive, ‘v_d’ is nothing but equal to ‘v_s’. So, let me draw the ‘v_d’ equal to ‘v_s’. The same way, the way the ‘vs’ is drawn, the same way, if you are following the same pattern, we have drawn the ‘v_d’. And in the negative half cycle, however, in the negative half cycle, ‘v_d’ is nothing but the negative of the ‘v_s’, which is nothing but, if you draw, it will be like this shape. So, this will become just the opposite negative of that. So, this will become like this. Similarly, at this point again, you have the same waveform, and at that point again, you have the same waveform.

So, what we see is that the ‘v_d’ is having positive polarity and negative polarity. However, ‘v_d’ has just the single positive polarity. However, this is still in the pulsating nature. This particular ‘v_d’ will be applying across the resistance R_L. Now, since this ‘v_d’ is applied across resistance

R_L, the current through the resistance R_L, which I have defined as 'i_d' in the circuit, will also be following the same pattern.

However, let us try to, so this is nothing but my 'i_d'. So, 'vs', 'i_d'. Since my 'i_d' is of this shape, let us see what my 'i_s' is. So, 'i_s' is nothing but equal to 'i_d' when 'v_s' is positive. So, this is nothing but equal to 'i_d' when 'v_s' is positive.

And it is equal to minus 'i_d' when it is the negative half cycle when 'v_s' is negative. So, let me draw the negative of that, and then again it is positive, and then again it is negative. This is nothing but the current drawn from the source. Now, if you look very carefully, this current drawn from the source has a sinusoidal variation and a unity power factor, which means that the source voltage and the current drawn from the source are in the same phase. If you try to draw the different values, so this is $v_{s,pk}$. This is again $v_{s,pk}$. What do we get?

This value is nothing but again $v_{s,pk}$. This particular value is nothing but '$i_{s,pk}$ '. This value is nothing but minus 'is, peak'. This is nothing but 'is, peak'. Similarly, this is $v_{s,pk}$, and this value is nothing but the peak value of 'i_d', which we can write as $i_{d,pk}$ which we can write down over here as well.

$i_{d,pk}$ So,

$$\frac{i_{d,pk} = V_{s,pk}}{R_L}$$

And, $$\frac{i_{s,pk} = V_{s,pk}}{R_L}$$

So, with this we understood that how the voltage which will be appearing across the load in case of full bridge rectifier and what will be the i mean how the current will which will be drawing from the source now in this particular thing if you try to calculate some of the expect which is you know let us try to see how i mean different components in the circuit the different experts circuit looks like so let us first calculate average voltage of v_d this average voltage will be applying across the resistive load 'R_L' so this average value of ed we can do again the same way.

Since if you look very carefully in this particular circuit we have the time period which is T given here now this particular v_d repeats itself after half of the cycle of your supply voltage that means if you are applying a 50 Hz input so if you are applying if your source voltage is varying 50 Hz so your ‘fs’ is let's say 50 Hz then your

$$T = \frac{1}{fs} = 20ms$$

And accordingly, we can write that,

$$\omega = 2\pi fs,$$

$$\omega T = 2\pi$$

And if you see carefully, after every $\frac{T}{2}$ time, it repeats itself. So, it is not the case in case of half bridge where the ‘v_d’ repeats itself after the total time period T.

In this case we are the voltage output voltage or the v_d voltage repeats itself in every $T/2$ time that's why we are writing now we are we are trying to find out average over the $\frac{T}{2}$ period.

$$v_{d,avg} = \frac{1}{T}\int_0^{T/2}\left(v_{s,pk} sin\omega t\right)\cdot dt = \frac{2v_{s,pk}}{\omega T}\left[-\ cos\omega t\right]_0^{T/2}] = \frac{2v_{s,pk}}{\omega T}\left[-\left(cos\frac{\omega T}{2} - cos0\right)\right] = \frac{2v_{s,pk}}{2\pi}[-$$

So, this is the average value which is exactly double the value which we get in the case of half bridge single phase half bridge diode rectifier. In this case in case of full bridge we are getting double the voltage since the power is being delivered in both the positive half cycle and negative half cycle of the input voltage. So let us see the diode selection criteria. I mean again it is the same ratings which will be defining this here our VRRM which is nothing but the peak repetitive reverse voltage which is nothing but if we look very carefully during this time period it is D1 and D4 is conducting in this time period D2 and D3 is conducting in this time period again D1 and D4 is conducting in this time period D2 and D3 is conducting Since in this time period D1 and D4 is conducting and in this period D2 and D3 is conducting and in this period again D1 and D4 is conducting and in this period D2 and D3 is conducting.

Since in this period D1 and D4 is conducting in the first half cycle as a result of which this D1 and D4 is on and as a result of which this ‘v_d’ voltage which is there at the output will be appearing across this D2. and the D3 because if this is on in this entire loop this voltage is getting dropped across this diode D2 thus we will see that the V_{RRM} is nothing but is the $v_{d,pk}$

which is nothing but equal to the $v_{s,pk}$. So that is why in the, while selecting the diode, one must make sure that the diode must have the peak repetitive reverse voltage of $v_{s,pk}$. And if we see the average current through the diode, so $I_{F,avg}$. Now let us see for the diode D1 and D4.

Now, when we see diode D1 and D4 it will be conducting it will be only conducting during this period while this in this period it is not at all conducting. So, thus we can write their average value as $\frac{1}{T}$, 0 to $\frac{T}{2}$, $\frac{V_{s,pk} sin\omega t}{R_L}$ because it is feeling to the resistive load and then we will do this.

So, this when we solve this particular expression what we will get is we will get $\frac{V_{s,pk}}{\pi R_L}$. This expression we have already solved in the case of half bridge circuit case.

$$I_{F,avg}(D1, D4) = \frac{1}{T}\int_0^{T/2} \frac{\left(V_{s,pk} sin\omega t\right)}{R_L} \cdot dt = \frac{\left(V_{s,pk}\right)}{\pi R_L}$$

So, the same expression we are deriving here. So, which we get $\frac{V_{s,pk}}{\pi R_L}$. Similarly, for D2 and D3 also, $I_{F,avg}$ D2 and D3 also, if you do, it will be $\frac{1}{T}$, $\frac{T}{2}$ to T, $\frac{V_{s,pk} sin\omega t}{R_L}$. I mean the integration over $\frac{T}{2}$ to T and it will again give you $\frac{V_{s,pk}}{\pi R_L}$. This expression we have already solved in the case of half bridge circuit case.

$$I_{F,avg}(D2, D3) = \frac{1}{T}\int_{T/2}^{T} - \frac{\left(v_{s,pk} sin\omega t\right)}{R_L} \cdot dt = \frac{\left(v_{s,pk}\right)}{\pi R_L}$$

So, the average forward current of the diode is nothing but again for D1, D2, D3, D4 is nothing but 'vs'peak by pi RL.

$$I_{F,avg}(D1, D2, D3, D4) = \frac{\left(v_{s,pk}\right)}{\pi R_L}$$

It only depends upon the the value of the load which this bridge rectifier is supplying and the input voltage which is applied at its input.

Now, let us also see the 'I_{rms}' rating for determining the I square t rating of the diode. So, let us also see the 'I_{rms}' rating of the diode which can again be calculated as $\frac{1}{T}$, 0 to $\frac{T}{2}$. Again, for D1, D2, D3, D4, the whole thing will remain true. $\frac{V_{s,pk}}{2R_L}$ whole square dt. Now, when we try to solve this, we will get a value VS peak by 2 RL.

$$I_{rms} = \sqrt{1/T\int_0^{T/2}\left(\frac{V_{s,pk}sin\omega t}{RL}\right)^2 \cdot dt}$$

$$I_{rms} = \frac{\left(v_{s,pk}\right)}{\pi R_L}$$

Now, this is the 'I_{rms}' current which is going or RMS value of current which will be flowing through each diode, and that is when you can define the I^2t rating using 'I_{rms}' value. where 't' is the time period for which it is conducting. Then, in this case, our 't' will be nothing but 10 milliseconds, so accordingly one can define the I^2t rating as well. Now, let us see what we understood by this particular converter. So, let us try to find the inference from this single-phase full-bridge converter. The first and foremost thing we have understood is that the output voltage is uncontrolled, that means it only depends on the input AC voltage. If you look, if you see here, the average output voltage is only depending upon the $v_{s,pk}$.

Second inference: we can observe that the input current is sinusoidal in nature. It is supplying the resistive load, which is why it has a sinusoidal nature. However, one thing to note is that power is delivered in both cycles—both the positive and negative cycles—to the R_L or resistive load. Additionally, we can observe that the output voltage is not constant. It is actually a rectified DC voltage, or you could say a rectified DC voltage. This means the output voltage varies from 0 to $v_{s,pk}$., then returns to 0 in the form of a half sine wave, repeating the same variation.

This implies that '$v_d(t)$'is nothing but the modulus of '$v_s(t)$, taking that particular form. And it is continuously varying.

$$v_d(t) = |v_s(t)|$$

It is continuously It is not constant. It is continuously varying. These are the inferences we derive from the full-bridge rectifier. By understanding and observing the operation of this single-phase full-bridge rectifier, these are some of the conclusions we can draw. In this particular case, since it supplies a resistive load, we observe a sinusoidal current drawn. Also, power is delivered in both cycles. However, the output voltage is not constant and keeps It is continuously varying.

So, we have seen how the single-phase half-bridge rectifier works. We have also seen how the single-phase full-bridge rectifier works. We have inferred some of the critical information which will be used by us in the future to understand why the kind of converter which is being used presently while doing the AC-to-DC power conversion in an EV charger looks the way it does. We will derive that particular converter and understand it. To understand how we reached that particular converter, it was important for us to infer some of the critical points while revisiting these diode rectifiers. We have understood that we could get the input current in the form of a sinusoidal wave when we have a purely resistive load.

We have also understood that the output voltage which we get from these half-bridge and full-bridge rectifiers is uncontrolled. That means we cannot control the output voltage; it is only dependent upon the input AC voltage. One would have to vary the input AC voltage, which is not the case in the majority of scenarios because the input is directly from the grid. We have also seen that, in the case of a full-bridge rectifier, power can be delivered to the resistive load in both the positive and negative cycles. We can also see that the output voltage we get—the DC output voltage—will keep varying continuously from zero to the peak value and then back to zero. Thus we will see in the next class or lecture how we can get a constant DC voltage at the output using the single-phase full-bridge rectifier. with a capacitive filter. We will derive it again and see what problems that particular converter introduces. That's when we'll move ahead. Thank you for patiently listening to this lecture. We will see you in the next lecture. Thank you.