CHARGING INFRASTRUCTURE

Prof. Apurv Kumar Yadav

Department of Electrical Engineering

Indian Institute of Technology Roorkee

Week-01

Lecture-5

Lec 05: Revisiting Diode Bridge Rectifier

Hello everyone, welcome to this lecture number 5 of NPTEL lecture on charging infrastructure. In this lecture, we will revisit the diode bridge rectifier portion. So, let us recap before starting the today's present lecture discussion, let us recap some of the things we have discussed up till now. So, the first thing we have discussed about the EV ecosystem.

where we understood that there are two voltage based battery packs which are there that means two different levels of voltage for the EVs are present for example we you have one low voltage batteries based powertrain where you know the battery voltage goes from 48 volt somewhere around 72 volt then you have high voltage battery based batteries based proportional system where the voltage goes from 350 volt to 500 volt, I mean the battery pack voltage goes from 350 volt to 500 volt then after that we have seen a building block of a dc charger comprises of DCEVSE And we have after that we have seen an AC charger building block of AC charger which comprises of AC EVSE. So both we have seen and we have understood what part of the charging system are present where whether it is on board the vehicle or whether it is placed outside the vehicle. So in DC EVSE case our power conversion unit is kept outside the vehicle.

is kept outside the vehicle that means in the EVSE itself which means that it requires I mean it does the power conversion outside the vehicle and thus it actually has a off-board charger because power conversion is taking place in the EVSE itself so outside the vehicle so that's why it is also sometimes called as a off-board charger in ACEVSE the power conversion is taking place is taking place inside the vehicle or on the vehicle using an onboard charger or called as an

OBC. So, you require an onboard charger along with whenever you are going and charging your vehicle using an AC charger or ACEVSE. while you are charging your vehicle using DC charger you are having DC EVSE where the entire power conversion is taking place inside the EVSE itself you are just plugging in the DC voltage into your vehicle then after that we have seen different types of charger which are there which are there in the ecosystem like we have seen different modes of charging

we have also seen different charger plugs which are used charger plugs or vehicle inlet connectors which are used in different parts of the world we have seen that as well and then after that we have seen the different levels of charging as well we have seen briefly So, we understood what all things are available in this EV ecosystem and we also understood some of the important jargons or some of the important terminologies which are present in this EV charging systems or associated with this EV charging system. Now, let us move ahead and understand the different aspect of power conversion unit. So, as I mentioned the power conversion unit consists of an AC-DC converter, input AC output DC followed by isolated DC-DC converter which gives a control DC at its output.

Now, depending upon whether it is an AC charger or DC charger, this will be either placed onto the vehicle or it will be placed outside the vehicle. So, we will discuss both scenarios and we will see one by one different AC-DC converters and try to understand different aspects of those converters. Before starting that, let us see some of the some of the need, I mean why we need an AC-DC converter or what does an AC-DC converter do and why it is being used in the power conversion unit. So, let us write AC-DC converter requirements or needs you can say

So, why we need an AC-DC converter? We need a AC-DC converter because of the first thing obviously conversion from AC voltage source to DC and while doing the conversion you want to have the controlled or you can say regulated DC output voltage and again along with having the regulated DC output voltage irrespective of whatever be the load you also want that the level of voltage can also be controlled that means let's say if you are putting I want to go for 450 volts so at a desired level the voltage can be controlled so the control and regulated DC output voltage at desired level maybe that could be a much simpler way of writing at the desired level then the third requirement okay so one requirement is done that we are converting ac to dc

and then we are also regulating the dc at its output irrespective of load whatever they are seeing that means irrespective of the charging stages in which the battery is so irrespective of that you could be in a position to control the dc output voltage and that too at its desired level i mean

What level you wanted to keep. So, that has to be defined. Then, after that, these two things are the primary objectives. Now, while doing this, you also want the current drawn from the source to have a unity power factor. That means you are converting an AC voltage into a DC voltage while doing this AC-to-DC conversion and feeding it to the load. You are ensuring that what you are drawing from the source has a unity power factor. Now, why do you need a unity power factor current? Obviously,

you do not want to have any reactive component flowing in your circuit, as well as you want to transfer the entire real power to the load without having reactive power flow within the circuit. So, it will also help in reducing the component sizing of your power converter. That means the RMS currents in the power converter may require less in the power devices. So, along with unity power factor current drawn, you also want the current drawn to have a sinusoidal variation or, if not, nearly sinusoidal variation, Or nearly sinusoidal variation. So, along with unity power factor current drawn, you also want the current drawn to be closer to a sinusoidal variation.

That means, if you have a sine AC source, you also want the current drawn to follow the voltage. So, the current drawn must have a sinusoidal variation, and along with this, you also want the harmonic content to be less. That means if the harmonic content is less, the THD of the current drawn or the THD is less. So, these are the things which an AC-to-DC power converter needs to do. First, obviously, it converts the AC voltage source to a DC voltage and then feeds it to the load. Along with doing that, you also want the DC output voltage you obtain to be at a desired level and, moreover, it must be controlled or regulated in nature. The current drawn from the source must have a unity power factor, meaning the voltage and current are in the same phase with no phase lag or lead between them. The current drawn from the source must have a sinusoidal variation, and along with that, the harmonic content in the current drawn from the source must be less, meaning the THD must be less.

So, this will help in making sure that you are drawing a sinusoidal current and ensuring you have a unity power factor, which is when you can have the more efficient power conversion. At the

same time, you are also not creating problems in the grid, meaning you are not injecting harmonics into the grid or polluting the grid because of the EV charger connection. So, these are some of the requirements. Let us revisit or see what converters we can have that can meet these particular requirements. and can be used and qualified as the AC-to-DC converter unit of a power conversion unit for an EV charger. So, let us see the first AC-to-DC converter, which is the simplest converter: the diode bridge rectifier. Before starting that, let me also discuss one thing: if you have a charger with a single-phase input, then you need a single-phase AC-to-DC converter. If a three-phase AC input is given, then you require a three-phase AC-to-DC converter.

So, let us focus our discussion on a single-phase AC-to-DC converter. The simplest form of an AC-to-DC converter is the single-phase diode bridge rectifier, also called an uncontrolled rectifier. We will discuss why it is called an uncontrolled rectifier. In this single-phase diode bridge rectifier, we have two kinds of rectifiers: the first one is a half-bridge rectifier, and the second one is a full-bridge rectifier. So, let us discuss the single-phase half-bridge rectifier with a resistive load. Let us revisit its circuit. It looks like we have a single-phase voltage source, which is fed to a resistive load via a single diode D. Let us define our resistive load as R_L, the diode as D, and our voltage source as:

$$v_s = V_{s,pk} sin\omega t.$$

It varies sinusoidally with time. So, V_s is a function of time. Now, if you consider this particular circuit, the diode D turns on when the $v_s(t)$ (or interchangeably, I will write 'small v_s') is in the positive half-cycle. Why?

Because if it is having a positive half cycle, the anode of this diode will have the positive polarity of voltage and thus it will be forward biased. While in the negative half cycle, the anode will be at the negative polarity of voltage, and that's why it will be reverse biased. So, it turns on when the v_s is in positive half cycle and it will allow the current to flow through it. The current flows through it in the direction from anode to cathode. This is its anode, and this is its cathode. Now, it turns on, or you can say it is forward-biased when v_s is in the positive half cycle, and it is

reverse-biased when v_s is in the negative half cycle. Let me draw the circuit here: R_L, D, v_s, $V_{s,pk} sin\omega t$. Now, let us see how the waveform looks.

Since we have a sinusoidal voltage source, let me draw the sinusoidal voltage. So, let me draw the sinusoidal voltage. Okay, now accordingly, you also have different timestamps. This is your Vs, and this point is nothing but Vs peak. The peak of the sine wave is here, and this is your -$V_{s,pk}$. It goes from this one, meaning the distance from here to here is $V_{s,pk}$. Let us also define one term, which is T, which is nothing but the time period between the start of the cycle and the end of the cycle. And so, if this is v_s , then in the positive half cycle, this particular positive half cycle, the anode of this diode sees the positive polarity of voltage, and as a result, it will get forward-biased and thus allow the current to flow through it. Also, let us define this voltage across it as v_d . So, since the diode is on in this positive half cycle, your v_d will be equal to v_s, assuming it is an ideal diode, meaning the forward voltage of the diode is 0.

So, since you are applying a positive half-cycle voltage from its input to the anode of this diode, it will be at a higher potential than the cathode, and as a result, the diode gets forward-biased. Since the diode gets forward-biased, what you will see is that the voltage will follow the same pattern as v_s. So, this is also following the same pattern which your v_s or voltage source is following. So, we can say that this v_d is equal to v_s when v_s is greater than 0. And it is zero when v_s is less than zero. Why? Because when v_s is in the negative half cycle, the anode of this diode is at a negative potential, which is when it gets reverse-biased and does not allow the current to flow through it. The entire voltage will drop across this diode itself. Since we have drawn the wheel, let me also draw

the diode voltage or more specifically the anode to cathode voltage voltage across the diode since during this time the diode is in is forward bias thus the voltage across diode is nearly zero as we assume that our forward voltage is zero so our voltage across the diode is zero and during this point you are our diode will be blocking or will be seeing the negative potential across it and that's when negative voltage across it that's when it will if we define we define this thing so the voltage across the diode will be of the same shape as that of the vs and then again it

goes to zero so and at this point is nothing but our $V_{s,pk}$ So, in this particular case we have seen that during this period of time during the positive during the positive v_s our diode is conducting and that is when the voltage will start appearing across the load and that is when the current will be drawn from the source and in the negative half cycle the diode will be reversed bias and the entire voltage will be blocking across this diode as drawn here. Now, let us also draw the current.

So, let me draw the current with the other color. So, since the voltage is in this shape which is the half sine wave shape appearing across the resistive load. So, current will also be following this. the voltage and they have the same shape as that of voltage where this peak will be nothing but $V_{s,pk}/R_L$. and if you take this peak which is nothing but your $V_{s,pk}$ While during this instance during this time period this current is nearly zero and then in this particular place again it will come it will come back and having the same with the peak same as that of previous peak which is $V_{s,pk}/R_L$.

So with this we can see that the current supply to the load is only happening in the or the power supply to the load is only happening in the only the positive half cycle that means just the $T/2$ period while in rest of the $T/2$ period the circuit, I mean the there is no power which has been delivered to the load now since our voltage is of the shape of the half sine, I mean half sine wave and then zero and then again the half sine wave so let us see what is the average voltage of average output voltage so the average value of v_d which you can say that $V_{d,avg}$ which is also you can say that the voltage applied across the load is nothing but if you do a simple calculation so the thing will be

$$V_{d,avg} \quad = \frac{1}{T}\int_0^{T/2}\left(V_{s,pk}sin\omega t\right)\cdot dt \quad = \frac{V_{spk}}{\omega T}[-\cos\omega t]_0^{T/2}] \quad = \frac{V_{spk}}{\omega T}\left[-\left(\cos\frac{\omega T}{2} - \cos 0\right)\right] \quad = \frac{V_{spk}}{2\pi}[-\left(\cos\pi - co \right.$$

So, this will be your $V_{d,avg}$ which will be applied across the load RL. and accordingly the current will be drawn from the source or a current will be drawn by the load so this is what we have seen the average voltage now average voltage will be somewhere if I draw the average voltage so average voltage will be somewhere here this line which is given as wingy average

let us see what will be my current drawn from the source now if I draw again a circuit then the current drawn from the source let's say 'is' is nothing but equal to 'id' which we have drawn you know your id the current in the same current so this this particular the red color thing is the current which is nothing but your 'id' so which is going into the load 'id' and here you have is

Similarly, here we can 'is' and current going into the load is 'id'. So, we can write that my 'is' current which is being drawn from the source 'is' nothing but 'id' when 'vs' is greater than 0 and 0 when 'vs' is less than 0. Now, if you see this particular circuit, in this particular circuit you have a load. which is again depend because you are supplying that particular load so it is the external thing which has been placed and you have the input source which is not the part of the power conversion unit now the only thing which is there is the diode so now let us see the diode selection how we can do this diode selection

in doing the diode selection depending upon the parameters of the circuit we have primary two things which is the voltages and the current so this we have the voltage ratings of the diode and in that voltage ratings what we have is we have several types of voltage rating which has been defined for the diode now the first voltage rating is your peak repetitive reverse voltage which means how much maximum voltage it can withstand or it can block and that too when the that peak will be in the repetitive form and along with that you also have peak reverse voltage sometimes in the data sheet it is been given the peak reverse voltage tells what is the maximum voltage it can block when it is reversed bias it is the once I mean in one time how much peak maximum peak voltage it can withstand and then you have the reverse voltage another rating which is defined as reverse voltage or it is also called as a DC blocking voltage which indicate what is the maximum DC voltage it can block now if we see if we try to understand what is the peak repetitive reverse voltage if you see let's say the cathode to anode voltage across the diode I mean the reverse voltage across the diode has shape which is repeating in nature so the this particular point is nothing but your peak repetitive reverse voltage which is also defined as V_{RRM}

while whenever it has to block a DC voltage then this maximum DC voltage it can block this is the your reverse voltage or dc blocking voltage and this is the vrdc the maximum dc voltage it can block so these are the two things which is there which is been given in the diode data sheets some voltages are given sometimes some are not given so the designer has to take a well judgment what voltage to be taken while defining the or while choosing the diode let's say if it is used for the rectifier application or the application where it is continue i mean where we have the repetitive on i mean forward bias and reverse biasing of diode then maybe peak repetitive reverse voltage is the best possible thing one can I mean is the best thing to be seen while when

the diode has to just block a DC voltage that's when they can see the reverse voltage or the DC blocking voltage similarly you also have the current ratings of the diode different current ratings of this diode are there in that you have first one which is average forward current This average forward current is again the average value of the current going through this through the diode when it is forward biased.

Then it has the sometimes you also have average rectified forward current and average rectified forward current. Sometimes in some of the diode data suite this has been given. However, most of the time this is average forward current and sometimes it is also called as a continuous forward current as well. Then you have another rating which is again repetitive peak forward current. given as I_{FRM} and some it is also given also there is one more rating even non repetitive peak forward current is I_{FRM}

Generally, while defining these two things, they will also mention the time period of the pulse current which is being or the time period for which this current can be applied, that maximum current can be applied. So, they will also mention that in the data sheet while defining these parameters. And along with this, there is another rating which is been defined which is called as the I^2t rating. This I^2t rating is actually used to select the appropriate fuse rating because fuse also have this I^2t rating. So, accordingly the fuse depending upon this I^2t rating the fuse can be selected while this diode will be used in the circuit.

So, for protection, the fuse can be selected. So, that is why this I^2t rating will be defined, where this 'I' is nothing but the RMS value of forward current or when the diode is forward biased, and you can say that 't' is the time period of the pulse or, you can say, the duration for which the current is allowed to flow through the diode. So, this is again one rating—one particular rating for the safe operation of the diode, which is defined. Now, if we consider designing our single-phase half-bridge diode rectifier, in this particular case, if we see the diode selection criteria, now if we talk about voltage rating, in voltage rating, if we talk about peak

repetitive reverse voltage, or you can say that V_{RRM} is nothing but, if you look carefully in our waveform, the peak value this diode will block is nothing but $V_{s,pk}$ value, ($V_{RRM} = V_{s,pk}$),

which is the peak value of your input AC voltage. And if we try to see the average forward current, average forward current is nothing but,

$$I_{F,avg} = \frac{V_{s,pk}}{\pi R_L}$$

Similarly, one can also calculate the RMS current which is going through the diode, which is nothing but you can calculate as:

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

$$I_{F,avg} = \frac{V_{s,pk}}{2R_L}$$

because this diode conducts from 0 to T/2 and it will be 0, and then again it will start conducting. So, this conduction of the diode repeats after the time That's why we are taking the mean for the entire fundamental cycle or for the entire line cycle, and it is going from 0 to T/2. Because in the positive cycle only, there is a current, while in the negative cycle, there is no current. That's why they are going from 0 to T/2. You can write $V_{s,pk}$ sin $sin\ \omega t\ /R_L$ is the current squared, and the integration and the detail. Now, if we solve this particular integration, one could easily get this particular integration. While solving, one could get a value nothing but $V_{s,pk}$ sin $sin\ \omega t\ /2R_L$. So, this is the RMS value using which the I^2t rating can be formed. This is the average value of the diode one can select, depending upon the value of the load it is supplying, and the voltage rating one can select using these three ratings—or, I mean, these three ratings—an appropriate diode can be selected. However, these are the ratings which I mentioned over here are the ratings which are determined by the circuit in which it is operated. However, there are other ratings also, like

The forward voltage drop of a diode and also the dynamic resistance—those things could also be considered. But depending upon the current and the voltage rating of the diode, one can select the family of diodes. Then, from the family of diodes, one can select the most appropriate one. That's when this particular converter can be designed and used to supply power to the load from the AC source. I mean, this AC source will be converted into DC, and that will be

supplied to the resistive load. So, in this way, one can select the required diode, and that is how one can obtain the single-phase diode rectifier which can supply the load from an AC source by converting that AC into DC and supplying it to the required load—I mean, supplying it to a resistive load.

Thank you for patiently listening to this lecture. In the subsequent lectures, we will see the full-bridge configuration of an uncontrolled rectifier. We will take some references from these two diode-based configurations and, accordingly, logically navigate to the circuits used among different EV chargers. Thank you.