Fundamental of Power Electronics
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Lecture - 11
Motivation for rectifier capacitor filter

In this video capsule, we shall look at rectifiers and capacitor filter. We will be focusing on the full bridge rectifier and only the capacitor filter for the filtering circuit. If you understand that there are many circuits that convert AC to DC; how the voltage rectifier capacitor filter combination is one of the most popular AC to DC converter that you will find and you will find it almost in every product. Even though the full bridge rectifier combination has lot of disadvantages like very low power factor, it draws peaky currents things like that. It has the advantages like very low component count, low cost and very high volumetric efficiency; it is very compact.

Because of these this has become very popular and we will study this particular circuit. Later on I will describe to you some of the problems that you will encounter with the circuit and the corrections needed and the protections needed to handle those issues and probably later on and we talked about DC converter. I will also talk about the power factor improvement techniques and methods. So, now, we will talk about the rectifier circuit, its operation and the waveforms.

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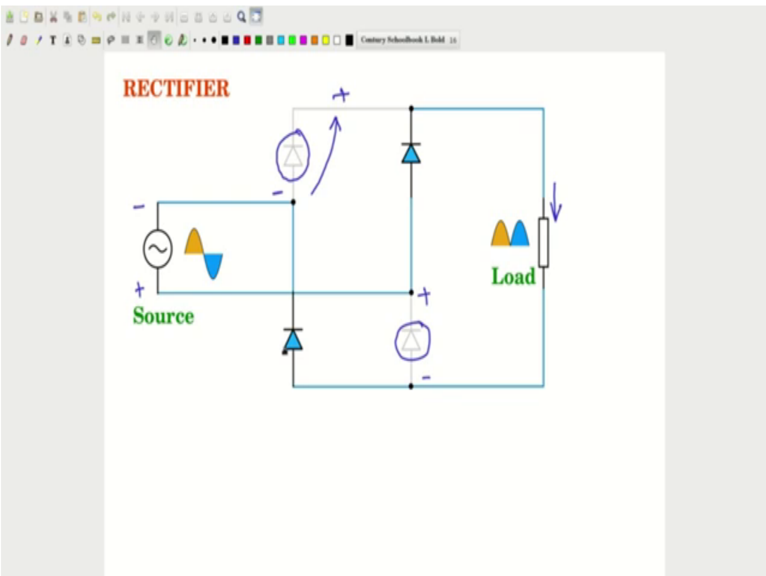

So, first let us start with the source. The source is generally the wall outlet 32 volts 50 hertz grid. It is sinusoidal in voltage wave shape and this needs to be interfaced to a load which expects unidirectional voltage wave shape. The key point here is that through the load, the current should always flow in the same direction; whatever may be the polarity of the source. Let us now interface the diodes step by step. First when the source is having a polarity; positive polarity, this is positive with respect to the other terminal diodes need to be connected. In this fashion such that the current flow completes as shown here. Notice the current flow direction here through the load which is in this direction.

Now, let us say that the polarity of the source is reversed. Now it is in the blue signal level. These 2 diodes will become reverse biased and turn off. I will explain a little later. Let us first see the current flow direction. This is positive with respect to this; so, you will see that. Here, this is positive during the negative half and the flow of current will be in this direction and again entering here at the same point terminal through the load resistor and then, comes back to the source.

Note again, here importantly that the current direction has been retained. Thereby, you will see that the voltage across the load is uni direction whether the source voltage is positive or negative. Now, let me just tell you how this diode gets reverse biased here. So, you saw that when the blue colored diodes are conducting, this is positive with respect to this terminal.

So, when this blue diode is conducting, this terminal, this point is at a positive potential with respect to this. So, this diode see the reverse biased voltage, reverse voltage; therefore, it is reverse biased and is off likewise this point is at a positive potential compared to this point. Again, this diode sees the reverse voltage and it is reverse biased and in the off situation.

By a similar argument, it can be seen that the other two diodes that is this diode and this diode will be turned off, when the voltage polarity is positive, when this is positive with respect to this. So, these other two diodes will be conducting and will make these two diodes go off. So, the total schematic of the rectifier is like this as shown. Now, to this if we how to connect a filter because this is a varying voltage we need to connect a filter.

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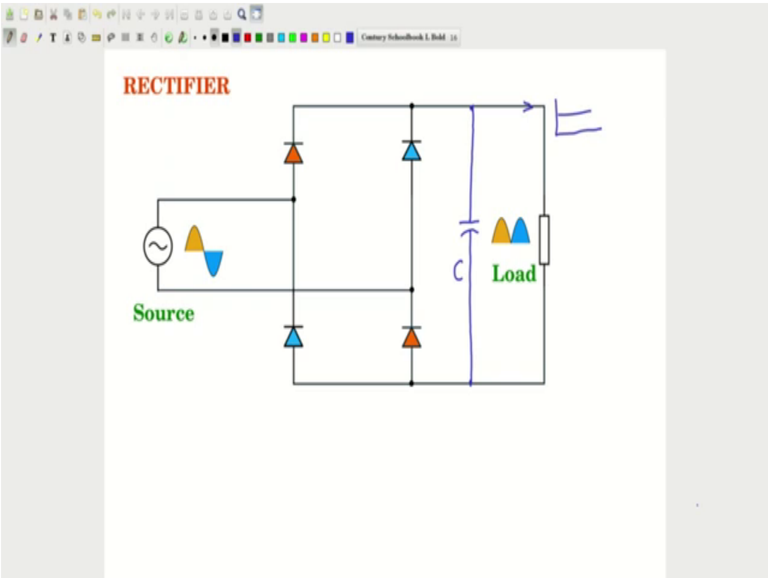

It is a simple matter of connecting a capacitor like this as shown. This is a capacitor C. Now this capacitor will act as a filter and trying to pass current through load which is more or less at DC. Now, at this point may be interesting to see some real components of the rectifier and the capacitors.

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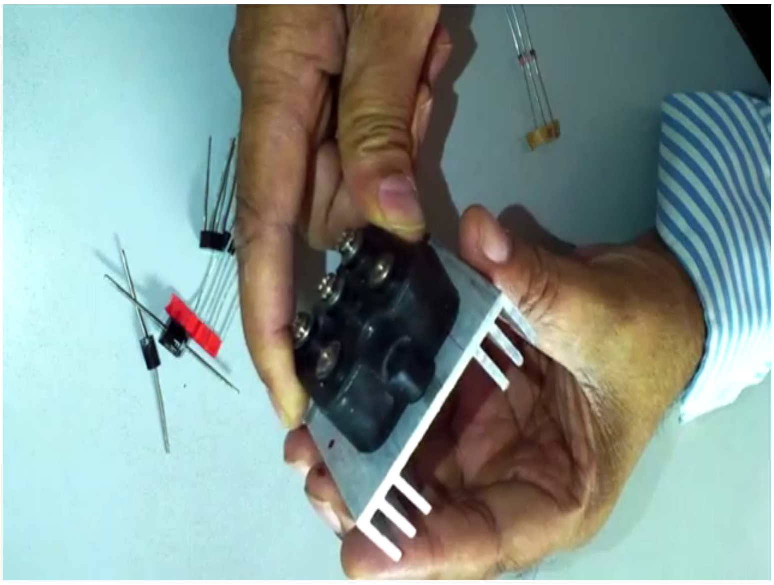

I would like to show you some common rectifier diodes. Now, this is a very common rectifier diode used in most of the products 1 and 400 11; 1 and 400 7 kind of series kind of diodes. It can handle just about 1 ampere so and pretty popular and common. They come strips like this and then, you will be mounting 4 of them to form a full bridge rectifier.

Like this you also have still smaller diodes these are 1 and 4 and 4 8 type diodes much smaller handles; only around 500 milliamps or 800 milliamps in that range for much smaller circuits. You have some fr series high amps; higher amps one. Also you see here this is the one on one which I am right now showing is around 3 amps range FR series diode; rectifier diodes can be used for rectification and then this is a 6 amp diode, what I am right now showing.

So, this can also be used for rectification. An interesting thing here would like to show you this you see this is a full bridge rectifier completely. It is having 4 diodes within it. So, 2 of the leads are connected to the AC and 2 of the leads are connected to the unidirectional port that is plus minus and to that unidirectional port pins you connect the load resistor r u and the filter capacitor.

So, this come this comprises 4 diodes within is the full bridge rectifier component available to you. Another interesting piece is this you see here, it is having 5 pins. This is actually a 3 phase rectifier. You connect the a phase, b phase, c phase to these 3 terminals and then, you can take the plus and the minus output from this and connect the capacitor or the load at this point. This is a 3 phase rectifier and you will see that the back side, there is an aluminum facing which can be used for connecting to the heat sink for thermal regulation.

So, the heat sink can be of this type like or any other type depends upon the design and one will mount it in this fashion to get a better thermal flow. So, like this rectifiers I have few capacitors also to show to you.

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So, these are the aluminum electrolytic capacitors which will be used. In the smaller ones, you will use these kind of aluminum electrolytic capacitors; the one with the line mark is the negative polarity usually and a slightly bigger one with this is 4700 microfarads. This is also aluminum electrolytic. Most of the time it is aluminum electrolytic that will be used as still bigger one normally used as d-ceiling capacitors in high power circuits, in inverters and things like that one, where there are terminal lux. You connect the lux there and this is from Aerovox this is 450 volt DC high voltage, 1000 microfarads capacitor.

This also aluminum electrolytic; these are some of the components actually. You see these are the 2 sets of components that will be using in the rectifier circuits, back to the circuiting. So, we have the full bridge rectifier and the capacitor connect as a filter here across the load.

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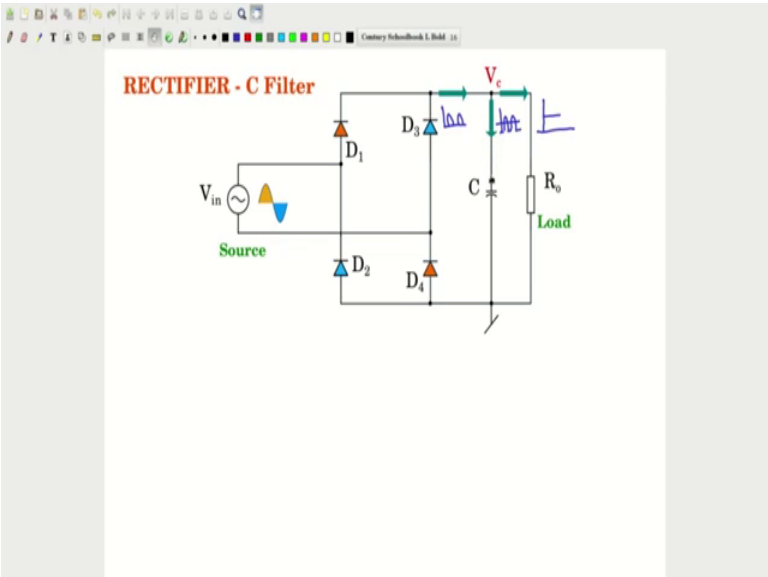

Now, let us name the parts we will call the input sources V in, diode D 1 and diode D 4 connect during the positive half cycle of the input. Diode D 2 and diode D 3 conduct during the negative half cycle of V in. There is a capacitor C and a load R naught are now we have put a resistive load. The point that is of interest is here and that is called V c.

V c is a voltage across the capacitor is of importance to you because that is the voltage that the load will also be seen and this actually would be the filtered voltage. Another point of interest of; points of interest or the 3 currents that flow at this node. This is the current coming out of the rectifier, this is the current that flows into the capacitor and this is the current that flows into the load.

So, here we expect that at this point; we expect the current to be a D C and around here, we expect the current to be spiky peaky current and here in the through the capacitor, we expect the current to have gone down by the load current value something like that. Anyway, we will discuss this current wave shape in more detail and the slides to come. But this is generally the idea that I want to convey that this is a current which is having an average value plus an AC component.

The average value part goes into the load resistor and the AC component part, the one which does not AC average value 0 average value flows through the capacitor. Must note that in the steady state, the capacitor can handle only a pure AC current that they should not be an average value; otherwise there will be charge buildup ok. So, under steady state the 0 average part of the current or the only the AC component flows through the capacitor. So, that is the action on the filter.

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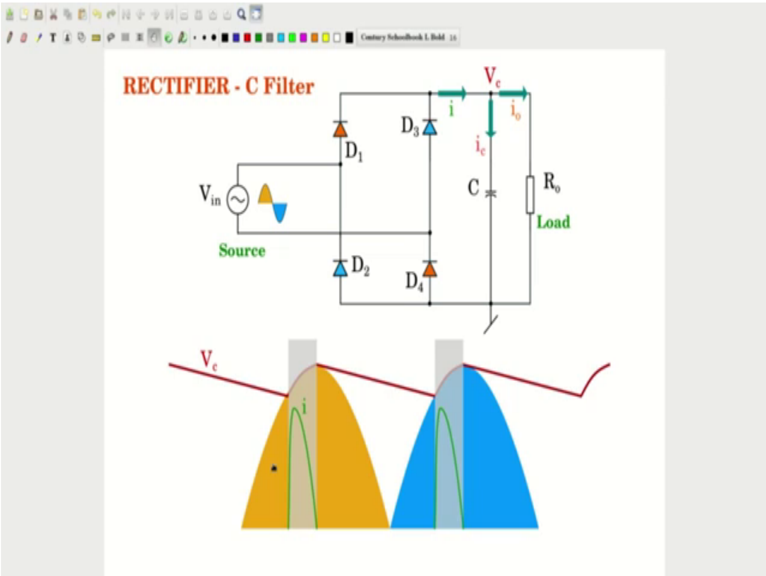

So, now let us see the waveforms in detail before that let us name the parts. So, the current that is coming out of the rectifier, you will call it as i. The current that goes through the capacitor as i c, the current that flows into the load R naught has i naught. Let us have this template. This is the sine wave shape of each rectified half. So, this is a positive half of the input source.

This is the negative of the input source rectified and placed in this fashion, the unidirectional fashion. Let us start from this point to speak point as a reference and then we will come back to it and extend it and let us say it is in a steady state which means that there is some charge accumulated in the capacitance. So, if I say it is we are starting at this point, the chart, the voltage at the capacitance will also be of this value V in value.

So, at this point, the capacitor is discharging through the load with some time constant. So, this is the discharge part of the capacitance; whereas, the input wave shape is following this path. So, if you look at the diodes in the full bridge the load voltage here is higher and the voltage on the input side is lower and all the diodes are reverse biased and off. So, during this part and up to this part you do not see any diode conducting because are there reverse biased and the capacitor portion is isolated from the input proportion.

So, capacitor is discharging on its own. Till it reaches at this point, when the input wave shape has taken at and it is rising up the moment the input rises beyond this, the diodes conduct.

So, in this case the blue colored diodes conduct and the capacitor follows the input. The moment the diodes conduct the capacitor node point is directly connected to the source and it will just follow the source up to this point. And then again, after this point the period repeats and you will see the capacitor discharging in this fashion and the moment capacitor starts discharging like this and the input also starts to flow down along the sinusoidal path.

You will see there is a differential difference and potential the diodes are reverse biased and they turn off. Likewise so and this would be the steady state waveform wave shape for the output at node V c. So, this is also the ripple that the output would see across the load and this ripple is controllable through design; we will see that later.

Now, if you see only during this portion, we see conduction in the diode; only during this portion, we see conduction of the diode. So, let us mark that off and during that only we will see current. Here, the current i is flowing. So, what would be the type of the current? So, the moment the diodes turn on at this point, the diodes turn on at this point, a voltage source is seen connected to a capacitance. So, there is two direct connection of two potential devices. So, there will be a huge current rise here and it is limited only by the track inductance diode impedance and any (Refer Time: 17:52) or the capacitance and the inductances here; these kind of non idealities only will limit the current.

So, the current wave shape will be something like this. It will have a very sharp rise and it will have a time constant based on only the series impedance is coming in the path. Now this current will repeat every half cycle as shown here. What happens during the first cycle when the capacitances start charged, we will look at that a bit later. Let us first clarify the other components of the current. Now we see that this is the wave shape of the voltage with a ripple and this is the current that is flowing output of the rectifier just before the filter.

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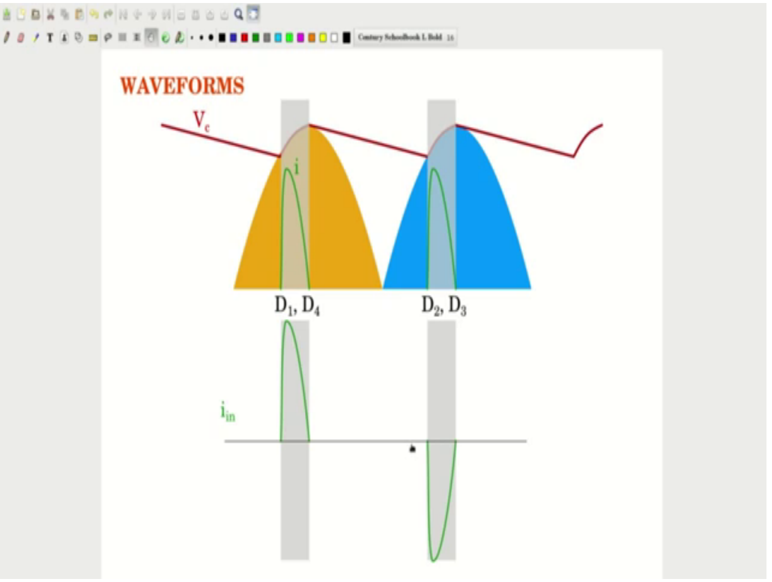

Now, during this time D 1 and D 4 are conducting; other two diodes are conducting during this period D 2 and D 3. So, basically this would form the diode currents and if you calculate, if you draw the waveform for i in, the input current. This is the wave shape for during the positive half cycle and during the negative half cycle, this would be in reverse like this. Now, these are the wave shape for the input current. Now, let us look at the load current and the capacitor currents.

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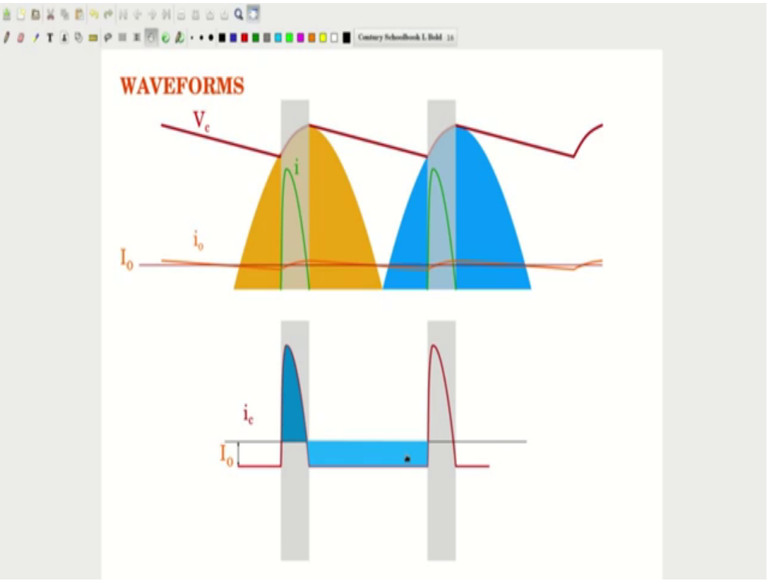

Now, the load current will follow the voltage at that node V c node. So, that V c value divided by R will be i naught and it will have some ripple as seen here. We can approximate the averages right through this as shown and for practical purposes, we can take this i naught as the current flowing through the output ripple free. But be aware that there will be a small ripple.

Now, if you remove this average component, from this i current, you will get the current that flows through the capacitance. So, let us draw the capacitance waveform during this period of conduction. Then, you will see that the capacitance would have gone down by an amount of i naught value as shown here. In the steady state, you should note that this area is equal to this area.

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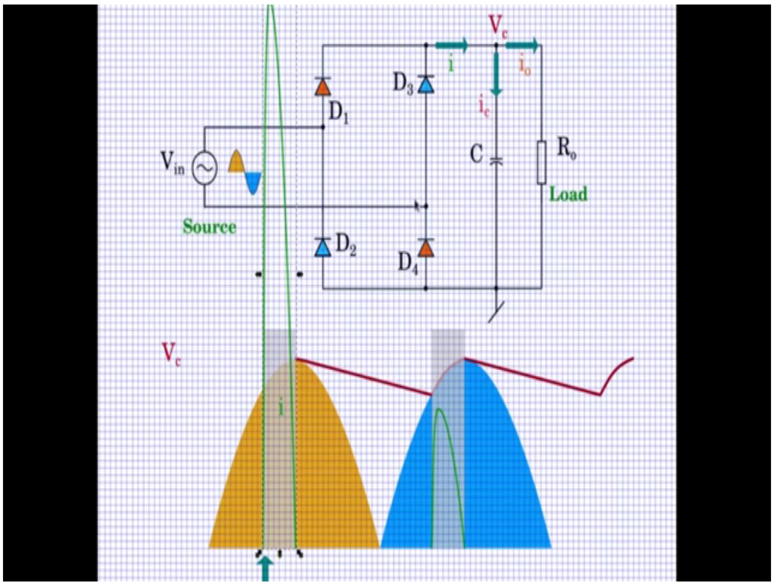

I would now like to revisit these waveforms to discuss about the current during starting. So, let me remove this part of the waveform. Now, you see at the time of starting the capacitor voltage is 0. So, the probably it will be at this level. Now if we apply a voltage and if by chance that voltage is starting at this point, then you will see that the capacitor build up the charge gradually from here on up to this point. So, as the capacitor is building up the charge there is current flow out of the rectifier and therefore, the rectifier current will be for this whole half cycle.

So, you see the conduction period will start increasing and before the complete half cycle. Likewise, the current wave shape also will get modified something like this. But you should understand that the capacitance had 0 voltage and therefore, 0 charge; unlike in the case of the steady state condition. At this point the charge on the capacitor was finite and there was some energy. It was only making up the difference energy. Now, this whole energy has to be made up. So, you will probably land up with current waveform at the first start up value which would be much higher than the following and the city state currents.

So, this may be the shape of the wave shape you will see from startup from the for the currents. But a problem could occur what if at the time of turn on; the turn on was not synchronized with the 0 of the input voltage, but it occurs somewhere here; which means the turn on occurs somewhere at this point and which means that the capacitor voltage is 0 and the grid voltage is pretty high value and you are connecting to potential devices together, there could be a huge surge current.

So, what happens to the current wave shape? The current wave shape may look something like this, but the aptitude may just go out of the screen, it may be a very large current and then, you start having the steady state. But the effect would be that by the time the first cycle is over the current will be so large, the devices the diodes may blow off and once the diode is blown off, the rectifier circuit will not see the second half cycle at all.

So, it never even goes beyond the first half cycle. So, it is very important that we do limit the first current search. Of course, I will discuss about the protection circuits and see how we limit the turn on current surges. But keep this in mind that all is not rosy and all is not well and good with the circuit that we have just discussed, the turn on current are just can be pretty high and it could be big drain even on the wall socket outlet. They have to be rated for such high currents. Therefore, we would like to put a series impedance somewhere here and limit the current surge.