Design and Simulation of DC-DC converters using open source tools

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Lecture - 02
Understanding Rectifier with C-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 filtric circuit. We should understand that there are many circuits that convert ac to dc; however, the full bridge 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 and 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 very popular and we will study this particular circuit and later on I describe to you some other problems, you will encounter with the circuit and the corrections needed and protections needed to handle those issues and probably later on when, we talk about dc-dc converter I will also talk about the power factor improvement techniques and methods.

So, now we will talk about the rectifier circuit it is operation and the wave forms.

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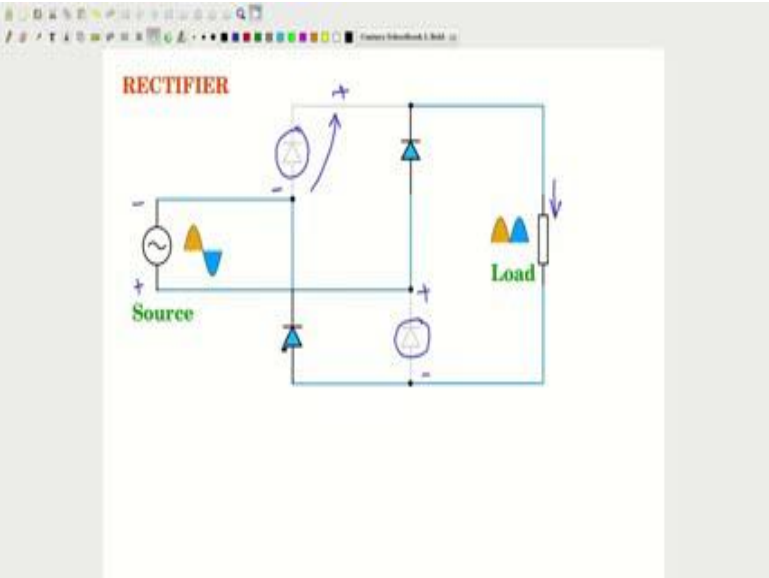

So, first let us start with the source the source is generally the valve outlet 230 volts, 50 hertz grid, it is sinusoidal in voltage wave shape and this needs to interfaced by load which expects unidirectional voltage wave shape, the key point here is that through the load the current should always 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 the polarity, positive polarity this is positive with respect to the other terminal diodes need to be connected in this direction 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 polarity of the source is reversed, now it is in the blue signal level these 2 diodes will become reversed biased and turned 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 reversed biased here. So, you saw that when the blue color 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 sees in the reverse biased voltage reverse voltage. Therefore, it is reversed biased and is off likewise this point is at the positive potential compared to this point again this diode sees the reverse voltage and it is reversed biased and in the off situation.

By similar argument it can be seen that the other 2 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, this other 2 diode will be conducting and will make these 2 diodes go off.

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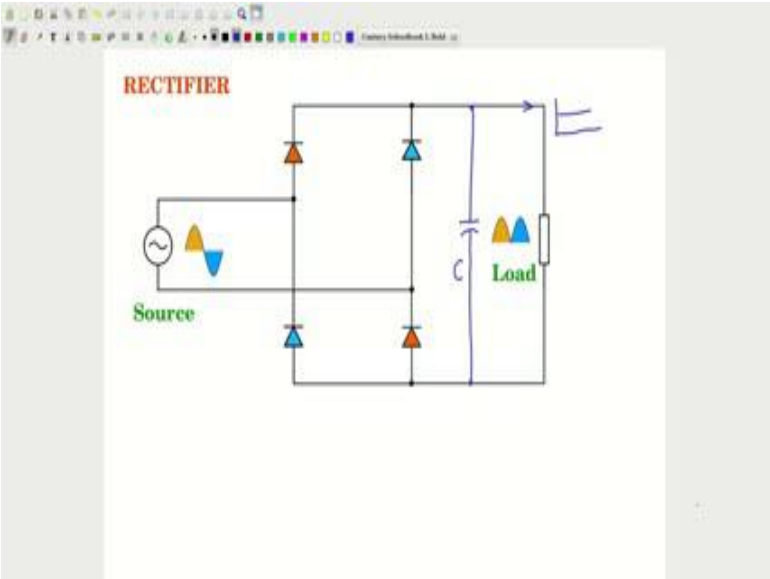

So, the total schematic of the rectifier is like this as shown. Now to this we have to connect a filter because this is a varying voltage we need to connect a filter it is a simple matter of connecting a capacitor like this as shown this is a capacitor c.

Now, this capacitor will act as a filter and trying to pass current through the load which is more or less like a dc now this point may be interesting to see some real components of the rectifier and the capacitors.

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I like to show you some common rectifier diodes. Now this is a very common rectifier diode used in most of the products 1N4001111 and 4007 kind of series kind of diodes it can handle just about 1 amp or 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 these smaller diodes these are 1N4148 type diodes much smaller handles only around 500 milliamps or 800 milliamps in that range for much smaller circuits.

You have some f r series high amps higher amps 1 also you see here, this is the 1 and 11. Which I am right now showing is around 3 amps range f r 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 full bridge rectifier complete it is having four 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; that means, you connect a load resistor or a filter capacitor.

So, this comprises 4 diodes with it is a full bridge rectifier component available to you another interesting piece is this you will 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 outputs from these 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 a aluminum phasing, 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 up on the design and 1 will mount it in this fashion to get the better thermal flow.

So, like this rectifiers I have few capacitors also to show to you. So, these are the aluminum electrolytic capacitors which will be used, in the smaller ones you will use this kind of aluminum electrolytic capacitors the 1 with the line mark is the negative polarity usually and slightly bigger 1 with this is 4700 micro farads this is also an aluminum electrolytic. Most of the time it is aluminum electrolytic that will be used I have still bigger 1 normally used as dc link capacitors in high powered circuits in inverts and things like that 1 where there are terminal lugs you connect the lugs there and this is from aerovox this is four fifty volt dc high voltage and thousand micro farads capacitor this is also an aluminum electrolytic. Yeah these are some of the components actually you see these are the 2 sets of components that will be using in the rectifier circuits yeah back to the circuiting.

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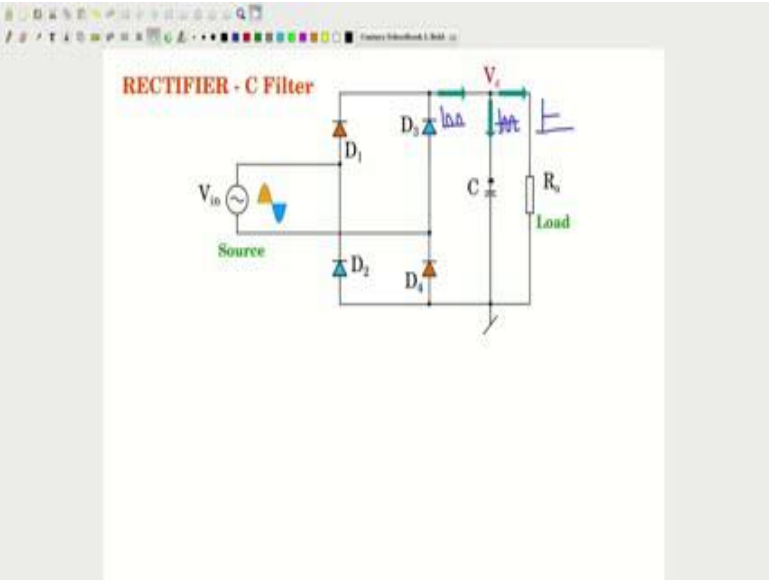

So, we have the full bridge rectifier and the capacitor connected as a filter here across the load. Now let us name the parts we will call the input source as v in diode D1 and diode D4 connect during the positive half cycle of the input diode D2 and diode d three conduct during the negative half cycle of v in there is a capacitor c and a load r not for now, we have put a resistive load the point that is of interest is here and that is called Vc. Vc or voltage across the capacitor is of importance to you because that is the voltage that the load will also receive and this will actually be the filtered voltage another point of interest or points of interest are 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 dc and around here, we expect the current to be spiky peaky current and here in the into the capacitor we expect the current to have gone down by the load current value something like that. Anyway we will discuss the current wave shape in more detail in the slides to come, but this is generally the idea that I want to convey that this is a current which is having a average value plus an ac component the average value part goes into the load resistor and the ac component part the 1 which does not have ac average value 0 average value flows through the capacitor must know that in the steady state the capacitor can handle only a pure ac current that there should not be an average value otherwise there will be charge build up.

So, under steady state the 0 average part of the current or the only the ac component flows through the capacitor. So, that it is the action of the filter.

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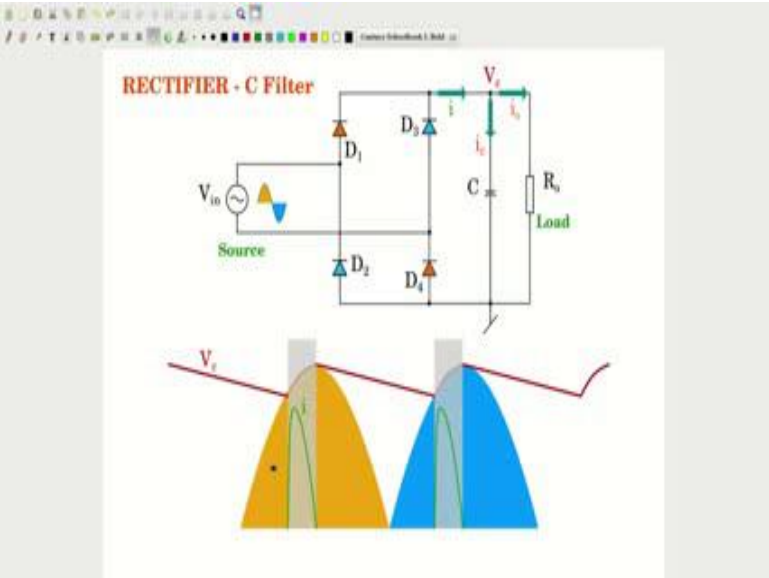

Now let us see the wave form in detail before that let us name the parts. So, the current that is coming out of the rectifier we will call it as I the current that goes through the capacitor as Ic the current that flows into the load r, not as I naught. Let us have this template this is the sine wave shape of each rectified half. So, this is the positive half of the input source this is the negative half of the input source rectified and placed in this fashion the uni direct load fashion.

Let us start from this point this peak point as a reference and then, we will come back to it and extend it and let us say it is in the 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 voltage or the capacitance will also be of this value Vm value. So, at this point the capacitor is discharging through the load with some time constant. So, there is the discharge part of the capacitance; whereas, the input wave length is following this path. So, if you look at the diodes in the full bridge the node voltage here is higher and the voltage on input side is lower and all the diodes are reversed biased and off.

So, during this part and up to this part you do not see any diode conducting because of they are reversed biased and the capacitor portion is isolated from the input portion. So, the capacitor is discharging on it is own till it reaches at this point when the input wave

shape has taken a turn and it is rising up the moment the input rises beyond this the diodes conduct.

So, in this case the blue color diodes conduct and the capacitor follows the input the moment the diodes conduct the capacitor node point is directly connect to the source and it will just follow the source, up to this point and then again after this point the red 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 in potential the diodes are reversed biased and they turn off like wise. And this would be the steady state wave form wave shape for the output at node Vc. 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 all and during that only we will see the current here current I 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 voltage source is seen connected to a capacitance. So, that is to direct connection of to potential devices. So, there will be a huge current rise here and it is limited only by the track inductance diode impedance and any esr of the capacitance etcetera inductance ocr 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 coming in the path.

Now, this current will repeat every half cycle as shown here what happens during the first cycle when the capacitance start charged we will look a bit later. Let us first clarify the other components of the current.

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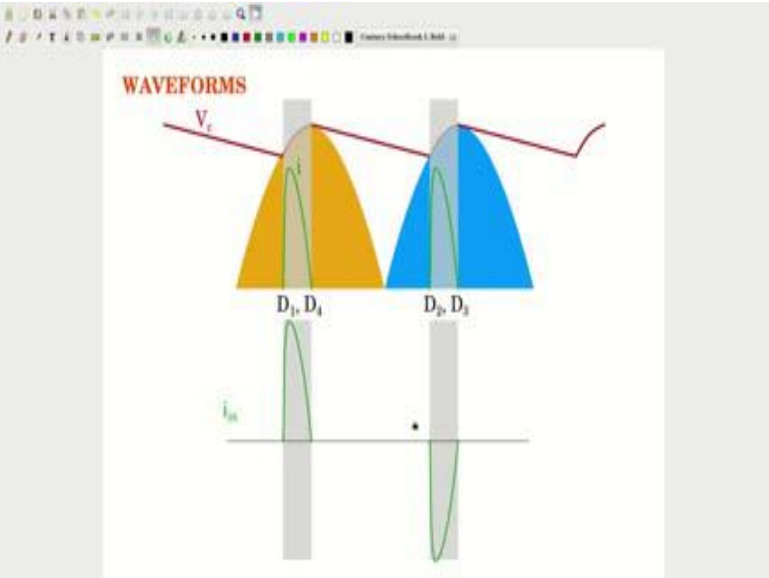

Now, we see that this is the wave shape of the voltage with a ripple and this is the current that is flowing output of the rectifier just before the filter now during this time D1 and D 4 are conducting and other 2 diodes are conducting during this peak D4 and D4. So, basically this would form the diode currents and if you calculate, if you draw the wave form Eigen the input current this is the wave shape for during the positive half of cycle and during the negative half cycle this would be in reverse like this.

Now, this is the wave shape for the input current.

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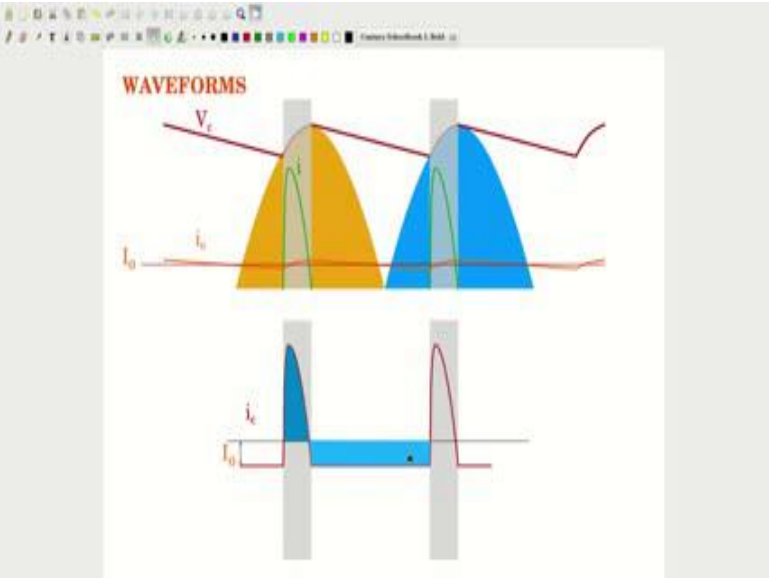

Now, let us look at the load current and the capacitor currents now the load current will follow the voltage at that node Vc node. So, that Vc value divided by r will be the I naught and it will have some ripple as seen here we can approximate the average is right through this as shown and for practical 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 wave form during this period of conduction then, you will see that the capacitance would now gone down by an amount of I not value as shown here.

In the steady state you should note that this area is equal to this area.

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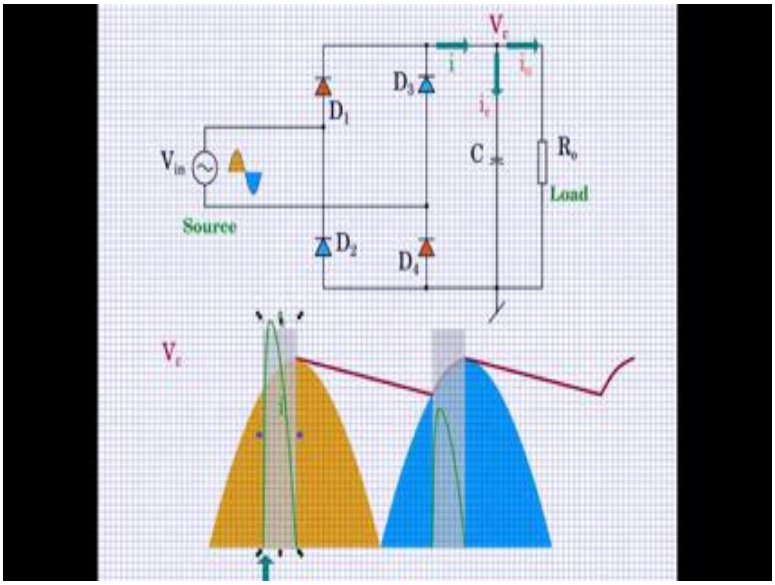

I would now like to revisit this wave forms to discuss about the current during starting. So, let me remove this part of the wave form now, if you see at the time of starting the capacitor voltage is 0. So, probably it will be at this level now if we apply a voltage and if by change that voltage is starting at this point then you see the capacitor built up the charge gradually from here on up to this point as the capacitor is building up the charge there is current flow to the rectifier and therefore, the rectifier current will be for this whole half cycle. So, you see the conduction period will start increasing and will be for the complete half cycle likewise the current wave shape also we will get modified something like this.

But if you understand that the capacitance had zero voltages and therefore, zero charge unlike in the case of the steady state condition at this point the charge of 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 wave form at the first startup value which will be much higher than the following and the steady 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 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 capacitor

voltage is 0 and the grid voltage is pretty high value and you are connecting two potential devices together there could be a huge surge current.

So, what happens to the current wave shape the current wave shape might look something like this, but the amplitude may just go out of the screen it may be a very large current and then, you will start having the steady state, but the effect would be that by the time the first cycle is over the current would be. So, large the devices the diodes may blow off some of 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 searches, 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 currents are just can be pretty high and it would be a big drain even on the wall socket outlet they have to be related for such high currents. Therefore, we would like to put series impedance somewhere here and limit the current surge.