Basic Electronics

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Lecture - 20
Diode rectifiers (continued)

Welcome to Basic Electronics. In the last class, we discussed a half-wave rectifier circuit, and looked at the various waveforms namely the input and output voltages, diode current and capacitor current. To help in visualizing the circuit operation, we will now look at an animation which mimics charging and discharging of the filter capacitor. The animation will help us to understand clearly the reason behind the ripple voltage at the output. We will also get to know which factors are responsible for the ripple voltage and therefore, how to make it smaller. We will then take up a numerical example, work out expressions for the various quantities of interest and calculate those quantities for the given circuit. Let us get started.

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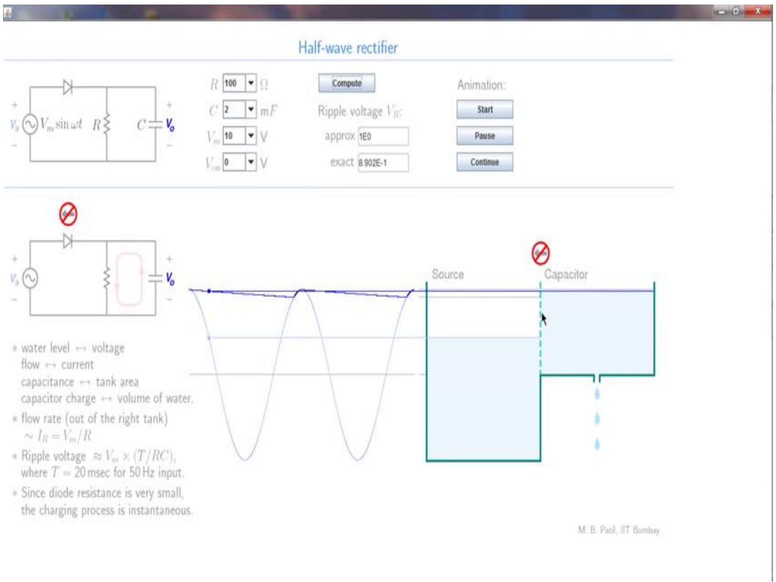

Here is an animation and the component values can be set here, for example, R can be 100 or 150 or 200 ohms; C can be 1, 1.5 or 2 millifarads; V m the peak of the input voltage can be 10 or 12 or 5; and V on for the diode can be either 0 or 0.7 volts. So, let us compute and when we compute many things happen here we will look at it soon. The ripple voltage V r is approximately 2, and we will look at this approximate way of calculating V r. And if you do it more exactly it turns out to be 1.66 volts.

Before we start the animation, let us note a few things. So, there are two tanks here, one corresponding to the source and the other tank corresponding to the capacitor. And there is going to be water in these tanks and that water level corresponds to the voltage either the source voltage or the capacitor voltage, which is the same as the output voltage. Water flow is going to correspond to current. So, there is going to be water flow out of this tank, there is going to be water flow into this tank, and that corresponds to current.

Capacitance corresponds to the area of the tank, for example, if this tank was wider then that means, the capacitor is larger. And the capacitors charge is equivalent to the volume of the water inside. So, if this tank has a certain volume of water that corresponds to the charge on the capacitor.

The flow rate out of the right tank that is the flow rate over there is equivalent to the load current, current through the resistor, which is approximately V m by R, because we have seen that the voltage across the resistor which is V o is nearly equal to V m. Also it is good to note this formula ripple voltage V r is given by V m times T - the period of the input waveform divided by R c. We are actually going to derive this formula soon. For our 50 hertz input, the time period is 20 milliseconds. Also since the diode resistance is very small the charging process is instantaneous as we have already remarked earlier.

So, with these in mind let us now look at the animation. So, what we will do is we will just let the animation run for some time and then comment on what is happening. So, just observe for two cycles. So, let us now relate what is happening in this picture to our actual circuit. So, there is this source, it is like an artificial tank, there is no such tank in nature. And its water level goes up and down, it just keeps going up and down forever, just like the source here. This source tank is separated from the capacitor tank with a membrane or a wall. Now this wall is rectifying. So, it allows water to flow from there to there, but not the other way, and that is the meaning of this arrow here; the same as this arrow because the diode does not allow current in that direction.

Let us now comment on the size of the currents involved, in particular the load current and the diode current; where is the load current in this picture? The load current is right here. So, the load current basically is responsible for discharging the capacitor here, and this water flow is responsible for emptying the tank - the capacitor tank and that is a relatively slow process because we do not want the level to drop drastically, we want the level to be in fact a constant. Now, what happens is this source level goes up and when it goes above the capacitor level, then there is a sudden water flow from the source to the capacitor.

And let us just watch it once again. So, as we see this process is going on continuously and whatever water is lost from the capacitor tank has to be replenished from the source in a very short time, because it is only a short time that the water level in the source is higher than the capacitor level. So, the water flow that happens in that short time must be larger much larger than this water flow. And that means that the peak diode current must be much larger than the average load current.

Let us now try to understand the relationship between the ripple voltages; that is this difference here. And the capacitance values, the resistance value and V m - the input amplitude. Let us consider the capacitance first. Where is the capacitance in this picture? The capacitance is the volume of this tank; it represents the capacity. Now, suppose we increase the capacitance from 1 to 2 millifarad, what would happen, the capacitance would then increase the tank would increase in size.

Now, we have not really change the resistance value, so the flow rate which corresponds to the average load current which is V m by R that is not changing. And therefore, in a given time that is in one period the water the volume of the water that is lost from this tank would still be the same, but now the area of this tank has increased. So, what it means is the height or the ripple that this situation corresponds to will now be lower. So, let us check that out.

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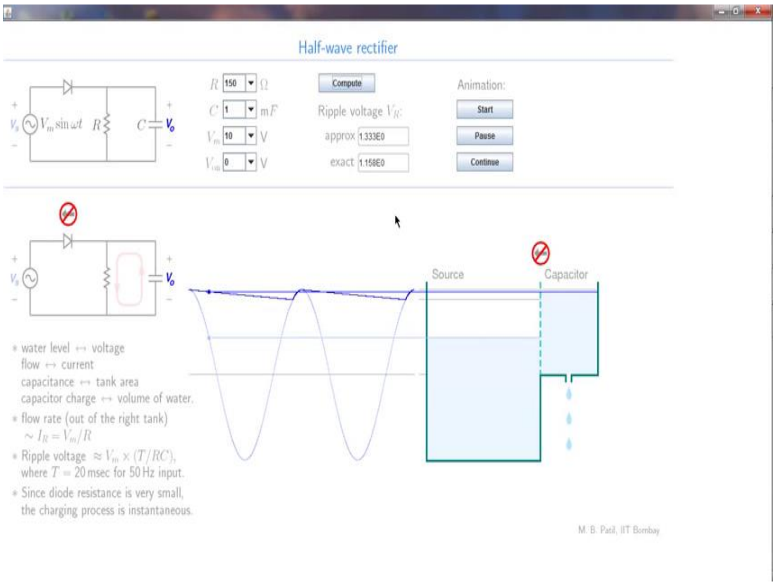

So, remember the earlier ripple is two. And now let us compute again. Now, the new ripple voltage is 1; and as we expected the size of this tank has increased. What if we increase the resistance value, let us say from 100 to 150. What would happen then? Now as you have seen the resistance controls this flow out of the capacitor tank and it is given by approximately V m by R. So, if I increase the resistance, this flow is going to decrease. And in the same amount of time that is one period the volume of the water that is lost from this capacitor tank will then reduce.

And we have to then replenish only a smaller volume and that corresponds to a decrease in the ripple voltage. And let us check that out or from 100 to 150, the ripple voltage with 100 is 2 volts and with 150. Let us compute, it is 1.33 volts and that is what we expect.

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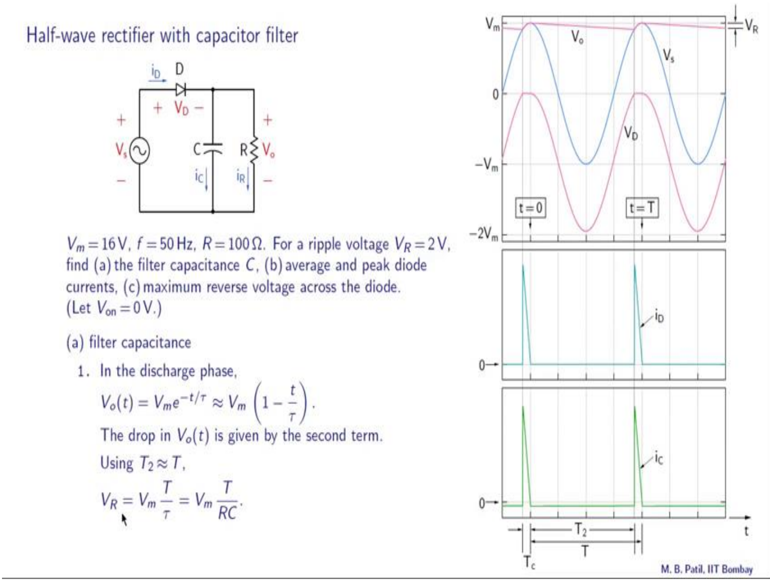

So, let us look at this example half-wave rectifier with capacitor filter. We are given V m to be 16 volts frequency, 50 hertz of course, about this we do not have too much choice because as same as the mains frequency, R -the load resistor is 100 ohms and for a ripple voltage of 2 volts, we want to find the filter capacitance. So, we will do that first, and with that capacitance value then we will look at what is the average and peak diode current, and what is the maximum reverse voltage that appears across the diode. And in all of these calculations, we will assume that V on is 0 volts; and in reality different V on like 0.7 volts does not really make too much difference and we already seen that in the plots that we saw earlier.

So, let us begin with the a-part calculation of the filter capacitance. Let us recall that the diode conducts in a relatively small interval, then it is off, then again it conducts in the next cycle and so on. This part corresponds to the charging that is increase of voltage and the maximum is V m. And these part this interval which is marked as T 2 here from there to there. This corresponds to discharging of the capacitor through the resistor. So, the diode is off, and because the capacitor is discharging through the resistor, we have this drop in the output voltage. At this point, once again the diode starts conducting and the capacitor voltage the output voltage increases.

So, now that discharging process corresponding to this R c circuit with the diode off is described by this equation V o of t is V m e raised to minus t by tau. Now, tau normally is selected for a small ripple and that happens if the time constant R c is much larger than one period. And if that is the situation this t by tau is much less than 1 and then V m e raised to minus t by tau can be approximated as V m times 1 minus t by tau. Now, at t equal to 0, our capacitor voltage is V m at t equal to T 2 this is 0, this is T 2; at t equal to T 2, our capacitor voltage has dropped by V r that is our ripple voltage.

In other words if we substitute t equal to T 2 here then V m times T 2 by tau should be equal to V r. Now, the problem is that T 2 is not known and this is where we make an approximation; that approximation is that t 2 is nearly equal to T. So, what we are saying is this T 2 is nearly equal to the entire time period. Now, this is not an unreasonable approximation because the time during which the diode conducts is indeed small compared to the time period, and therefore this is a reasonable approximation. So, with that approximation, we now get V r is V m times T 2 by tau; now T 2 is approximately T. So, therefore, V r is V m T by tau which is V m T by R c.

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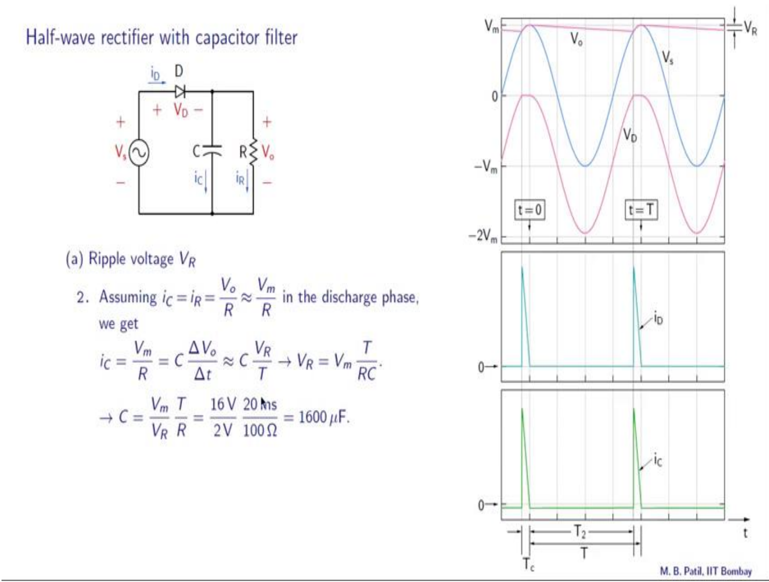

Here is another way of computing the ripple voltage; we start with i C equal to i R in the discharge phase, the diode is not conducting and i C and i R are therefore, equal in magnitude. I R is V o by R and V o is approximately constant which is equal to V m and that holds if the ripple voltage is small. So, we have i C equal to V m by r; and i C is also equal to C d V o d t which is V o appears across the capacitor as well. And if we look at V o in the discharge phase, it falls linearly and we have seen the condition for that to happen that is the time constant R c is much larger than the period T of the input waveform.

So, if V o is falling linearly then the derivative is constant. And we can calculate the derivative by using delta V o divided by delta t and that is written here delta V o is the same as V r and delta t in the discharge phase is actually T 2 if we come down that is T 2. And once again we will make this approximation that T 2 is nearly equal to T and therefore, we get i C equal to V m by R equal to C V r by T and that gives us a value for V r. So, V r is V m T by R c.

From this expression for V r we can now obtain C V m by R times T by R. And we have been given these values and we want to find C. So, V m is 16 volts, V r we require it to be 2 volts, the time period corresponds to the input frequency of 50 hertz which is 20 milliseconds and R the load resistance is 100 ohms. When we calculate this number, it turns out to be 1600 microfarads or 1.6 millifarads.

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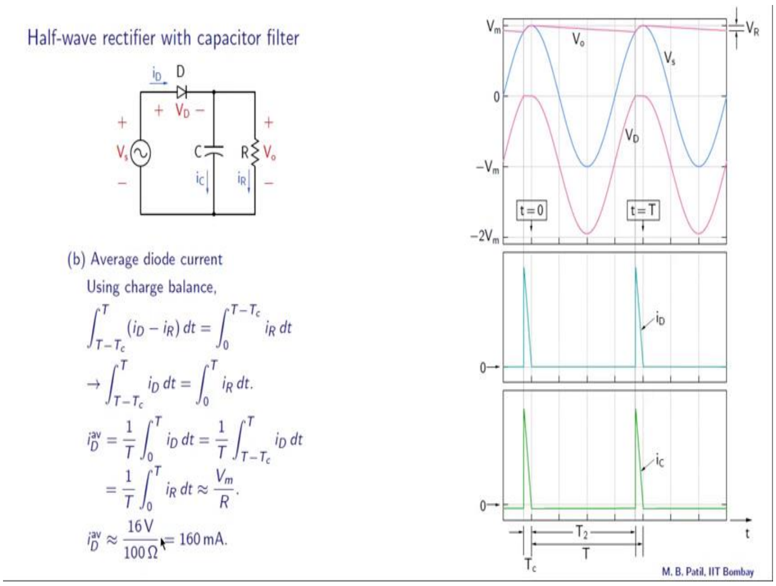

Let us now look at the average diode current, and we can use charge conservation to obtain this. Charge conservation requires that the change in Q for the capacitor in one period must be 0. And since i C is D Q dt we require the integral of i C over one period to be 0. So, let us look at the capacitor current which is shown here. Now, in this interval marked T c here, the capacitor current is positive, the diode conducts the capacitor gets charged like that. And in this second interval, the diode is not conducting i D is 0 and we have only this R and C in parallel. Now, the capacitor is supplying current to the register. So, i C is negative.

So, we see that here this is a negative current. And now charge conservation requires that the integral under this curve should be exactly equal and opposite to the integral of this curve or the area under i C in that interval, so that is our starting point. And let us see what that implies. In the charging phase, i D is equal to i C plus i R. So, therefore, we can write i C as i D minus i R; and in the discharging phase this i D is 0 and therefore, i C is equal to minus i R.

So, let us now put it all together and obtain an equation which results from charge conservation that is what we get. So, this i D minus i R is nothing but i C in the charging phase, and therefore the limits here are T minus T c to T, what is T minus T c, this is our 0, this is our T, this point T minus T c is this point right here. So, T minus T c to T is basically this interval marked here. What about 0 to T minus T c, this is our 0 and 0 to T minus T c. So, we are talking about the discharge phase now. So, these two integrals must be equal. And we can simplify things, we can club this integral i R d t with the one on the right hand side. And then we get integral i D dt T minus T c to T is integral i D dt from 0 to T.

And now we want the average value of the diode current. What is the average value? It is simply the integral from 0 to T i D dt and 0 to t essentially means t minus t c to t because the diode does not conduct in this other interval, and that we need to divide by the period t, so that is what we get. And since this and that are equal, we get i D average equal to 1 over T integral i R dt over one period. Now, i R is nearly constant as we have seen before. So, it is just V m by R and the average value of i D turns out to be equal to the average value of i R that is V m by R. And for this example it turns out to be 16 volts by 100 ohms that is R and that is 160 milli amperes.

To summarize, we have used an animation based on the analogy between the half-wave rectifier and hydraulic system. This analogy helped us to identify the factors responsible for a nonzero ripple voltage at the output. After that we worked out an approximate formula for the ripple voltage; and used it in a numerical example. In the next class, we will complete the half-wave rectifier problem and then take up the full-wave rectifier circuit, until then goodbye.